CHARTS OF THE O₁, K₁, N₂, M₂, AND S₂ TIDES IN THE CELTIC SEA INCLUDING M₂ AND S₂ TIDAL CURRENTS

BY

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in the Celtic Sea
including $M_2$ and $S_2$ tidal currents

by

J.E. Jones

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SUMMARY

A two-dimensional numerical model of the West Coast of the United Kingdom has been used to compute co-tidal and co-amplitude charts for the five tidal constituents $O_1$, $K_1$, $N_2$, $M_2$ and $S_2$ in the Celtic Sea area. Charts showing tidal current ellipse parameters for the $M_2$ and $S_2$ tidal currents of that area have also been drawn on the basis of results obtained from the model.

A comparison of observations and model results has been carried out and a series of scatter plots have been prepared which indicate the overall deviation of the model from observation.

This report contains the computed charts, scatter plots and tables of observations and it is intended that, by their combined use, the $O_1$, $K_1$, $N_2$, $M_2$ and $S_2$ tides as well as the $M_2$ and $S_2$ tidal currents may be determined for any point in the Celtic Sea.
INTRODUCTION

The tidal information presented in this report was obtained from a two-dimensional numerical tidal model of the West Coast of the British Isles. The model area, delineated in Figure 1, comprised part of the sea area north of Ireland and west of Scotland (South of 56° 52'N and East of 8° 48'W), the entire Irish Sea and most of the Celtic Sea (North of 48° 48'N, East of 9° 48'W and West of 4° 12'W). The open sea boundaries of the model are represented by dashed lines in Figure 1 and the land boundaries are shown by the short straight lines approximating the actual coast.

The grid resolution of the model was 4 minutes of arc in latitude and 6 minutes of arc in longitude. This mesh size is indicated by the tick marks along the edges of Figure 1 and also by the short lines used to approximate the coast. Input consisted of prescribed elevations along the open boundaries composed of five tidal constituents O1, K1, N2, M2, S2. These were derived by reference to a number of sources including a larger model of the Continental Shelf (Flather 1976), on- and off-shore tide gauge observations (Cartwright et al 1980), and results from a hydraulic model of the English Channel. (Chabert d'Hières and Le Provost 1978).

In the numerical model itself, non-linear friction terms were used and the drying of shallow areas was also represented. Convection terms however were not included. Tide-generating forces and the effects of Earth tides and Ocean tide loading were ignored.
From an initial state of rest the model was run for the equivalent of 7 days to allow the damping out of transients. The run was then continued for a further 28 days and provided hourly values of elevation and current at each grid point. A tidal analysis was then performed to extract the five tidal constituents at each model grid point in the Celtic Sea area, both for elevations and east and north components of current. The shaded area of Figure 1 defines the Celtic Sea portion of the model as used in this report.

For the elevations, co-tidal and co-amplitude charts were then plotted, however for the currents further processing was required before the tidal current ellipse parameters could be presented in contour form.

The work described here was performed to provide basic tidal information for a programme of three-dimensional numerical modelling of the current structure and circulation in the Celtic Sea.
2 EXPLANATION OF CHARTS

2.1 General Remarks

In deciding how best to present the data produced by the model various publications were consulted (Chabert d'Hieres and Le Provost 1978, Deutsche Demokratische Republik Seehydrographischer Dienst 1975, Great Britain Hydrographic Department 1973 and 1974, Pingree and Griffiths 1982, Robinson 1979) The co-tidal and co-amplitude charts are presented in a fairly standard form. However it is difficult to present information on currents briefly and without ambiguity. Although the presentation used here produces some ambiguity in certain restricted areas of the charts, it should be possible to extract the M2 and S2 current information simply and clearly for most of the Celtic Sea.

The charts as presented here depict the coasts bordering the Celtic Sea, the 100 fathom isobath in the south-western corner, the outline of the model boundaries and the contour field appropriate to the parameter being plotted. Thus the relation of the model to the actual coastline may be seen and the model mesh size is also indicated.

