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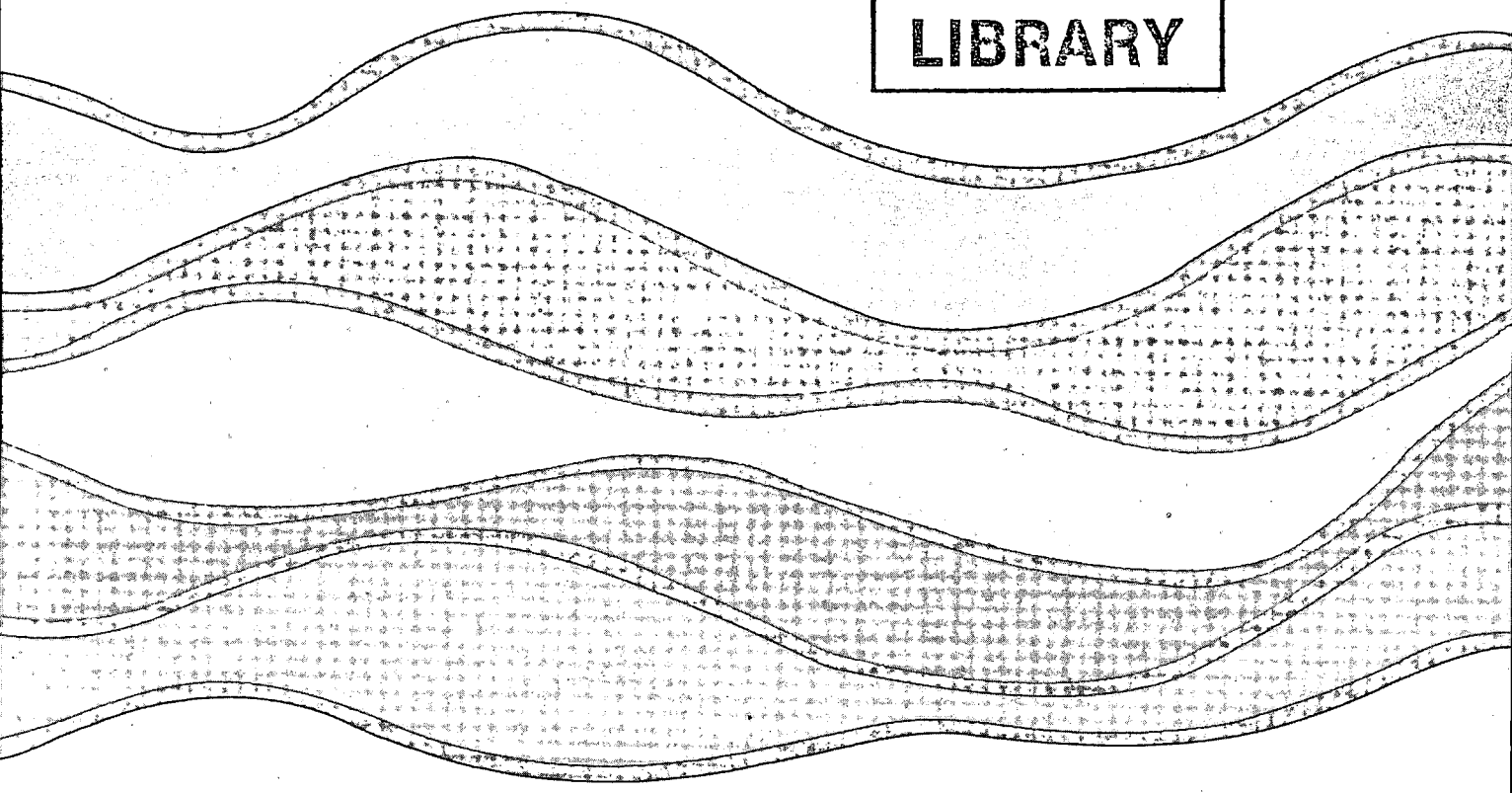

DIRECTIONAL SPECTRA FROM THE SWATH SHIP IN SWADE

M.A. Donelan, W.M. Drennan, N. Madsen, K.B. Katsaros, E.A. Terray and C.N. Flagg

NWRI Contribution No. 92-11

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DIRECTIONAL SPECTRA FROM THE SWATH SHIP IN SWADE

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NWRI Contribution No. 92-11

MANAGEMENT PERSPECTIVE

Climate and global change are at the forefront of environmental concerns. The scientific community has become increasingly aware that the role of the air-water interface, in terms of waves and the fluxes of heat and momentum, is central to these issues. It is that interface that connects the two most important subsystems controlling the changes. The Surface Wave Dynamics Experiment (SWADE) was a major international experiment which will improve our understanding and provide the basis for parametrizing the processes at the interface; this will subsequently lead to improved prediction capability. This data report describing the directional wave characteristics during the experiment is one of many reports, upon which scientific papers will be based, that will address these issues.

PERSPECTIVE DE LA DIRECTION

Les changements climatiques et globaux constituent des préoccupations environnementales de premier plan. Les scientifiques sont de plus en plus conscients que l'interface air-eau, notamment les vagues et les flux de chaleur et de la quantité de mouvements, jouent un rôle primordial dans ces questions, car il s'agit de l'interface des deux principaux sous-systèmes à l'origine de ces changements. L'étude de la dynamique des vagues de surface (Surface Wave Dynamics Experiment (SWADE)), étude internationale d'envergure, nous permettra d'approfondir nos connaissances à ce sujet ainsi que d'établir les paramètres des processus propres à la interface, ce qui, ultérieurement, se traduira par un meilleure capacité de prévision. Ce document décrivant les caractéristiques directionnelles ds vagues relevées pendant l'étude est l'un des rapports nombreux, sur lesquels reposeront d'autres études scientifiques en la matière.

ABSTRACT

One of the primary goals of the Surface Wave Dynamics Experiment (SWADE) is the study the evolution of the directional wave spectrum. This was achieved through the use of three independent measurement techniques: a series of low resolution directional buoys were deployed in order to measure spatial variability in the spectrum; an array of wave staffs mounted on the Swath ship *Frederick G. Creed* was used to collect high resolution data suitable for the investigation of the temporal variations; radars operated at a variety of frequencies. The successful completion of the field experiment (October, 1990 - March, 1991) has resulted is a large amount of high quality data. This data report summarizes the directional spectrum estimates based on measurements from the Swath ship.

RÉSUMÉ

L'un des principaux objectifs de l'étude de la dynamique des vagues de surface (Surface Wave Dynamics Experiment (SWADE)) était d'examiner l'évolution du spectre directionnel des vagues. À cette fin, on a employé trois méthodes de mesure distinctes : un ensemble de bouées directionnelles faible résolution ont été déployées pour mesurer la variabilité spatiale du spectre; diverses perches à houle, montées sur le bateau de type SWATH *Frederick G. Creed*, ont servi à recueillir des données haute résolution pour examiner les variations temporelles; et des radars on été utilisés à diverses fréquences. Les études sur l'océan Atlantique (octobre 1990 - mars 1991), qui ont été couronnées de succès, ont permis de rassembler une foule de données d'une grande utilité. Ce rapport résume les estimations du spectre directionnel obtenues d'après les mesures effectuées à partir du bateau SWATH.

1. INTRODUCTION

The Surface Wave Dynamics Experiment (SWADE) took place off the Virginia coast between October 1990 and March 1991. Among its central objectives was the improvement of our understanding of the dynamics of the evolution of the wave field in the open ocean. This was to be achieved through the deployment of an array of buoys, which would record wave and flux data continuously during the six month period, and through the use of aircraft based remote sensing techniques during three intensive operating periods (IOPs) – see Weller et al. (1991). The buoy array, designed to estimate spacial variations, consisted of five Discus buoys (two of which, Discus-East and -North, were modified with additional flux instrumentation and on-board optical storage units for time series data) and four meteorological buoys situated around the Brookhaven Spar buoy. This latter buoy was equipped with an array of capacitance wave gauges to provide the high resolution directional spectra critical to the study of spectral response to changing conditions.

Unfortunately, the Spar was sunk, probably as the result of a collison with a passing ship, on 26 October 1990, just prior to the first IOP. In order to meet the objectives of SWADE, it was necessary to replace the measuring capabilities of the Spar. Its place in the array was taken by a new Discus buoy, Discus-Centre. In addition, the SWATH (Small Water Plane Area – Twin Hull) ship *Frederick G. Creed*, operated by the Canadian Department of Fisheries and Oceans, was chartered and equipped to perform the high resolution measurements. The ship, 20 metres long by 10 m wide, was designed to produce minimal flow disturbance at the water surface and, because of its high design cruising speed, is much better streamlined than typical ships. It is thus an excellent air-sea interaction research platform. Buoyancy is provided by two hulls/pontoons located below the surface which are attached to the upper deck by two narrow struts running the length of the ship. Engines located in each pontoon allow

for ship speeds of up to 26 knots, although for the purposes of SWADE speeds of 5-15 knots were typical.

The *Creed* operated in the SWADE area during IOPs 2 (14-25 January 1991) and 3 (25 February-9 March 1991). Although the opportunity for six months of continuous high resolution data collection was lost with the Spar, the mobility of the ship allowed for several innovations. For instance, it became possible to study the effects of currents and fetch on wave spectra. Also, cross calibration of the various Discus buoy wave measurements was feasible.

2. SWATH ship data

The transformation of the SWATH ship into a mobile research platform required the addition of a variety of special equipment. A global positioning system (GPS) receiver and two magnetic compasses (digicourse and fluxgate) were installed to allow the ship's position and heading to be recorded. Mounted on a sprit two metres fore of the bow, and well ahead of the pontoons, was the principal wave sensing apparatus which initially included an array of wave staffs, an acoustic current meter and an Elliot pressure probe. Six 4.5 m long capacitance wave gauges arranged in a centered pentagon of 75 cm radius made up the wave staff array employed to estimate the directional properties of the wave field. The high resolution array functioned very well and yielded 12 hours of detailed wave directional information during IOP 2 and the first half of IOP 3.

Unfortunately, the array, current metre and pressure probe were lost when the bow sprit was destroyed by a large wave on 27 February 1991 at 02:30 GMT. On return to Norfolk a replacement array, consisting of two wave staffs across the bow 2 m apart with a third 1 m ahead of the centreline of the two, was designed, constructed and

installed. Three days later, the *Creed* was ready to sail again in support of SWADE.

A mast mounted on the foredeck just ahead of the cabin held the meteorological sensors. These included a K-gill anemometer (at 12 m), a single propellor anemometer (7 m), lyman-alpha humidity sensor (11 m), wet and dry bulb thermometers (each at 7 and 11 m) and a video camera. As all velocity and displacement measurements were made with respect to the moving ship, it was crucial that the ship motion be recorded. To achieve this, a motion package consisting of a pair of angular accelerometers and a gyroscope (each measuring pitch and roll) and two triplets of linear accelerometers (each measuring heave, surge and sway) was installed at the bow, just aft of the bow sprit. Duplicate sensing of the ship motion allowed for the possibility of equipment failure. All equipment was calibrated after completion of the experiment either at CCIW (anemometers, motion package, wave array and compasses) or at the University of Washington (all meteorological apparatus). The compasses and K-gill anemometer were also calibrated against the ship's gyroscope during several special data runs. During the runs, each of the instruments was sampled at 20 Hz and the data recorded on optical disk. Data quality was monitored during the run and adjustments and repairs were carried out as necessary.

Limitations on the material strength of the wave wires and on the fidelity of their measurements required the cruising speed to be limited to 4 m/s when the wave staff array was deployed. Hence, two types of data runs were made: low speed runs (typically 2-3 m/s) into the wind with the array deployed, and high speed flux runs with the array out of the water. For the present, we are concerned with the first type of run. A total of some 29 hours of data suitable for the estimation of wave directional spectra was collected. A further 14 hours of data was unusable, due either to the malfunctioning of one of the three wave staffs or to the wave staff array being exposed (popping entirely out of the water) during the larger wave excursions. An example of

the latter event is evident as a clipping of the signal in Figure 1. The limited length of the wave wires restricted, to some degree, the wave amplitudes that could be measured from the ship. Although the position of the array in the water could be adjusted somewhat by using control surfaces on the pontoons to change the pitch angle of the ship, the practical operating limit for the collection of useful wave data was a significant height of less than 2.8 m.

3. Analysis and results

The process of obtaining estimates of directional spectra from the wave staff data was a somewhat lengthy one due to the motion of the ship. After a visual quality check, the wave height signals were corrected for ship motion following a procedure based on Anctil and Donelan (1992). The maximum likelihood method (MLM), with directional resolution of 10°/15° (for the 6/3 gauge array, respectively) was employed to obtain the directional estimates – see Isobe et al. (1984). The spectra of Appendix A are based on blocks of length 1024 (runs longer than 26 min) or 512 of 5 Hz data, averaged to produce 256 frequency bins yielding (600/256) x run length (in minutes) degrees of freedom.

The wave staff signals are corrected for ship accelerations and angular motion, but the resulting directional spectra are Doppler shifted in frequency due to the constant forward velocity of the ship. Unfortunately, the transformation between apparent frequency and wave number is not one-to-one over the full range of frequencies, so that a portion of the wave number field cannot be unscrambled – see Kats and Spevak (1981). The effects of this were minimized by pointing the ship into the wind so that the observed wind sea was shifted up in frequency. All waves travelling towards the ship are uniquely mapped onto an expanded Doppler shifted frequency range. At speeds of 4 m/s the inversion process is unique for waves of periods 6 seconds and longer

travelling with the ship. We assume that shorter waves are unlikely to be travelling against the wind.

During IOPs 2 and 3, the *F.G. Creed* spent approximately 200 hours in (and around) the SWADE operating area. In Figure 2, the ship's positions at the start of each of the 37 runs yielding directional spectra are designated by the run numbers. Further information on each run appears in Table 1 which is described below. Each of the principal buoys (Discus-N, -E & -C and CERC, with respective U.S. National Data Buoy Center codes N44001, N44015, N44023 and N44014) was visited at least once, with the majority of the runs taking place in the vicinity of Discus-C. The concentration of runs in this region was largely due to the sea state during the March 7-8 period – attempts to make measurements east of Discus-C during those days were thwarted due to excessive wave heights and a more sheltered operating area was sought. Similar conditions near the CERC buoy on March 4 account for the runs near Cape Hatteras.

The position listed for each run in Table 1 is that at the start of data collection. At a typical ship speed of 3 m/s, the ship would move at the rate of approximately 6 minutes/hr. During IOP 3, the Gulf Stream passed through the heart of the SWADE operating area. The bucket sea surface temperature measurements T_w appearing in Table 1 provide a marker for its potential influence on wave measurements. The wind data presented in Table 1 are based on measurements from the K-gill anemometer, corrected for ship motion (see Katsaros et al., 1992). Exceptions to this are runs 13, 14 and 15 when the K-gill was not functioning and measurements from nearest buoy (respectively Discus-N, -N, and CERC) were used. Also appearing in Table 1 are the average depth, significant wave height (H_s, 4 × the rms surface elevation), ship heading (based on the digicourse compass) and total sampling time for each run.

The directional spectra $F(f,\theta)$ themselves appear as polar contour plots in

Appendix A. North and East appear respectively at the top and right hand side in each of these plots, following standard meteorological convention. Grid lines are 30° apart, with frequencies every 0.1 Hz to a maximum of 0.4 Hz. The wave spectra are shown in the direction of propagation with equally spaced contour lines normalized to the energy maximum of each spectrum. As the wind sea is often dwarfed in magnitude by the underlying swell, an alternative presentation is necessary to study the former. Hence we also present contour plots of the directional spectra multiplied by the fourth power of frequency – see Donelan et al. (1985). The average wind vector appears on each contour plot as an arrow pointing in the direction of the wind, with 1 radial line equivalent to a wind speed of 10 m/s. One-dimensional spectra, both as measured (Doppled shifted, - -) and as determined from the directional analysis (—), appear in the third part of each figure on log-log axes.

In general, the quality of each directional spectral estimate is a function of the length of the run (assuming stationarity) and of the number of wave staffs in the array. In a few of the runs (numbers 15, 23 and 24) however, the height of the waves encountered resulted in a small fraction of the signal being clipped – typically, 2-3 points clipped on 5-10 % of the troughs. This error, which along with its approximate frequency of occurrence is noted on the relevant figures, will increase the uncertainty of the spectral estimates. However, numerical experiments carried out on good data indicate no significant directional effects from clipping at this level.

Although the ship heading was generally within ±30° of the upwind direction, this was not the case for runs 21 and 22 where the ship headed at about 135° to the upwind direction and at 90° to the swell. Although the wind seas for these runs are not correctly represented in the spectra, the swell components are believed to good because the Doppler shifting problem is relatively unimportant for waves travelling perpendicular to the ship. Again, any extraordinary factors pertinent to a particular

run are noted on the appropriate figures in Appendix A.

ACKNOWLEDGEMENTS

The introduction of the SWATH ship in SWADE was brought about by the loss of the Spar buoy. Consequently, financial decisions and engineering designs had to be realized in an unusually short time. This could not have been possible without the full cooperation of many people. In particular, we thank D. Beesley, S. Bodwin, A. Brandt, J. Bull, K. Davis, F. Dobson, J. Ford, J. Gabriele, H. Graber, F. Herr, F. Lambert, W. Patzert, S. Peck, M. Pedrosa, S. Roberts, H. Savile, M. Skafel, S. Smith, B. Taylor and L. Vincent.

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LIST OF TABLES AND FIGURES

Table 1: Directional spectra from the *F.G. Creed.*

Figure 1: Example of clipped wave staff signal.

Figure 2: Locations of the SWATH directional spectra.

