Generation of UK Tidal Stream Atlases from Regularly Gridded Hydrodynamic Modelled Data

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Accurate charts of tidal streams are needed in many fields of science and industry. The Proudman Oceanographic Laboratory's numerically modelled hydrodynamic data sets provide a suitable source for the production of such charts. Different methods of producing data in 'tidal diamond' format were investigated and the most suitable was selected for implementation over the UK continental shelf.

1. INTRODUCTION. If tidal predictions are required over a large area offshore, the traditional method is to use tidal diamond data from Admiralty charts and tidal stream atlases. This is basically a set of numbers that describe the tidal currents at certain times relative to high water at a reference port. The description at each time-interval is simply the direction the current is flowing, and the speed of the current (given for both spring and neap tides).

To obtain tidal diamond data, a small boat is anchored over at least a 12-hour period at the site of the tidal diamond. Every hour, a current meter is deployed over the side of the anchored boat and the current is read off with the meter just below the surface. The measurements are made during a meteorologically quiet period (otherwise residual flows have to be removed), and factored based on the mean spring and neap tidal range at a chosen reference port to reflect these conditions (Table 1). The current variations are given at hourly intervals over a 12- or 24-hour period related to the time of high water at a given reference port.

The data are not analysed but the results derived from using the tidal diamond data are, at best, equivalent to using the harmonic constituents M_2 and S_2 (the gravitational effects of the Moon and the Sun respectively).

The main disadvantage of tidal diamonds is that the period of observation on which they are based is very short (often less than 25 hours). This is only able to encapsulate the most basic tidal constituents. Current tidal stream atlases have a further drawback in that they are produced by interpolation between sparse tidal stream data, collected at different times. Considering a longer period of observations would give more confidence in the results.

To increase the accuracy at a location, some of the additional astronomical phenomena that affect the tide (such as variation in lunar distance, lunar and solar declination etc.) must be included. This requires harmonic analysis with a realistic minimum period of observation of 30 days.

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Table 1. Example of tidal diamond data for one location (taken from Admiralty Cha
777, diamond A)

Location: 50° 7.2'N 5°49.5'W Reference Port: Devonport			
Hours	Direction	Speed (knots) (springs)	Speed (knots) (neaps)
HW - 6	332°	0.4	0.2
HW - 5	002°	1.5	0.7
HW - 4	009°	2.4	1.2
HW - 3	010°	2.5	1.2
HW - 2	009°	1.6	0.8
HW - 1	031°	1.1	0.5
HW	123°	0.6	0.3
HW + 1	168°	1.7	0.8
HW + 2	181°	2.5	1.2
HW + 3	194°	2.5	1.3
HW + 4	210°	2.1	1.0
HW + 5	223°	1.1	0.6
HW + 6	295°	0.4	0.2

2. COMPUTING TIDAL DIAMONDS FROM HARMONIC CONSTITUENTS. Two methods were investigated. The first was to compute the mean spring and neap current speed using formulae based on those in Pugh (1987).

$$\text{Mean Spring Current Speed} = H_{M2} + H_{S2}$$
$$\text{Mean Neap Current Speed} = H_{M2} - H_{S2}$$

The second method was to produce a 24-hour predicted time series for two different dates – one during an average spring tide and the other during an average neap. This is similar to the way tidal diamonds are produced at present, although using the time series method, modelled predictions based on up to 50 harmonic constituents (available for each grid cell of the Proudman Oceanographic Laboratory (POL) 12 km Continental Shelf Model) are used instead of a very short period of observations. The model has been validated against observed currents (Flather, 1976, 1987).

The results of comparing these two methods against two diamonds taken from Admiralty Charts are shown in Tables 2 and 3.

Tables 2, 3: The two pairs of values given for the Admiralty Tidal Diamonds (atds) ar
ebb and flood currents. The four values for the Ppol time series are for two adj
high waters at the reference port.

Chart 109, diamond B, 53° 33.8'N 0° 13.8'E

	ATD		Formula	Time Series	
	Speed	Dir	Speed	Speed	Dir
Spring	1.34	209	1.32	1.34	203
	1.76	040		1.22	027
				1.38	203
				1.37	027
Neap	0.82	209	0.65	0.90	024
	0.72	040		0.84	202
				0.69	024
				0.70	203

Chart 777, diamond D, 49° 52.2'N 5° 10.9'W

	ATD		Formula	Time Series	
	Speed	Dir	Speed	Speed	Dir
Spring	1.19	247	0.68	0.80	259
	1.19	067		0.72	081
				0.77	259
				0.74	081
Neap	0.57	247	0.26	0.25	255
	0.57	067		0.28	084
				0.23	255
				0.22	084

Although the errors in speed are greater for the second comparison, it can be shown that this is partly caused by a 6 km spatial difference between the tidal diamond and the nearest modelled grid point.

The table shows that using the formulae gave a rather simplistic picture of the tidal regime due to the omission of diurnal constituents, hence it was decided to investigate further and refine the time series method.

3. HYDRODYNAMIC MODELLED TIDAL DIAMONDS. Utilising harmonic constants derived from POL hydrodynamic numerical models, the POL offshore prediction software computes the current for any chosen time at any chosen location. Given an input of spring and neap high water times for a specific reference port, this prediction software was refined to compute the corresponding tidal diamonds. These are referred to here as the hydrodynamically modelled tidal diamonds from the 'time series' method.

In the initial assessment of the time series method of section 2 above, the tidal diamonds – that is, the currents in the 13-hour window from 6 hours before to 6 hours after high water – were those for one specific spring tide. Improvement to the time series method was achieved by computing the modelled tidal diamonds to reflect a mean HW spring; that is, to average out variations due to the diurnal inequality present in British waters and the seasonal variation in tidal range.