Labelling of contour levels has been omitted in areas where contours are crowded, however the value of an un-numbered contour should be easily obtained by inspection.

The contour interval varies from chart to chart and is as follows:
### Elevations

<table>
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<tr>
<th>CONSTITUENTS</th>
<th>AMPLITUDE INTERVAL</th>
<th>PHASE INTERVAL</th>
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<tr>
<td>O1, K1</td>
<td>1 cm.</td>
<td>10 degrees</td>
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<tr>
<td>N2</td>
<td>5 cm.</td>
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</tr>
<tr>
<td>M2, S2</td>
<td>10 cm.</td>
<td>10 degrees</td>
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</table>

### Currents

<table>
<thead>
<tr>
<th>PARAMETER(M2)</th>
<th>INTERVAL</th>
<th>PARAMETER(S2)</th>
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<tr>
<td>a</td>
<td>10 cm/s</td>
<td>a</td>
<td>2 cm/s</td>
</tr>
<tr>
<td>b</td>
<td>10 cm/s</td>
<td>b</td>
<td>2 cm/s</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>10 degrees</td>
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</tr>
<tr>
<td>(\frac{\delta}{\omega})</td>
<td>1 hour</td>
<td>(\frac{\delta}{\omega})</td>
<td>1 hour</td>
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#### 2.2 Elevations

The co-tidal and co-amplitude contours are presented in usual form. The tidal amplitudes are given in centimetres and the phase in degrees - in the usual sense of being the lag of the phase of the tidal constituent behind the phase of the corresponding equilibrium constituent at Greenwich.

#### 2.3 Currents

There are five charts for each of the M2 and S2 tidal current regimes and they depict the five tidal ellipse parameters.

The semi-major axis is shown in the chart labelled \(a\), and the semi-minor axis is given on the chart labelled \(b\). Because of the contour interval chosen, the \(b\) chart for M2 has little information
along the southern Irish coast. As a guide, values of \( b \) given by the model close to this coast range from 1.5 to 4 cm/s. The orientation of the major axis is given on the chart for \( \alpha \): where \( \alpha \) is the angle of the major axis to the easterly direction, constrained to lie between +90 degrees, due North and -90 degrees, due South. \( \alpha = 0 \) is therefore due East. The chart labelled \( -\varepsilon_\omega \) gives the time in solar hours (after transit of the M2 or S2 equilibrium constituent at Greenwich) at which the current due to the harmonic constituent is a maximum (given by \( a \)) in the direction \( \alpha \). Here, \( \varepsilon \) denotes the phase lead and \( \omega \) the angular speed of the constituent. The fifth chart gives the direction of rotation of the current vector.

Restricting \( \alpha \) to lie between +90 degrees and -90 degrees has led to a rather convoluted appearance to the \( -\varepsilon_\omega \) contours in areas where the direction of the semi-major axis is close to the North-South direction, shown on the charts in the vicinity of headlands where tidal streams merge or diverge. This restriction on \( \alpha \) however was felt necessary to indicate unambiguously the times of ebb and flood currents. In the Celtic Sea as a whole, flood currents are generally in an Easterly direction.

Note also the "amphidromes" in the \( \alpha \) chart. These are not current amphidromes i.e. where tidal currents are zero; rather they are points where the tidal ellipse approaches circularity and the distinction between major and minor axis becomes ambiguous. These areas also produce further convolutions in the \( -\varepsilon_\omega \) charts.
3 COMPARISON WITH OBSERVATIONS

A survey was next carried out to assess how closely the model reproduced the actual tidal regime in the Celtic Sea. The locations of the tide-gauge and current meter observations used for comparison purposes are given in Figures 2 and 3.

