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ON THE PREDICTABILITY OF CURRENTS

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ABSTRACT

The inclusion of current predictions in conventional tide tables is questioned, since currents are known to have a high level of irreducible variability and since the quality of the predictions can seldom be controlled by a systematic comparison with observations. Two months of current observations at Race Rocks, B.C., are checked against their predicted values : the accuracy of the predictions is found to be much lower than that implied in the tables.

Tides and currents

The sight of current predictions alongside conventional predictions of the water level in tide tables has disturbed me for a long time because this implies that water levels and currents possess the same degree of predictability. I suggest that it is not so, by comparing the characteristics of the two variables : the tide (vertical) and the current (horizontal) :

(*a*) Tidal elevations are coherent and change smoothly over hundreds of kilometres.

Currents correlate poorly over a few metres in the vertical and over a few hundred metres in the horizontal.

(*b*) The measurement of water levels is simple and direct.

The measurement of currents is difficult and, as yet, there exists no definitive method to measure them reliably.

(*c*) We have years of records on the water levels in our major harbours.

Current measurements cover an interval of a few days to a few months.

(*d*) Tide predictions are based on the hypothesis that the variation in the water level can be modelled by a superposition of harmonics of constant amplitude and phase; this hypothesis is supported by the reliability of the predictions.

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Current predictions are based on a similar hypothesis; still, the assessment of conventional harmonic analyses of current data indicates they seldom account for more than 60 to 90% of the tidally induced variability.

(*e*) The tide has only one degree of freedom, the vertical, while the current is a displacement within a fluid and has at least two, if not three, degrees of freedom.

(*f*) Tide predictions are controlled by comparing them with later observations. If ever they are found wanting, the constituents are modified in order to improve them.

(*g*) Current predictions cannot be checked against predictions in general, because the current meters have long since been removed from the site, once the predictions find their way into the tables. This is their most disturbing feature since the scientific method consists in making predictions which are then checked later by observations. One could predict the end of the world by the year 3000, but this does not constitute a scientific prediction, as one may choose to believe it or not. This is the very position of current predictions : they may be right or they may be wrong, and there is usually no way of finding out unless they are checked by further measurements.

(*h*) Currents have additional irritating characteristics of their own. In zones of shallow depths and complicated topography, it often happens that the ebb and flood directions are not colinear. A conventional analysis of such a current will give misleading results : it will suggest the presence of a net flow which is completely fictitious, it will underestimate the length of the semimajor axis of the ellipse component and it will add spurious contributions to the higher harmonics (see the Appendix). In addition, for any depth, the field of velocity varies with the state of the tide and with weather perturbances; this type of variability, even if it has a periodic component, cannot be fully represented by methods applicable to the vertical tide.

(*i*) Measurements in one area of a strait may be quite unrepresentative of what is happening in another section because of the low horizontal and vertical coherence of currents : since current measurements impede navigation, lines of current meters in busy channels have to be installed away from where we wish to know the velocities. Current measurements are also affected by wave action in the top 15 metres of the water column. This is the zone for which we have the least information while at the same time what happens in these first 15 m is of prime importance to navigation.

Therefore, even in the absence of checks on current predictions, I have many a priori reasons to doubt their accuracy using methods and hypotheses identical to the ones serving for the vertical tide.

Check on the current predictions for Race Rocks, B.C., during the winter of 1978

Currents were monitored almost continuously at the site of Race Rocks, B.C. (48°18'N - 123°32'W) between November 1971 and March 1974. Additional observations were taken between January and April 1978. The whole file of current data collected at this site was kindly supplied to me by the Institute of Ocean Sciences, Victoria, B.C., for further study. It consists of 22 sets of continuous measurements and 14 of these sets were retained because of their good quality. The tide tables predictions could not be checked for the years 1971, 1972 and 1973 because Race Rocks was not included for those years, but they certainly could for the year 1978 as Race Rocks had replaced the station Turn Point in the tables. Records 21 and 22 cover the year 1978; unfortunately, record 22 could not be used for the verification because its scrutiny revealed problems with the data. Similarly record 20, covering the observations in 1974, had to be rejected for the same reason. This underlines the paradoxical nature of current predictions, since out of three possible sets of observations that could be used to control them, two had had to be rejected because the observations were « wrong ». Still we are left a longish record (#21), of acceptable quality, which we may compare with the predictions listed in the 1978 Tide Tables (Anonymous). Record #21 covers the interval:

10 hours 11 January 1978 to 10 hours 17 March 1978,

some two months of observations. This appears as the only record in existence in Canada which can be used to test the quality of the current predictions which have taken up increasing space in the Canadian Tide Tables.

The comparison between observations and predictions was done in the following way. The original measurements taken every ten minutes were smoothed and decimated to one value per hour. The maxima and minima of $\sqrt{u^2 + v^2}$, the current speed, were searched for by interpolation and the corresponding times were noted. The search yields the times of flood, ebb and turn, to the minute and their associated speeds, to the cm/sec. The tide tables predictions covering the interval 14 h 25 min January 11 to 3 h 20 min March 17 1978, were key punched and entered into the computer. Since the times and speeds in the predictions are rounded off to the 5 minutes and to 0.1 knot, this implies that such an order of accuracy is expected from the predictions.

