Further Tests of a Directional Wave Recorder

The Sea Data 621

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Report SR 258
February 1991

HR Wallingford

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Contract

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Prepared by .... (name) Project engineer (job title)

Approved by E C Bowers. Project manager

Date 24/12/92

Summary

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The Sea Data 621 is an electromagnetic current meter and pressure transducer combined so as to be suitable for measuring both wave heights and directions when positioned on a shallow sea bed. HR Wallingford purchased an example. Its performance in its first sea trial (described in Reference 1) was however unsatisfactory due to various malfunctioning components.

This report describes a subsequent field trial, undertaken off Folkestone in April 1989. Comparison with contemporary Waverider Buoy measurements made a few miles away indicate the Sea Data unit can be used to record wave heights. But several significant faults discovered during the earlier trial recurred on this one. The instrument appeared to fail to record wave directions correctly. Its performance therefore cannot be considered satisfactory.

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1 Introduction

A previous report (Reference 1) described HR's intentions in purchasing a directional wave recording device (the Sea Data 621 Directional Wave Current Meter) as well as laboratory tests carried out, and its initial trial deployment in the sea off Aberdeen. Results of that trial were not satisfactory due to various malfunctions of the device. It was subsequently returned to the manufacturers for overhaul. Further laboratory tests were carried out on its return; then, although HR staff were not entirely satisfied all the problems encountered earlier had in fact been cured by the manufacturers, it was decided to try another field deployment. The field trial took place in March - April 1989 off Folkestone. It was anticipated that this was not too late in the year for large waves, but a feeling that time was running out for the wave recording season, as well as a need to establish the suitability of the instrument as quickly as possible were major factors in going ahead despite misgivings. This report describes that deployment and the results obtained from it.

The Sea Data 621 is a directional wave measuring instrument made by the Sea Data Corporation in the USA. It consists of a pressure transducer and an electro-magnetic current meter together with a compass and electronic control and recording equipment housed in a pressure capsule (Reference 2). It is deployed immersed, usually at or near the sea bed in shallow water but outside the surf zone. The current meter measures two horizontal perpendicular components of water flow past the instrument, and an on-board processor resolves them into northerly and easterly components using the compass reading. North and east flow velocities, and pressure are recorded at pre-set time intervals; the recommended interval between measurements for wave recordings is about 0.5 seconds.

The analysis method to obtain directional information is described in another HR report (Reference 3); Reference 1 also contains a brief description. It is a spectral method involving conventional energy spectra and cross spectra of the two velocity time series and pressure. Extrapolated to the sea surface, the pressure spectrum is equivalent to wave height. The velocity data are used in determining the mean direction of wave energy propagation and a measure of wave directional spread (a choice of measures is available). Both directional parameters are found as functions of wave frequency. Indications in References 1 and 3 are that mean direction can be estimated quite reliably, but spread measurements are often not trustworthy, particularly where there are crossing seas (for example due to reflections).

2 Deployment

The Sea Data 621 was deployed on 9 April 1989 at a site in East Wear Bay near Folkestone (Figure 1). The site was close to the 5m CD contour, and the instrument was held upright in a frame so that the pressure transducer was 1.09m above the bed. Some 4 km to the east was a waverider buoy HR had on station in connection with another project. It was anticipated that wave conditions at the two sites would be similar (after making due allowance for shoaling and refraction), so wave height and period measurements from the waverider would be a check on the Sea Data unit.

The waverider could not detect wave direction, but directions were routinely being hindcast from wind data for the other project (Reference 4). There would therefore be confirmatory evidence for wave direction results.

The Sea Data Unit was recovered on 28 April 1989. Its tape was found to be fully recorded, apparently as intended with 1024 second long recordings of current and pressure data taken at 0.5 second intervals, and with three hour gaps between recordings. One hundred and seven complete recordings were found.

3 Results

3.1 The Clock

Data recorded by the Sea Data wave recorder include elapsed times since the last clock reset. Standard operating procedure is for the clock to be reset shortly before deployment and the time of resetting to be noted; elapsed times recorded on the tape then allow recording times and dates to be known.

