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The Admiralty Tidal Predictions of 1833: Their Comparison with Contemporary Observation and with a Modern Synthesis

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Predicting the tide in four ports, the Admiralty Tide Table (ATT) came out in early 1833. The table was for London and three naval dockyards. The observations at those dockyards, from which the ATT was first made, have recently come to light (Anonymous, 1833). This paper exposes the circumstance of the tables' construction; it is also an analysis of the later part of the observation series. The analysis is a comparison of the difference between observation and contemporary prediction, and to tides synthesised from the modern method. The ATT were only admitted into production after comparisons were made to its competitors. Those comparisons were for London alone and a recent study also concentrates on that one area. This study extends comparison to the remaining three-quarters of the early ATT: to Sheerness, Portsmouth and Plymouth.

KEY WORDS

1. Tide. 2. History.

1. INTRODUCTION. Until well into the nineteenth century, tides were predicted by a method elaborated by the Venerable Bede more than a millennium earlier; that method was based upon knowing, by simple observation, the time of a place's High Water (HW) when the moon is in either of her extreme phases. The extreme phases being when the moon is full and when it is new; new moon is also called the change of the moon. Among seamen, this led to the once essential, but now arcane, acronym for the time of HW at Full & Change (HWF&C). For the needs of the period, the time of HW at full moon was accepted as being the same as the time at new moon. To know the time of a particular tide on a day that intervenes with either day of extreme phase, one had to count out an allowance for how much later per day, the moon, and hence roughly the tide, would pass the observer's meridian. Despite Bede having indicated how to make an allowance that amounted to 50', tidal prognostication employed an allowance of at best 48' and often only 45'. The method was a rule of thumb, adequate to contemporary commercial requirements and to time measured by sundial.

2. EARLY BRITISH PROGNOSTICATION. When Daniel Bernoulli jointly won the Paris Academy of Sciences competition of 1740 for an essay on tidal causes, he gave an equation and crude semi-diurnal general tide table, which presented a seminal idea of how tides could then be better predicted (Woodworth, 2002). After the Nautical Almanac was first published in Britain in 1767, several people appear to have taken up the idea, with Bulpit, Epp, Gregory, Holden, Innes and White all evidently publishing a calendar year of daily tidal time ephemeris; some also added a height prediction. Holden's predictions were for Liverpool; dating from 1770, they continued into the twentieth century, and were a lucrative form of income at 1/- each. Because of the income which they fetched, the Holden generations throughout the eighteenth and nineteenth centuries would not divulge their method; but lately Philip L. Woodworth has shown that it was descended from Bernoulli's method (Woodworth, 2002). George Innes, a watchmaker and astronomical calculator, published predictions for Aberdeen and the adjacent coast from 1820 onwards and deplored the secrecy of other prognosticators. Innes' tables were founded upon a method published in Dr. Andrew MacKay's *Complete Navigator*. Although he used French tabulations and ephemeris, Innes declared himself unaware of what Bernoulli had devised (Innes, 1832). Gregory published for Leith and the others for London, mostly by methods unknown. As timepieces were substantially improved from 1765, when Harrison won the Longitude Prize, use could then properly be had of an improvement in predicted HW times; the new contemporary tabulations were then being given to the accuracy of a minute.

The Holden tide tables, in their initial accuracy, fulfilled a commercial need at Liverpool Docks; then their commercial success enabled the tables' revision, improving their utility still further. William Vaughan, one of the directors of the London Dock Company, was inspired by the Liverpool tidal record from which predictions were devised and instituted similar records at the site of London Docks, stating that they 'would some time or other be useful' (Pierce, 1833). The London Dock tidal record was begun in August 1801, four years before the dock opened in late 1805. Vaughan's desire that the record should be utilised was fulfilled, as at Liverpool, when the first year or two of the records were extracted and used by a Mr. Bulpit to calculate London tidal predictions; these predictions were founded on tables of the hydrographer, Joseph Huddart FRS (Pierce, 1831).

The eighteenth century lassitude of the Royal Society (RS) enabled a reshaping of science to take place in Britain at the start of the second quarter of the nineteenth century (Airy, 1832). This involved the Society for the Diffusion of Useful Knowledge (SDUK), the *Nautical Almanac* (NA), the British Association for the Advancement of Science (BAAS) and the rejuvenated RS itself. The SDUK, created in 1826, published a *British Almanac for 1829* (BA) from 1828 onwards. The BA included a tide table for London, which was also founded upon MacKay's method, although the precise authorship of the tide-table's computer remains unknown.

