as part of the International Field Year for the Great Lakes. The mean wind stress is from the southwest at about 0.1 dyne cm^{-2}.

Figure 2 shows the longshore component of the surface current at 3 km from each shore and the difference between the two for a 3-day period beginning with the 8th day. As expected, the difference increases both during the relatively strong winds on the 8th day and during the decay stage on the 9th and 10th days.

The mean longshore component of the surface current for the 14-day period for the case of uniform winds is the solid line in Fig. 3. Although it is toward the east even in the center of the lake, the flow at the southern (warm) shore is 4 cm sec^{-1} stronger than at the northern shore.

To compare this result with the Emery-Csanady theory I ran the model again adding a constant curl to the wind stress given in Fig. 1. This added 0.018 dyne cm^{-2} to the south shore and subtracted the same from the north shore for each day. This difference of 0.036 dyne cm^{-2} is consistent with Emery and Csanady's estimate of a difference of 0.5 dyne cm^{-2} acting for 8 hr if we assume that such a wind impulse occurs every 5 days. The mean longshore current for this case is given by the dashed line in Fig. 3. The addition of the wind stress curl to the uniform winds increases the cross-lake surface current difference from 4 to 8 cm sec^{-1}. Thus, both the variation of lake static stability and the variation of surface stress across the lake have comparable effect on surface circulation and complement one another.

If one includes the classical explanations of cyclonic circulation, the tendency for river inflows to be deflected to the right by the Coriolis force and the geostrophic circulation during spring and fall when the shore zones respond faster to thermal forcing, there are now five possible explanations. I am now attempting to evaluate the relative importance of them for Lake Ontario using a three-dimensional numerical model.

John R. Bennett

Massachusetts Institute of Technology
Cambridge 02139

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Morphometric control of variation in annual heat budgets

Abstract—The extent of variation in annual heat budget of 23 European, North American, and Australian lakes tends to be related to lake volume and mean depth.

In a 3-year study of the comparative limnology of Lakes Purrumbete, Bullenmerri and Gnotuk, near Camperdown, in western Victoria, Australia (Timms 1973), mean heat budgets were not only related to mean depth and area, as expected (Gorham 1964), but the extent of annual fluctuations was also morphometrically controlled. This latter relationship may be widely applicable and more reliable than the observation that lakes in continental climates tend to have more constant heat budgets than those in oceanic climates (Hutchinson 1957).

*Table 1. Morphometry and heat budgets of some European, American, and Australian lakes.**

Group	Lake	Country	V (m^3 x 10^3)	<z> (m)	Mean heat Budget g. cal. cm^{-2}	C.V. (%)	Years of data
1	Bullenmerri	Australia (Vic.)	19.2	39.3	19,235	8.6	3
1	Purrumbete	Australia (Vic.)	15.7	28.5	16,945	6.1	3
1	Gnotuk	Australia (Vic.)	3.2	15.3	13,365	4.0	3
1	West Basin	Australia (Vic.)	0.1	5.8	7,180	1.9	3
2	Skaneateles	U.S.A. (N.Y.)	156	43.5	39,100	7.2	3
2	Owasco	U.S.A. (N.Y.)	78	29.3	35,757	4.9	4
3	Green	U.S.A. (Wisc.)	98	33.1	34,000	4.1	11
3	Mendota	U.S.A. (Wisc.)	48	12.4	24,073	5.4	3
3	Monona	U.S.A. (Wisc.)	10.8	7.7	17,559	2.2	3
3	Waubesa	U.S.A. (Wisc.)	3.8	4.6	11,362	3.5	3
4	Como	Italy	2699	185	31,987	19.9	11
4	Bolsena	Italy	893	78	31,600	6.0	4
5	Geneva	Switzerland	8970	154	36,433	24.3	6
5	Constance	Switzerland	7546	90	23,265	6.7	4
5	Zürich	Switzerland	321	44	21,800	7.9	4
5	Zug	Switzerland	386	84	31,325	38.4	4
6	Gmundener	Austria	230	90	33,350	32.4	4
6	Wörth	Austria	84	43	25,250	6.4	6
6	Hallstatt	Austria	56	65	26,660	8.5	3
7	Ness	Scotland	754	133	37,233	7.8	3
7	Morar	Scotland	232	87	29,433	6.9	3
8	Vettern	Sweden	7402	39	30,040	16.7	5
8	Mjösen	Norway	6721	187	41,760	25.3	5

*Data from Birge (1915) except lakes in group 1 - Timms (1973) and Timms & Brand (1973); and Mendota, Monona and Waubesa - Stewart (1973).