Table 1 : Directional spectra from the *Frederick G. Creed*

Run	GMT Start		Length	Lat	Long	Depth	T_w	Hdg	Wind		H_s
No.	Date	Time	mins	N	W	m	°C	deg	dir.	speed	m
1	Jan. 21	21:48	26	37° 18'	75° 36'	12	10	337	337	10.1	0.9
2	Jan. 22	00:07	51	37° 12'	75° 30'	22	11	350	353	11.5	1.5
3	Jan. 22	00:58	51	37° 15'	75° 30'	20	11	348	358	11.8	1.5
4	Jan. 22	17:40	60	37° 42'	74° 54'	31	10	321	331	10.5	2.1
5	Jan. 22	18:40	60	37° 45'	74° 56'	31	10	318	328	10.1	1.9
6	Jan. 22	20:16	60	37° 54'	75° 00'	24	10	317	337	8.9	1.6
7	Jan. 23	03:08	60	37° 24'	74° 24'	185	16	332	318	3.7	1.3
8	Jan. 23	04:08	60	37° 28'	74° 25'	130	16	332	334	2.8	1.3
9	Jan. 23	05:08	60	37° 32'	74° 27'	85	14	332	314	3.0	1.3
10	Jan. 23	06:08	60	37° 36'	74° 28'	70	13	332	320	2.0	1.2
11	Feb. 25	17:10	60	37° 28'	74° 23'	185	23	17	7	10.7	2.6
12	Feb. 25	18:59	43	37° 35'	74° 18'	180	22	17	15	9.5	2.6
13	Feb. 27	01:03	11	38° 18'	73° 37'	270	9	343	334	10.0	2.9
14	Feb. 27	02:05	26	38° 21'	73° 37'	200	10	343	322	11.0	2.2
15	March 4	11:42	4	36° 33'	75° 05'	31	12	196	206	14.9	2.7
16	March 4	18:56	60	36° 09'	75° 15'	33	11	200	218	9.6	2.9
17	March 4	20:13	43	36° 06'	75° 16'	33	12	200	219	10.3	2.7
18	March 5	01:00	60	35° 49'	75° 04'	40	16	273	260	9.5	2.7
19	March 5	02:00	60	35° 49'	75° 09'	35	14	270	248	8.8	2.6
20	March 5	03:00	60	35° 48'	75° 14'	30	15	270	245	8.7	2.2
21	March 5	12:55	43	37° 32'	74° 34'	65	15	88	310	10.6	2.6
22	March 5	13:37	43	37° 32'	74° 36'	65	16	88	315	10.6	2.6
23	March 5	15:00	77	37° 33'	74° 15'	600	17	320	315	7.5	2.4
24	March 5	21:09	68	36° 50'	74° 00'	2500	19	325	304	3.3	2.5
25	March 5	23:09	68	37° 00'	74° 10'	2000	19	319	287	4.1	1.9
26	March 6	02:15	17	37° 14'	74° 21'	1300	20	305	260	1.1	1.8
27	March 6	17:17	68	37° 17'	73° 27'	2600	20	200	181	7.7	2.1
28	March 7	19:08	26	37° 40'	74° 21'	80	15	302	323	7.3	2.3
29	March 7	20:32	17	37° 43'	74° 26'	65	13	302	311	5.2	2.2
30	March 7	22:29	43	37° 49'	74° 36'	50	11	315	307	7.0	2.1
31	March 8	00:33	68	37° 58'	74° 46'	30	10	316	322	9.3	1.9
32	March 8	21:23	60	37° 32'	74° 42'	50	11	326	321	7.6	1.5
33	March 8	22:23	60	37° 32'	74° 44'	50	10	326	315	6.8	1.4
34	March 8	23:36	26	37° 42'	74° 37'	55	10	322	315	6.1	1.1
35	March 9	00:06	22	37° 44'	74° 38'	55	11	297	331	7.0	1.1
36	March 9	00:33	19	37° 45'	74° 40'	55	10	354	323	7.7	1.1
37	March 9	01:00	17	37° 47'	74° 40'	50	10	323	328	7.9	0.9

Fig. 1a - Example of clipped wave staff signal

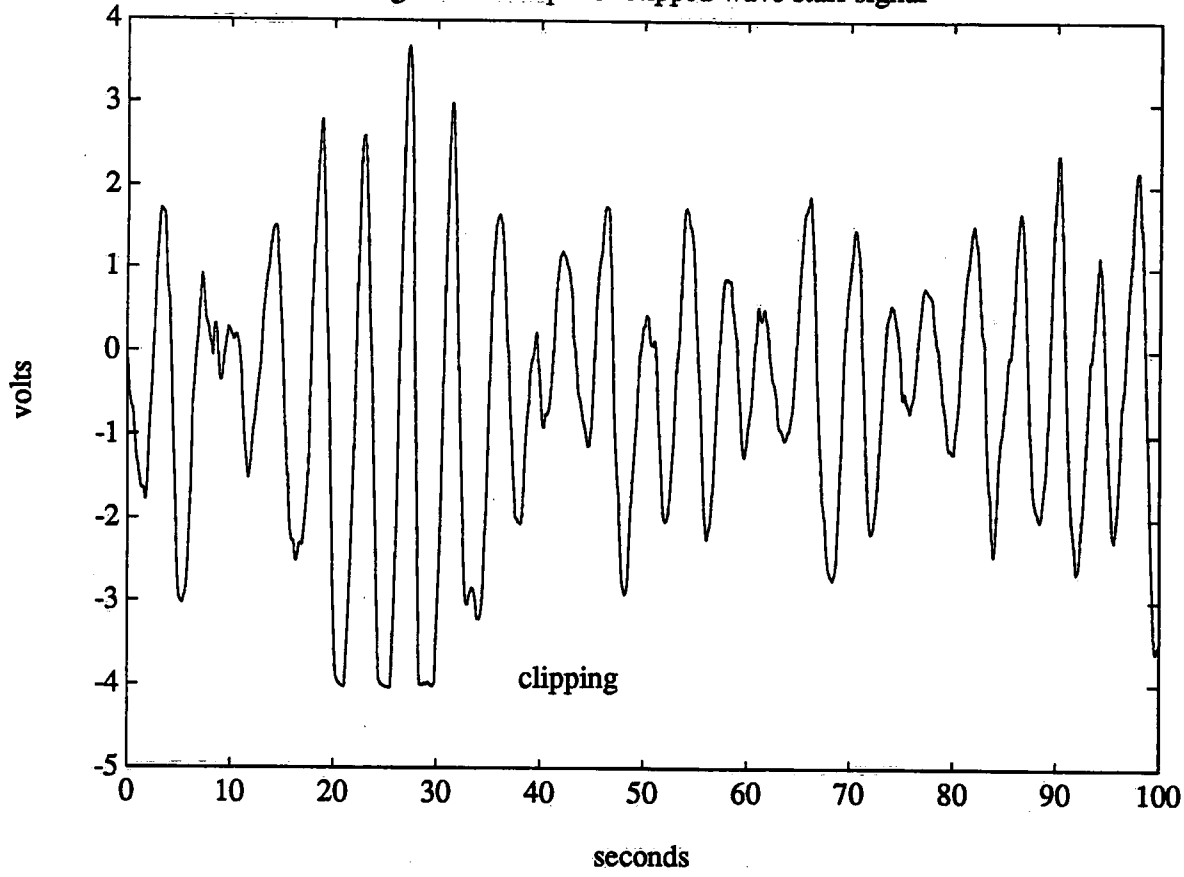


Fig. 1b - Example of good wave staff signal

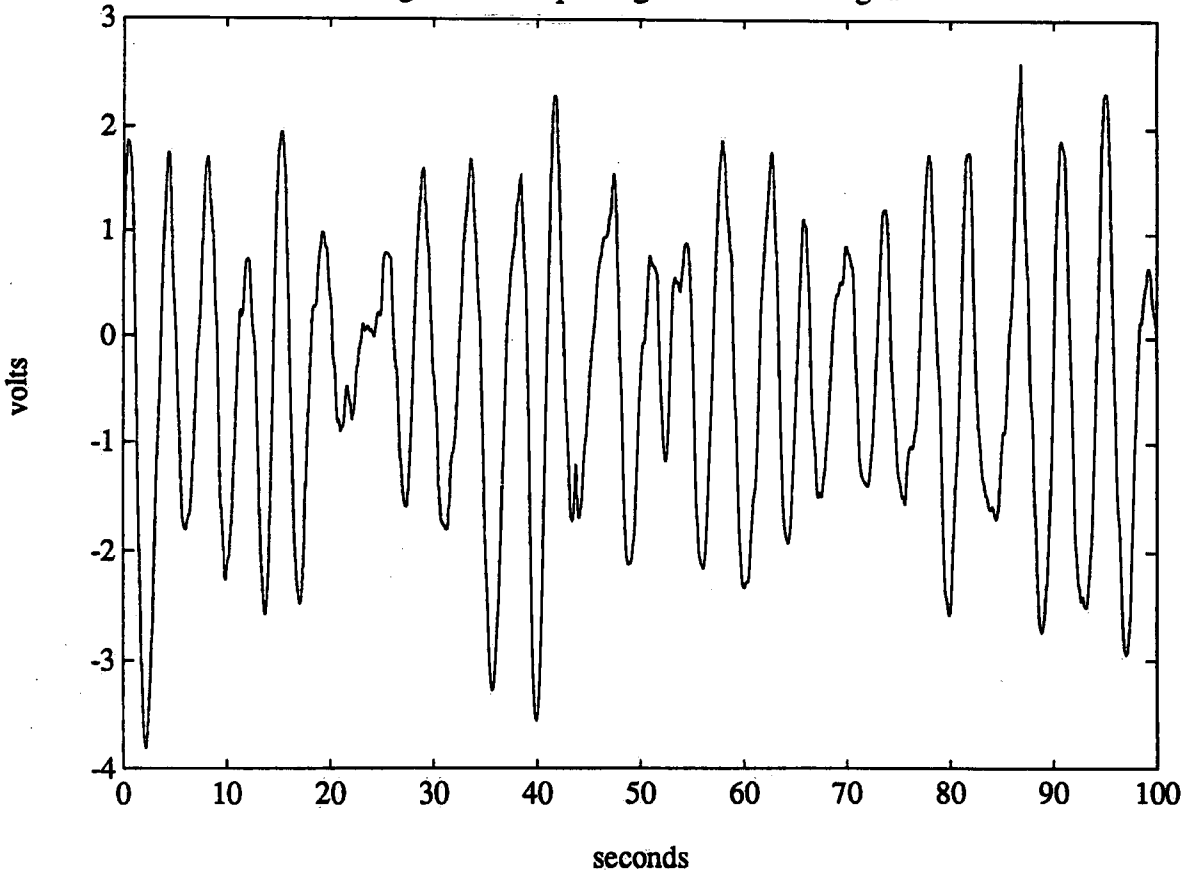


Fig. 2a - SWATH directional spectra during IOP2, January 1991

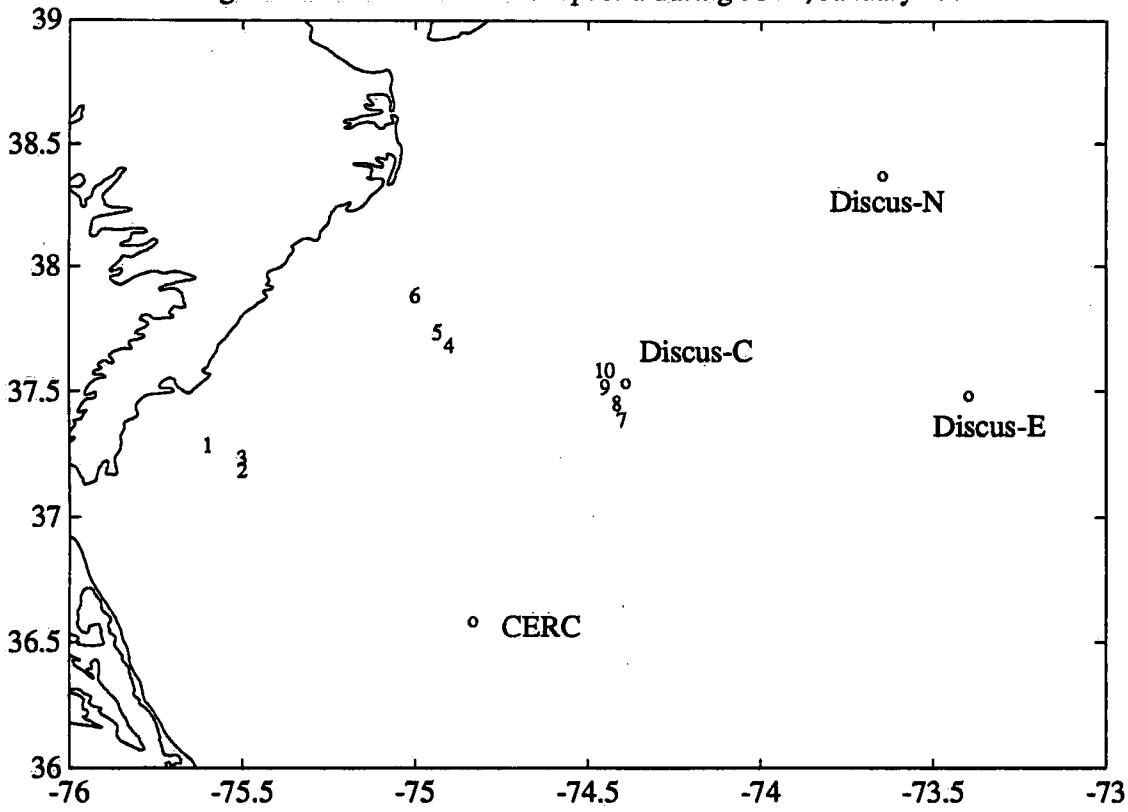


Fig. 2b - SWATH directional spectra during IOP3, February 1991

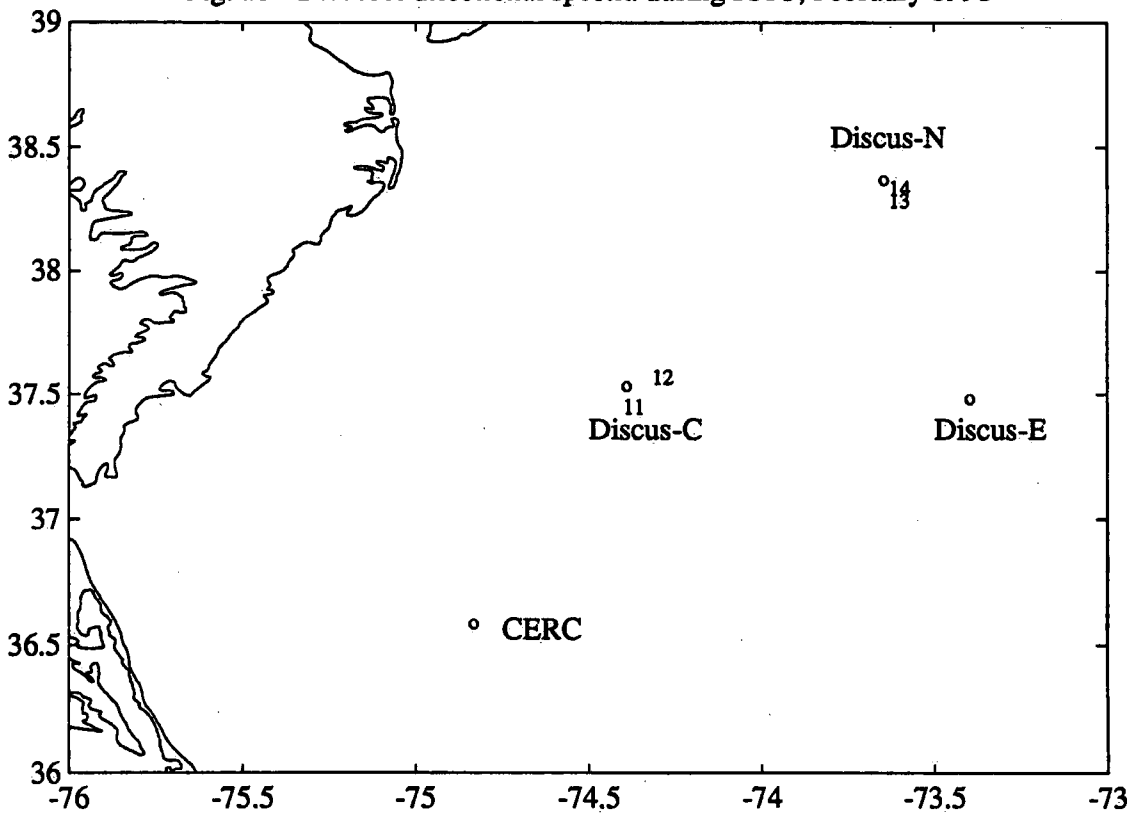


Fig. 2c - SWATH directional spectra during IOP3, 4-6 March 1991

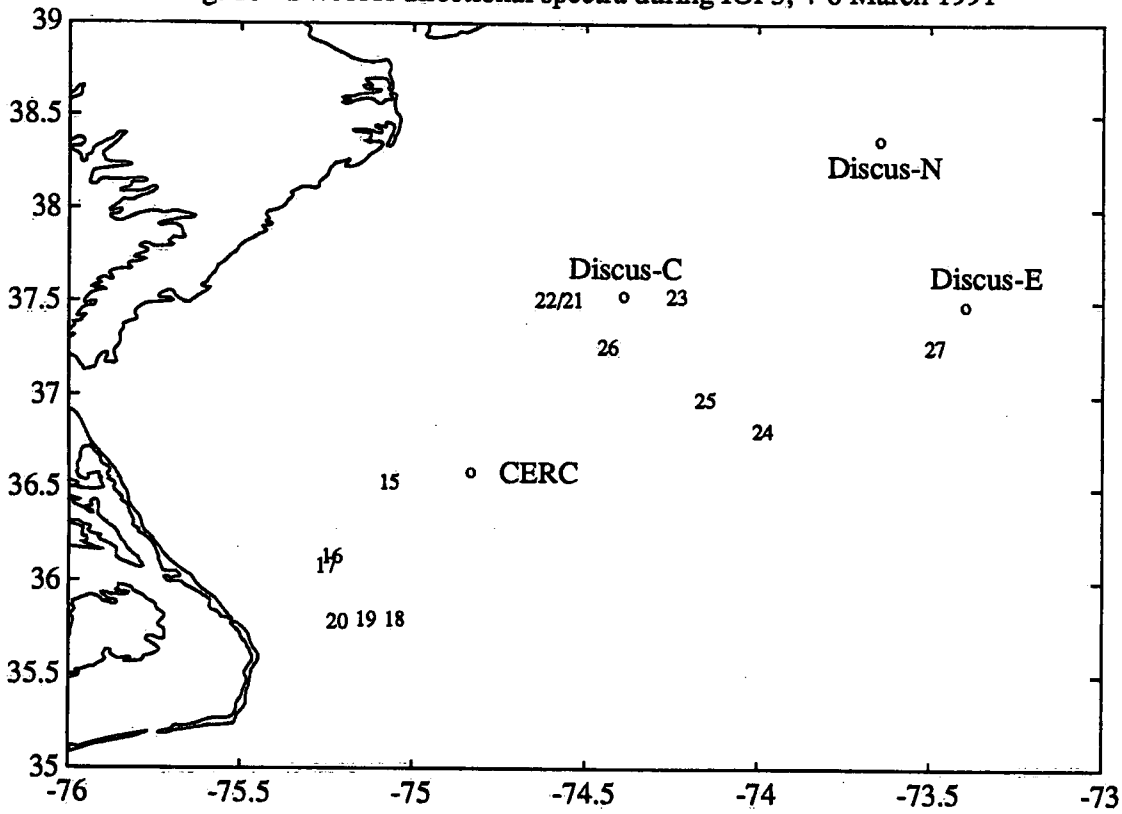
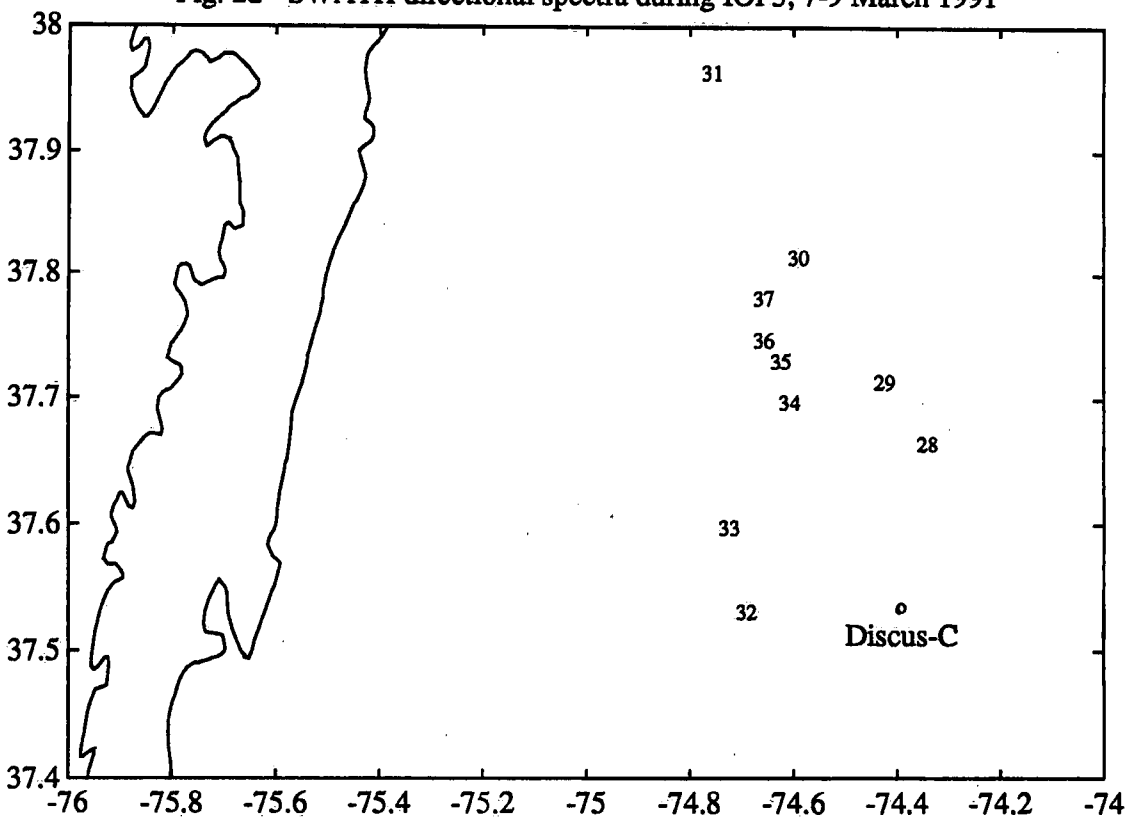
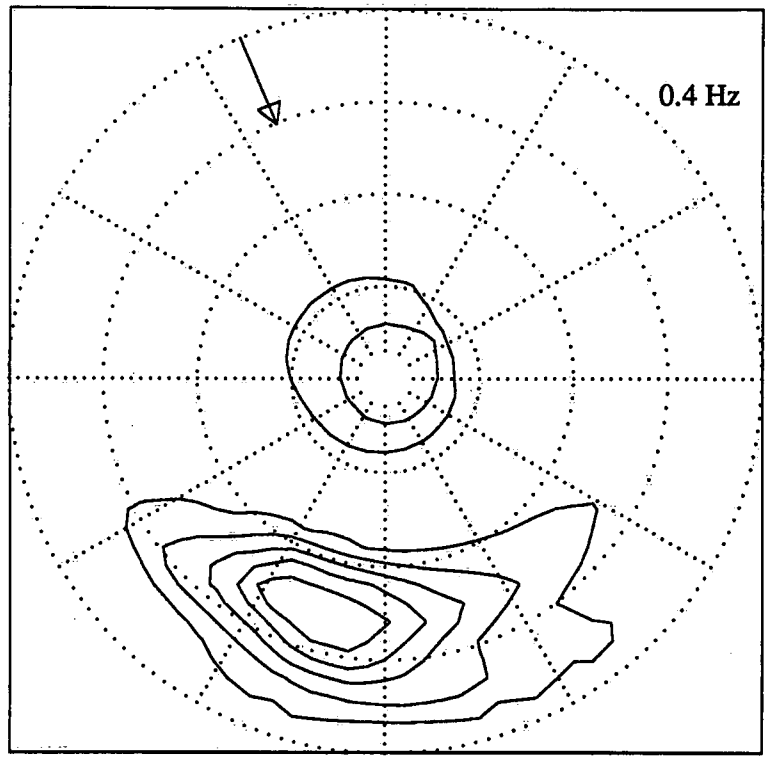