Elapsed times recorded on the tape for the start of each recording in East Wear Bay are listed in column 2 of Table 1. Except for a few gaps, recordings have been made at three-hourly intervals as intended, but the elapsed time for the first recording is anomalous. It is 8689 hours, or about 362 days. Notes made at the time indicate that the clock was reset on the morning of deployment: clearly, things did not go as intended, but the reason is unknown. The malfunction is of great inconvenience because it makes it impossible to be certain exactly when each of the recordings were made; indirect methods could be used to estimate times and dates (see Section 3.3), but uncertainty is introduced and comparisons with contemporary waverider measurements are made more difficult and less reliable than they would otherwise have been.

The clock appears to have reset itself to zero between recordings 16 and 17. What almost certainly happened is the following: the wave recorder clock measures time in thirty second intervals, and the most it can count up to is 20^{20}, which is 8738 hours 8 minutes, so when it reached that time, it went 'round the clock' and returned to zero. The interval between the two recordings is therefore three hours, as it is between most recordings; the timer functioned correctly on this occasion.

3.2 Tidal depth variations

The mean water depth over the transducer was calculated for every recording. Results are shown in column 3 of Table 1. There is a clear tidal variation with heights varying in approximately twelve hour cycles over a maximum range of about 6.3m. The largest spring tidal ranges at Dover (slightly to the east) in April 1989 were 6.5m (Reference 5), so the measured depths are consistent with what we would expect at the site with the instrument deployed in about 5m CD depth of water (See also Table 2).

3.3 Wave heights and comparisons with waverider measurements

Assuming linear theory, it is possible to extrapolate the pressure power spectrum at a transducer near the seabed up to the water surface and thus obtain an estimate of the surface elevation spectrum (see, for example, Reference 1). This has been done for this data set, and rms wave elevations obtained. Results are shown in column 4 of Table 1.

A significant limitation on this method is imposed by depth attenuation; the pressure signal decays approximately exponentially with distance beneath the surface, and the decay is faster for short period wave components. For short period waves therefore it can be difficult to distinguish pressure wave signals above background noise in recordings made some distance down.

In this data set, there appeared to be a high proportion of recordings made with small wave heights and short wave periods. These are the worst possible conditions for accurate use of a bed mounted device like the Sea Data 621. It was found that noise levels became significantly large compared to the pressure signal in most recordings for frequencies above about 0.25 or 0.3 H_z; these components therefore could not be extrapolated to the surface at all reliably.

RMS wave elevations given in the table are based on longer period components only, with a high frequency cut-off being imposed at some frequency which differed between recordings depending on data quality and water depth. In many recordings the bulk of the spectrum appeared to lie at high frequencies, above the cut-off; no height has been recorded for these cases, the waves seemed generally small.

The small number of recordings made in reasonably high seas (rms elevations greater than about 0.4m) and with peak periods greater than about 6 seconds unfortunately make this a poor data set for its intended purpose - as a test of the Sea Data's suitability for routine use. A seabed based recorder of this type simply cannot be expected to work well under the conditions experienced here much of the time.

Concentrating our attention on those recordings in which wave conditions do appear to have been suitable (ie Nos 9-11 and 16-20), the first question that needs to be answered is; when were they made?

The recorder should have started recording as soon as it was switched to 'operate' mode, and this should have happened during deployment. The recorded tape should therefore contain a first recording made as the equipment was lowered to the bed, then recordings made at three hourly intervals starting early on the day of deployment (9 April 1989). This is what we appear to have. The first recording does seem to be during deployment and we have fairly large waves recorded between 24 hours and 60 hours (recordings 9-20) after the start of the tape; this corresponds well to the only extended period of high wave activity observed about that date at the waverider site. Reference 4 gives a waverider height of 1.89m during 10/04/89 and a height of 2.47m during 11/04/89. There was a period of relative calm about midnight, and this too appears consistent with waverider data. After 11 May, there is a long calm period, which persists until the 23rd in agreement with the waverider by which time the Sea Data recording has ended. The wave height records there fit this hypothesis, as do tidal heights. Table 2 shows the times and heights of high and low tides at Dover (taken from Reference 5). Tides at Folkestone occur ten minutes or so earlier. In all significant details, the tables concur; for example, the tide table shows a neap tide on the morning of 14 April, and this is seen in the Sea Data results too with approximately the expected tidal range and timing.