For the elevations, harmonic constants derived from tide-gauge observations were compared with constants derived at the nearest corresponding points of the numerical model grid. These comparisons are given in Table I. Scatter plots were drawn and are presented here with a distinction between on-shore tide gauges (dots) and off-shore tide-gauges (crosses).

As a further step a linear regression was carried out on each scatter plot with the assumption that the observations were correct and the model results contain all the errors. The regression line is drawn on each scatter plot and the regression coefficients of r (correlation), m (slope) and b (intercept) are noted below each graph.

To give an idea of the confidence level in the regression line two further dashed lines have been drawn placed at a distance of two standard errors of estimate each side of the regression line. Their interpretation is as follows: given any observed value there is a 95% chance that the corresponding model value will lie between the dashed lines on the vertical line through the selected observed value.

For the currents a different approach was required.

In general at a current meter station there may be two or three current meters located at different levels through the water
column. As the model provides only depth-integrated currents it is necessary in some way to average out the current meter observations at each station to provide an "observed" depth-integrated current.

From each current meter harmonic constants were derived for both the East and North components of current. For each component a parabolic fit through depth was applied and thus an average harmonic constant could be determined. In the case of only one current meter it was necessarily assumed that the components of current derived from the meter represented the average values.

Combining the East and North components of each depth-integrated harmonic constant the "observed" tidal ellipses could then be calculated. The model results and the comparisons are given in Table II. As for the elevations, scatter plots and regression lines were drawn for the ellipse parameters excepting rotation.
4 HOW TO USE THE CHARTS

4.1 Elevations

It is a simple matter to extract the Ol, K1, N2, M2, or S2 tide at any point in the Celtic Sea by reference to the appropriate chart.

If it is required generally to know how far the actual tidal constants may deviate from the model values given by the charts, reference may be made to the corresponding scatter plot. Having obtained a value from the chart find this value on the vertical (i.e. model) axis on the scatter plot and from this point draw a horizontal line across the graph. The intersection of this line with the upper and lower dashed lines defines a lower and upper observed value respectively which may be read off on the horizontal (observed) axis. One can say that the model value obtained from the chart lies at the upper 95% limit of the lower observed value and the lower 95% limit of the upper observed value.

If more specific information is required for a particular area Table 1 may be consulted and a comparison made between observations and model results in the particular locality.

4.2 Currents

By combination of the five M2 (or S2) charts giving a, b, \( \alpha \), \( \gamma \), and rotation, the depth-integrated tidal ellipse may be constructed generally for any point in the Celtic Sea.

From the chart giving a the semi-major axis may be drawn, while from the chart giving b the semi-minor axis may be found.
The inclination of the semi-major axis to the easterly direction is given by $\alpha$ read from the appropriate chart. The time of the maximum current, $a$, in that direction is given by the $-\varepsilon/\omega$ chart as explained previously.

As for the elevations, scatter plots have been drawn for the ellipse parameters and these may be used in a similar fashion to determine how far the model tidal ellipses deviate from those found in nature.

Table II also enables comparisons to be made in local areas.
5 REMARKS

5.1

It is an assumption of the regression lines drawn on the scatter plots that all the observations are correct. However this need not necessarily be the case. Apart from possible instrumental problems the constants themselves may be subject to apparent change, such as K1-see below.

Tables I and II contain several instances of tide gauges or current meters fairly close to each other or even observations taken at the same location but at different times. These give an indication of the variations possible in the observed values.

In addition the observed values quoted in this report may be updated from time to time as the results of new measurements.

5.2

It may be noted that the comparisons between the observed and model results for the K1 tide are substantially poorer than for the rest of the components.

This is due to the difficulty in determining the actual K1 tide from observations. It cannot be separated from the tidal constituents P1 and S1 without using records of at least six months and one year respectively. Only a few on-shore tide gauges provide records of this length; off-shore tide gauges usually provide records of one month's duration. Problems with the K1 tide in the Celtic and Irish Seas have been noted elsewhere (Baker and Alcock 1983). In the present case the poor comparison may be due to the fact that a large
number of the off-shore tide gauge measurements were made in 1978, a
time when the nodal factors reduced the K1 amplitude to a smaller than
average value. Under these conditions K1 can nearly cancel with P1
twice a year near the equinoxes. Therefore at this time the S1 compo-
nent may have been a significant proportion of the K1 signal in any
harmonic analysis.