Fig. 2d - SWATH directional spectra during IOP3, 7-9 March 1991



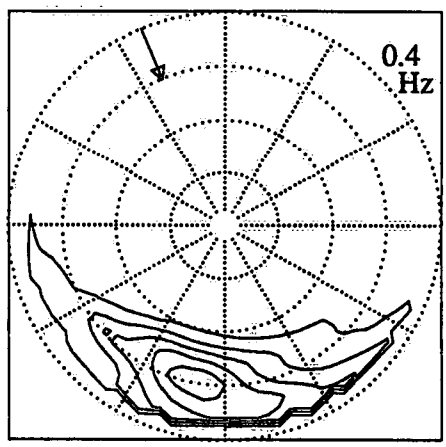
Appendix A : SWATH ship directional spectra

SWATH 1 91.1.21 21:48Z @ 37 18 N 75 36 W. (26 mins)



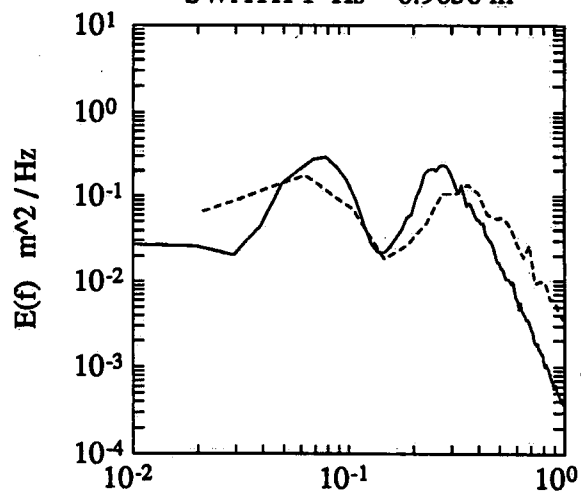
ship hdg: 337 @ 2.2 m/s. D = 12 m (6 staffs)

DS * f^4

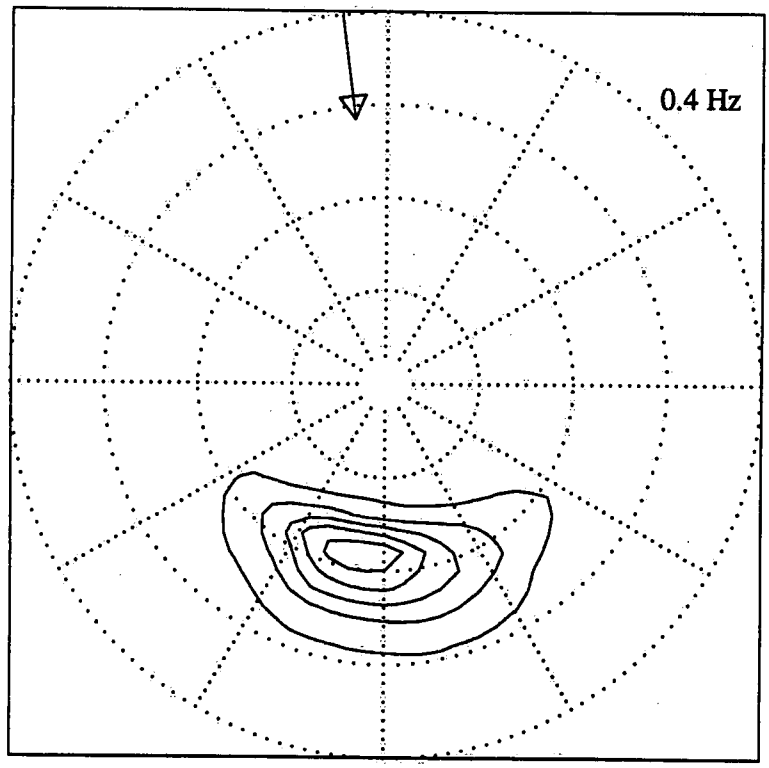


Wind speed 10.2 m/s from 337 degrees T

SWATH 1 Hs = 0.9056 m

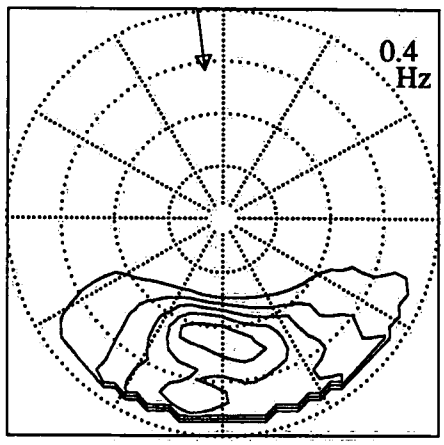


SWATH 2 91.1.22 00:07Z @ 37 12 N 75 30 W. (51 mins)



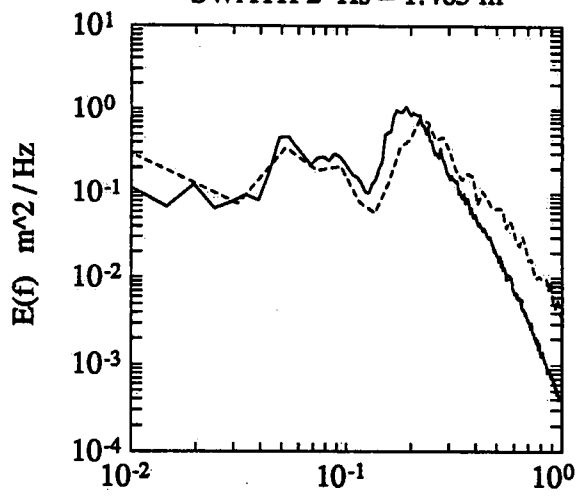
ship hdg: 350 @ 1.95 m/s. D = 22 m (6 staffs)

DS * f^4



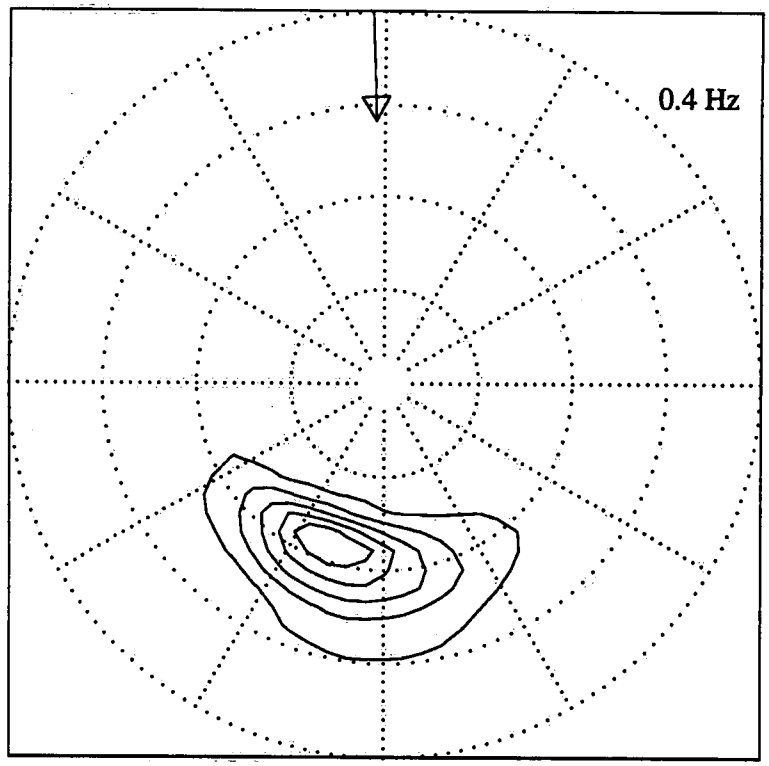
Wind speed 11.5 m/s from 353 degrees T

SWATH 2 Hs = 1.465 m



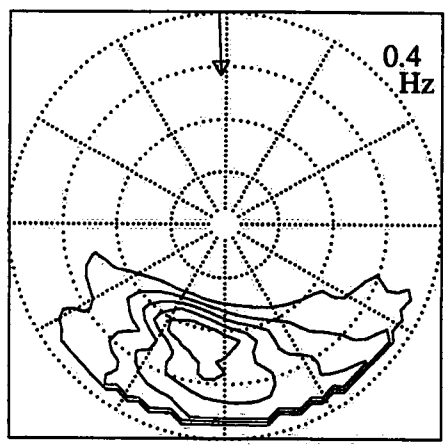
frequency [Hz]

SWATH 3 91.1.22 00:58Z @ 37 15 N 75 30 W. (51 mins)

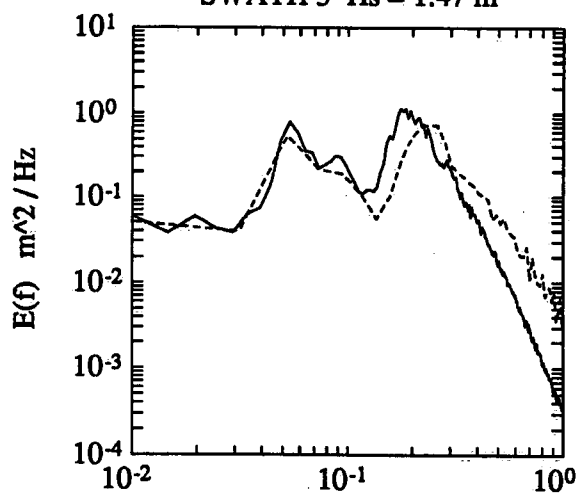


ship hdg: 348 @ 1.95 m/s. D = 20 m (6 staffs)

DS * f^4

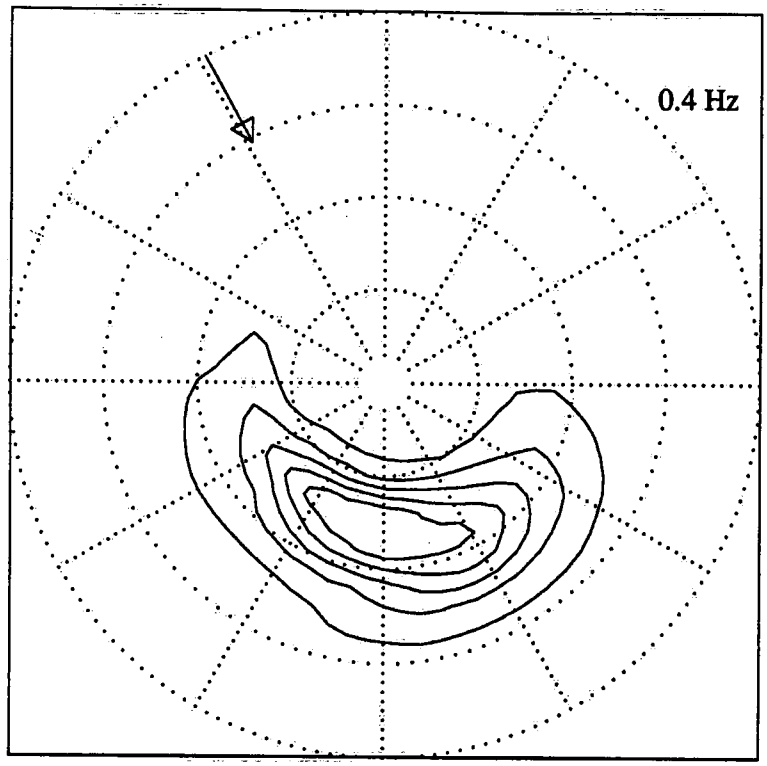


SWATH 3 Hs = 1.47 m



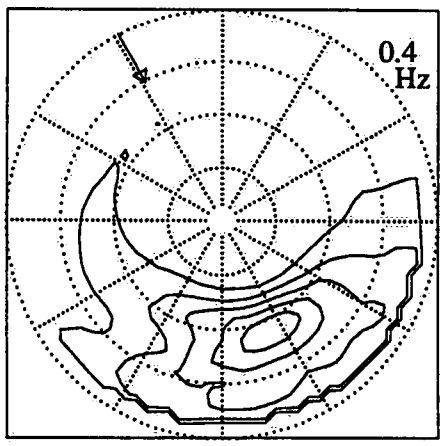
Wind speed 11.8 m/s from 358 degrees T

SWATH 4 91.1.22 17:40Z @ 37 42 N 74 54 W. (60 mins)



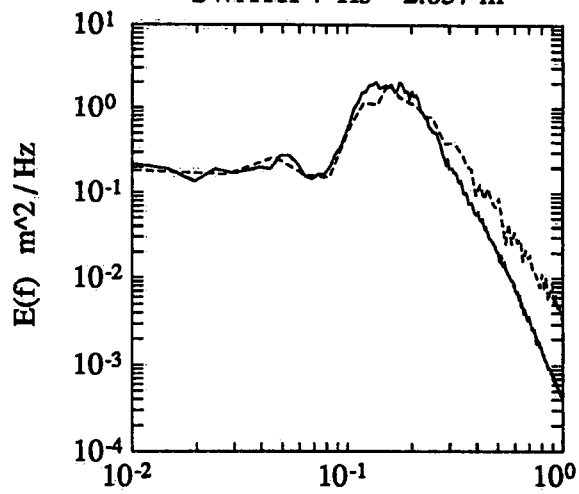
ship hdg: 321 @ 1.93 m/s. D = 31 m (6 staffs)

DS * f^4



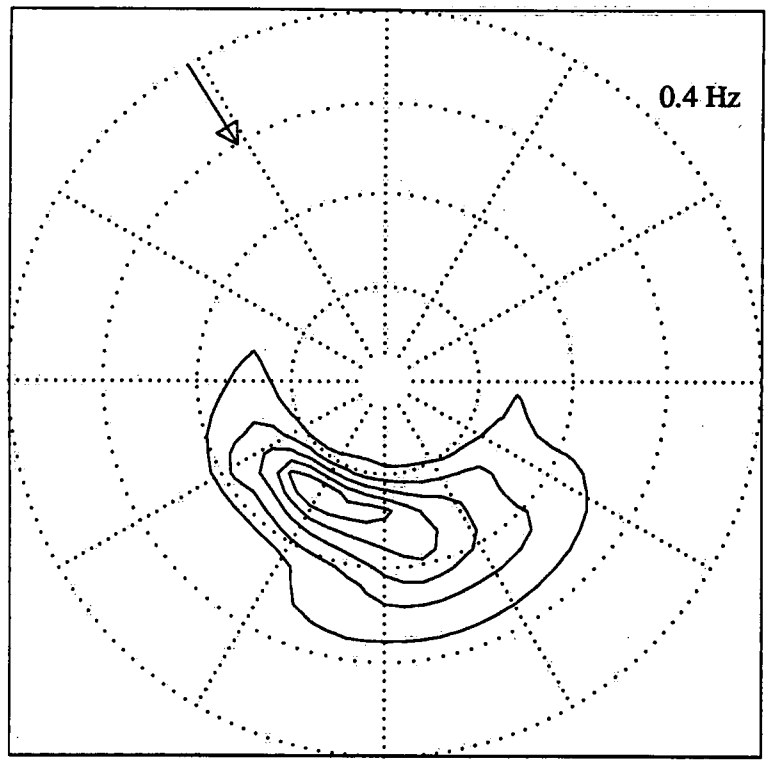
Wind speed 10.5 m/s from 331 degrees T

SWATH 4 Hs = 2.057 m



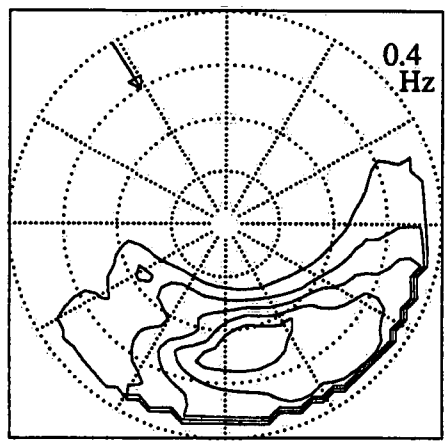
frequency [Hz]