The BA tide table for London was specifically for London Bridge, but in the late 1820's the bridge was not in a proper state of existence. A new bridge had been begun by John Rennie in 1825, about thirty yards upstream of the old bridge, and was eventually completed on August 1st 1831 (Smiles, 1891). The new bridge, with three fewer arches, offered less resistance to tidal flow than the old bridge. With the London Bridge a peripatetic focus for the tide table, the accuracy of the newly published table was immediately called into question. The Admiralty Hydrographer asked the Warden of Trinity House what their Elder Brethren considered should be HWF&C at London Bridge. The quantified reply, in January 1829, added that it had been based upon an earlier determination of Huddart's (Herbert, 1829). However the BA in total was a resounding success, so that the SDUK co-opted the banker and mathematician John W. Lubbock to direct a sustainable computation of the tide table part.

3. A PUBLISHED METHOD. Lubbock had interested himself in tidal data from London's St. Katherine's Dock as early as October 1828 before becoming involved with the SDUK (Kater, 1828). When the committee resolved to improve their tide table Lubbock tried to see what information about the method employed he could get from established sources. Neither Bulpit nor any of the other London tide table makers would divulge to Lubbock the method whereby they were able to predict tides; as they sold their predictions for a living, the method was their remunerative trade secret. However by late spring of 1829 Lubbock had located the long London Dock records, and because of their abundance he sought additional help to make an analysis of them. The SDUK were particularly lucky in obtaining in June 1829 the services of Joseph Foss Dessiou, the renowned and prolific hydrographer, as their computer to work on the London Dock series (Dessiou, 1838). The Astronomer Royal, John Pond, commended Dessiou to the SDUK. The combine of Dessiou and his father Joseph had been involved in marine cartography and tidal information since at least 1770; Dessiou himself having improved editions of the first of James Cook's hydrography. That hydrography was for around Newfoundland and up the St Lawrence, an area near to the world's largest tidal range. The tutelage for Cook's surveying had been gained from DesBarres, and DesBarres had in turn received his schooling from Bernoulli. Both DesBarres and Dessiou were Huguenots and both compiled charts of Boston harbour, which are dated in the same revolutionary year of 1780.

The Duke of Clarence, First Lord of the Admiralty, had appointed Joseph Foss Dessiou to the Hydrographic Office (HO) in February 1828. Originally, Dessiou was engaged as a naval assistant to compile sailing directions but increasingly he became wrapped up in tidal work. From the summer of 1829 he was working on tides both in the office during the day as his official duty and at home during the night for pocket money. At first the pocket-money was derived from the SDUK, then when the BAAS was created in September 1831 the BAAS took the cost of discussing tides under its wing before some of the burden was eventually passed, not without opposition, to the office of the NA. At first, discussion of London Dock tides was an acceptable part of Dessiou's office duties, because both the then Astronomer Royal, whilst he still had the NA under him, and the Admiralty Hydrographer, Francis Beaufort, simply wanted a reliable tide table available. They wanted one that was derived by a published method, not by something akin to astrology. So there was a straightforward mood for Dessiou discussing the London data for predictions in the BA and for the method whereby they had been derived to be published in the *Companion* to the BA. Once Dessiou had completed the first discussion for the BA of 1830, it was decided to revise immediately for the 1831 edition.

The method examined tidal extrema as functions of lunar age, parallax, declination and the time of year (Cartwright, 1999). In principle, while the method demands the use of data covering a full nineteen-year lunar cycle to produce HW heights, a year suffices for HW times. The later harmonic analysis of the whole tide has not entirely supplanted the pioneering non-harmonic method.

4. THE ADMIRALTY INVOLVEMENT. The Admiralty was the effective science research department of the Hanoverian government (Reidy, 2000). The changing arrangements of the department at the time were a little Byzantine. Its work done, the Board of Longitude was dissolved in 1828 and residual responsibility passed from the defunct Board to the Admiralty. That important residual work, administered by the Astronomer Royal based in Greenwich, was publication of the NA based in London. At the Board's dissolution, it had published the NA down to 1831. At first, under the new arrangement, the Admiralty kept the NA under the Astronomer Royal, and then later on in the 1830's, their Lordships relieved the Astronomer Royal of the NA and created an actual Superintendent of the Nautical Almanac Office. Even then, overall control remained with the Admiralty Hydrographer. Equally Byzantine was the infighting among the scientific men, right at the very heart of the booming Empire.

