MOVEMENTS OF THE WATERS OF LOCH NESS, AS INDICATED BY TEMPERATURE OBSERVATIONS.

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The view that the waters of the Scottish lochs were at rest, and that the temperature changes were due to the transmission of heat through the stagnant waters, was long ago rendered untenable. In a paper * published in the year 1888, Sir John Murray showed that the distribution of temperature in the waters of Loch Ness was very largely dependent on the force and direction of the winds blowing over the surface of the loch. In connection with the Survey of the Scottish Lochs, which is being carried on under the superintendence of Sir John Murray and Mr Laurence Pullar, it was considered desirable to undertake a detailed study of the temperature conditions of the waters of Loch Ness.

* Murray, "On the Effects of Winds on the Distribution of Temperature in the Sea and Fresh-water Lochs of the West of Scotland," *Scott. Geogr. Mag.*, vol. iv. p. 345, 1888.

Accordingly, I, together with Sir John Murray, Mr. E. M. Wedderburn, and other members of the Lake Survey Staff, commenced in July, 1903, a systematic study of the temperatures of the different strata of water in Loch Ness. As a first step, the temperatures were taken at the station near Fort Augustus several times a day for several days. Temperature-depth curves were drawn from these observations and examined. Fig. 1 gives a few of these curves. Had the waters of the loch been at rest, there would have been observed considerable regularity in the temperature changes—a steady seasonal rise of temperature compounded with a slight diurnal fluctuation in the upper strata, and the magnitude of the temperature changes always smaller for the deeper strata than for the upper strata. There was observed no such regularity in the temperature changes, as will be seen by a glance at Fig. 1. On a first examination, it

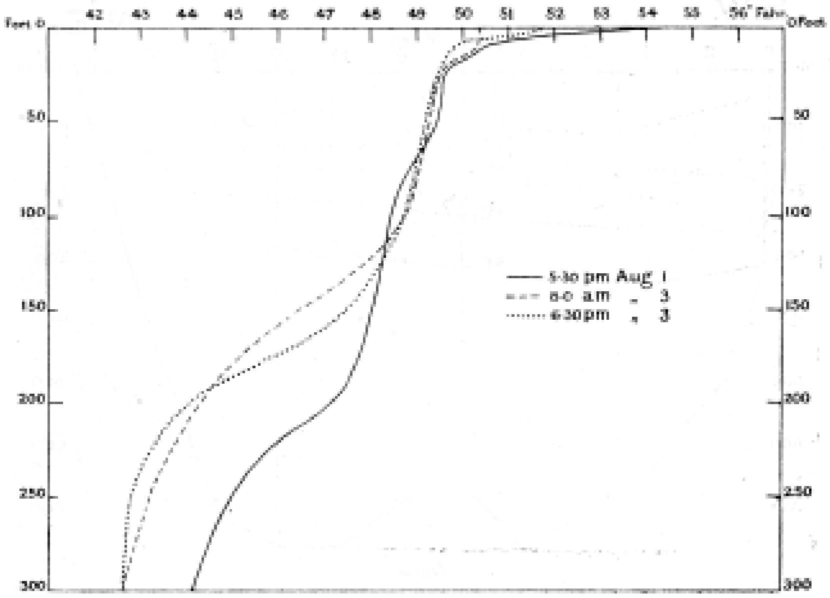


Fig 1.

seemed that the temperature at any depth down to 300 feet was liable to large and sudden changes, by which it was either increased or decreased, and there seemed to be no relation or co-ordination between the temperature changes at different depths. The only conclusion which could be drawn from such observations was that the waters of the lake were continually moving—that there were considerable currents throughout the whole volume of water from the surface right down to 300 feet at least, and that the temperature changes were due to these currents, which were continually replacing the water at any one point by water at some other temperature.

The observations were now extended. Cruises were made along the loch in a steam-launch, and temperature series taken at four or five stations equally spaced along the axis. It was found that these large and irregular temperature changes were not confined to the station near Fort Augustus, but that changes equally large and irregular occurred at all the stations. But, at the same time, the temperatures at any one of the stations differed from those at the other stations.