Differences between the observed and predicted currents

The quantity which is of foremost practical importance is the vector difference between the current actually observed at the predicted time of flood or ebb, and the predicted current. This would be the drift noticed by a mariner trying to steer his ship by the tide tables. This can be quite large if the time of maximum has been missed by an hour or more; one may even encounter situations when the two currents point in opposite directions.

One could also use as an error parameter the vector difference between the observed maximum current and the predicted maximum current, disregarding the time difference between them. The vector difference once again can be quite large if there are appreciable discrepancies in speed or orientation.

A more conventional approach is to calculate the difference between the observed and predicted times of maxima, the difference between the observed and predicted speeds and finally, the difference between the observed and predicted directions of the maxima. Here I make a distinction between the ebb and flood currents in order to check if they flow in parallel directions and if they have the same intensity.

I calculated all the above mentioned error measures for the data available at Race Rocks in 1978 and I give the results in Table 1. The interpretation of the

Table 1

Comparison between the currents observed and the currents predicted at Race Rocks, B.C. (48° 18' N - 123° 32' W) between the 11th of January and the 18th of March 1978

	Vector difference between the current observed and the maximum current predicted				Conventional error statistics on ebb and flood						Error on times of turns
	At the predicted time of maximum		At their respective time of maximum		Time all	Speed all	Speed		Speed		
	v_r	θ_r	v_r	θ_r	Δt	Δv	flood Δv	ebb Δv	flood $\Delta\theta$	ebb $\Delta\theta$	Δt
Average of the absolutes values ..... $\|\bar{x}\|$ =	0.65 kt	74°	0.78 kt	78°	29 min	0.48 kt	–	–	–	–	–
Average ... $\bar{x}$ =	0.65 kt	– 23°	0.78 kt	– 26°	– 10 min	0.36 kt	0.25 kt	0.45 kt	0°	25°	– 8 min
Standard deviation... σ =	0.54 kt	82°	0.61 kt	84°	40 min	0.53 kt	0.37 kt	0.67 kt	19°	17°	33 min
Maximum value...... x_M =	4.0 kt	176°	2.6 kt	177°	109 min	1.9 kt	–	–	+ 65°	+ 59°	103 min
Minimum value...... x_m =	0.0 kt	– 166°	0.0 kt	– 177°	– 115 min	– 0.7 kt	–	–	– 60°	– 8°	– 126 min

Number of samples : N = 239 flood and ebb
N = 114 flood
N = 125 ebb
N = 225 turns

vector differences in the first two panels of the tables is the following : they give the characteristics of the vector joining the predicted velocity and the velocity observed either at the predicted or the observed time of maximum, in order to form a closed triangle. The drift vector has an average speed of 0.65 kt, an average inclination of − 23° (trigonometric degrees measured counterclockwise from the east). It reached a value of 4.0 knots but it may also be 0. The average angular discrepancy between the two vectors is 74° when I disregard the sign of the discrepancy. I now move to the difference between the two vectors at their respective times of maximum. The mean speed of the drift is 0.78 kt; it reached 2.6 kt once but it also may be 0. I now review the more conventional statistics. I give the time and speed differences for all flood and ebb currents taken together and then give separate statistics on the flood and ebb speeds and directions. The average time error is − 10 minutes and indicates that the errors in the predicted times are more or less evenly centered around the correct value.

The RMS value, however, indicates that it amounts on the average to 40 minutes and, on occasions, it exceeds ± 100 minutes. The average speed error is 0.36 kt and therefore indicates a systematic underestimation of the speed of the current at Race Rocks; it has also a rather high variability indicated by the value of 0.53 kt of the standard deviation. The scatter does not reflect on the quality of the predictions but on the variability of the current at the selected point of measurements, one of the fundamental characteristics of currents, as discussed previously. The statistics on the flood and ebb speeds show that the ebb current is systematically larger than the flood current and that it is twice as variable. The orientation data show that the ebb current is not colinear with the flood current and that it is orientated towards 204° rather than 179° (271° True) as indicated in the tide tables. The latter statistics do reflect on the quality of the predictions for Race Rocks or, more precisely, on the analysis.

Sources of errors and of uncertainties in the current at Race Rocks

Currents with a marked asymmetry in strength and direction, between ebb and flood, are the rule rather than the exception in zones of shallow water with a variable bathymetry. The observations at Race Rocks indicate that the local flow has a highly variable character. The current may rotate to the right or to the left or it may be rectilinear; the directions of flood and ebb are seldom parallel and vary appreciably with time; the circulation may be very strong at times, running mostly westward, but with episodes of easterly flows. The appendix shows the misleading results which can be obtained by analysing a simple harmonic current running more strongly in the ebb than in the flood direction. A drift deduced from a point measurement of currents may be caused by an asymmetry of the flow or by a genuine circulation : the situation can be clarified only by taking additional measurements across the section. Table 1 suggests that the ebb current runs stronger than the flood by some 0.2 kt; this may mean a net circulation (which cannot be predicted) or an asymmetry in the flow (which could be taken into account).