The success of Dessiou and Lubbock's effort at first producing, and then improving, tidal predictions by a published method was noted among the growing network of scientific society committees and their officers. The Astronomical Society (later the Royal AS), at the invitation of the Admiralty, recommended various changes and improvements to the NA; among those recommendations was one that the NA should bear a supplementary tide table. William Samuel Stratford was appointed to superintend those changes to the NA in April 1831. Despite Lubbock having also desired the appointment, it at first seems bizarre that Stratford should have as vigorously opposed the inclusion of a supplementary tide table as he did, but there were reasons for his opposition.

The opposition involved reasons of control of cost, inspection of the discussion and a balance between ideal science and the pragmatic needs of the highly commercial Port of London. The work begun by Dessiou and Lubbock on London Dock tides for the SDUK, which was allowed to overflow into HO work at Lubbock's request, became the responsibility of the NAO by the time that office published the first ATT. The modern title, the *Admiralty Tide Tables*, did not emerge until 1917. However that ATT is in direct descent, by incremental addition and improvement, from that with the title *Tide Tables for Plymouth, Portsmouth, Sheerness and London, for the year 1833*, and published by the Admiralty.

By 1833 the discussion, originally just for London, had grown to include the three additional ports. That is not to say that the actual labour of computing was undertaken at 3 Verulam Buildings, the home of the NAO. The labour continued to be performed much as it had before Stratford's appearance. The work was undertaken in the HO principally on the top floor at the back of the newly built Admiralty on Whitehall. Work was also undertaken at night, at Dessiou's home in Lambeth. The responsibility manifested itself to the tidal investigators as to who they were to present accounts to, to Stratford at the NAO rather than to Beaufort at the HO. This had the effect of curtailing some disbursements to Dessiou. The responsibility also meant that it was Stratford who regulated the amount of Admiralty computing power that was to be applied to the discussions. The arrangements were tortuous. Stratford did not have the main computer, Dessiou, under his direct supervision. In contrast, Dessiou enjoyed immense patronage and became the effective director of the ATT from their inception until his retirement in 1847, with additional workers directly under him. This effective directorship strengthened, particularly as Lubbock's interest waned in the mid 1830's, once the initial work was complete.

There was a simple scientific objection of Stratford's, to the wholesale adoption by the NAO, of the material tables produced by Dessiou and Lubbock, for London predictions. Stratford wanted it to be demonstrated that their predictions were superior, or at least as good, to those already produced. Stratford remarked that predictions were to be had so relatively cheaply, from Bulpit, White and the others. The fact that those latter productions were secret did not weigh at all with Stratford; he wanted a comparison done. Lubbock read Stratford's comparison before the RS on June 25th 1832, together with a comparison made by Dessiou (Lubbock, 1833). Irrespective of both objection and the comparisons, to include predictions in any forthcoming publication Stratford had either to adopt the method of Dessiou and Lubbock already on offer, or devise a method himself. Stratford was eventually instructed by Beaufort to accept Lubbock's offer and to be grateful for it. The other main advantage of taking the method and material already constructed, was that it was considered to be adaptable for the further three ports to be included in the new ATT, of Sheerness, Portsmouth and Plymouth.

For the general Thames levelling the Admiralty had had tides automatically recorded at their Medway dockyard for some time. Then at the suggestion of the RS, additional observations of the tide were initiated by the Admiralty at their two south coast dockyards as part of the same series. The south coast observations were made manually from October 1831 and were carried through to May 1833, when they were also automated. Part of the Medway series, from January 1832 through to April 1833, was then added and the whole printed (Roget, 1831). That those observations were carried through into the year, in which the ATT predictions were first made for, enables this present comparison for those ports to be made.

5. COMPARISON OF LONDON TIDES. London Bridge is the place where a daily tide table was drawn up for in the thirteenth century, and was where John Flamsteed made tidal predictions for in the seventeenth century. London Bridge, crossing the Thames estuary and marking the furthest upstream point of the Pool of London, is the place from where English cartographers first measured their longitude. Thus, London Bridge was once rather a special place in the surveying world because of its coincidence of the separate datum's of two dimensions, one vertical and the other horizontal. The coincidence did not last, as Greenwich functioned as a Prime Meridian from 1738 (Badger, 1970). Nor did the tidal datum of London Bridge ever gain ascendancy except that, for a place remote from present commercial need, it is surprisingly still retained in the modern ATT and thereby forms a long continued link to the place of Europe's oldest tidal record.