In order to study the observations made during cruises, a vertical longitudinal section through the loch basin was made, and vertical lines drawn at the observation stations. The temperature observations made were recorded at the proper distances below the surface along these lines, and isothermal lines were drawn connecting the points having a common temperature. For convenience, the isotherms 53°, 51°, 49°, 47° Fahr., etc., were drawn. Such a section is shown in Fig. 2.

It may here be mentioned that Loch Ness is a long, narrow, straight basin, and that consequently it is possible, by means of this one vertical longitudinal section, to give an almost perfect representation of the distribution of heat throughout the loch.

By an examination of a series of such diagrams, it was found that—

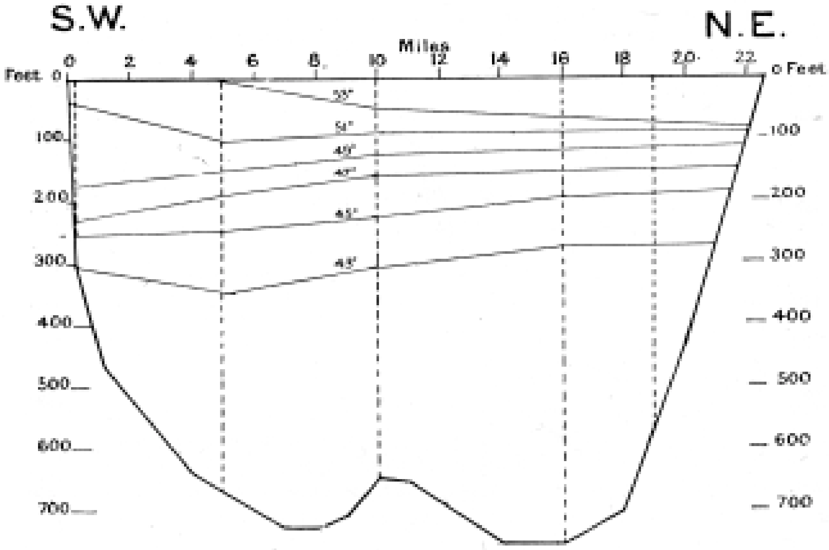


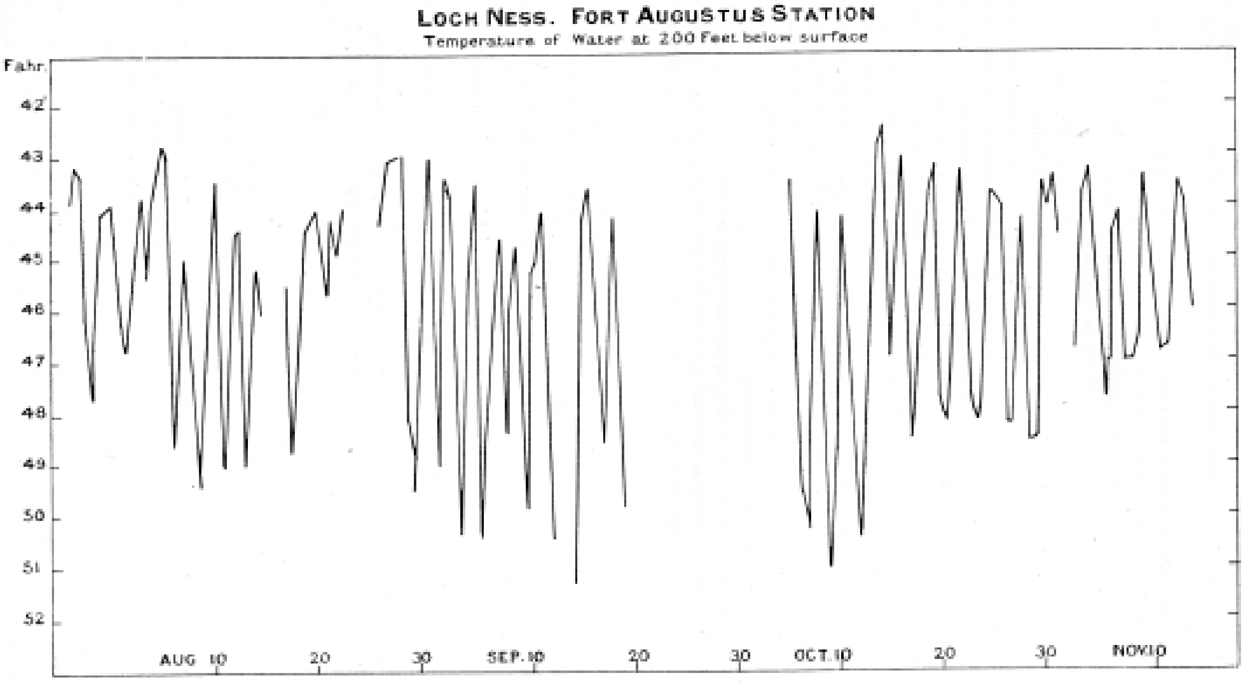
Fig: 2

(1) *The isotherms are never horizontal, but are inclined at all possible angles, some being, as a rule, sloping in the opposite direction from others.*

(2) *The isotherms are continually and quickly altering their inclinations:* the changes are so great and rapid that the diagram drawn as the result of one day's cruise would be found entirely different from that given by the preceding day's cruise.

(3) The area between two consecutive isotherms remained practically constant from one day to the next, although of course the shape of this area had entirely altered.

This last result was of the greatest use for a study of the currents: it meant that the bulk of water at any particular temperature remained practically constant, although this water was being continually moved to and fro by currents, and that if it had been possible to replace the isothermal surfaces by watertight but perfectly flexible membranes, then these membranes would not have affected the changes occurring in the loch. But it is obvious that by watching the movements of such membranes we could have gained a great insight into the current system of


LOCH NESS. FORT AUGUSTUS STATION
Temperature of Water at 200 Feet below surface
Fahr.
42
43
44
45
46
47
48
49
50
51
52
AUG 10
20
30
SEP. 10
20
30
OCT. 10
20
30
NOV. 10
Fig. 3

the loch—hence the utility of a study of the motion of the isotherms, for they are nothing but these hypothetical watertight partitions made visible by temperature observations.