There exists within the data an irreducible variability which cannot be improved by an analysis, no matter how refined it may be. The 14 good records at

Race Rocks indicate that some 0.32 kt of current velocity cannot be represented by the superposition of a constant current and a set of harmonic constituents. An investigation of the net current itself during all the years of observations reveals that its average value varied between 0 and 0.6 kt depending on the season, the flow being more steady in summer than in winter, with larger superimposed variations of a shorter period.

The following sources of error and uncertainty exist for the current at Race Rocks:

(*a*) a possibly fictitious drift,

(*b*) a systematic underestimation of the semi-major axis of the tidal components as indicated by the statistics on Δv, some 0.4 kt if not more,

(*c*) the unknown value of the outward circulation, some 0.6 kt at times,

(*d*) an irreducible variability within the current signal of some 0.32 kt.

Totalling these up, excluding *a*) and *b*) which can be eliminated by doing a better analysis, I get a limbo value of 0.92 kt on a current whose order of magnitude is 2.5 kt, some 37% of it. I try to put this uncertainty in perspective by assuming that it applies to the vertical tide at Victoria, which amounts to 1 or 1 1/2 m. The tide there is routinely predicted to within a few minutes and a few centimetres of its actual value, except when there is a major storm. If it had the variability of a current, it could be missed by over an hour and by more than 30 cm, as if there were a major storm all the time; the natives of Victoria would have lost patience with their tide tables a long time ago.

Going back to Table 1 and taking a t value of 1.96 in $\bar{x} \pm t\sigma$, it insures at a level of 95% confidence that the tide table predictions will give a drift vector of magnitude less than 1.7 kt, an error less than ± 1.3 hours in the time of maximum, an error less than 1.4 kt in the speed of the ebb or flow current and an error less than $\pm 35°$ in its direction, if we disregard the systematic error in the ebb direction. The RMS error on the predicted time amounts to 40 minutes while that on the speed is 0.5 kt, besides its systematic underestimation; this is 5 to 8 times as large as the accuracy implied in the tables. Such predictions clearly do not compare in accuracy with those of the vertical tide.

CONCLUSIONS

The intuitive belief that currents cannot be predicted with the same level of precision as the tide, has been confirmed by comparing a set of observed currents with their predicted values: the errors have the same order of magnitude as the variable itself. It is unwise to include such predictions in conventional tide tables because it suggests that we can forecast currents as accurately as the tide. Straightforward analysis methods used to process water levels can also give rather erroneous results when applied to currents. The study of currents is essentially a research problem and should not be considered a matter for routine data processing at the clerical or technical level. Once a set of current data has been carefully studied, analyzed and interpreted, there is no harm, on the other hand, to include some statistics about it in the pilot books. The times of turns, of ebb and flood could be given by time differences with the tide at some nearby mainland station, rounded off to the hour, as well as the order of magnitude of the speed for large and small tides. This represents the maximum extent of our knowledge about the predictable part of currents.

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Reference

Anonymous : Canadian Tide and Current Tables, 1978, Vol. 5. Fisheries and Oceans, Ottawa.

APPENDIX

Spectral analysis of an oscillatory current which ebbs and floods at different velocities in directions which are at an angle distinct from 180°.

Description of the current

It has frequency s. It floods with a maximum velocity a; it ebbs with a maximum velocity b in a direction separated by 180 + c° from the flood direction. I work in trigonometric degrees, that is to say, I measure angles counterclockwise from the east. I take the flood direction as pointing to the east (0°); the ebb direction has therefore orientation 180 + c°.

Analytic description

$$v = \begin{cases} (a \cos st,\ 0) \text{ for } st \in [-90°,\ 90°] \\ (b \cos c \cos st,\ b \sin c \cos st) \text{ for } st \in [90°,\ 270°] \end{cases}$$

Spectral analysis

$$\mathbf{v}(t) = \mathbf{v}_0 + \sum_{j=1}^{\infty} v_j \cos s_j t$$

$$v_0 = \frac{1}{2\pi}\int_{-\pi/2s}^{3\pi/2s} v\,(t)\,dt$$

$$v_j = \frac{1}{\pi}\int_{-\pi/2}^{3\pi/2} v\,(t) \cos s_j t \; d\,(st)$$

Only cosine terms survive in the Fourier expansion and only frequencies being even multiples of s give non-zero contributions.

$v_0 = ((a - b \cos c)/\pi,\ (-b \sin c)/\pi)$, a fictitious drift current different from $c \neq 0$ and $b \neq a$.

$v_1 = ((a + b \cos c)/2,\ (b \sin c)/2)$,

a component at the frequency s of the current. It indicates a rectilinear current running in a direction intermediate between the correct ones and having a magnitude larger than the flood current and less than the ebb current.

$$v_n = \frac{(-)^{n/2}}{\pi}\left[\frac{1}{n+1} - \frac{1}{n-1}\right]((a - b \cos c), - b \sin c) \qquad \textbf{n even}$$

These are fictitious high frequency components whose frequency is an even multiple of that of the current and which are created by this type of flow.