We now consider the various spectra from recordings 9 to 20 in greater detail.

The first point to note is that the spectra look sensible. Table 3 shows spectra from recording 18, at about 12.30 on the 11 April. Seabed pressure and velocity spectra have the sort of shape, with the sort of random scatter typical of field recordings.

There is evidence of a fault on the pressure transducer that was reported in Reference 1 recurring. Then, a faulty pressure reading was found to occur fairly regularly every four seconds in some recordings; it caused a spike in the pressure spectrum at 0.25 Hz. A similar spike can be seen in Table 3. In this case, it is small enough not to be a serious problem in itself. But it demonstrates that a fault in the machine still exists which has been found to cause serious difficulties in the past. It is also possible that some of the problems, experienced with other recordings during this deployment in extrapolating high frequency spectra to the surface have been exacerbated by noise pollution from this or a similar source. When reported to the makers during the machine's overhaul, they were unable to suggest a cause for the fault; it has evidently not been fixed.

At other frequencies, the pressure transducer and current meter appear to have functioned correctly. Evidence for this is the generally good agreement seen between theoretical and estimated wave number. The theoretical wave numbers in the table are derived from the wave dispersion relationship:

$$\frac{\omega^2}{g} = k \tanh kh$$

The estimated wave numbers come from the calculated values of the pressure spectrum, S_{pp} (f), and velocity spectra, S_{uu} (f) S_{vv} (f), and the relationship between them (from linear theory):

$$k \cosh kh \sqrt{[S_{pp}(f)]} = \rho\omega \cosh kh_p \sqrt{[S_{uu}(f)+S_{vv}(f)]}$$

where

ω = radian frequency = $2\pi.f$
k = wave number
h = water depth
h_v = height of current meter above bed
h_p = height of pressure transducer above bed
g = gravitational acceleration
ρ = water density

Good agreement between the two wave numbers indicates that linear potential wave theory is applicable to the situation being studied, and that both current meter and pressure transducer are functioning. Reasonable agreement, like that shown in Table 3, was found in most recordings.

Wave heights obtained from the Sea Data unit do not seem discrepant from those from the waverider. Given the difficulties and uncertainties in fixing the times of the Seadata recordings, and that the two measuring sites are several kilometres apart in different depths of water so there will be shoaling and refraction effects on wave height, it is not advisable to make close comparisons between the two sets of results.

3.4 Wave frequencies and periods

In column 4 of Table 1 are noted ,fp, the frequencies at which surface wave elevation spectra taken from the Seadata were at their largest. In some cases, depth attenuation made it impossible to observe such a peak, and no result has been given.

A frequency of 0.19 (5.3s) corresponding to a height of 1.84m on the Sea Data unit compares with a zero crossing period of 4.7s on the waverider on 10/04/89. And on 11/04/89 a frequency of 0.15 (6.7s) corresponding to a height of 2.28m on the Sea Data unit compares with a zero crossing period of 5.9s on the waverider. This correlation between the two recorders is reasonable given that the zero crossing period is always shorter than the spectral peak period.

3.5 Wave directions

The purpose of using the Sea Data recorder is to be able to measure wave directional characteristics as well as heights and periods. This type of recorder provides enough data to estimate wave mean direction and to make a measure of the spread of wave propagation directions present. A choice of spread measures is available: we have chosen to present a spreading angle, Θ_s, defining a 'top hat' spreading function:

$$F(\theta) = 0 \qquad |\theta-\bar{\theta}| \geq \Theta_s$$

$$= 1/(2\Theta_s) \qquad |\theta-\bar{\theta}| \leq \Theta_s$$

Where $\bar{\theta}$ is mean direction. Our directional analysis finds Θ_s values equivalent to measured wave spreads; but it must always be remembered that the real wave directional behaviour is likely to be greatly different from what has been assumed; for example, our spreading angle cannot represent well a sea produced by two crossing long-crested wave trains. References 1 and 2 both indicate mean direction measurements are more reliable than spread measures.