SWATH 5 91.1.22 18:40Z @ 37 45 N 74 56 W. (51 mins)

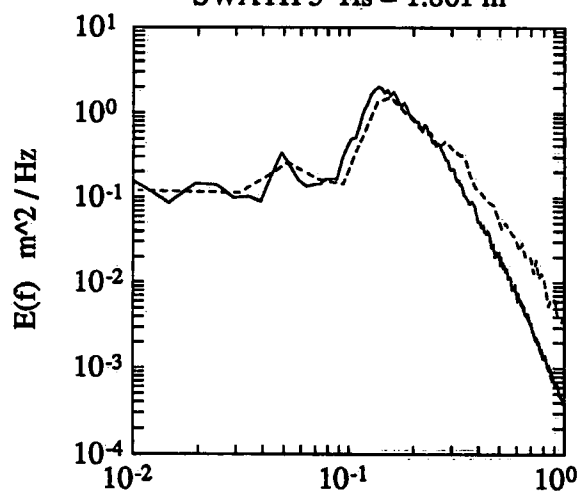


ship hdg: 318 @ 1.97 m/s. D = 31 m (6 staffs)

DS * f^4

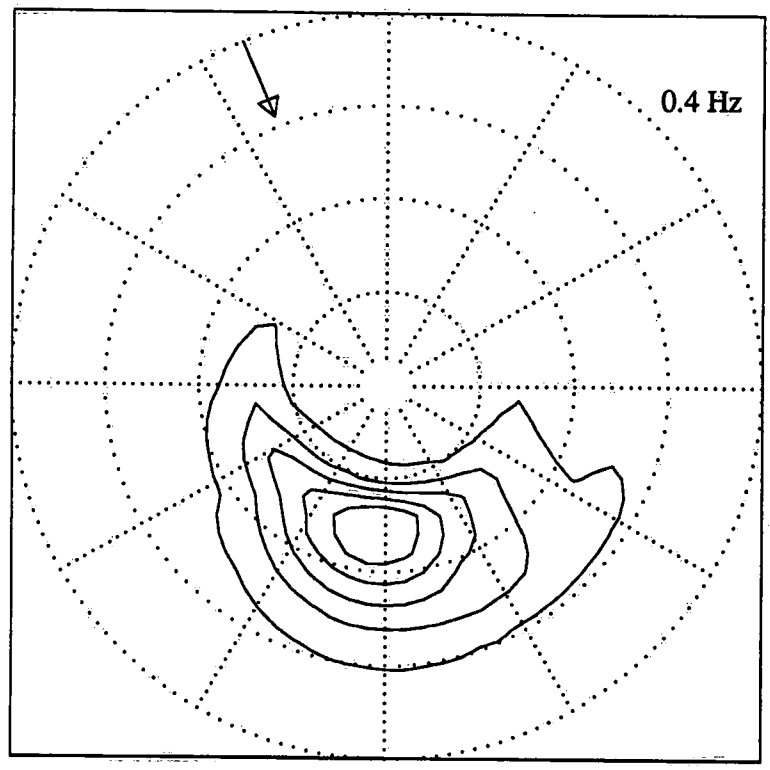


SWATH 5 Hs = 1.861 m



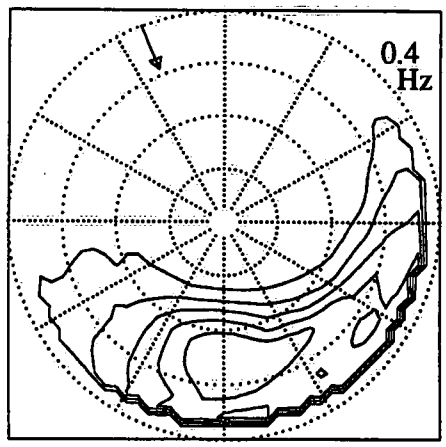
Wind speed 10.1 m/s from 328 degrees T

SWATH 6 91.1.22 20:16Z @ 37 54 N 75 0 W. (60 mins)



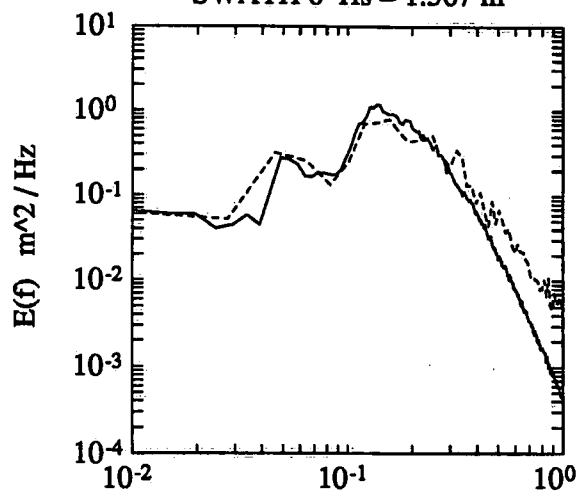
ship hdg: 317 @ 1.85 m/s. D = 24 m (6 staffs)

DS * f^4



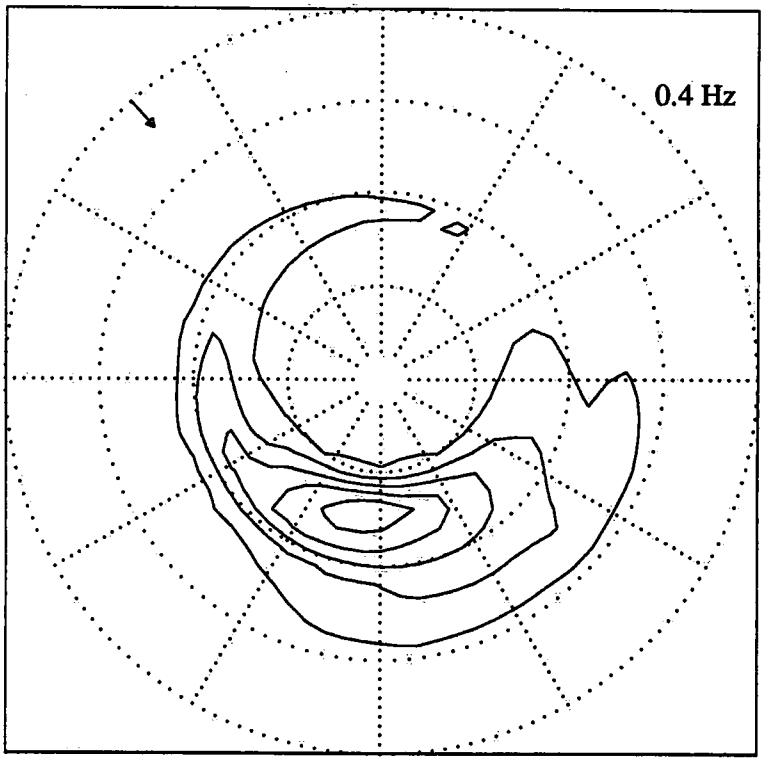
Wind speed 8.9 m/s from 337 degrees T

SWATH 6 Hs = 1.567 m



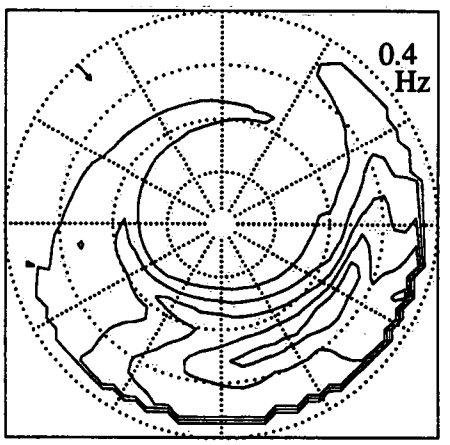
frequency [Hz]

SWATH 7 91.1.23 03:08Z @ 37 24 N 74 24 W. (60 mins)

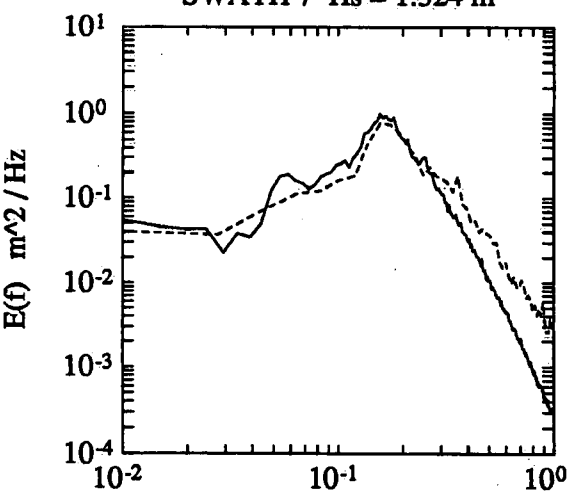


ship hdg: 332 @ 2.16 m/s. D = 185 m (6 staffs)

DS * f^4

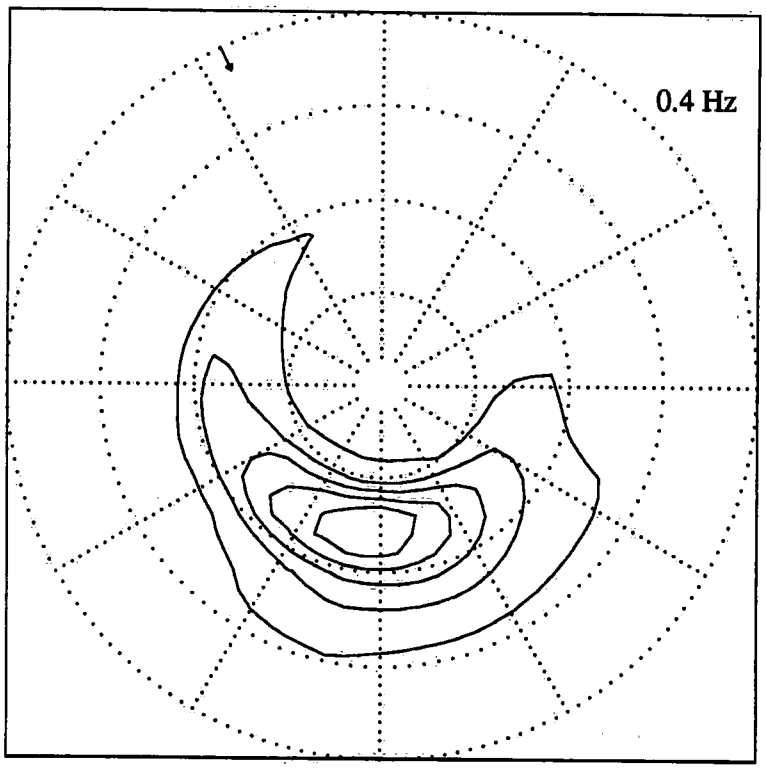


SWATH 7 Hs = 1.324 m



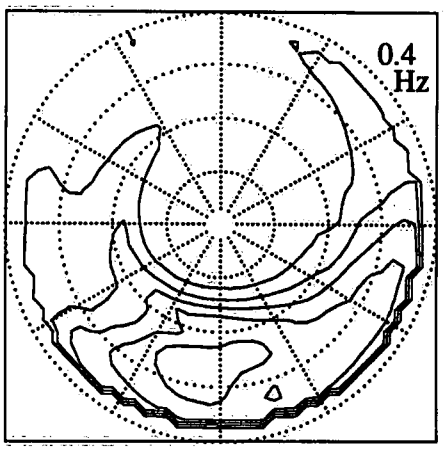
Wind speed 3.7 m/s from 318 degrees T

SWATH 8 91.1.23 04:08Z @ 37 28 N 74 25 W. (60 mins)



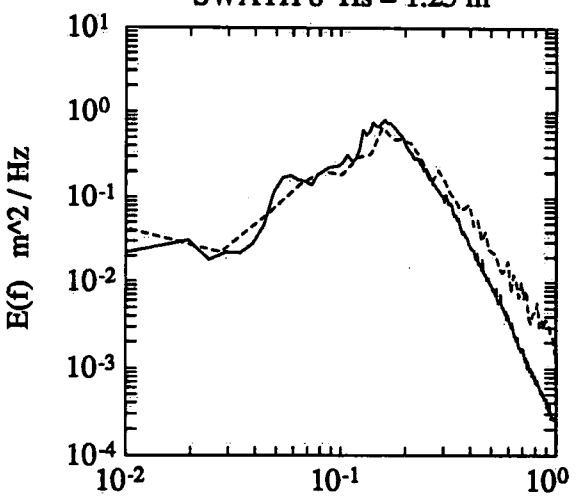
ship hdg: 332 @ 2.16 m/s. D = 130 m (6 staffs)

DS * f^4

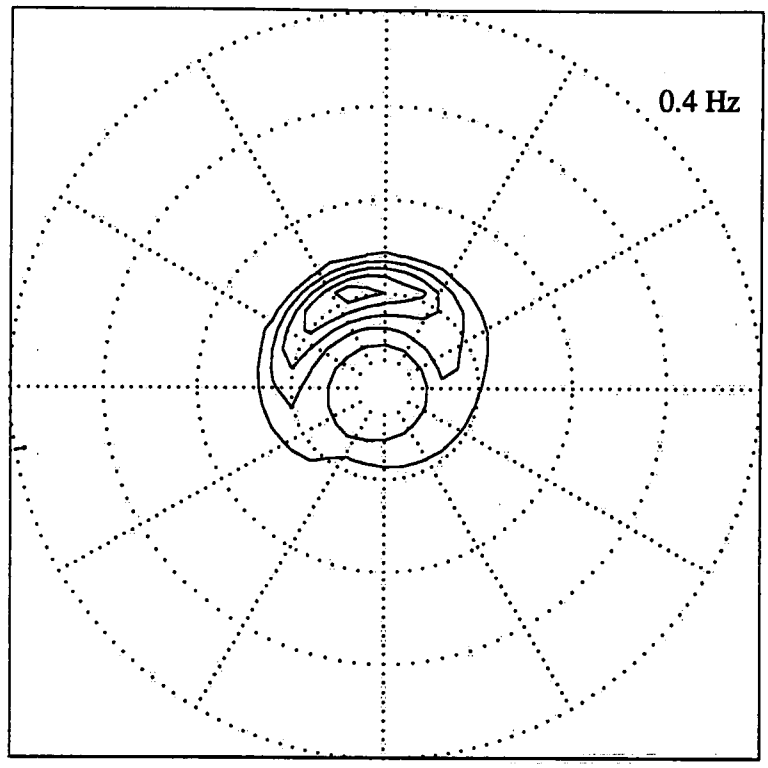


Wind speed 2.8 m/s from 334 degrees T

SWATH 8 Hs = 1.25 m

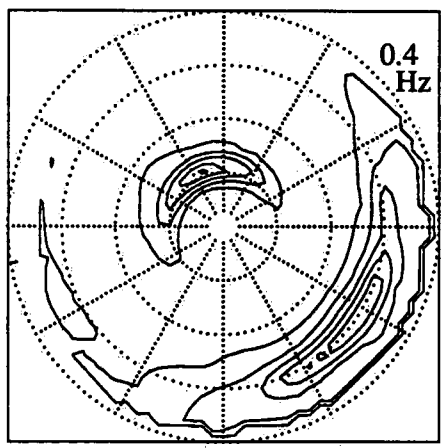


SWATH 26 91.3.6 03:06Z @ 37 17 N 74 27 W. (15 mins)



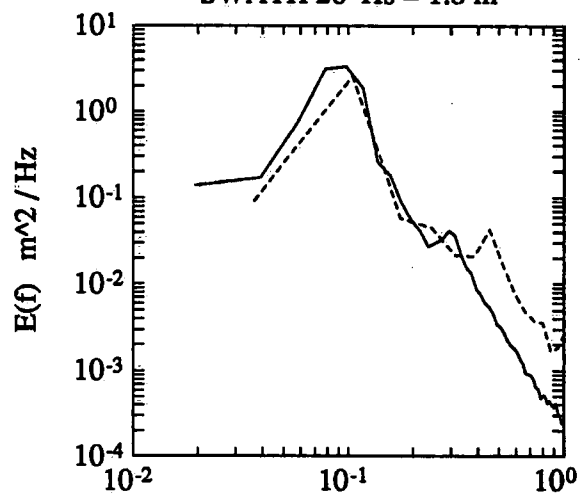
ship hdg: 305 @ 3 m/s. D = 1300 m (3 staffs)

DS * f^4



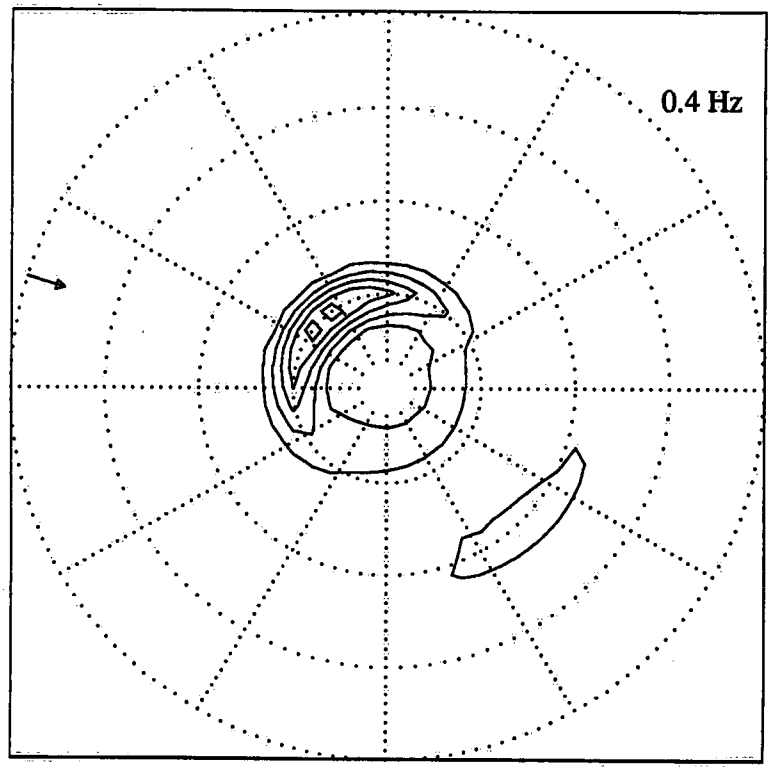
Wind speed 1.1 m/s from 260 degrees T

SWATH 26 Hs = 1.8 m



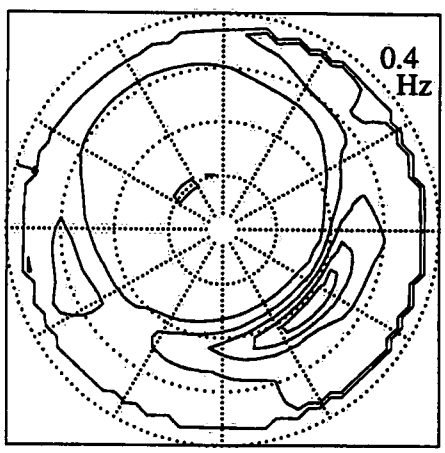
frequency [Hz]

SWATH 25 91.3.5 23:09Z @ 37 0 N 74 10 W. (68 mins)