Along the Thames, in the early nineteenth century, there was a profusion of places where tidal observations were being gathered. Sheerness was the lowest point, where the tides were measured with Maskelyne's old transit clock. Higher up, towards the various dock systems, were first the East India Docks. Then Mitchell had erected a gauge at Greenwich. Above Greenwich were the East Country Docks. Then beyond

Limehouse Reach came Eastern London Docks, the Shadwell entrance where the London Dock tide gauge was situated. Close by the older, upriver Wapping entrance to London Docks was St. Katherine's Dock, effectively marking the lower limit of the Pool of London.

The first comparison paper that Lubbock presented to the RS, in June 1831, was based upon the work that Dessiou had done on the London Dock observations of 1808 to 1826. The subsequent comparison paper was for the short period of the first quarter of 1832. That comparison, between observation and prediction, contains some confusion about where some of the figures were for. The paper read by Lubbock, containing notes by Stratford, was presented at a time of utmost friction between the two, so communications might not have been of the best of order. Stratford appears to be the misleading party, which, as he was only concerned with management rather than any hands-on data gathering, might have been due to his lack of knowledge of the geography involved. The paper states that Bulpit's tables were for the entrance to East India Docks, not the eastern entrance to London Docks. William Pierce, the observer at London Docks, was of the opinion that Bulpit had made the tables for his (Pierce's) dock, and that is what Lubbock had expressed. Nevertheless, Stratford reduced all the data to London Docks; adding twenty minutes to Bulpit's times for the ostensible East India Docks and deducting ten minutes to the times of White and the BA for London Bridge. Consequently the validity of the comparison is somewhat compromised.

Lubbock presented more of Dessiou's comparison work concerning London observation and prediction to the RS on June 18th 1835. Whilst this comparison was of the first six months of an unspecified year, inspection of the tabulations from the BA indicate that year to have been 1835 (Lubbock, 1835). Data from that paper was used again only recently (Amin, 1983) showing that there have been large changes in the phase of the tide. The changes are due to secular trends and man-made alterations.

6. QUALITY OF DATA.

London, during the whole of the nineteenth century, was the world's premier port. It was a port with a sufficiently significant tidal regime that any English tidal study could not ignore because of its commercial significance. However London presented a problem of extrapolation. The data gathered in at one place, London Docks, was being used for predictions for another place, London Bridge. That particular problem was not to be found in the non-commercial military ports to which the Admiralty first extended the wider study. This extension of the concerted study of several places over a large geographic area – from the Thames to the Western Approaches – is the second element of Dessiou and Lubbock's endeavour which marks the work out as special, the emerging global nature of which has been described as Humboldtian science (Cannon, 1978).

The basic data of the observations is of time and extreme height at each location. Attached to the published record of the observations are notes that state that the *time* is *mean time*, and respectively that: at Plymouth time is,

> 'observed by the Dockyard clock, which is regulated by a person of the town employed for that purpose. The Height of the Tide is ascertained by a self-registering Tide-gauge, made to range between the lowest and highest limits, from zero to 20 feet: zero being 2 feet above the lower Sill of the Gates of the North New Dock';

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at Portsmouth time is,

> 'obtained through the Royal Naval College; and the Dock-yard Clock, which is used for ascertaining the *Times* of High and Low Water, is regulated thereby, by Mr. Smithers, Clockmaker, Portsea. The Height of the Tide is ascertained by Lloyd's Tide-gauge. The Line from which the Heights are measured, is the Sill of the North Dock Gates';

at Sheerness time is,

> 'as shown by a clock in the Tide-gauge House, adjusted by the Dock-yard clock, which clock is regulated by a sun-dial and the Equation of Time. The height of High and Low Water is registered above the entrance of the basin, or from a fixed line 31 feet below Lloyd's standard mark + XXXI on the Quay. For a description of the Tide-Gauge, see the *Nautical Magazine* for October 1832.'