Mean directions and spread angles are found as functions of frequency by spectral analysis. Values for each recording with suitable data at the spectral peak frequency are listed in Table 1.

Reference 4 contains mean wave directions obtained using the HINDWAVE hindcasting model to estimate wave conditions at the waverider site.

Agreement of mean directions is very poor. The larger waves, for example on 10-11 April, show directions of 148°N to 157°N on the Sea Data Unit but the hindcast directions are about 200°N. The two sites are some distance apart and in different water depths, so refraction might be expected to cause some directional differences. In this case the Sea Data directions are more easterly than the others. We might expect the seabed topography to refract southerly waves at the waverider site to a more easterly direction in East Wear Bay, so

Bay, so the sense of the deviation in the measurements is no surprise; but we would not expect refraction at the site to bend wave rays as much as 50°.

Spreading angles from the Sea Data analysis are much larger than we would expect, but we have no other field data at the site to make a comparison. Overall, there must be considerable doubt about the validity of our results regarding wave direction. It is conceivable that wave reflections off cliffs along the coast could account for some of the discrepancies in wave directions and the very wide angular spreads the Sea Data recorded. Similar problems with directional measurements are reported in the earlier Sea Data deployment in Reference 1. In that report they are associated with faults in the Sea Data compass; it seems quite probable that the same or other faults in the Sea Data recorder caused errors in directional wave measurement during this deployment too.

4 Conclusions

1 Wave conditions during this deployment were poor for our purposes. There were few occasions when there was significant wave activity to rigorously and fairly test the equipment.

2 Failure to reset the clock correctly caused difficulties in knowing exactly when Sea Data recordings were made.

3 Wave heights at the site seem to have been correctly measured, and measured wave current strengths seem consistent with pressures. There are grounds for believing the pressure transducer and current meters functioned correctly in at least most circumstances.

4 There was a fault in pressure recording causing a quasi-regular faulty value to appear once per burst (ie once every 4 seconds) in some recordings. The fault has been observed before (Reference 1) and reported to the manufacturers. They however cannot explain how it happens and failed to repair it when our machine was returned for overhaul.

5 Our Sea Data seems still not to measure wave directions correctly although the other problems and limitations encountered on this deployment make it difficult to be sure. Until the instrument is shown to make accurate and reliable directional measurements, it will be of no use to us for any practical requirements.

6 If the pressure transducer and current meter work separately (as I believe they do), but they do not work in conjunction to give accurate directional wave measures, then suspicion falls on the other electronic components of the recorder and on the compass.

7 We still cannot test the equipment adequately in the laboratory because we do not have any device for reading the recorder output. This makes fault detection almost impossible. On the other hand, the manufacturers seem to be no better at it than we are!

8 Having to send all data tapes to Wormley for translation causes excessive delays whenever IOS is using their translation equipment on a cruise.

9 Sooner or later HR will have to do directional wave recording. The Sea Data 621 has the required capability but the example we have bought still does not work properly; there must be doubts as to whether it ever will.

5 Acknowledgements

This work was done at Hydraulics Research Ltd under the supervision of Dr E C Bowers. Mr D Perrott conducted the laboratory tests of the instrument. Mr C J Teal supervised the field deployment off Folkestone. Mr J M A Spencer wrote and ran the analysis programs (and wrote this report). We are grateful to Dr C H Clayson at the Institute of Oceanographic Sciences Worley for translating our data tapes for us.

6 References

1 Spencer J M A. 'Test on a directional wave recorder: The Sea Data 621', HR Report SR 158, February 1988.

2 '621 Directional Wave Recorder/Current Meter User Manual'; Sea Data Corporation, March 1986.

3 May R W P; 'Measurement of mean direction and spread of wave spectra'; HR Report IT 247, April 1983.

4 'Validation of wave direction predictions at Shakespeare Cliff'. HR Report EX 2111, June 1990.

5 'Admiralty Tide Tables, Volume 1, 1989'; The Hydrographer of the Navy, 1988.

