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John Murray LL.D. (Edin.) Ph.D. (Jena)

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# THE SCOTTISH GEOGRAPHICAL MAGAZINE.

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ON THE EFFECTS OF WINDS ON THE DISTRIBUTION OF  
TEMPERATURE IN THE SEA- AND FRESH-WATER LOCHS  
OF THE WEST OF SCOTLAND.

BY JOHN MURRAY, LL.D. (EDIN.), PH.D. (JENA).

## INTRODUCTORY.

THERE have been many theories to account for the circulation of oceanic waters, but all these have been for the most part modifications of two principal views. One of these refers the origin of oceanic currents to the action of the trade-winds or prevailing winds of the globe on the surface waters of the sea. The other maintains that equatorial waters, being greatly heated and lighter, stand at a higher level than the cold and denser polar waters, and that, consequently, there is a flow of warm surface waters towards the Poles, which is compensated for by a return flow of deeper layers of water from Poles to Equator.

This latter view, which is called the gravitation or thermal theory, has been upheld in recent times by Lenz and Dr. W. B. Carpenter. It seems more than likely, however, that the difference of level here invoked is very much less than would be produced by the attractions of continental land, by the action of the wind, and by evaporation. The former view, known as the wind theory, has been advocated by Humboldt, Herschell, Croll, and the majority of modern writers. In a recent publication, however, Alexander Agassiz does not appear to consider the wind a sufficient cause for existing currents.<sup>1</sup>

Along with the additions to our knowledge, lately made by the *Challenger* and other expeditions, regarding the depth of the ocean, there has been acquired an altogether new series of facts concerning the distribution of temperature in ocean water at various depths, and these, when carefully considered and discussed, appear clearly to point to the prevailing winds of the globe as the agents chiefly concerned in the pro-

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<sup>1</sup> *Three Cruises of the "Blake,"* vol. i. p. 247.

duction of oceanic currents; for it is often more easy to trace currents by the temperature of the water than by direct observation.

While the influence of wind is regarded as paramount, the secondary effects of variations of temperature, of density, of evaporation, of the rotation of the earth, and even the pressure of the superincumbent waters, must not be lost sight of in any discussions dealing with ocean circulation. But these secondary causes are, most of them, largely determined by the movements of the atmosphere; in considering the phenomena of the ocean, it is therefore essential to take account of the superincumbent atmospheric ocean which everywhere rests on its surface; for the composition of ocean water, the currents, the distribution of salinity, density, temperature, and deep-sea deposits can ultimately be connected with the general movements of the atmosphere.

It has been shown by Mr. Buchan's discussion of the *Challenger* observations that the daily variation of the temperature of the sea surface does not exceed  $1^{\circ}$  F., and also that the yearly variation is very small compared with the large variation over the land surfaces; to the first of these are due land and sea breezes, and to the second the monsoons.

The most important, as well as the most direct effect, of the unequal distribution of temperature over the surface of the oceans and continents is a more or less permanent distribution of atmospheric pressure. There are portions of the earth's surface where atmospheric pressure remains much higher than in adjoining regions, with little variation throughout the year, and from which winds blow in all directions towards surrounding areas. Such an area is that situated between the north of Africa and America; and out of this anticyclonic region of high pressure, observations show that the winds blow in all directions to where the pressure is less. To the westward of North Africa the prevailing winds are northerly and north-westerly; towards the equator, on the south of this anticyclonic area, the winds are easterly, while along the coasts of North America, to the west of this same high-pressure area, the winds are southerly. Similar areas are found in the South Atlantic, in the North Pacific, and in the South Pacific; and in all these regions the general direction of ocean currents is determined and maintained by these winds, with, in some cases, seasonal variations.

In the great bulk of the wind-driven oceanic currents the circulation is horizontal, and the return currents at the surface may in some instances be wholly out of the influence of the original generating winds. Soon after the publication of the *Challenger* observations, it was argued that these afforded evidence of a vertical circulation as well as a horizontal. Dr. Carpenter maintained that the rising of the glacial waters near the equator was due to the meeting of Arctic and Antarctic underflows, but it was at once pointed out by Mr. John Aitken,<sup>1</sup> among others, that this was more probably due to the lifting up of the cold water beneath to supply the place of the water driven forward by the action of the winds on the surface, the rest of the necessary supply rushing in at the sides. All subsequent observations and discussions appear to support this explanation.

<sup>1</sup> "On Ocean Circulation," in *Proc. Roy. Soc. Edin.*, vol. ix., 1874, p. 394.

To the direct and indirect action of the prevailing winds must be attributed the fact that relatively cold water is met with at and nearer the surface along those continental shores from *off* which winds blow, and not along similar shores *towards* which the winds are directed. For instance, the surface water is colder off the western coasts of Africa than off the West Indies, towards which the trade-winds blow, a temperature of 45° F. being met with at a depth of 200 fathoms off the former coast, and at over 400 fathoms off the latter. A like temperature of 45° F. is found at 600 fathoms off the coast of Britain—that is to say, warmer water is encountered at a depth of half a mile off Britain than off the tropical coasts of Western Africa.

The great bulk of the water of the ocean has a low temperature: it is ice-cold at the bottom even under the Equator in the Atlantic, and only a little above that in other oceans. The surface warm water is a relatively thin film, and this film is much deeper towards the western parts of the tropical Atlantic and Pacific than towards the eastern. On the other hand, the layers of warm water are deeper in the eastern parts of these oceans in the temperate regions, where western winds prevail. These facts are more clearly shown on the *Challenger* maps showing the distribution of temperature at 10, 20, 50, 60, 100, and 300 fathoms, than by the surface observations.

This drawing of deeper water towards the surface along windward shores has an important bearing upon the distribution of climates<sup>1</sup> and of marine organisms,<sup>2</sup> which renders any observations concerning the effects of wind on the movements of water of special interest; for instance, the fact that there are no coral reefs off the western shores of Africa or of America is directly connected with this action of the wind.

No detailed observations have hitherto been recorded showing the amount of change effected by the wind with varying velocity in any one locality and within any definite time. With the view, therefore, of throwing some light on the subject, I have embraced any opportunities which presented themselves for making experiments during the past two years on the waters of the western lochs of Scotland, and in this paper I propose to refer to some of the results.

It has been stated that in the open ocean the return current may be, and usually is, chiefly at the surface, rushing in at the sides to supply the place of the water driven forwards by the wind. In some conditions, however, there would appear to be return under-currents in the open ocean, like those observed by Buchanan<sup>3</sup> in the Gulf of Guinea, which probably owe their origin to causes similar in some respects to those which, as we shall see, produce return currents in enclosed lochs.

In a lake or sea loch, as the wind blows over the whole surface of the water, there can be no return current at the surface, so that the supply of water to take the place of that driven forward must come from beneath and as an under-flow.

<sup>1</sup> "On Similarities in the Great Oceans," by J. Y. Buchanan, *Proc. Roy. Geog. Soc.*, 1887.

<sup>2</sup> "On Coral Reefs," by John Murray, *Trans. Royal Institution*, 1888. "On Observations in the Indian Ocean," by John Murray, *Scot. Geog. Mag.*, 1887.

<sup>3</sup> *Loc. cit.*, page 9.