An attempt was now made to study the cause and method of these movements of the isotherms—in other words, the current-system of the loch was examined.

It has long been held by oceanographers that a wind blowing along the surface of the ocean will produce a surface-current in the same direction as itself, and such a surface-current will necessarily produce consequent-currents. Sir John Murray has shown the existence of similar currents in several Scottish lochs.

By the use of these suggestions it was found possible to make a short statement describing briefly, but accurately, the cause and mode of movement of the upper isotherms. A wind blowing along the surface of the loch blows with it the hot surface-water, which is thus gathered to the lee end of the basin, whilst colder water comes to the surface at the windward end to take its place. In terms of isotherms, a wind blowing along the surface of the loch produces, or tends to produce, a slope of the upper isotherms down towards the lee end of the loch. I say "tends to produce," because the observations on Loch Ness show that a south-west wind produces this effect much more easily than a north-east wind. There seems to be a predisposition on the part of the upper isotherms to slope down towards the north-east end of the loch. This may be due to the head-to-foot flow of the loch, which is from south-west to north-east.

But whilst the movements of the upper isotherms are thus easily summarized, those of the lower isotherms remained for a considerable time a complete mystery. It was natural to suppose that the deeper the isotherm the less would it be influenced by the winds, and that perhaps a strong wind would produce a slight tilt in the deeper isotherms in the same direction as the tilt in the upper isotherms, but that, as a rule, the deeper waters would remain uninfluenced and at rest, and that the deeper isotherms would be horizontal surfaces. This, however, was found to be by no means the state of affairs. It was found that—

(*a*) Very often the lower isotherms had a tilt in the opposite direction from the upper isotherms;

(*b*) There was no more approach to horizontality in the lower isotherms than in the upper;

(*c*) Even after a protracted calm the isotherms were still not horizontal, and still in motion.