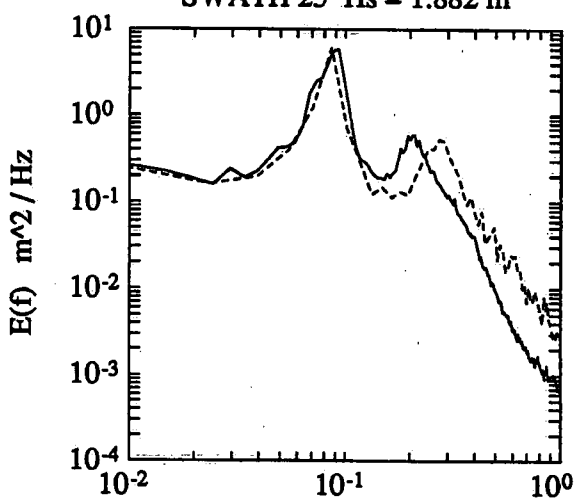
ship hdg: 319 @ 3.1 m/s. D = 2000 m (3 staffs)

DS * f^4



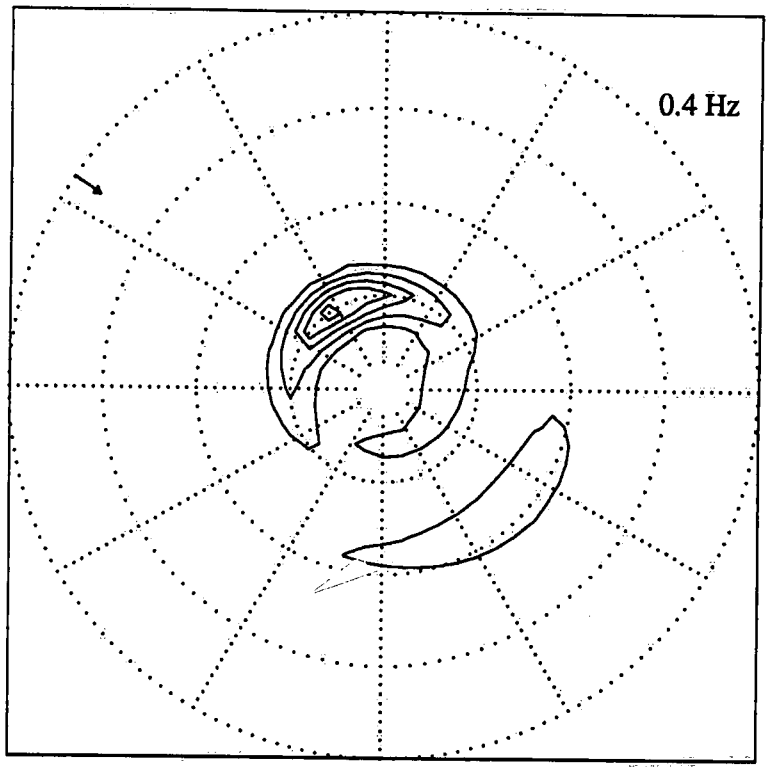
Wind speed 4.1 m/s from 287 degrees T

SWATH 25 Hs = 1.882 m



frequency [Hz]

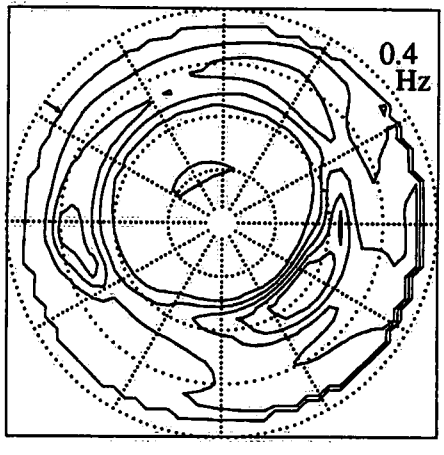
SWATH 24 91.3.5 21:43Z @ 36 50 N 74 0 W. (34 mins)



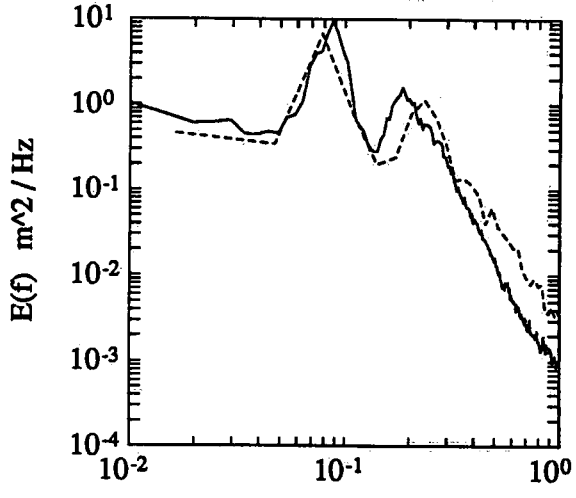
ship hdg: 325 @ 2.9 m/s. D = 2500 m (3 staffs)

some signal clipping at 8-10% of troughs

DS * f^4

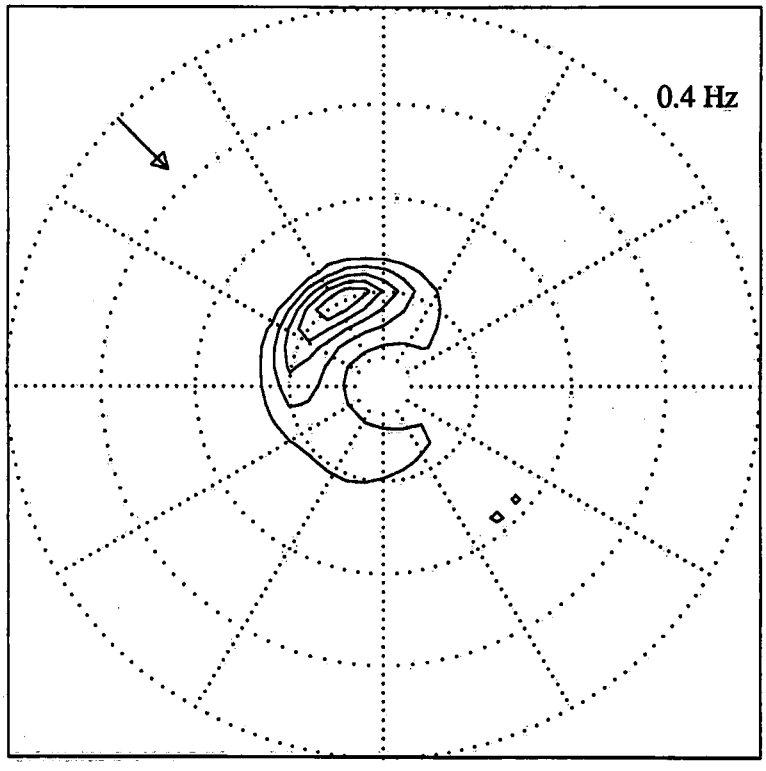


SWATH 24 Hs = 2.499 m



Wind speed 3.3 m/s from 304 degrees T

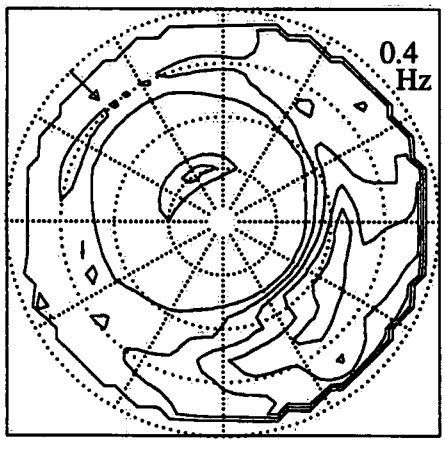
SWATH 23 91.3.5 15:17Z @ 37 33 N 74 15 W. (17 mins)



ship hdg: 320 @ 2.57 m/s. D = 600 m (3 staffs)

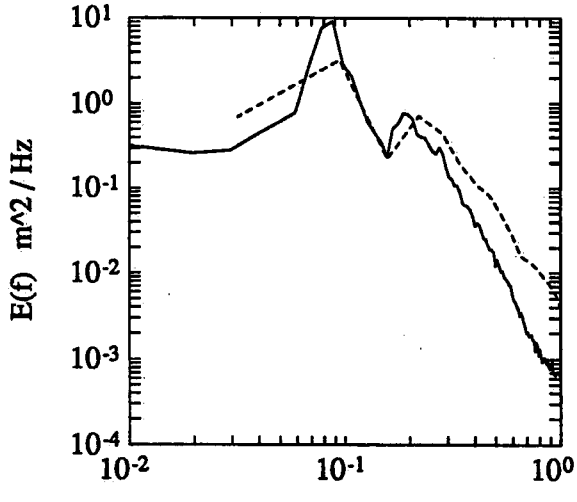
some signal clipping at 8-10% of troughs

DS * f^4



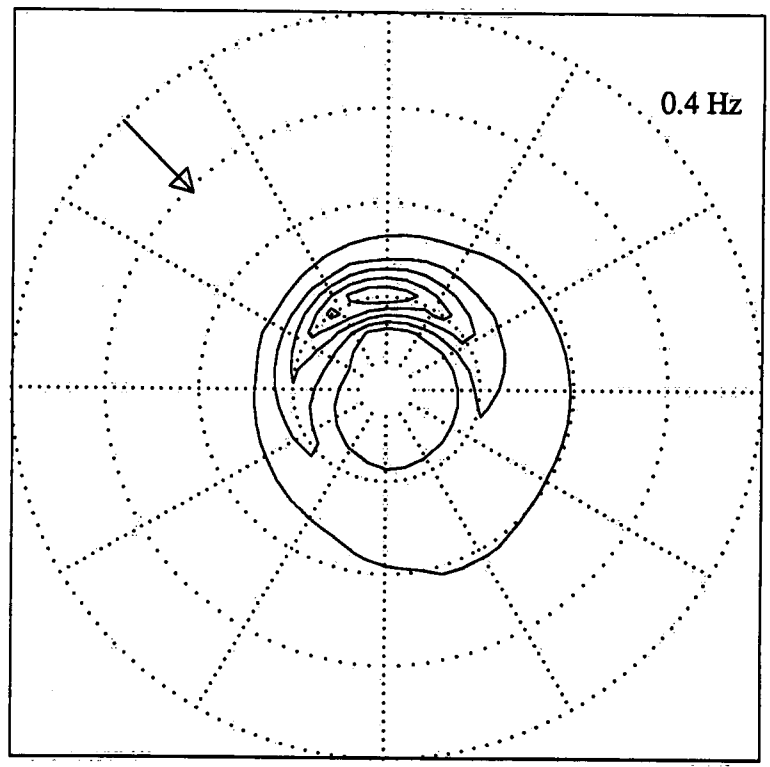
Wind speed 7.5 m/s from 315 degrees T

SWATH 23 Hs = 2.419 m



frequency [Hz]

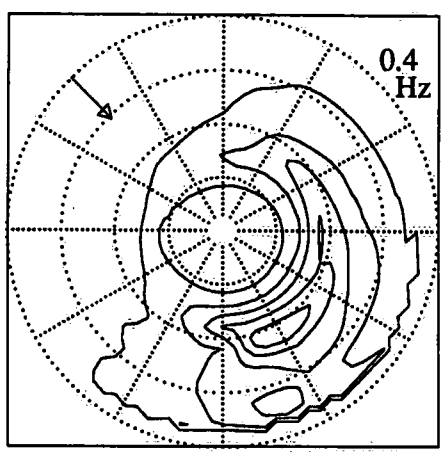
SWATH 22 91.3.5 13:37Z @ 37 32 N 74 36 W. (43 mins)



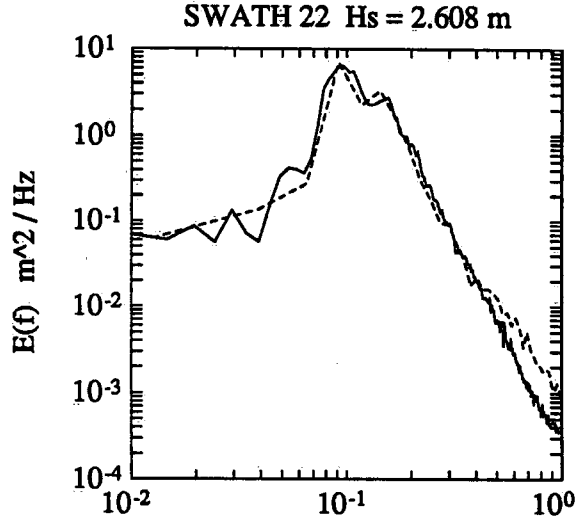
ship hdg: 88 @ 2.57 m/s. D = 65 m (3 staffs)

ship heading at 135 deg to wind

DS * f^4

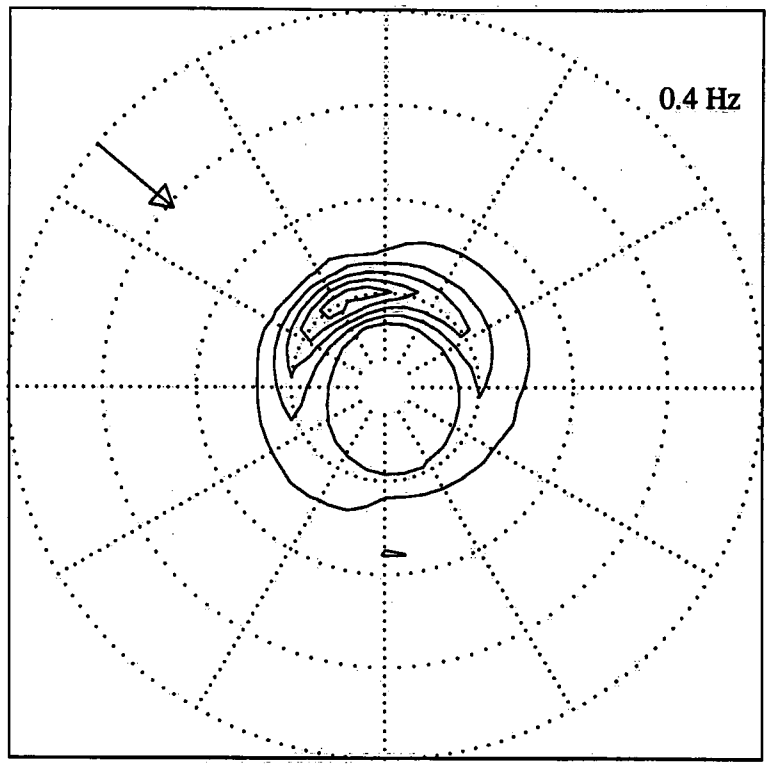


SWATH 22 Hs = 2.608 m



Wind speed 10.6 m/s from 315 degrees T

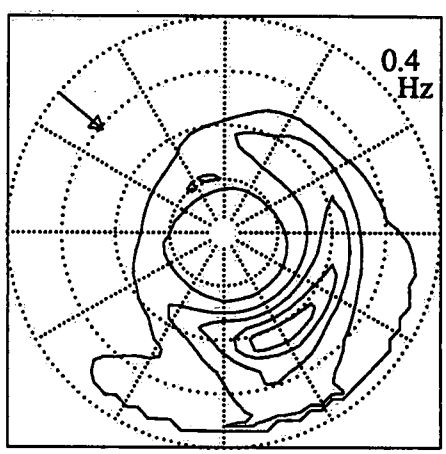
SWATH 21 91.3.5 12:55Z @ 37 32 N 74 34 W. (43 mins)



ship hdg: 88 @ 2.57 m/s. D = 65 m (3 staffs)

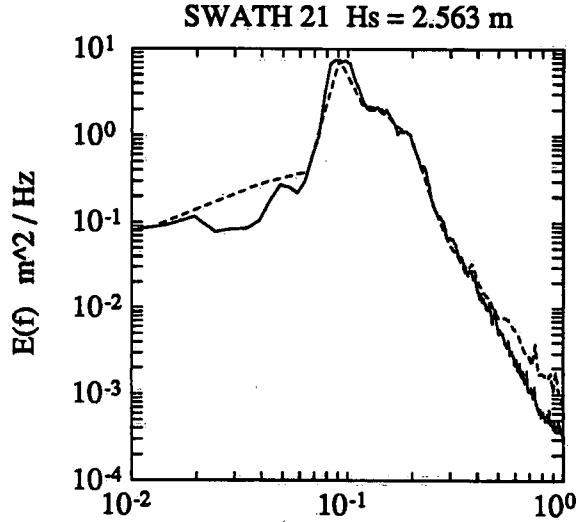
ship heading at 135 deg to wind

DS * f^4

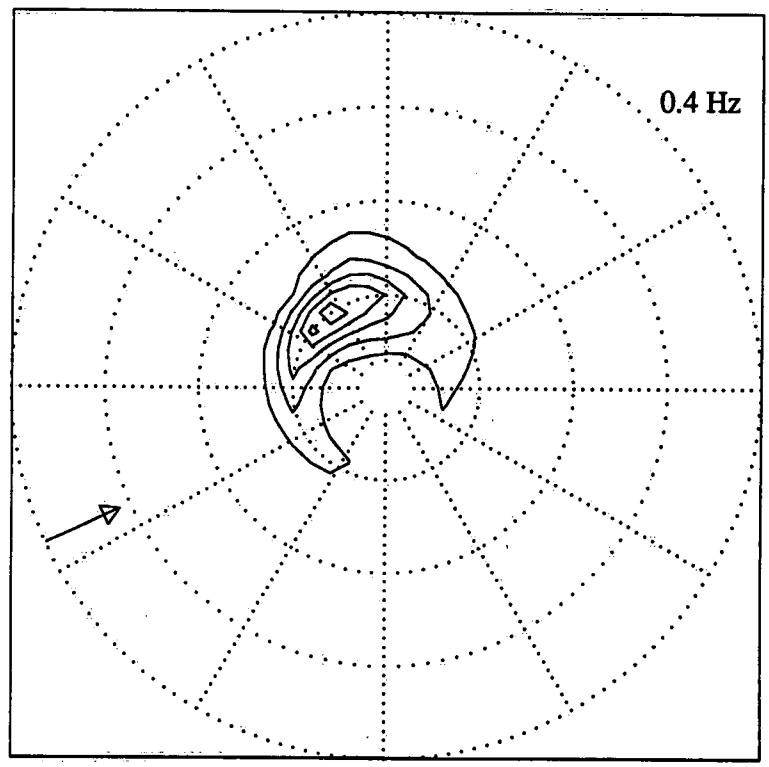


Wind speed 10.6 m/s from 310 degrees T

SWATH 21 Hs = 2.563 m

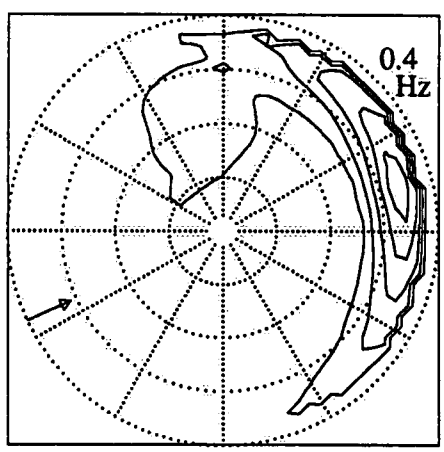


SWATH 20 91.3.5 03:00Z @ 35 48 N 75 14 W. (60 mins)



