V. *On the Results of Tide Observations made in June* 1834 *at the Coast Guard Stations in Great Britain and Ireland. By the Rev.* WILLIAM WHEWELL, *F.R.S., Fellow of Trinity College, Cambridge.*

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IN the conclusion of "An Essay towards a first Approximation to a Map of Cotidal Lines," published in the Philosophical Transactions for 1833, I stated my opinion that simultaneous tide observations, made at the stations of the Preventive Service, and continued for a fortnight, would give us a clearer view of the progress of the tide along the coasts of this country than we could acquire from any records then extant. A representation to this effect being made to Captain BOWLES, the Chief Commissioner of that Service, and to Captain BEAUFORT, the Hydrographer of the Admiralty, those gentlemen entered with great interest and activity into the proposal for promoting this branch of science by such a series of observations; and they undertook to give orders for carrying the plan into effect, and directions for its execution. Such observations were accordingly made at all the Preventive Service stations on the coasts of England, Ireland, and Scotland, from June 7 to June 22 inclusive, and the registers of the observations were sent to the Admiralty, where they now are.

I expected to be able to deduce from these returns the solution of several curious and important questions respecting the tides, and probably to obtain some new laws of their phenomena. For this purpose, however, it was necessary to perform a previous reduction of the registered observations, correcting the times as far as the methods employed would allow, and subtracting from each time of tide the time of the previous transit of the moon, in order to obtain the interval. Though this operation was very simple, the performance of it in so many cases (above 12,000) required more time than I could devote to it. Captain BEAUFORT kindly allowed it to be executed by Mr. DESSIOU, of the Hydrographer's Office; and it was my intention to defer laying the account of the observations before the Society till the whole of them had been reduced, and their results investigated. But Mr. DESSIOU, having executed this reduction for the whole of the south coast of England, has been prevented by illness and by more pressing employments, from proceeding to the remaining coasts. In the mean time, having examined the reduced observations, I have been led to some conclusions which appear to me interesting and important; and which, I think, considering the delay which may attend the reduction of the remaining returns, and the intention which is entertained of repeating the observations in the ensuing June, it may be worth while very briefly to announce. I shall defer the communication of

the details by which these results are established till I am able to include in them the east coast of England and the coasts of Ireland and Scotland.

1. In the first place I will observe, that I am convinced from the examination which I have given to the subject, that observations made in this manner may be depended upon for many extensive and important inferences. The returns of last June are more consistent and accurate than I could have anticipated. I have reason to believe that in much the greater part of the cases they were made with care and fidelity, and in many instances with ingenious and suitable contrivances. It is impossible not to take the opportunity of saying that they reflect great credit both upon the intelligence and the punctuality of the officers and men of the coast-guard service.

2. One of the reasons for wishing to obtain such simultaneous tide observations, was the hope of ascertaining by this means whether there are *general irregularities* which affect the tides at all places along an extensive line of coast. Such irregularities are beforehand very conceivable. The tide-wave which visits our coasts has been propagated up the Atlantic, and influenced at least, if not produced, by the tide of the Antarctic Ocean. If the causes which determine the velocity of this wave could in any case so far vary as to make it an hour behind its time in the Atlantic, that one tide would at all our ports take place an hour later than the regular time; and the existence of an influence of this kind would be detected by such an anomaly appearing in the observations of the whole or a large portion of the British coast.

I think I may venture to say that no such general irregularity affected any of the tides from the 7th to the 22nd of last June. Partial anomalies of greater or less extent occur in the observations, but nothing which can be considered as being of a general character, and indicating a distant origin, like what has been spoken of.

This result is, I conceive, important; for it appears to render it probable that we may, with care and perseverance, make our mathematical prediction of the time of the tide much more accurate than we might otherwise have hoped. Since the tide is not affected by distant and general irregularities, it is irregular only so far as it is influenced by causes which operate in the neighbourhood, and vary from one place to another; as, for instance, the effect of the wind in connexion with the form of the land. Now, not only will irregularities arising from such causes disappear in the *means* of long series of observations, but where such mean results have been obtained, the effect of the disturbing causes (as, for instance, the wind blowing at and near the place,) may be determined empirically. We should thus have a *local* meteorological correction to apply to the prediction of the tide, in addition to the astronomical corrections; our tide tables would be much improved, and our knowledge of the tides rendered more correct and complete.