The published observed times and the published contemporary predictions are taken to be *local* mean time. The modern calculations, which synthesise old predictions, like true predictions themselves, are in Time Zone UT (GMT). Consequently the observations and contemporary predictions were also reduced to UT, so as to be both on the same basis as the modern calculations and so that a simple straightforward comparison could be made.

The London records used for predictions extended back over many years. For the dockyards there was at least one full year, part of 1831 and the whole of 1832, from which to base the time predictions for 1833.

The observations, from which the ATT was computed, originated from two types of sources: a privately owned commercial dock in London and three government owned military dockyards. The London records were noted specifically for the commercial convenience of the Docks (Airy, 1843). In contrast, the dockyard observations were made specifically for the purpose to make tidal predictions. The different natures of the observations' origin explain why the recently located record is only of the military tidal stations and that it does not include the private records made at the tidal station on London docks. The Sheerness record, complete from January 1832, is perhaps because of the observations made there for the great levelling which John Augustus Lloyd carried out on the Thames, in the late 1820's. All of the Sheerness records were made by an automatic tide gauge. The month of installation of the automatic gauge at Plymouth remains uncertain but appears to have been some time in 1832. At Portsmouth, the intended installation of an automatic gauge appears not to have been undertaken before May 1833, when the records cease.

The published observations were once given some analysis in the past. In 1840 George Biddell Airy, the Astronomer Royal, considered that they contained anomalies that he wanted to investigate (Airy, 1840a). However his manuscript papers contain nothing relevant in this direction.

The Proudman Oceanographic Laboratory has supplied the modern calculations for the three ports. Amin in 1983 subtracted 'tides synthesised by modern constituents' from the corresponding observed time of high water. The following data was derived for HW times for the three ports in the same way. From the observations the contemporary predictions have been deducted to produce time intervals in minutes; similarly, from the observations the modern synthesis has also been subtracted, producing further time differences. This gave a negative or positive interval of difference, in whole minutes. The frequency, the number of semi-diurnal observations of each

Table 1. Plymouth data analysis.

	Contemporary	Modern
Mean difference (Mins)	−1	1
Median difference (Mins)	0	1
Standard Deviation (Mins)	12	9
Range (Mins)	78	71
No. of observations	292	292

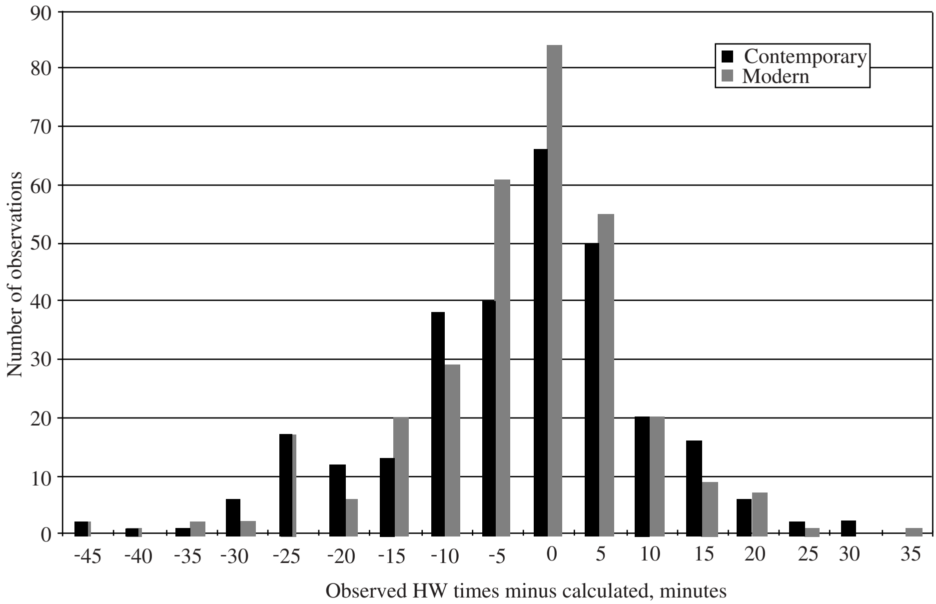

Figure 1. Plymouth 1833: Comparison between contemporary and modern HW calculations.

same time difference was then plotted for the whole four or five months in histogram form.

There are two comparisons to be made of the data. The first comparison is between the observed tide at a particular port and the calculated tide, both contemporary and from a modern synthesis. The second comparison is between the three ports. The contemporary predictions are those that were published in the beginning of 1833, based on the data preceding that year. The modern calculations are based on twentieth century tidal knowledge.