Tables

Table 1 Summary of Recordings

Recording	Clock time from reset (Hours)	Water Depth (m)	Hs at surface (m)	fp (Hz)	$\bar{\theta}$ Mean wave angle	$\bar{\theta}$ Wave spread angle	Estimated time of recording	Estimated date
1	8689	5.05	0.16	0.23	144°	48°	6.30	9/4
2	8692	5.26					9.30	
3	8695	11.34					12.30	
4	8698	9.30	0.28				15.30	
5	8701	5.36					18.30	
6	8704	5.06	0.16				21.30	
7	8707	11.17					00.30	10/4
8	8710	9.75	0.96				3.30	
9	8713	5.81	1.84	0.19	148°		6.30	
10	8719	10.41	1.48	0.17	149°		12.30	
11	8722	10.01	1.00	0.19	157°		15.30	
12	8725	6.30	0.64	0.18	161°		18.30	
13	8728	5.03	0.44	0.22	130°		21.30	
14	8731	10.20					00.30	11/4
15	8734	10.49					3.30	
16	8737	7.05	1.24	0.19	153°		6.30	
17	2	5.21	1.68	0.15	147°	80°	9.30	
18	5	9.17	2.28	0.15	147°	70°	12.30	
19	8	10.41	2.28	0.15	150°	40°	15.30	
20	11	7.35	1.72	0.14	157°		18.30	
21	14	5.13					21.30	

Table 1 Continued

Recording	Clock time from reset (Hours)	Water Depth (m)	Hs at surface (m)	fp (Hz)	$\bar{\theta}$ Mean wave angle	$\bar{\theta}$ Wave spread angle	Estimated time of recording	Estimated date
22	17	8.06				95°	00.30	12/4
23	20	10.04	0.72	0.10	163°	74°	3.30	
24	23	7.77	0.72	0.11	162°	34°	6.30	
25	26	5.56	0.40	0.07	165°		9.30	
26	29	7.70					12.30	
27	32	10.29	0.28	0.09	172°	108°	15.30	
28	35	8.43	0.48	0.10	188°	120°	18.30	
29	38	6.09	0.32	0.08	160°	50°	21.30	
30	41	7.28	0.20	0.08	159°	68°	00.30	13/4
31	44	10.10	0.32	0.10	41°	84°	3.30	
32	47	8.89	0.40	0.08	161°	83°	6.30	
33	50	6.72						
34	53	6.86	0.16	0.07	163°	47°	9.30	
35	56	9.68	0.28	0.08	171°	111°	15.30	
36	59	9.19	0.36	0.08	191°	119°	18.30	
37	62	7.10					21.30	
38	65	6.56	0.20				00.30	14/4
39	68	9.05	0.24	0.08			3.30	
40	71	9.54	0.36	0.08	204°	153°	6.30	
41	74	7.86	0.20	0.09	167°	88°	9.30	
42	77	6.75	0.20	0.08	153°	46°	12.30	
43	80	8.44	0.20	0.10	161°	95°	15.30	
44	83	9.88					18.30	

Table 1 Continued

Recording	Clock time from reset (Hours)	Water Depth (m)	Hs at surface (m)	fp (Hz)	$\bar{\theta}$ Mean wave angle	$\bar{\theta}$ Wave spread angle	Estimated time of recording	Estimated date
45	86	8.31					21.30	
46	89	6.50					00.30	15/4
47	92	7.44					3.30	
48	95	9.68					6.30	
49	98	8.87					9.30	
50	101	6.86					12.30	
51	104	6.95					15.30	
52	107	9.86					18.30	
53	110	9.30					21.30	
54	113	6.81					00.30	16/4
55	116	6.21					3.30	
56	119	9.41					6.30	
57	122	9.72	0.76	0.17	278°	67°	9.30	
58	125	7.40	0.40				12.30	
59	128	6.13	0.48	0.18	222°	62°	15.30	
60	131	8.93					18.30	
61	134	10.02	0.64	0.16	281°	54°	21.30	
62	137	7.28	0.40	0.17	260°	103°	00.30	17/4
63	140	5.58					3.30	
64	143	8.29					6.30	
65	146	10.26					9.30	
66	149	7.88	0.32	0.19	251°	65°	12.30	
67	152	5.76	0.28	0.17	221°	59°	15.30	