3. My examination of the results of the observations of the time of high water has been conducted for the most part by the method already so often employed by Mr. LUBBOCK; namely, by erecting a series of equidistant ordinates to represent the

intervals of the moon's transit and high water, and drawing a continuous line through the extremities of these ordinates. The curves present, in general, the form of that deduced by Mr. LUBBOCK from the London Observations, though of course in the rude observations of a single fortnight there are great irregularities. But the means of several places, and even, in most instances, the tides of a single place, present the features of agreement with theory, which Mr. LUBBOCK has shown to obtain with such remarkable exactness in the London tides; that is, the ordinate of the curve has in the course of a fortnight a minimum and a maximum magnitude, so that the curve assumes the form ∽. Moreover, it is not symmetrical on the two sides of the minimum and maximum, the slope being greater after the minimum than before it. The curve descends from the 7th to about the 13th of June; it then ascends till the 18th or 19th, and ascends more rapidly than it had descended, and then descends again less rapidly. All this agrees with the form given by theory.

4. But though the general course of the curves has this resemblance, the amount of flexure is not the same at different places. This result had already been obtained by the comparison of previous observations, especially those made at Brest, Plymouth, and London; it is confirmed so clearly by the observations here referred to, that I think it may now be assumed to be a general fact.

The inferences from this fact are very important; for in the first place it puts an end to all attempts to deduce the mass of the moon from the phenomena of tides, or to correct the tables of the tides by means of the mass of the moon. The approximate agreement of the mass of the moon deduced by LAPLACE from the tides of Brest, with the mass obtained from other phenomena, cannot be considered as otherwise than accidental. If he had employed the tides of London, he would have obtained a mass very different, as Mr. LUBBOCK has shown; if he had taken those of Plymouth, or of Brighton, the mass would have been again very different.

This evidence of the inapplicability of this part of the theory will not surprise any one who recollects how remote the hypotheses of the theory are from the case of nature. Such a theory may point out the general features of the phenomena, but any assumption of the actual correctness of the magnitudes determined by means of it is altogether gratuitous. The force of the moon *determines* the amount of the semimenstrual inequality; but probably we shall never be able to ascertain otherwise than empirically, *by what rule* this force, producing oscillations in an ocean of irregular form and depth, as the actual ocean is, determines the semimenstrual inequality at each point.

5. But since the semimenstrual inequality is thus determined in general by the force of the moon, and has a common form at different places, and yet is different in amount (and in other circumstances) at each place, we may represent it by resolving it into two parts, one of which shall be common to the whole ocean, or to a large portion of it, and the other part shall be a smaller and *local* correction, also following a cycle of half a month.

By the introduction of a *local semimenstrual inequality*, in addition to the general semimenstrual inequality, we should be able to reconcile the discrepancies of the curve which represents this inequality for different places, as London and Plymouth; discrepancies which have hitherto been a source of perplexity to those who have studied the subject.

The existence of these discrepancies, and their general prevalence, which is shown by our observations, make it clear that we cannot correctly use the tide table of one place to determine the tides of another, by adding or subtracting a constant interval, as is often done. For such a purpose the difference of the local semimenstrual inequalities of the two places requires also to be applied.

I have not attempted to determine the amount or form of the local semimenstrual inequalities of different places, not thinking our present materials sufficient; but a comparison of the curve of the semimenstrual inequality of different places is the way in which it must be obtained, and on this subject I have some remarks to make.

6. By what causes is the semimenstrual inequality at one place made to be different from that at another? There are some circumstances which we can readily imagine may produce such an effect, though we should probably not succeed in guessing what the effect would be; as, for instance, the form of the coast, the distance which the tide wave has travelled over, and the meeting of tides proceeding different ways. I think I can discover in the observations of last June indications of the effect of all these circumstances.

In the first place it appears that the curves (by which I mean here, and in what follows, the curves of the semimenstrual inequality) are *flatter* when the observations are made at promontories than they are for the general line of coast. I speak here of the promontories of the first order, which divide the south coast of England into large or primary bays, as the Lizard, the Rame Head, Prawle Point, Portland Bill, St. Alban's Head, St. Catherine's Point, Beachy Head. At such places the amount of the semimenstrual inequality appears from the observations to be less than it is in the intervening bays.

7. In the next place it seems to follow from the observations that the curves are flatter and flatter as the tide wave proceeds further and further. Thus the curve is flatter in Brighton Bay than it is in Mount's Bay on the coast of Cornwall, the tide having travelled further from west to east.