Figure 1 and Table 1 present the results for Plymouth. At Plymouth the values for the contemporary and modern are about the same. This suggests that there has been little change in tidal characteristics at Plymouth, as expected for a deep water port, and that the cruder prediction methods for the contemporary are almost as good as for the modern. The modern histogram is less skewed than the contemporary one. The histograms for both Plymouth and Portsmouth are from 292 observations of HW made over five months.

At Sheerness, the outcome is decidedly mixed (See Figure 2 and Table 2). The mean is not improved using the modern method, but both the standard deviation and range

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Table 2. Sheerness data analysis.

	Contemporary	Modern
Mean difference (Mins)	0	11
Median difference (Mins)	2	1
Standard Deviation (Mins)	18	12
Range (Mins)	89	72
No. of observations	232	232

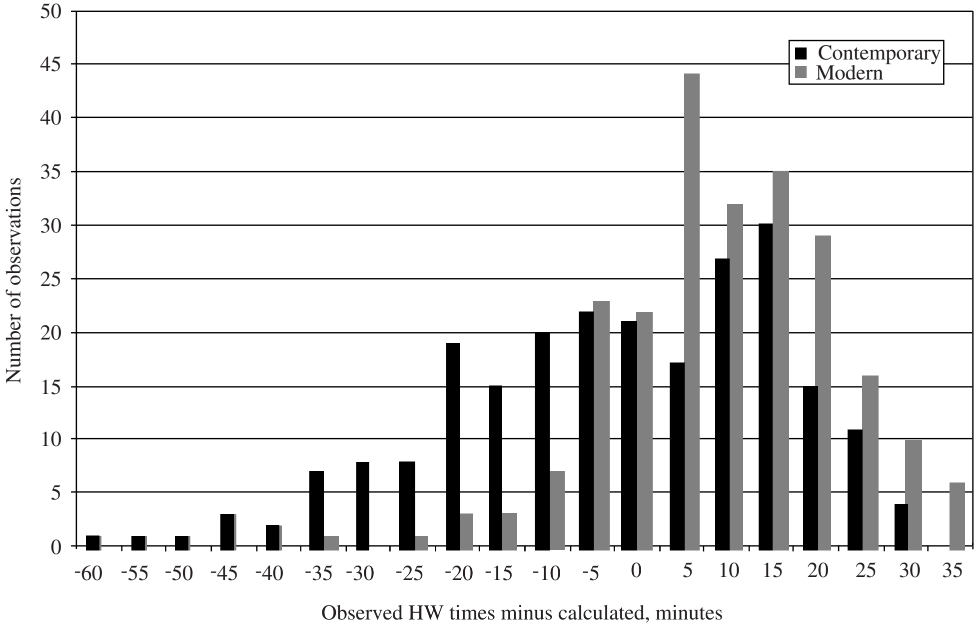

Figure 2. Sheerness 1833: Comparison between contemporary and modern HW calculations.

are reduced. At this port the published data only ran into four months of 1833, giving 232 observations. The time series gave large monthly signals in the contemporary predictions, which are not understood because of the limited data.

In the early autumn of 1832 Lubbock had reminded Beaufort how vitally necessary it was to have the observations annotated with precise details of the time, height, manner of recording and the observer (Lubbock, 1832a). Most of these facts were being supplied from Sheerness but not from Portsmouth or Plymouth. By the end of that season it was Lubbock's inference that what was being supplied from Portsmouth was actually in apparent time (Lubbock, 1832b). Whilst the published observations are explicit about the time being mean time rather than apparent, their graphed time series produced an offset which was so distinct as to cause the following investigation to be made. In Figure 3 the original observations have been assumed to be in apparent time, as Lubbock inferred, and have been adjusted by the equation of time. The result suggests that Lubbock's suspicion was correct.

Were the observations for Portsmouth available for a full twelve months then it could definitely be stated whether the assumed application of the equation of time has been valid or not. With only four months available it can only be guessed at. The

Table 3. Portsmouth data analysis.