Table 1 Continued

Recording	Clock time from reset (Hours)	Water Depth (m)	Hs at surface (m)	fp (Hz)	$\bar{\theta}$ Mean wave angle	$\bar{\theta}$ Wave spread angle	Estimated time of recording	Estimated date
68	155	7.91	0.48	0.18	240°	87°	18.30	
69	158	10.69	0.60	0.15	276°	73°	21.30	
70	161	8.14	0.44	0.14	240°	44°	03.00	18/4
71	164	5.57	0.24	0.15	212°	105°	3.30	
72	167	7.22					6.30	
73	173	8.67					12.30	
74	176	5.85					15.30	
75	179	6.90					18.30	
76	182	11.07					21.30	
77	185	9.09	0.16				00.30	19/4
78	188	6.01	0.12				3.30	
79	191	6.28	0.16				6.30	
80	194	10.94	0.32	0.17	284	123°	9.30	
81	197	9.41	0.36	0.16		89°	12.30	
82	200	6.13	0.24	0.19		122°	15.30	
83	206	11.02	0.32	0.15	287°	85°	21.30	
84	209	9.76	0.28				00.30	20/4
85	212	6.22	0.20	0.08 9.19	147° 235°	83° 115°	3.30	
86	218	10.76	0.20				9.30	
87	221	10.12	0.24				12.30	

Table 1 Continued

Recording	Clock time from reset (Hours)	Water Depth (m)	Hs at surface (m)	fp (Hz)	$\bar{\theta}$ Mean wave angle	$\bar{\theta}$ Wave spread angle	Estimated time of recording	Estimated date
88	224	6.58	0.24				15.30	
89	227	5.41	0.32	0.20	226°	63°	18.30	
90	230	10.66	0.56	0.19	279°	93°	21.30	
91	233	10.44	0.40	0.16	296°	59°	00.30	21/4
92	236	6.73	0.28				3.30	
93	239	5.14	0.20	0.16	203°	118°	6.30	
94	242	10.14	0.48	0.13	267°	113°	9.30	
95	245	10.60	0.44	0.15	276°	84°		
96	248	7.03	0.44	0.18	256°	112°	12.30	
97	251	5.19	0.20				15.30	
98	254	9.78	0.56	0.18	229°	106°	18.30	
99	257	10.88	0.48	0.15	228°	74°	21.30	
100	260	7.23	0.40	0.16	216°	107°	00.30	22/4
101	263	5.09	0.20	0.17	214°	98°	3.30	
102	266	9.03	0.40	0.16	288°	98°	6.30	
103	269	10.99					9.30	
104	272	7.51	0.48	0.19	233°	105°	12.30	
105	275	5.14	0.12	0.19	177°	104°	15.30	
106	278	8.59	0.20				18.30	
107	281	11.13	0.24				00.30	23/4

Table 2 Tidal Heights at Dover, April 1989

	TIME	M			TIME	M
1	0036	2.2		11	0206	6.4
	0261	5.0			0936	1.2
SA	1331	2.2		TU	1436	6.0
	1907	5.1			2152	1.3
2	0219	1.9		12	0300	6.4
	0749	5.4			1023	1.2
SU	1458	1.8		W	1532	6.0
	2018	5.6			2244	1.3
3	0334	1.4		13	0406	5.4
	0846	5.8			1123	2.1
M	1603	1.3		TH	1642	5.2
	2108	6.1			2356	2.1
4	0433	0.9		14	0537	5.0
	0932	6.2			1250	2.3
TU	1658	0.9		F	1819	5.1
	2150	6.5				
				15	0131	2.1
5	0526	0.6			0716	5.1
	1013	6.5		SA	1422	2.1
W	1749	0.7			1941	5.3
	2233	6.8				
				16	0254	1.7
6	0615	0.4			0822	5.4
	1055	6.7		SU	1529	1.8
TH	1834	0.5			2037	5.7
	2313	7.1				
				17	03.52	1.4
7	0700	0.3			09.08	5.7
	1137	6.8		M	16.20	1.5
F	1912	0.5			21.19	5.9
	2354	7.1				
				18	04.38	1.2
8	0740	0.3			09.46	5.9
	1219	6.8		TU	17.01	1.3
SA	1949	0.5			21.56	6.1
9	0036	7.0		19	05.16	1.1
	0819	0.5			10.17	6.0
SU	1302	6.6		W	17.36	1.2
	2029	0.7			22.30	6.3
10	0120	6.7		20	0550	1.0
	0857	0.8			1045	6.2
M	1348	6.3		TH	1804	1.1
	2108	1.0			2259	6.4