I do not consider this point as quite firmly established, because, though the curves do exhibit such a modification in going eastward, when we get as far east as the Isle of Wight we seem to perceive the influence of another cause which has been mentioned, the meeting of the two tides, which may produce this apparent modification.

8. This subject, the meeting of the tides, appears to be often misunderstood. For instance, in a paper published in the Philosophical Transactions for 1819, it is taken for granted, that when the two tides meet which come up the British Channel and down the German Ocean there must be a visible and marked conflict of opposite cur-

rents of the water. But this supposition is altogether gratuitous. The place of the meeting of the two *tide-waves*, which come in opposite directions, is the part of the coast where the tide is later than it is on either side of that part. For example, we know that on the coast of Dorsetshire and Hampshire the tide-hours are VII. VIII. IX. going eastward, and that on the coast of Norfolk the tide-hours are VII. VIII. IX. proceeding southwards. The tide-waves, therefore, move in an opposite direction along these coasts, and must *meet* at some intermediate point, as, for instance, on the coast of Kent; and at this point the tide is later than it is if we go along the coast either to the east and north, or to the south and west. But these motions of the *tide-waves* must be distinguished from the motions of the *streams* which bring the tide, as will be obvious when it is recollected that the tide-wave travels from the Land's End to the Isle of Wight in six hours. At the place where the tides meet there will not necessarily be anything more marked in the stream of flood and ebb than at any other point. The tendencies to opposite tide-streams may partially balance each other during a part of the flow and of the ebb, and leave only the difference of tendency in actual operation. There may be strong and conflicting tide-streams produced under certain circumstances; but these results will depend much more upon the local conditions of the ground than upon the general course of the tide-wave.

The meeting of the tides, however, will not be a single point; for by the laws of fluids the two opposite undulations, which we term the tide-waves, will be propagated independently of each other, and the fluid will be affected by both. If they were thus propagated without any loss of magnitude, we could easily trace the consequences. Let the tide-wave on the south coast move eastward so as to bring high water to certain places,

A. B. C. D. E. F. G. H. K. L. M.,

at the hours

VI. VII. VIII. IX. X. XI. XII. I. II. III. IV.,

and let the tide coming from the north and east in the opposite direction arrive at the same places at the hours

IV. III. II. I. XII. XI. X. IX. VIII. VII. VI.

It is then manifest that the tide at F. will still take place at XI.; also the tides at E. and D. will occur about XI., the hour intermediate between X. and XII., and between IX. and I. In the same way the tide at G. and H. will be about XI. I do not say *exactly* at XI., because each tide may diminish in amount as it advances; and for this reason each tide may, at a certain distance after their meeting, less affect the other. From these considerations we may expect the tide-hours along such a coast to be as follows:

A.	B.	C.	D.	E.	F.	G.	H.	K.	L.	M.
VI.	VII.	IX.	XI.	XI.	XI.	XI.	XI.	IX.	VII.	VI.

The question now remains to be answered, Do we find any such succession of tide-hours as this on the coast of Britain? And to this the coast-guard observations

on the south coast enable us to reply, that the hours do follow an order of this kind. Along a great extent of coast (from the Land's End to the Isle of Wight) the tide-hours increase in order from $4^h\ 30^m$ to $11^h\ 30^m$. But from the Isle of Wight eastward, the tide-hour continues to be about $11^h\ 30^m$, with small and irregular changes only: and this is true as far along the coast eastward as the observations have been reduced. The examination of the eastern-coast observations will show how far this peculiarity extends.

Thus "the tides meet," in reality, along the whole coast, from the Isle of Wight to the Downs, and perhaps to the coast of Suffolk; that is, along the whole of this tract the water is affected by the tide-waves which arrive in the two opposite directions.

It may appear strange that the influence of the eastern tide should cease suddenly when it reaches the Isle of Wight, not extending any further to the west. If, however, we look at the map, and observe the sudden widening of the channel to the west of Cape La Hogue, we shall be at no loss to conceive that the tide-wave may be extremely diminished by this rapid diffusion, as we know that the tides are greatly increased by the gradual contraction of their beds in estuaries and rivers. But whether or not this be the cause, the fact is indisputable in the observations, that to the east of this point the tide-hour changes very little, while to the west it diminishes with comparative rapidity.

If it were at all doubtful that this difference arises from the interference of the eastern tide as far as this point, the question would, I conceive, be settled by the two following articles.