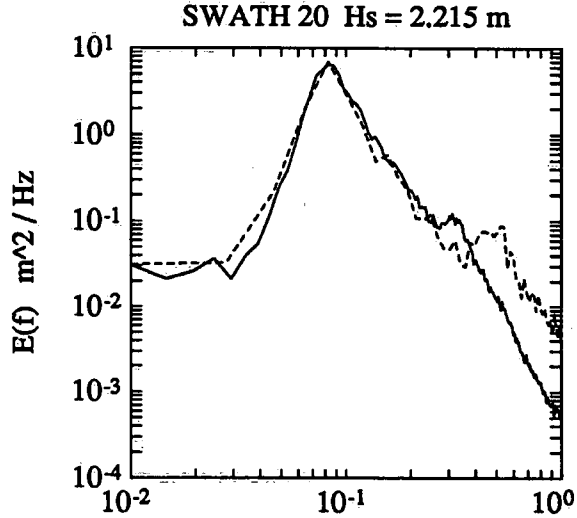
ship hdg: 270 @ 2.55 m/s. D = 30 m (3 staffs)

DS * f^4



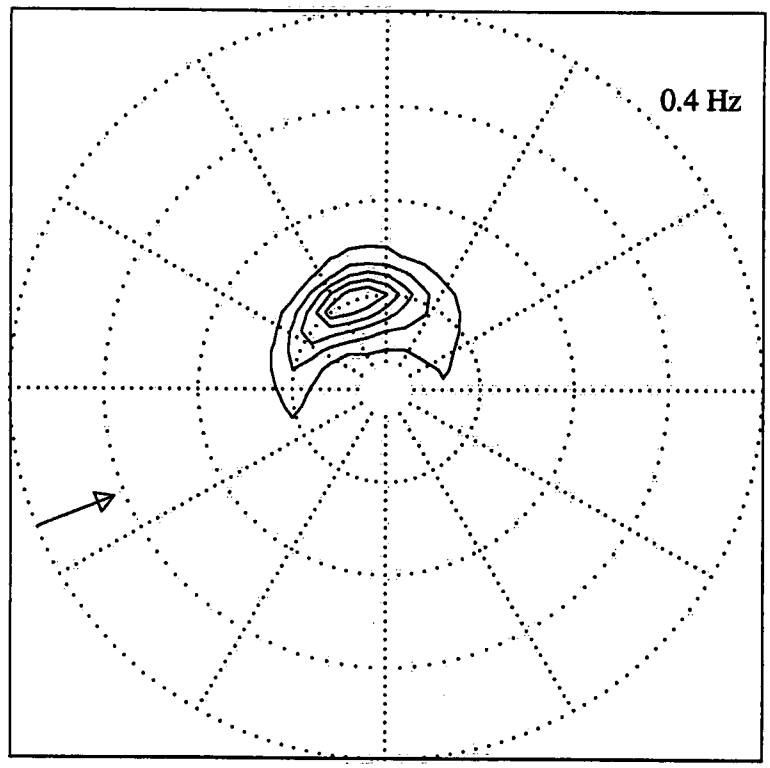
Wind speed 8.7 m/s from 245 degrees T

SWATH 20 Hs = 2.215 m



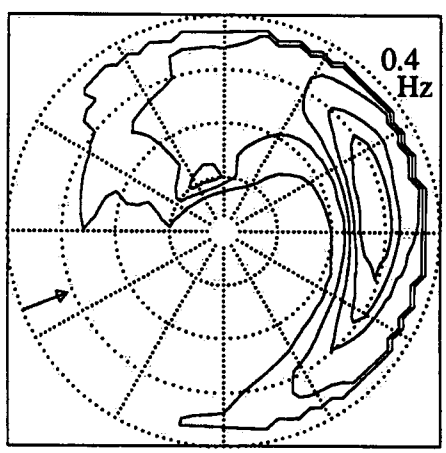
frequency [Hz]

SWATH 19 91.3.5 02:00Z @ 35 49 N 75 9 W. (60 mins)



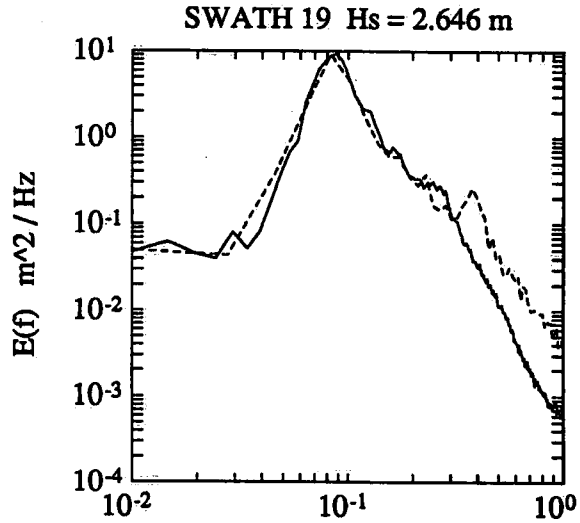
ship hdg: 270 @ 2.55 m/s. D = 35 m (3 staffs)

DS * f^4

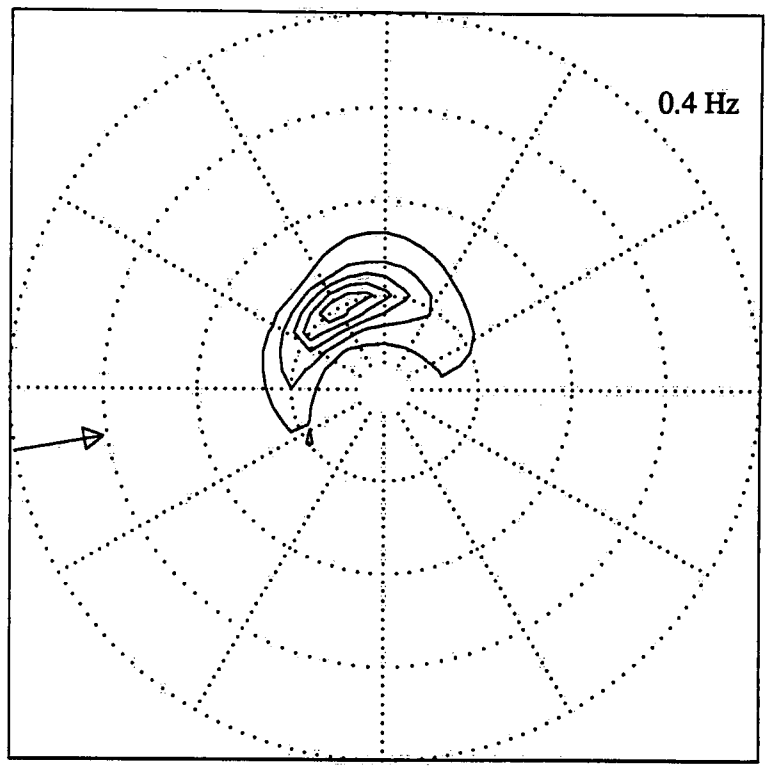


Wind speed 8.8 m/s from 248 degrees T

SWATH 19 Hs = 2.646 m

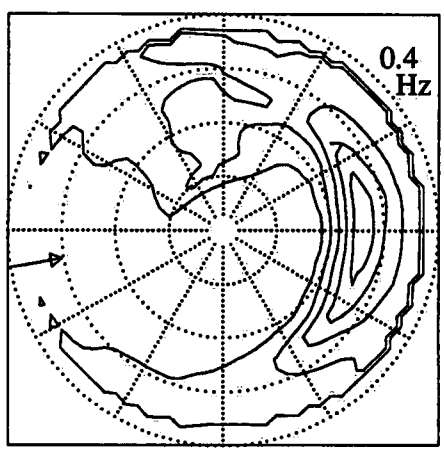


SWATH 18 91.3.5 01:00Z @ 35 49 N 75 4 W. (60 mins)

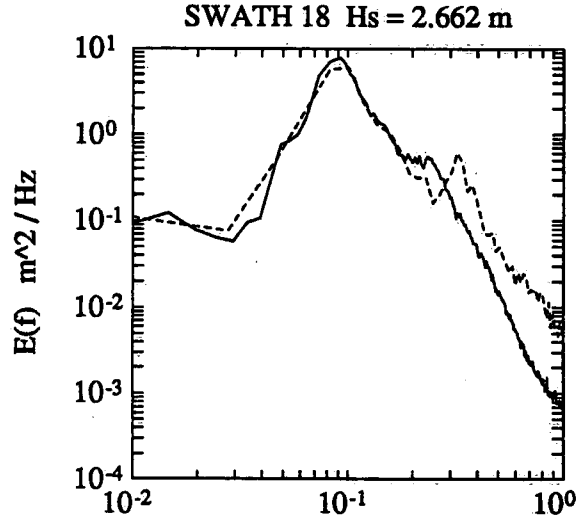


ship hdg: 273 @ 2.55 m/s. D = 40 m (3 staffs)

DS * f^4

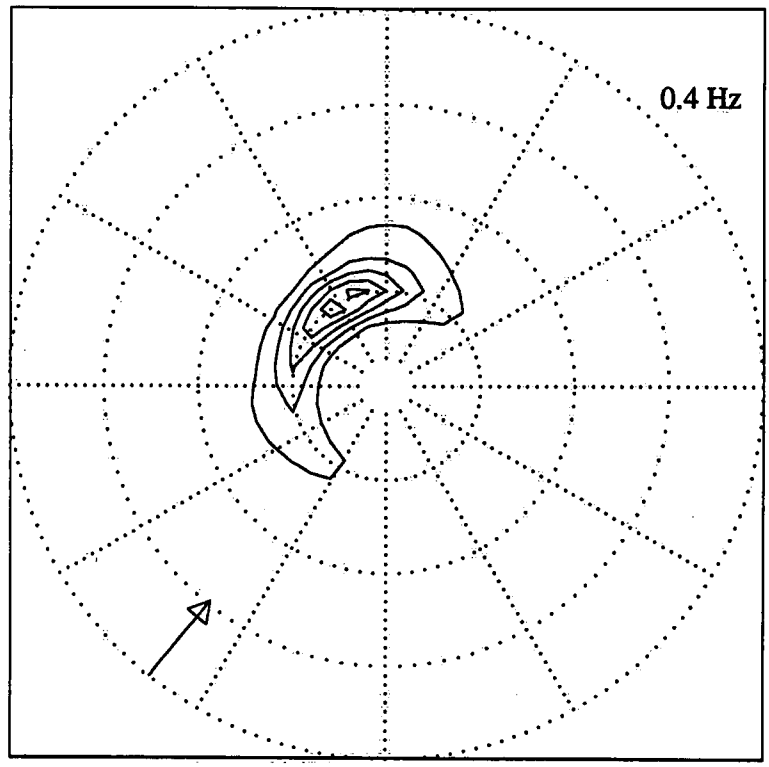


SWATH 18 Hs = 2.662 m



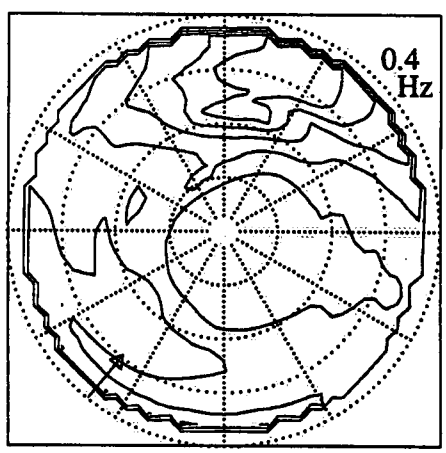
Wind speed 9.5 m/s from 260 degrees T

SWATH 17 91.3.4 20:13Z @ 36 6 N 75 16 W. (43 mins)

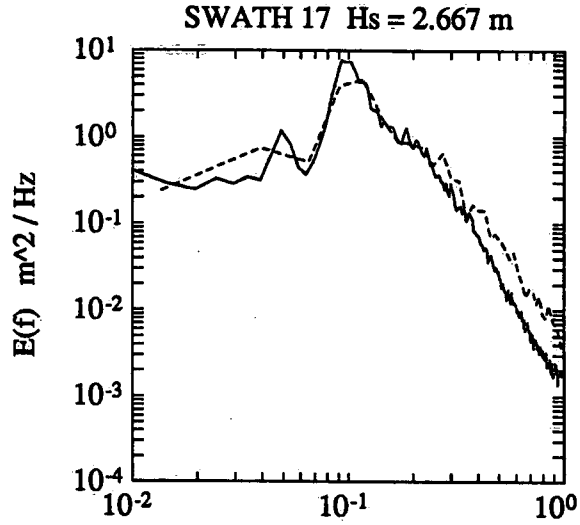


ship hdg: 200 @ 2.2 m/s. D = 33 m (3 staffs)

DS * f^4

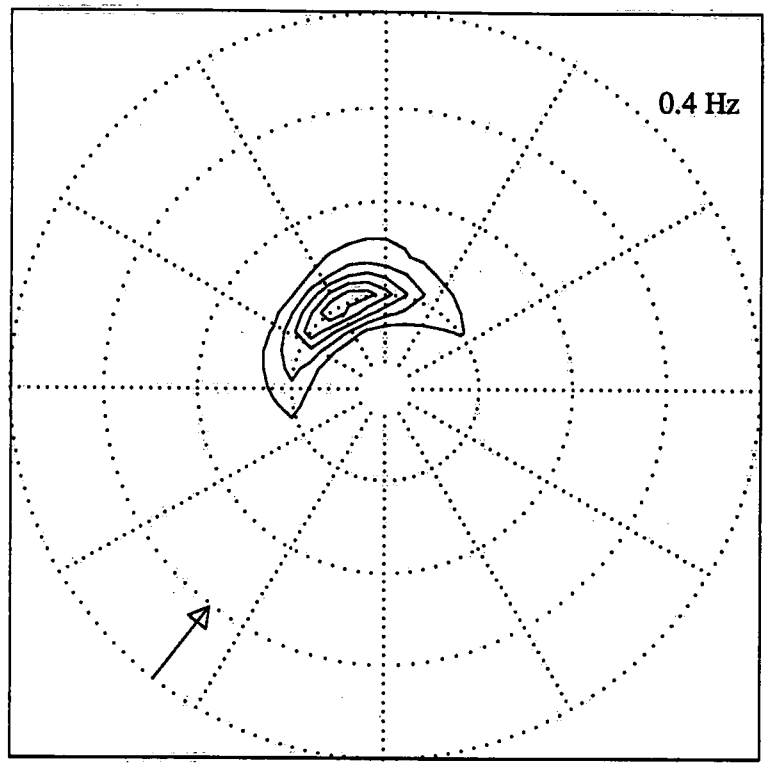


SWATH 17 Hs = 2.667 m



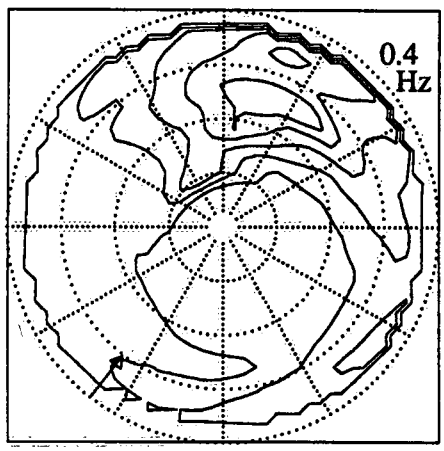
Wind speed 10.3 m/s from 219 degrees T

SWATH 16 91.3.4 18:56Z @ 36 9 N 75 15 W. (60 mins)



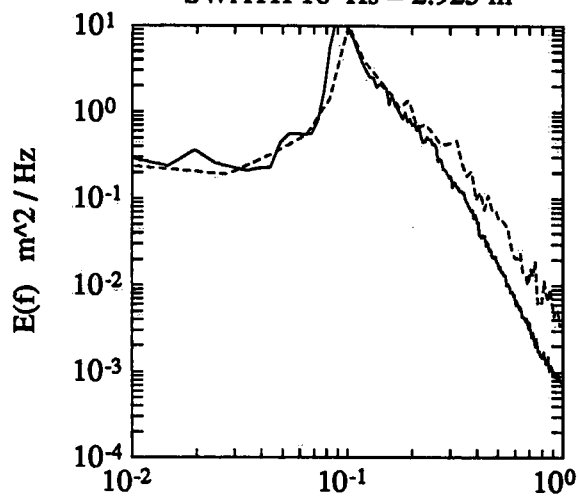
ship hdg: 200 @ 2.2 m/s. D = 33 m (3 staffs)

DS * f^4



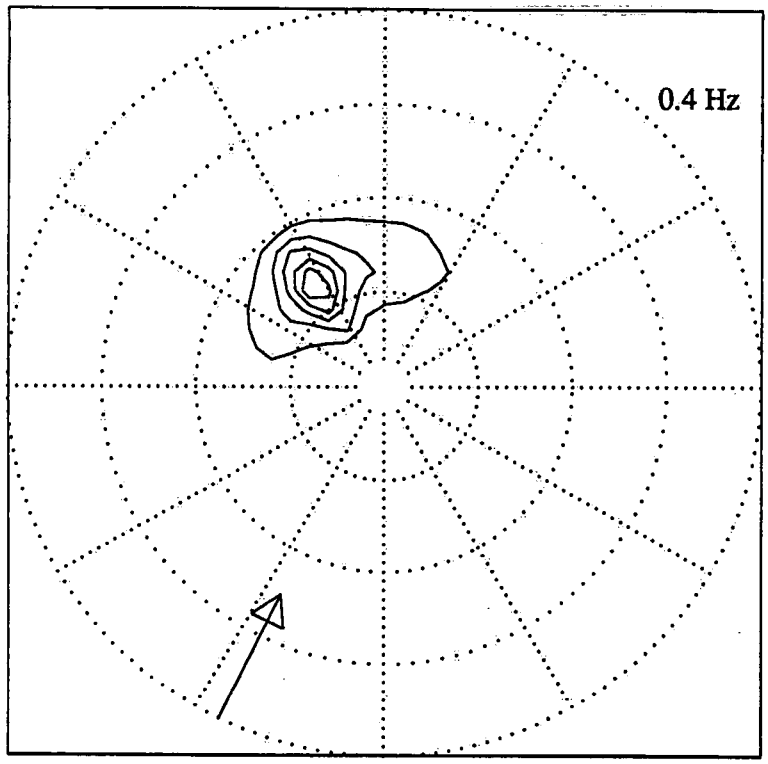
Wind speed 9.6 m/s from 218 degrees T

SWATH 16 Hs = 2.925 m



frequency [Hz]

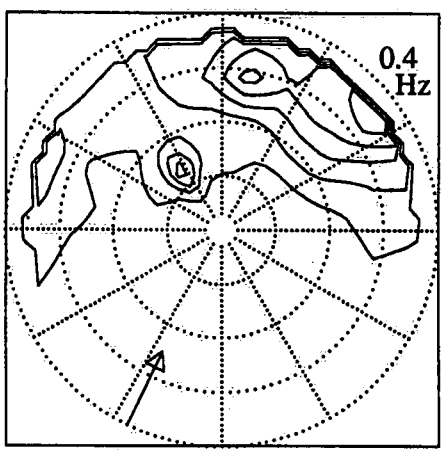
SWATH 15 91.3.4 11:49Z @ 36 33 N 75 5 W. (3.5 mins)