Table 2 Continued

	TIME	M			TIME	M
21	0621	0.9		26	0114	6.0
	1111	6.3			0856	1.4
F	1832	1.0		W	1338	6.0
	2326	6.4			2114	1.5
22	0650	0.9		27	0154	5.8
	1137	6.3			0935	1.7
SA	1902	1.0		TH	1425	5.7
	2350	6.4			2159	1.7
23	0720	0.9		28	0249	5.5
	1203	6.3			1026	1.9
SU	1933	1.0		F	1531	5.4
					2258	1.9
24	0015	6.3				
	0751	1.0		29	0416	5.2
M	1231	6.3			1136	2.1
	2005	1.1		SA	1702	5.2
25	0042	6.2		30	0018	1.9
	0822	1.2			0603	5.2
TU	1302	6.1		SU	1303	2.0
	2037	1.3			1835	5.4

Table 3 Spectra from Recording 18

SPECTRA

Freq	Wave No lin theory	Wave No est from record	Pressure m^2/Hz	X-velocity $(m/s)^2/Hz$	Y-velocity $(m/s)^2Hz$	Surface Elevation m^2/Hz	Mean Heading °N	Spread Angle
0.099	0.070	0.096	0.028	0.034	0.029	0.040	-34	43
0.107	0.076	0.084	0.059	0.062	0.026	0.092	-9	115
0.115	0.083	0.077	0.104	0.085	0.028	0.175	-37	95
0.123	0.090	0.103	0.288	0.365	0.131	0.524	-32	45
0.130	0.097	0.087	0.472	0.402	0.114	0.938	-27	71
0.138	0.104	0.086	0.822	0.571	0.210	1.80	-33	82
0.146	0.111	0.108	2.60	2.30	0.819	5.71	-34	71
0.154	0.119	0.102	2.36	2.00	0.783	7.04	-33	71
0.162	0.128	0.120	0.782	0.654	0.396	2.39	-39	91
0.169	0.136	0.134	1.01	1.08	0.468	3.53	-32	77
0.177	0.145	0.132	0.590	0.571	0.222	2.37	-30	84
0.185	0.155	0.125	0.173	0.108	0.085	0.805	-42	144
0.193	0.165	0.174	0.167	0.216	0.117	0.918	-33	74
0.201	0.176	0.165	0.157	0.129	0.130	1.03	-40	72
0.209	0.187	0.175	0.168	0.179	0.108	1.32	-37	68
0.216	0.199	0.158	0.156	0.122	0.082	1.49	-35	100
0.224	0.211	0.235	0.085	0.164	0.064	1.00	-29	73
0.232	0.224	0.249	0.064	0.108	0.073	0.945	-42	66
0.240	0.237	0.200	0.061	0.073	0.030	1.13	-11	127
0.248	0.252	0.117	0.156	0.043	0.043	3.71	-28	153
0.255	0.266	0.284	0.021	0.052	0.011	0.650	-12	56
0.263	0.282	0.292	0.027	0.048	0.032	1.08	-16	99
0.271	0.298	0.269	0.012	0.013	0.016	0.654	-49	113
0.279	0.315	0.327	0.011	0.030	0.008	0.807	-16	79
0.287	0.332	0.465	0.007	0.024	0.018	0.640	-52	100
0.294	0.350	0.375	0.008	0.020	0.012	1.08	-36	108
0.302	0.369	0.538	0.002	0.012	0.007	0.459	62	152