To study these movements of the lower isotherms, I made use of the systematic temperature observations which have been taken several times a day at the Fort Augustus station, begun July, 1903, and continued right on till the waters had become of almost uniform temperature throughout. I drew curves giving the change with time of the temperature at different depths. Fig. 3 gives the change with time of the temperature at 200 feet below the surface.

The table on page 435 gives the observations from which Fig. 3 was constructed.

It will be seen that the temperature at this depth at the Fort Augustus station changed in a regular periodic fashion, the length of a period being about three days, and the difference of temperature between a maximum and a minimum being about 5° Fahr. By drawing similar curves for other depths, I found that at greater depths the temperature exhibited the same periodic change, the length of the period being the same and the phase the same, whilst the amplitude got less and less the greater the depth of the point considered. Similarly, at less depths than 200 feet the change had the same periodicity and the same phase, and again smaller amplitude than at 200 feet, but here the regular nature of the change was somewhat obscured, apparently by other changes occurring at the same time—those changes due to the wind which we have already mentioned.

Loch Ness, Fort Augustus Station. Temperature of Water at 200 feet below Surface.

Time.	Temp. (corr.) Fahr.	Time.	Temp. (corr.) Fahr.	Time.	Temp. (Corr.) Fahr.
	°		°		°
July 27, 7.45 a.m.	43·9	Sept. 1, 8.0 a.m.	49·1	Oct. 20, 4.30 p.m.	48·2
,, 27, 5.0 p.m.	43·2	,, 1, 7.0 p.m.	43·4	,, 21, 10.30 a.m.	47·1
,, 28, 8·0 a.m.	43·4	,, 2, 8.0 a.m.	43·8	,, 22, 10.0 a.m.	43·3
,, 28, 9.0 p.m.	46·3	,, 3, 8.0 a.m.	50·3	,, 22, 4.0 p.m.	43·3
,, 29, 8.0 a.m.	47·8	,, 3, 6.0 p.m.	47·4	,, 23, 10.0 a.m.	47·8
,, 29, 12.0 noon	46·7	,, 4, 8.0 a.m.	45·1	,, 23, 6.0 p.m.	48·2
,, 30, 12.0 noon	44·1	,, 4, 7.0 p.m.	43·5	,, 24, 10.30 a.m.	47·5
,, 31, 8.0 a.m.	43·9	,, 5, 8.0 a.m.	50·4	,, 24, 4.30 p.m.	47·4
,, 31, 9.0 p.m.	45·1	,, 5, 6.0 p.m.	48·0	,, 25, 10.30 a.m.	43·7
Aug. 1, 8.0 a.m.	46·4	,, 7, 8.0 a.m.	44·6	,, 26, 10.0 a.m.	44·0
,, 1, 6.0 p.m.	46·8	,, 7, 5.0 p.m.	48·4	,, 26, 4.0 p.m.	48·2