9. The heights, as well as the times of high water, were observed; these heights I have hitherto examined for a particular purpose only, namely, to ascertain the existence of a diurnal difference of height, which follows from the theory, as I have observed in a former paper*. From this examination it appears that this diurnal difference manifests itself with remarkable constancy along a large portion of the coast now under consideration. From the Scilly Islands to Portland Bill, most of the stations exhibit this inequality operating upon the greater part of the tides. The law is, as is well known, that at a certain season of the year the morning tide is greater than the afternoon tide, and at a certain other season it is less. In June the evening tide was the greater; this appears clearly in the early part of the observations. As the morning tide approaches noon, the difference diminishes; and when the morning tide is become the afternoon tide, the diurnal difference has *skipped* one tide, so as still to be found conforming to the rule. The diurnal difference of height is variable, ranging from two or three inches to one foot.

10. I have said that this diurnal difference may be traced as far as Portland Bill. Eastward from this point the tides do not appear to be affected by it, the morning and evening tide not having any steady relation of greater or less.

This change is remarkable, and the more so when we observe that it takes place

* Philosophical Transactions, 1833, p. 221.

at the limit of the influence of the eastern tide, according to what was said in article 8. Will the interference of the tides explain such a change?

It obviously will do so; for the two tides at their meeting differ by twelve hours in the extent of their course, the one which has come round the northern extremity of Scotland and down the east coast being so much older than the channel tide. If, therefore, one of the two be a morning tide (when referred to its origin), the other must be an afternoon tide; and each compound tide being made up of such a pair, will show no peculiar character of either one or the other. Thus we may expect that, as far as the interference of the tides extends, the diurnal difference will disappear.

Taking the two considerations of Article 8. and this article together, I think it cannot be doubted that the sea, from the Isle of Wight to the Downs, and probably further, is affected by both the western and the northern tide.

11. It is natural to inquire whether we can, from our observations, discover the nature of the effect which the form of the coast produces on the time and height of the tide. On this subject I can offer some reply, though a more complete discussion of the existing returns, and of future observations, is desirable to confirm and extend our views.

The principal feature which appears in the observations of June is, that the tide-hour varies very rapidly in rounding the main promontories of the coast, and very slowly in passing along the shores of the intervening bays. Thus, along the whole of the great bay formed by the coast of Devonshire and Dorsetshire, from Prawle Point to Portland Bill, the tide hour is nearly the same, ranging only from about $6^h\ 5^m$ to $6^h\ 20^m$. But in passing round into Weymouth Bay the hour becomes 7^h, and on going round St. Alban's Head into Swanage Bay, it becomes suddenly 9^h.

If we draw the cotidal lines so as to correspond with these conditions, it is clear that the ends of these lines will be brought close together at the promontories, and that the lines will run along nearly parallel to the shore. Thus, the extremity of the 6^h cotidal line is near Prawle Head, the line itself following nearly the coast of the bay to Portland Bill. The 7^h cotidal line ends at Portland Bill, and the 8^h and 9^h lines end at St. Alban's Head. The 10^h and 11^h lines appear to meet the coast near St. Catherine's Head in the Isle of Wight; and, agreeably with what has already been stated, the 11^h line runs at a little distance from the coast through the straits of Dover. The cotidal lines drawn in my Essay printed in 1833 require to be modified according to these remarks.

12. At points of the coast where the cotidal lines are brought near together, the place of high water moves slowly; so that it is high water at one point, while at another point not far off, the water is still considerably deficient from its greatest height. Hence there will be a difference of level and a rapid tide-stream in such cases. Thus the peculiarity just noticed in the reference of cotidal lines to promontories is con-

nected with the occurrence of strong currents governed by the tide, like the Race of Portland and the similar current which is found off St. Alban's Head.

I abstain from making any further remarks till the reduction of the whole of the returns of last June shall give me more complete materials. I am the more desirous to draw attention to the results which such observations may supply, on account of its being intended to repeat the observations at the Coast Guard stations in the ensuing June, from the 9th to the 27th. I am also glad to be able to state, that the subject having been laid before the Lords of the Admiralty by CAPTAIN BEAUFORT, Their Lordships expressed their wish that application should be made to foreign maritime states, with a view to induce them to make contemporaneous observations on their coasts; and that such applications are now in the course of being made. The extension of such results as have been stated in the present paper to other coasts, and the discovery of other similar laws, cannot but be looked upon as a valuable and interesting addition to our knowledge.