	Contemporary	Modern
Mean difference (Mins)	−4	9
Median difference (Mins)	−3	10
Standard Deviation (Mins)	13	17
Range (Mins)	72	93
No. of observations	292	292

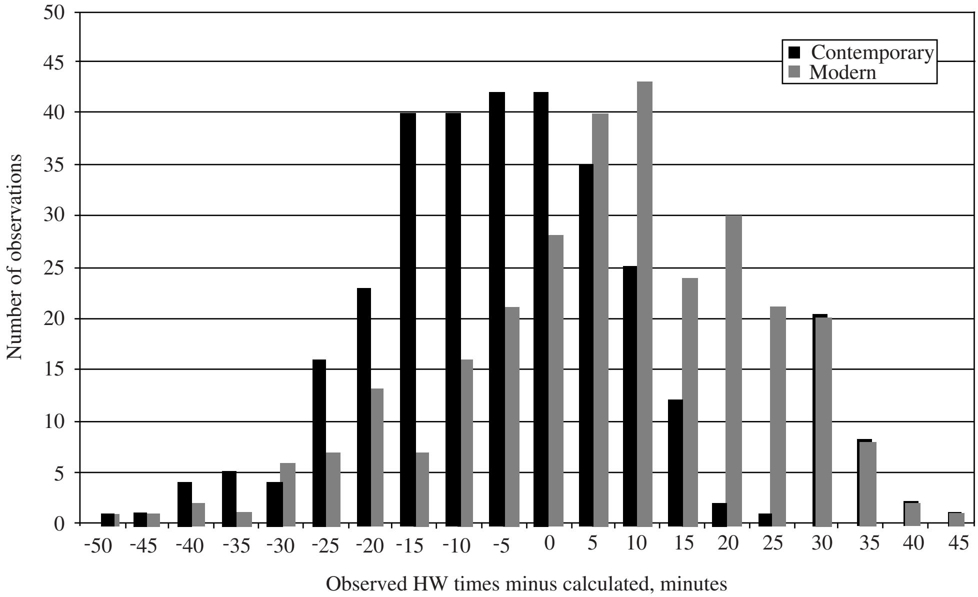

Figure 3. Adjusted Portsmouth 1833: Comparison between contemporary and modern HW calculations.

spread in the distributions for Portsmouth in Table 3 could be due to measurement errors or to errors in manually made predictions. Most importantly some spread is likely to be due to the effect of storms which cause small changes in HW times, and which no normal tidal prediction method can include.

7. DISCUSSION. The BA tide table was solely for London yet gave both HW height and time. In contrast the first ATT, uniformly for the four ports concerned, gave HW times alone; the height of HW and the time and height of LW, which were not then given, developed erratically. A comparison of the observed heights could be made with heights from a modern synthesis but it would not be germane to the purpose of this paper, which is a comparison involving the 1833 predictions. This exclusivity of HW time over height for all four ports may be partly attributed to the then relative ease of producing time rather than height predictions. In particular, data from the naval ports was not available for a full cycle.

Some thought can be given to the basic data and the measurement accuracy. The automatic devices were then new inventions and untested, nevertheless, as simple clockwork devices they were uncomplicated. The automatically-made record is of

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a superior quality to the man-made one because it is a continuous record of the actuality, whereas that manually made is a reactionary record of extrema alone. Whilst the times are recorded to the minute this discrimination is acceptable from the automatic gauges using stilling wells, but it is a matter of coarse judgement in the case of manual recording, as the tide takes several minutes to make any discernible height change where the level is observed in the open dockyard. A further complication with manual recording is how to secure illumination of the water surface in order to see accurately enough in the dark of night.

Shifts in the range of time differences are of the same order at all three ports. In summary both contemporary and modern methods show remarkably similar distributions when plotted against observed times of HW. At all three places the mean and median are both negligible for the contemporary method. However the modern method has mixed results with a negligible mean and median for Plymouth but values over 10 minutes for Portsmouth and Sheerness. Whilst the heights were recorded to an accuracy of half an inch, it is the magnitude of range which is useful in helping an accurate high water time to be measured. Fortunately all three ports exhibit good spring ranges, with Plymouth and Sheerness being about 18 feet and Portsmouth a little less at 14 feet.

The observations were carried on in a second series up to 1838, after which Airy considered that there were certain anomalies in the time. Despite his doubt they do appear to be of good standard (Airy, 1840b). This is justified by the contemporary predictions appearing to be as good a match to the observed value (if not better) than the modern predictions. The distributions of differences show that the contemporary method was generally as good as the modern method for one port but was looking superior for the other two ports. Thus two ports show a bias error. However this should be not interpreted that the modern method is actually less accurate but is more probably because of one or all of the following causes.