,, 3, 8.0 a.m.	43·8	,, 8, 8.0 a.m.	46·2	,, 27, 10.0 a.m.	48·2
,, 3, 7.0 p.m.	45·3	,, 8, 6.0 p.m.	44·7	,, 27, 8.0 p.m.	46·0
,, 4, 9.30 a.m.	44·0	,, 9, 8.0 a.m	46·6	,, 28, 8.0 a.m.	44·6
,, 5, 8.0 a.m.	42·8	,, 9, 7.0 p.m.	49·9	,, 28, 10.0 a.m.	44·2
,, 5, 9.0 p.m.	43·0	,, 10, 8.0 a.m.	45·3	,, 28, 8.0 p.m.	48·5
,, 6, 8.0 a.m.	48·6	,, 10, 7.0 p.m.	45·0	,, 29, 8.0 a.m.	48·4
,, 6, 6.0 p.m.	46·7	,, 11, 8.0 a.m.	44·1	,, 29, 8.0 p.m.	48·6
,, 7, 7.0 a.m.	45·0	,, 12, 8.0 a.m	50·4	,, 30, 8.0 a.m.	43·5
,, 8, 12.0 noon	48·0	,, 14, 8.0 a.m.	51·4	,, 30, 8.0 p.m.	44·1
,, 8, 9.0 p.m.	49·4	,, 15, 8.0 a.m.	44·2	,, 31, 8.0 a.m.	43·4
,, 10, 12.30 p.m.	43·5	,, 15, 6.0 p.m.	43·6	,, 31, 4.0 p.m.	44·6
,, 11, 8.0 a.m.	49·0	,, 16, 8.0 a.m.	45·0	Nov. 2, 10.30 a.m.	46·8
,, 12, 8.0 a.m.	44·5	,, 17, 8.0 a.m.	48·6	,, 2, 5.0 p.m.	46·0
,, 13, 8.0 a.m.	49·1	,, 18, 8.0 a.m.	44·2	,, 3, 10.0 a.m.	43·7
,, 13, 12.0 noon	47·3	,, 19, 8.0 a.m.	49·8	,, 3, 5.0 p.m.	43·3
,, 14, 8.0 a.m.	45·2	Oct. 5, 5.0 p.m.	43·5	,, 4, 10.0 a.m.	45·7
,, 14, 8.0 p.m.	46·0	,, 6, 9.0 a.m.	47·5	,, 4, 5.0 p.m.	46·0
,, 17, 10.0 a.m.	45·5	,, 6, 5.0 p.m.	49·5	,, 5, 10.30 a.m.	47·7
,, 17, 7.0 p.m.	48·7	,, 7, 9.0 a.m.	50·2	,, 5, 3.0 p.m.	47·1
,, 18, 10.0 a.m.	47·6	,, 7, 4.0 p.m.	48·4	,, 5, 9.0 p.m.	47·1
,, 18, 8.0 p.m.	46·8	,, 8, 9.0 a.m.	44·1	,, 6, 9.30 a.m.	44·5
,, 19, 9.0 a.m.	44·5	,, 9, 9.0 a.m.	51·0	,, 6, 9.30 p.m.	44·1
,, 19, 7.0 p.m.	44·2	,, 10, 10.30 a.m.	48·4	,, 7, 10.0 a.m.	47·0
,, 20, 8.0 a.m.	44·0	,, 10, 1.0 p.m.	44·2	,, 8, 10.30 a.m.	47·0
,, 20, 4.0 p.m.	44·1	,, 12, 9.0 a.m.	50·1	,, 8, 6.0 p.m.	46·5
,, 21, 8.0 a.m.	45·7	,, 12, 2.30 p.m.	50·4	,, 9, 10.0 a.m.	45·0
,, 21, 6.0 p.m.	44·2	,, 13, 9.0 a.m.	46·6	,, 9, 9.0 p.m.	43·4
,, 22, 8.0 a.m.	44·9	,, 13, 4.30 p.m.	44·4	,, 10, 10.0 a.m.	46·3
,, 22, 7.0 p.m.	43·9	,, 14, 9.0 a.m.	42·7	,, 10, 9.0 p.m.	46·3
,, 26, 8.0 a.m.	44·2	,, 14, 4.30 p.m.	42·3	,, 11, 9.30 a.m.	46·8
,, 26, 6.0 p.m.	43·3	,, 15, 10.0 a.m.	46·9	,, 11, 9.0 p.m.	46·7
,, 27, 8.0 a.m.	43·1	,, 15, 3.30 p.m.	46·5	,, 12, 1.0 p.m.	45·3
,, 28, 8.0 a.m.	43·0	,, 16, 5.0 p.m.	43·0	,, 12, 10.0 p.m.	43·4
,, 28, 6.0 p.m.	43·0	,, 17, 8.30 a.m.	48·5	,, 13, 3.0 p.m.	43·8
,, 29, 8.0 a.m.	48·0	,, 19, 10.0 a.m.	43·5	,, 13, 9.0 p.m.	46·0
,, 29, 6.0 p.m.	49·2	,, 19, 4.0 p.m.	43·2		
,, 31, 8.0 a.m.	43·0	,, 20, 10.0 a.m.	47·7		