Figure

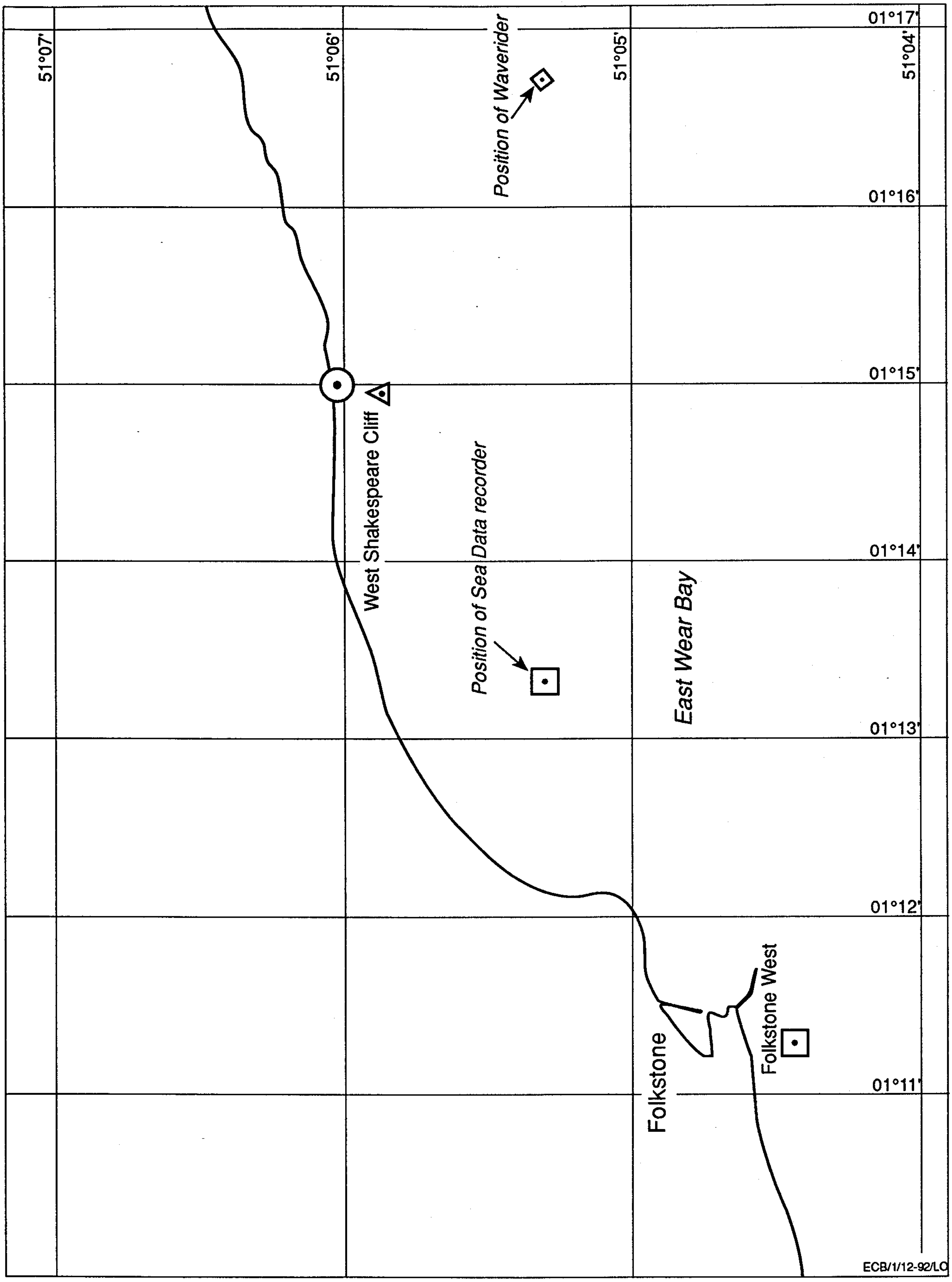

Figure 1   Site location map