Physical change can occur in the underwater landscape in a port and its approaches. This could have particularly affected Sheerness which is above the shifting banks and estuarial shoals of the Thames mouth. The relative deep-water approaches to Plymouth would be clear of sedimentary factors. Portsmouth is somewhere within the middle of the other two types of port landscapes and subject to some of the complex tidal influences peculiar to the inner Isle of Wight area. Of the three ports it is in Portsmouth, where the period of high water is extended, that there is extra difficulty in deciding which is the particular minute of HW.

8. CONCLUSION. The tide prediction method developed in the early nineteenth century remained the Admiralty method for a century; it is generically called the non-harmonic method. The harmonic method was developed in the second part of the nineteenth century, and was eventually adopted by the Admiralty as its method in the 1920's. While the harmonic method remains in use throughout the world, some tides in parts of the eastern North Sea remain suitable for prediction by the non-harmonic method. As has been demonstrated, very acceptable HW times were produced from the first by the non-harmonic method compared to a modern synthesis.

With Portsmouth, Plymouth and Sheerness being directly open to their respective influencing sea, at none of those places can changes be significantly attributable to man-made alterations; as was the case with the examination undertaken in the Thames. For London Bridge, Amin ascribed some of his differences to changes in the secular trends in tidal harmonics. Effectively we have now extended the study to four ports. As there is conflicting evidence for the three relatively close military places and that two of the four ports are on the Thames, then it cannot be said that there is one common time-development in the phase of the tide, within the English south coast area.

Over the years a total of at least three comparisons have been made of the intrinsic use of the published prediction method used for the first ATT. Although they were each for merely one of those four ports that made up that ATT, London. This study extends judgment, and justification, for the original publication being brought into existence to the authority of the modern harmonic method and the advantage of electronic computation.

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REFERENCES

Airy (1832). Royal Society of London, LUB.A.96.

Airy (1840a). Cambridge University Library, RGO/6/499/16.

Airy (1840b). Cambridge University Library, RGO/6/499/147.

Airy (1843). Cambridge University Library, RGO/6/499/82.

Amin, M. (1983). On perturbations of harmonic constants in the Thames Estuary, *Geophysical Journal of the Royal Astronomical Society*, **73**, 587–603.

Anonymous (1833). *Observations of the tides communicated to the Royal Society by the Admiralty and printed by order of the President and Council*, London, 1833. The only known copy of this publication is presently located in Cambridge, at the library of the Institute of Astronomy, with shelfmark Rc.606.

Badger, G. M. (1970). *Captain Cook navigator and scientist*, p. 38.

Cannon, S. F. (1978). *Science in culture*, New York, 104–105.

Cartwright, D. E. (1999). *Tides a scientific history*, Cambridge, p. 91.

Dessiou (1838). University College, London, SDUK LUB.24.

Herbert (1829). Hydrographic Office, Taunton, *Letters in Before 1857* H.517.

Innes (1832). Royal Society of London, LUB.I.8.

Kater (1828). Royal Society of London, LUB.K.2.

Lubbock (1832a). Royal Society of London, *Letter Book 425*.231.

Lubbock (1832b). Royal Society of London, *Letter Book 425*.273.

Lubbock, J. W. (1833). Note on the tides in the port of London, *Philosophical Transactions of the Royal Society*, Part I 1833, 595–599. Note there is a typographical error on page 595 which states Deacon instead of Dessiou.

Lubbock, J. W. (1835). Discussion of tide observations made at Liverpool, *Philosophical Transactions of the Royal Society*, **125**, 275–299.

Pierce (1831). Royal Society of London, LUB.P.119.

Pierce (1833). Royal Society of London, LUB.P.121.

Reidy, M. S. (2000). *The Flux and Reflux of Science: The Study of the Tides and the Organization of Early Victorian Science*, University of Minnesota, PhD thesis.

Roget (1831). Royal Society of London, LUB.R.114.

Smiles, S. (1891). *Lives of the engineers harbours – lighthouses – bridges Smeaton and Rennie*, London, p. 370.

Woodworth, P. L. (2002). Three Georges and one Richard Holden: the Liverpool tide table makers, *Transactions of the Historic Society of Lancashire and Cheshire*, **151**, 19–51.