Furthermore the S1 signal may contain a significant radiation
tide which varies from place to place in the Celtic Sea. For an
off-shore measurement, having obtained a value for K1 it is possible
to estimate what proportion of this value is actually due to S1 by
reference to a nearby on-shore tide gauge measurementprovided of
course that this tide gauge has produced at least one year of data).
However this may be a very approximate procedure as the radiational
part of the S1 tide may be different between the on and off-shore
positions. As an example at Station H two analyses which respectively
ignore S1 and then include it using St. Marys as a reference give the
following results for the K1 amplitude: No S1, 7.1 cm.; Including S1,
10.2 cm. The error in the amplitude can thus be of the order of 30%.

5.3

In addition to the M2 and S2 tidal currents, the east and
north components of current for the O1, K1, and N2 tidal currents have
been extracted. These are available in tabular form at I.O.S. Bidston.

5.4

It is a point worth noting that the \( \mathcal{K} \) charts for the M2
and S2 currents are very similar. There is perhaps a difference of
only ten degrees between them at any point. Thus the semi-major axes of the M2 and S2 tidal ellipses are very nearly aligned and so it may be stated that the maximum tidal current due to the M2 and S2 components, generally throughout the Celtic Sea, can simply be taken as the arithmetic sum of the individual maximum currents.

6 ACKNOWLEDGEMENTS

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REFERENCES


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* : + = anticlockwise ; - = clockwise
FIGURE 2

- TIDE GAUGE POSITIONS
CURRENT METER STATIONS
$- \frac{\varepsilon}{\omega} (M_2)$
\( \alpha (S_2) \)
\[- \frac{\varepsilon}{\omega} (S_2)\]
$O_1$ amplitude

MODEL (CM)

15

10

5

OBSERVED (CM)

5

10

15

$r=0.887; m=0.787; b=1.98$
$K_1$ amplitude

$r = 0.709; m = 0.629; b = 3.27$
$r=0.836; \ m=0.697; \ b=43.08$
$N_2$ amplitude

$r=0.969; m=0.861; b=1.79$
$N_2$ phase

$r=0.922; m=0.951; b=0.74$
$M_2$ amplitude

$r = 0.981; \ m = 1.030; \ b = 1.18$
$M_2$ phase

0.953: $m=1.019; b=-7.01$
\textit{S}_2 \text{ amplitude}

\begin{align*}
S & = 0.974; \quad m = 0.936; \quad b = 4.72
\end{align*}
$S_2$ phase

$r = 0.969; m = 0.939; b = 4.39$
\( b (M_2) \)

- Model CM/S
- Observed CM/S

\( r = 0.946; \ m = 1.153; \ b = 0.96 \)
$r = 0.955; \ m = 0.904; \ b = 6.65$
$\frac{-\epsilon}{\omega} (M_2)$

$\text{MODEL HRS.}$

$\text{OBSERVED HRS.}$

$r=0.981; m=0.860; b=0.40$
$a \ (S_2)$

$r = 0.941; \ m = 0.961; \ b = 1.49$
$b (s_2)$

$\text{MODEL CM/S}$

$\text{OBSERVED CM/S}$

$r=0.822; m=1.048; b=0.74$
\[ \alpha (S_2) \]

MODEL DEG. 60

OBSERVED DEG.

\[ r = 0.858; m = 0.820; b = 9.46 \]
\( \frac{-\varepsilon}{\omega} (S_2) \)

OBSERVED HRS.

MODEL HRS.

\( r = 0.984; m = 0.914; b = 0.29 \)