In terms of isotherms, these observations revealed a pendulous swinging of the ends of the isotherms, the amplitude of the swing being greatest for the isotherm in the region 200 feet below the surface, and dying off both above and below this region. A few other observations taken simultaneously with these at other parts of the loch show that the isotherms are swinging as a whole about a transverse central axis.

To what can this swinging be due?

If we take a long rectangular trough with glass sides, and put into it a layer of water, and above the water a layer of lighter oil, and then disturb the arrangement, one of the movements observed will be a swinging of the interface between the oil and water. The longer the trough the slower will be the period of this movement; a large difference of density between the upper and lower liquids will give a quick period, and a small difference of density a slow period. The time of swing can be calculated from the formula—

$$t = \frac{2l}{\sqrt{\dfrac{g(\rho - \rho')}{\dfrac{\rho}{h} + \dfrac{\rho'}{h'}}}}$$

where t = time of swing,
l = length of trough,
ρ' = density of upper layer,
ρ = density of lower layer,
h' = depth of upper layer,
h = depth of lower layer,
g = acceleration due to gravity.

Now, in the loch we have warmer, and therefore lighter, water lying above colder and heavier water, and, roughly speaking, the greatest temperature change occurs about 200 feet below the surface. So it seems to me that, after a suitable displacement, the waters may swing with a movement similar to that observed in the trough, the warmer upper waters taking the place of the oil, and the isotherm in the region of most abrupt temperature change, *i.e.* at about 200 feet, taking the place of the interface between the oil and water. Such a swinging would produce the observed periodicity in the temperatures, would account for the observed fact that sometimes the lower isotherms are tilted in a direction opposite from that of the upper isotherms, and for the fact that even after a protracted calm the isotherms are still in motion. To calculate exactly the period of such a swinging would be a very difficult matter, but we can obtain an approximate value by assuming that the waters above 200 feet are of a uniform temperature equal to the mean, and similarly for the waters below 200 feet.

Thus in August we should have—

ρ' = density of water at 50°·5 Fahr. = 0·999704
ρ = density of water at 43° Fahr. = 0·999965

also we have—

h' = 200 feet
h = 400 feet
l = 131,000 feet

From which we calculate—

t = 68 hours

which is of the same order as the period observed.

Since winds produce a tilt in the isotherms, and the stronger the wind the greater the depth to which its effect is felt, it seems probable that these swingings are started by strong winds which are able to displace the isotherms in the critical region.

It is very important that the observations which have been begun in Loch Ness should be continued and amplified, in order that we may learn more about this extraordinary phenomenon. Up to the present we have only routine observations at one station, taken at intervals of several hours.

During the next season it will be possible to use the electrical thermometers which have now been satisfactorily installed at Fort Augustus, and thus to obtain a continuous record of the temperature change at a suitable depth at the Fort Augustus station. Besides this record, it is very important that we should have simultaneous observations at other stations, say at the centre of the loch and at the north-east end, in order that the movements of the isotherms throughout their whole length may be studied. These observations should extend over a considerable period.

It seems probable that similar movements will exist in other lochs, and it would be exceedingly interesting to determine the periods of such movements in basins of different dimensions, but for the present it would be preferable to study the phenomenon more thoroughly in Loch Ness. I may mention, however, that Prof. Forel believes that certain observations which he has made in Lake Geneva may perhaps be explained by the existence of similar movements in this lake, and that he intends during the forthcoming season to look further into the matter.