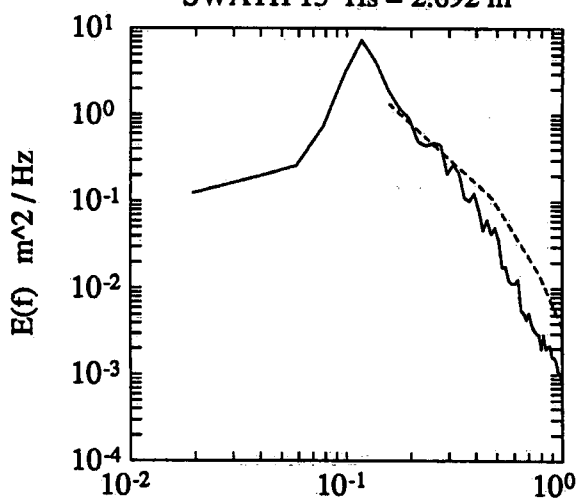
ship hdg: 205 @ 1.54 m/s. D = 31 m (3 staffs)

very short series; some signal clipping (5%) at troughs

DS * f^4

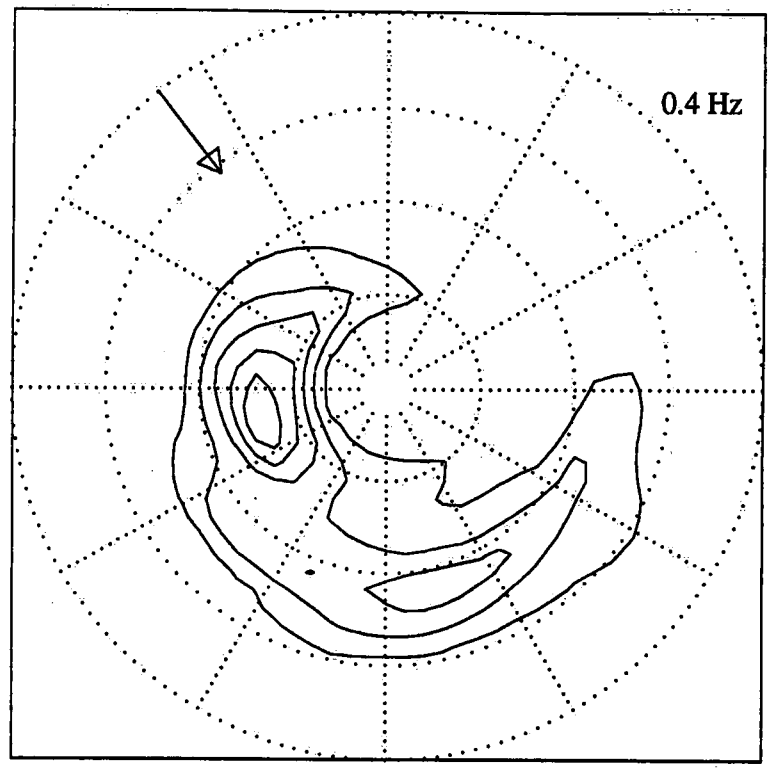


SWATH 15 Hs = 2.692 m



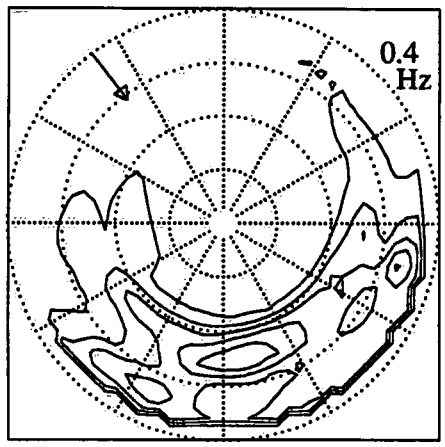
No K-gill; CERC wind 14.9m/s from 206 T

SWATH 14 91.2.27 02:05Z @ 38 21 N 73 37 W. (26 mins)

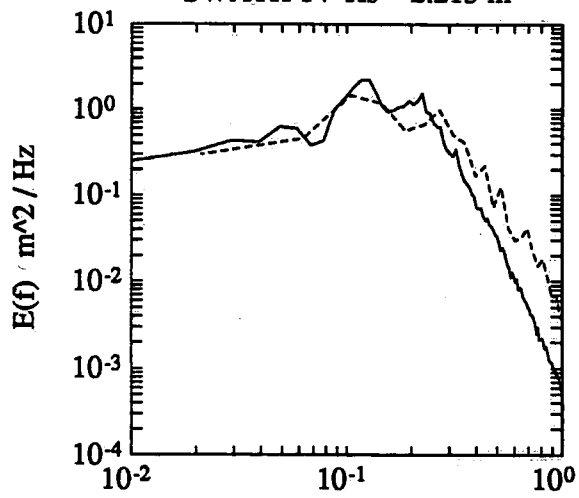


ship hdg: 343 @ 1.8 m/s. D = 200 m (6 staffs)

DS * f^4

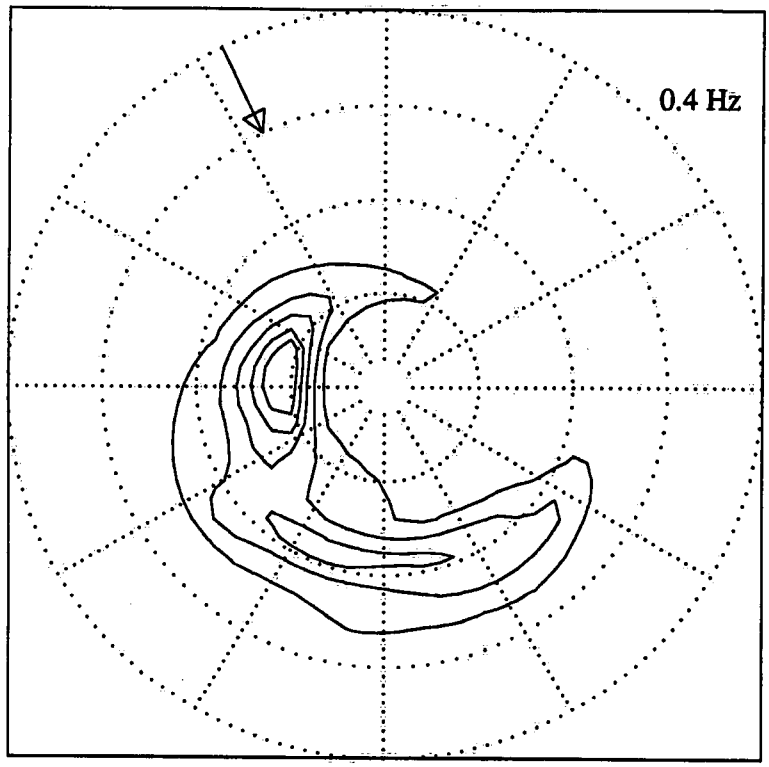


SWATH 14 Hs = 2.213 m



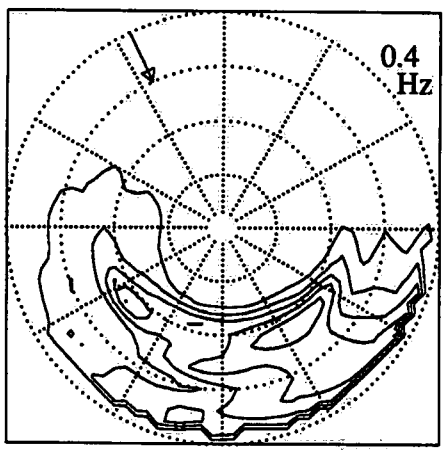
No K-gill. Discus-N wind 11m/s from 322T

SWATH 13 91.2.27 01:03Z @ 38 18 N 73 37 W. (14 mins)

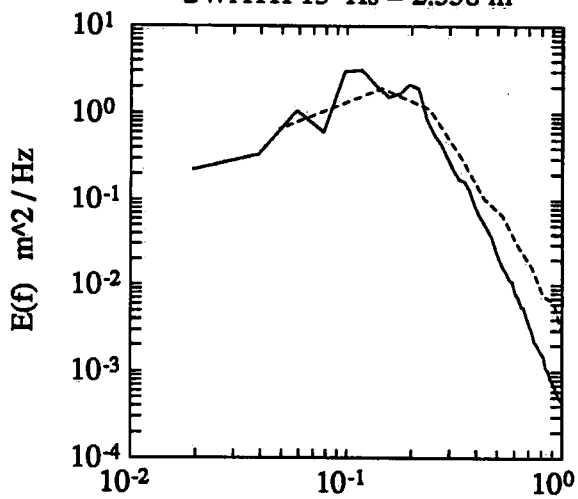


ship hdg: 343 @ 1.8 m/s. D = 270 m (6 staffs)

DS * f^4

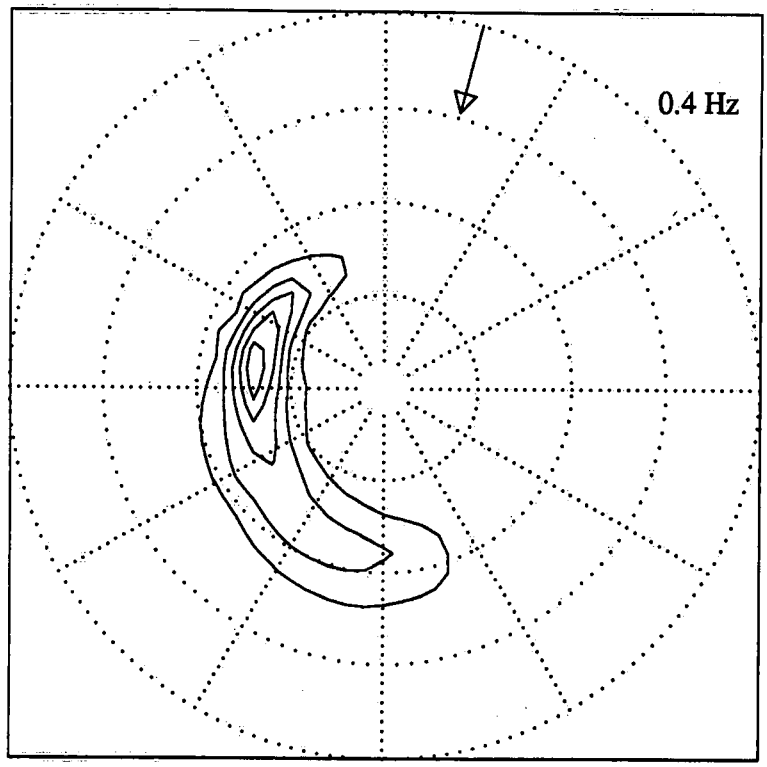


SWATH 13 Hs = 2.558 m



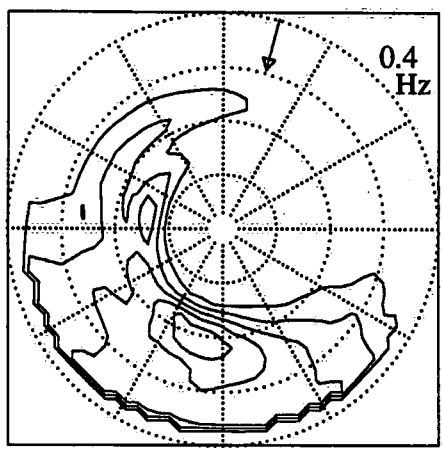
No K-gill;Discus-N wind 10m/s from 334T

SWATH 12 91.2.25 18:59Z @ 37 35 N 74 18 W. (43 mins)



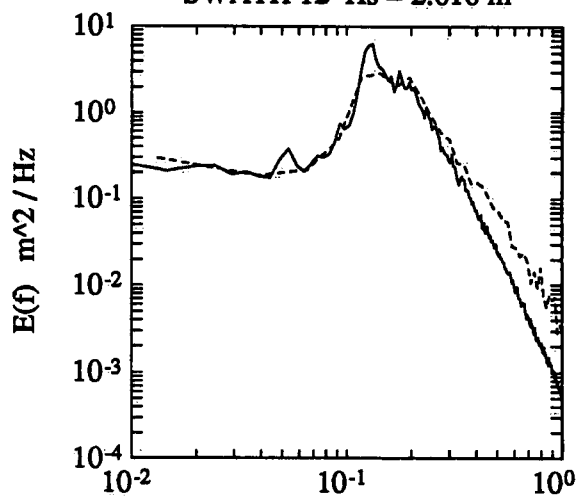
ship hdg: 17 @ 1.65 m/s. D = 180 m (6 staffs)

DS * f^4



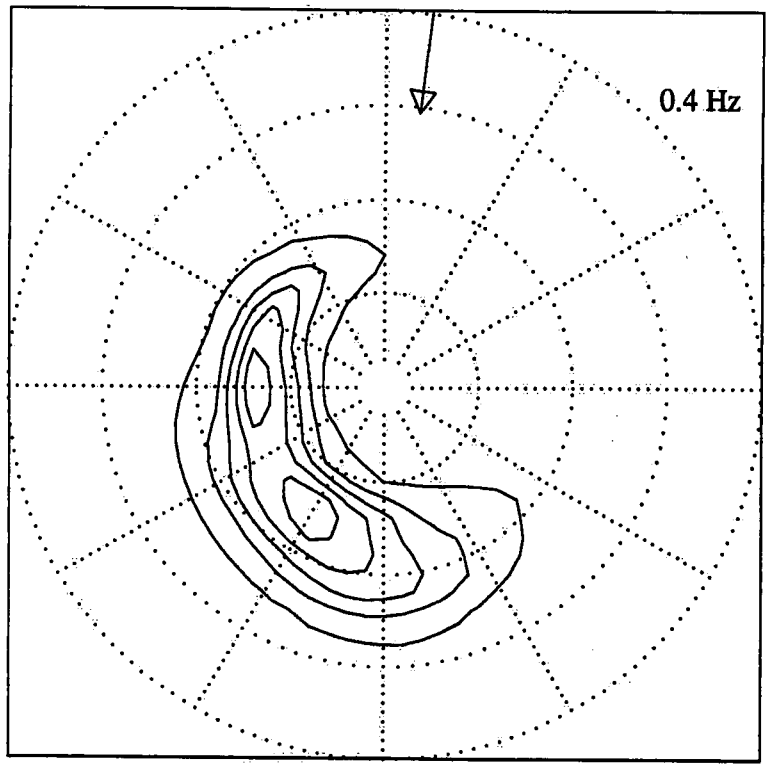
Wind speed 9.5 m/s from 15 degrees T

SWATH 12 Hs = 2.616 m



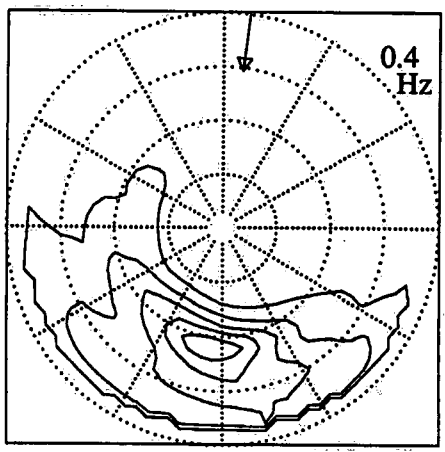
frequency [Hz]

SWATH 11 91.2.25 17:10Z @ 37 28 N 74 23 W. (60 mins)



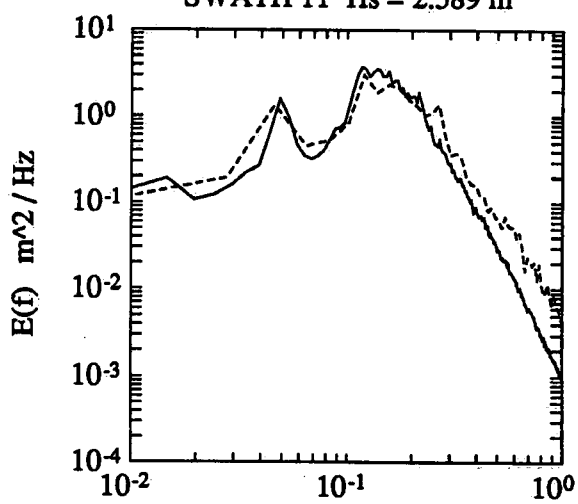
ship hdg: 17 @ 1.65 m/s. D = 185 m (5 staffs)

DS * f^4

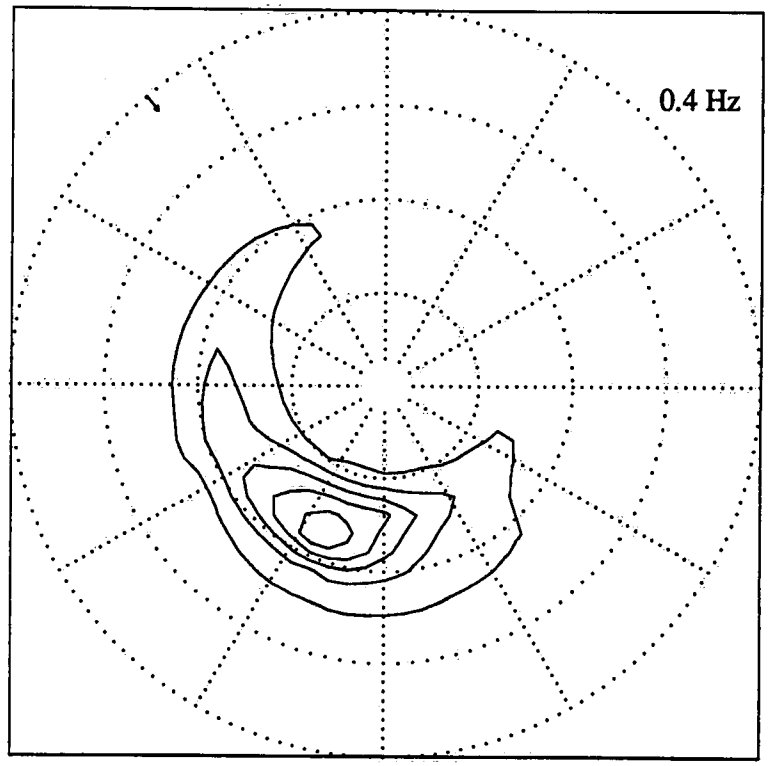


Wind speed 10.7 m/s from 7 degrees T

SWATH 11 Hs = 2.589 m

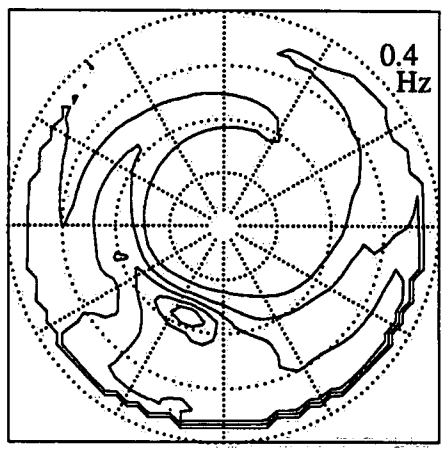


SWATH 10 91.1.23 06:08Z @ 37 36 N 74 28 W. (60 mins)



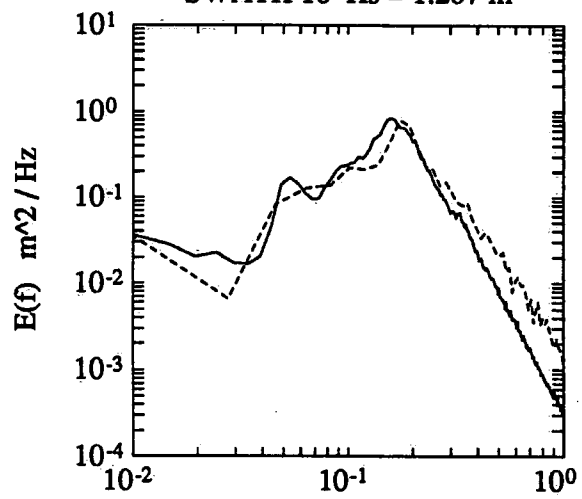
ship hdg: 332 @ 2.16 m/s. D = 70 m (6 staffs)