Thus, for each spring tide, a pair of consecutive high waters was used to 'remove' the diurnal inequality. Likewise the consecutive high waters of each HW spring tide occurring over a six-month period were used to average out the seasonal variation.

Hence the spring tidal diamonds are based on 13-hour windows from two consecutive high waters of each of 12 HW springs; that is, twenty-four 13-hour time series covering a six-month period; rather more than when observations are used.

The improved time series method was likewise applied for neap tides.

For comparisons with Admiralty Tidal Diamonds, Dover was selected as the reference port because of the wide availability of tide tables.

4. RESULTS. Comparisons were made between results derived from this work and Admiralty Tidal Diamonds from various charts.

Good agreement between existing Admiralty Tidal Diamonds and those generated from the model can be observed (Table 4). The values with the largest difference (†) occur at the point in time when the current is changing direction rapidly – often by more than 10° every minute.

5. PRODUCING THE CHARTS. The program was run for the complete UK Continental Shelf using 20 harmonic constituents: 3 long-term constituents, 5 diurnal, 9 semidiurnal and 3 higher frequency terms. A file was created containing a description of the tide for 6 hours either side of Dover High Water for both springs and neaps.

As an initial check for spatial continuity over the shelf, data visualisation software was used to produce colour plots showing current speed and direction for an arbitrary time. These were used to check for any abrupt changes in the tidal current.

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Table 4. Comparisons were made between results derived from this work and Admiral
Tidal Diamonds from various charts.

Chart 278, diamond E, 57° 50'N 0° 16'E

	ATD	POL	ATD	POL	ATD	POL
	Direction		Speeds (kn) (Springs)		Speeds (kn) (Neaps)	
HW-6	009	358	0.6	0.6	0.3	0.3
HW-5	009	359	0.6	0.7	0.4	0.4
HW-4	020	000	0.5	0.6	0.3	0.3
HW-3	027	002	0.4	0.4	0.2	0.2
HW-2	068	049	0.1	0.1	0.1	0.1
HW-1	167	172	0.3	0.3	0.2	0.1
HW	183	176	0.6	0.6	0.3	0.3
HW+1	187	178	0.7	0.7	0.4	0.4
HW+2	191	181	0.6	0.6	0.4	0.4
HW+3	199	184	0.4	0.4	0.2	0.3
HW+4	242†	204	0.2	0.1	0.1	0.1
HW+5	340	349	0.3	0.3	0.2	0.1
HW+6	010	357	0.5	0.6	0.3	0.2

After carrying out this validation exercise, the software was further developed to plot a vector field for any user-specified area of the Continental Shelf. This more closely resembles the traditional Admiralty Tidal Stream Atlases, although current speed is presently only represented by the length of the arrow. A sample of one of these charts is shown in Fig. 1.

6. CONCLUSION. Hydrodynamic models can be used to produce tidal current atlases. This has the advantages over traditional methods that (1) in effect, a much longer period of 'observations' is used and, (2) the properties of the hydrodynamic model are used to give a much smoother spatial interpolation between the tidal diamond positions, based on temporally consistent data.

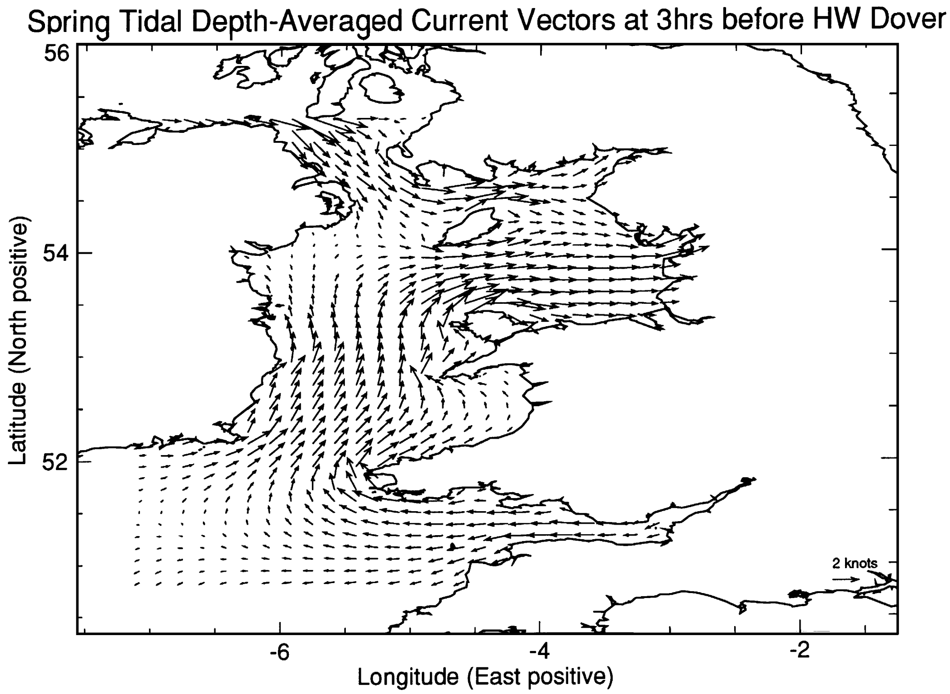

Fig. 1. Sample of one of the charts produced by the visualisation software

The methods outlined in this paper have been used to compute tidal diamond data for HM Coastguard at Holyhead for use in Search and Rescue operations. POL will also be using them to produce tidal stream atlases of the European Continental Shelf.

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KEY WORDS

1. Tidal streams. 2. Hydrography. 3. Oceanography.