The extent of annual variation in heat budget was measured by the statistic, coefficient of variation. However, even in those few lakes for which data on heat budgets for consecutive years are available, there is an insufficient run of years for statistical validity. Hence the C.V. value is no more than a guide to the variation possible in the heat budget in any given lake. Only lakes with three or more years of data were chosen for analysis; to require four or more would have restricted the choice of lakes severely and if lakes with but two years' data were included, their C.V. values would have been almost meaningless.

As a measure of lake morphology, the parameters volume and mean depth were chosen. Gorham (1964) has shown them to be the most important parameters influencing heat budgets.

Relevant data for 23 lakes are recorded in Table 1.

For the whole series there is a definite tendency for lakes of greater volume and mean depth to have more variable heat budgets, though there are some startling exceptions (e.g. Lakes Constance and Zug). It is for lakes in circumscribed areas that the relationship is most obvious, as in the Victorian lakes, a group of adjacent, similar maars (Timms 1973; Timms and Brand 1973) and in the New York and Italian pairs.

Annual variation in heat budget seems to be more influenced by mean depth than by volume, as shown particularly by the Scandinavian and Austrian groups. Data for the Victorian, New York, and Italian groups point to a similar conclusion, in that the relative values for mean depth reflect those for C.V. better than the volume figures.

The Wisconsin and Swiss groups seem to be exceptions to the relationships claimed above. The low value for Monona in Wisconsin could be associated with its use in power station cooling (Stewart 1973).

Variation in Green Lake is also less than expected, but this could be largely because its C.V. is based on more data than that for the other lakes. (It can be shown for Green and Como that as the data increase, the C.V. decreases.) The great mean depth of Lake Zug in Switzerland partly accounts for its large C.V., but the C.V. for Lake Constance is inexplicable according to this hypothesis. Perhaps meltwater inflow, which is known to depress heat budget (Strom 1944), also damps fluctuations.

The magnitude of the heat budget for any lake is influenced by several factors, including latitude, altitude, and thermal behavior (Hutchinson 1957) and by morphometric parameters such as mean depth, area, and volume (Gorham 1964). The last are important because they influence the effectiveness of heat distribution by wind. In large lakes thermal stratification is often delayed and the thermocline is deeper, largely due to more effective heat distribution by wind action (Hutchinson 1957). The epilimnion is of greater relative volume than in small lakes and therefore more likely to be influenced by any abnormal weather patterns. Hence it is not surprising that large, deep lakes tend to have more variable heat budgets than small, shallow lakes.

There are insufficient data to prove this relationship unequivocally. Furthermore, there are indications of influencing factors, such as warm water (or meltwater) inflows, damping variations. Degree of protection from wind action is also likely to be important. In the four Australian lakes the order of a subjective appraisal of protection from wind action by crater rims (West Basin > Gnotuk > Bullenmerri > Purrumbete) almost agrees with the order of C.V. values (Table 1). Finally some climates have more variable weather patterns than others; hence Hutchinson's (1957) observation of more variable heat budgets in maritime regions.

The last two factors, protection from wind action and climate, influence the active component in the effectiveness of heat distribution in lakes. The morphometric parameters of volume, mean depth, and area are the passive components. Both contribute to heat budget variability, but the passive components seem to be the more important.

B. V. Timms[1]

Department of Zoology
Monash University
Clayton
Victoria, Australia 3168

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[1] Present address: Sciences Department, Avondale College, Corranbong, New South Wales, Australia 2265.