DS * f^4



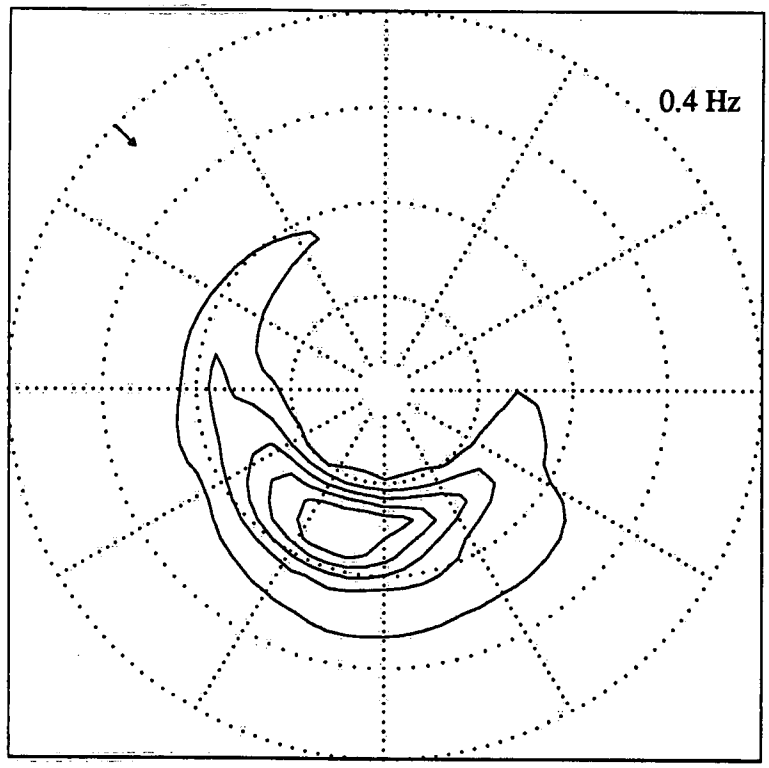
Wind speed 2 m/s from 320 degrees T

SWATH 10 Hs = 1.207 m



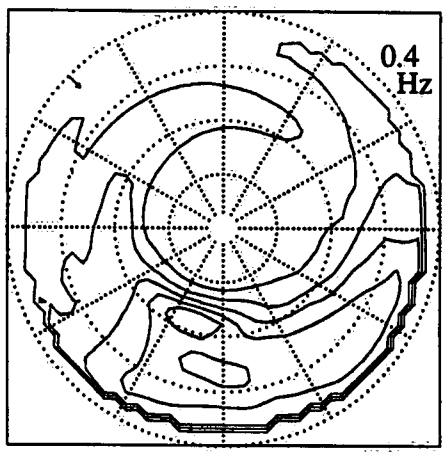
frequency [Hz]

SWATH 9 91.1.23 05:08Z @ 37 32 N 74 27 W. (60 mins)



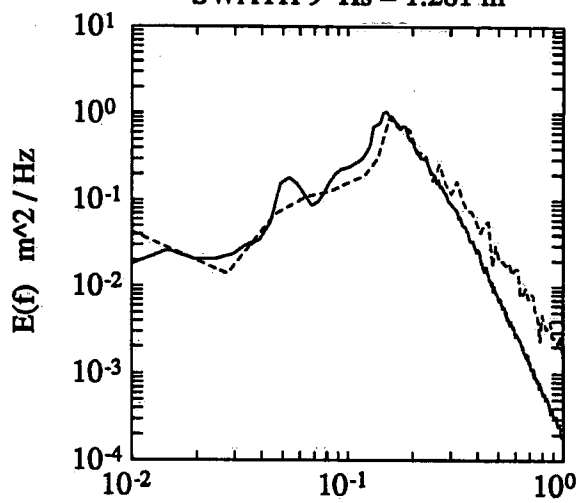
ship hdg: 332 @ 2.16 m/s. D = 85 m (6 staffs)

DS * f^4

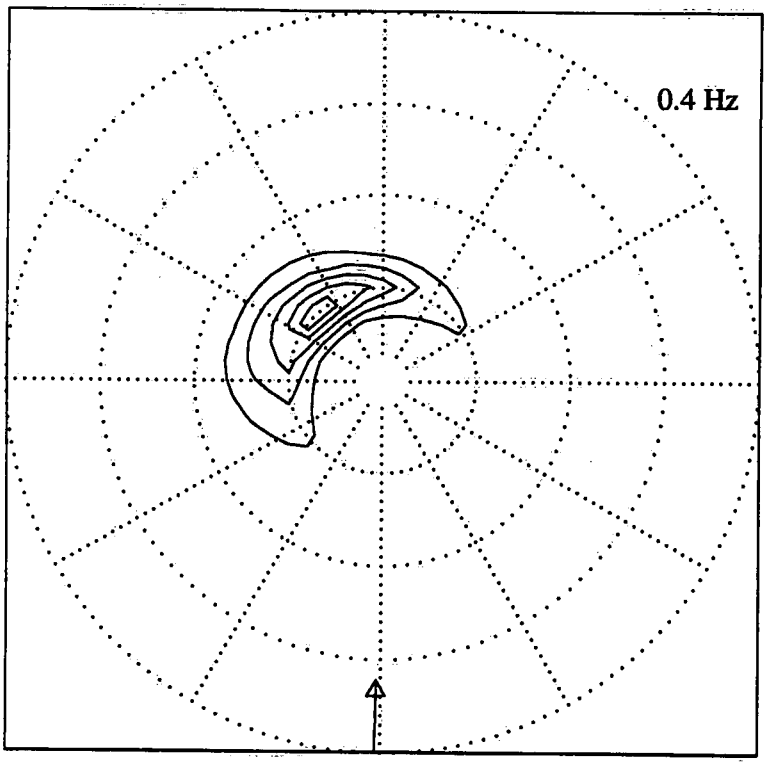


Wind speed 3 m/s from 314 degrees T

SWATH 9 Hs = 1.281 m

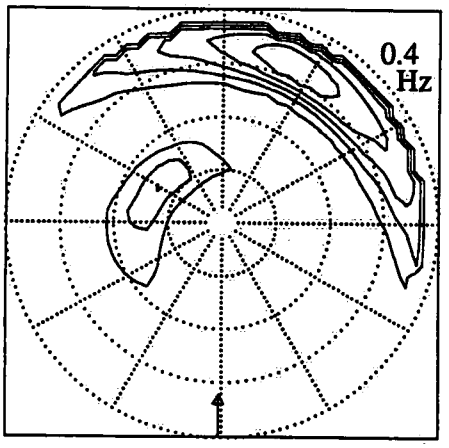


SWATH 27 91.3.6 17:17Z @ 37 17 N 73 30 W. (68 mins)



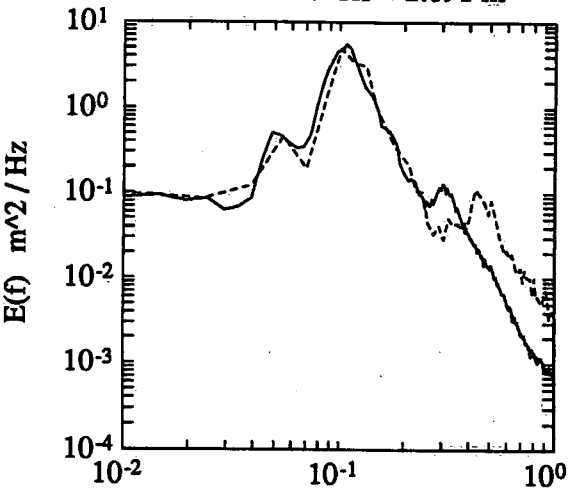
ship hdg: 200 @ 2.7 m/s. D = 2600 m (3 staffs)

DS * f^4



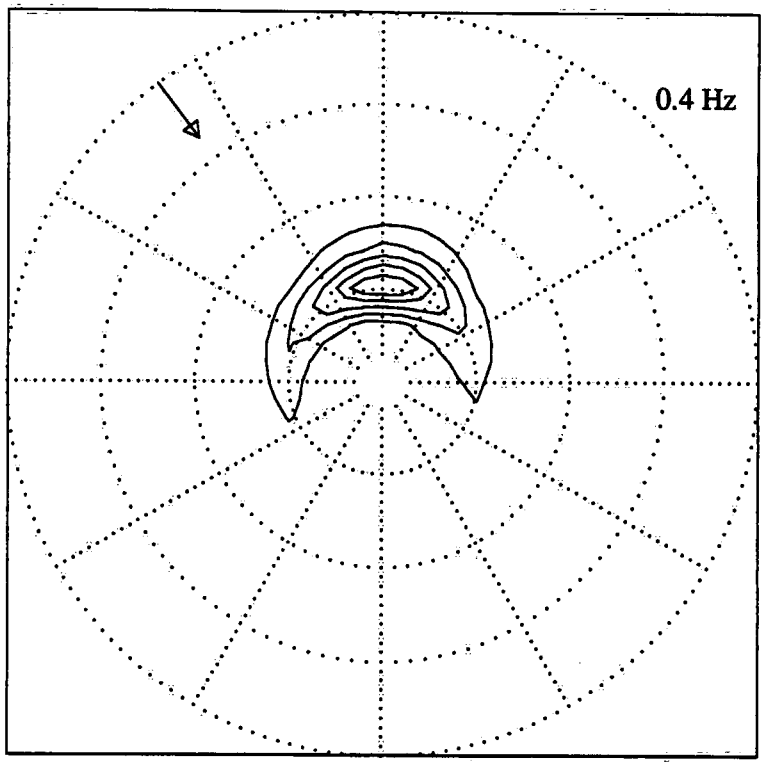
Wind speed 7.7 m/s from 181 degrees T

SWATH 27 Hs = 2.091 m



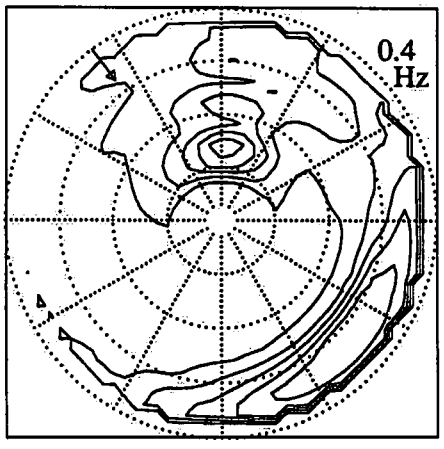
frequency [Hz]

SWATH 28 91.3.7 19:08Z @ 37 40 N 74 21 W. (26 mins)

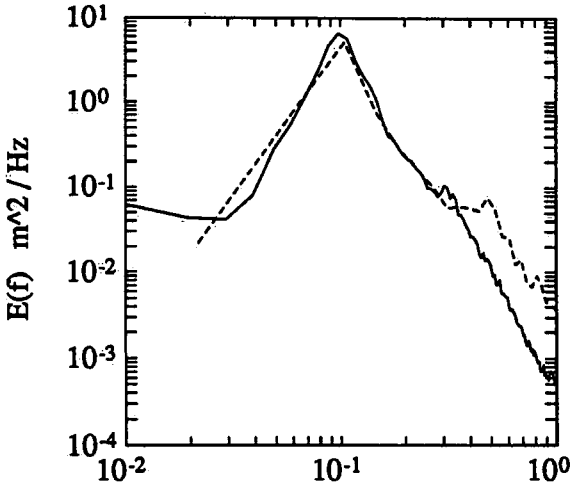


ship hdg: 302 @ 2.57 m/s. D = 80 m (3 staffs)

DS * f^4

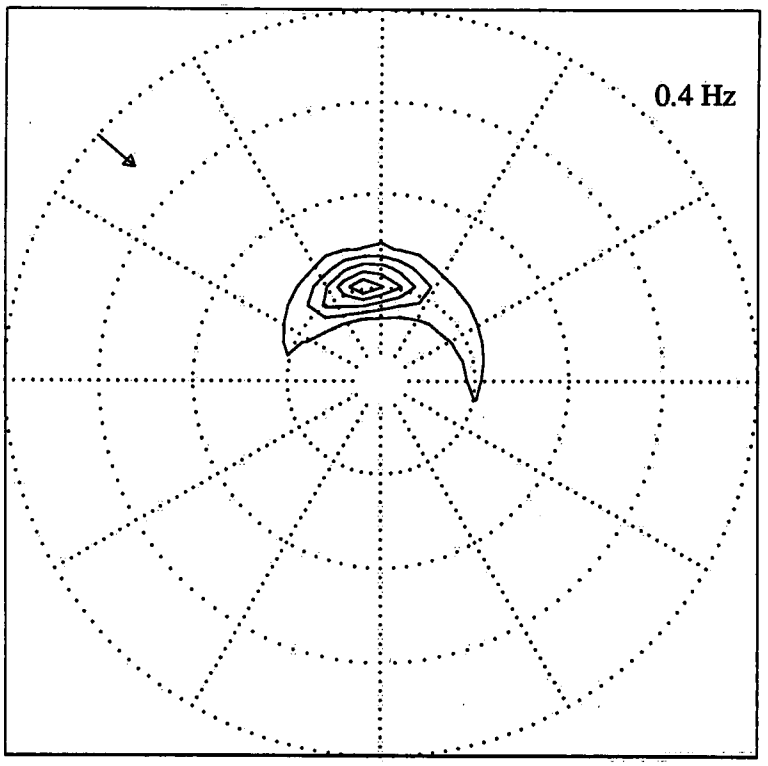


SWATH 28 Hs = 2.282 m



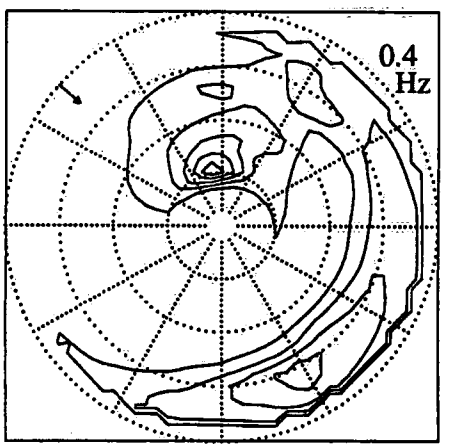
Wind speed 7.3 m/s from 323 degrees T

SWATH 29 91.3.7 20:32Z @ 37 43 N 74 26 W. (17 mins)



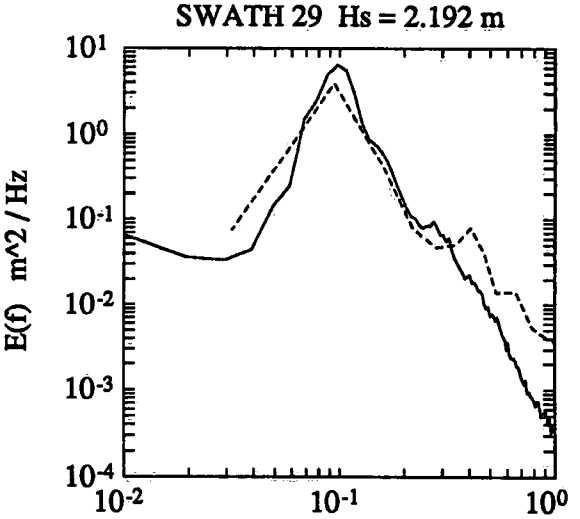
ship hdg: 302 @ 2.31 m/s. D = 65 m (3 staffs)

DS * f^4

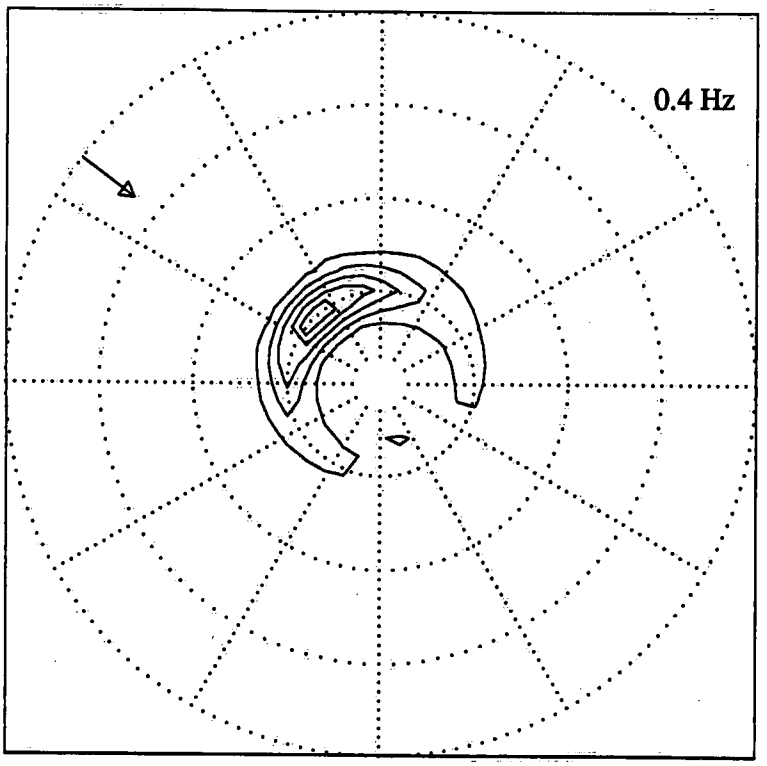


Wind speed 5.2 m/s from 311 degrees T

SWATH 29 Hs = 2.192 m

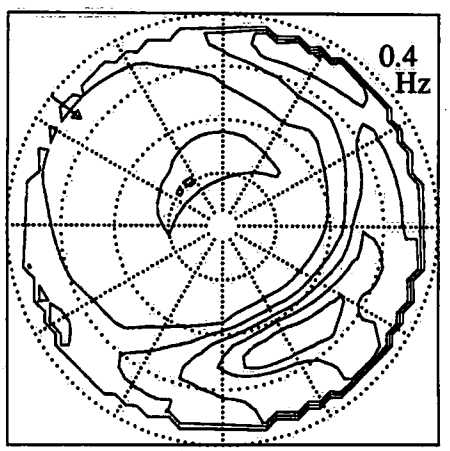


SWATH 30 91.3.7 22:29Z @ 37 49 N 74 36 W. (43 mins)



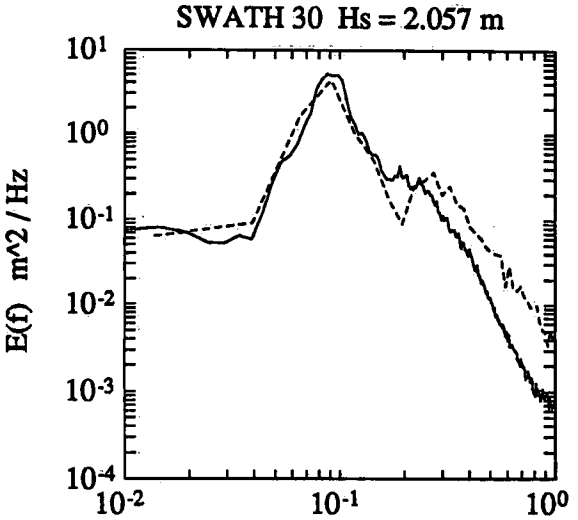
ship hdg: 315 @ 2.83 m/s. D = 50 m (3 staffs)

DS * f^4



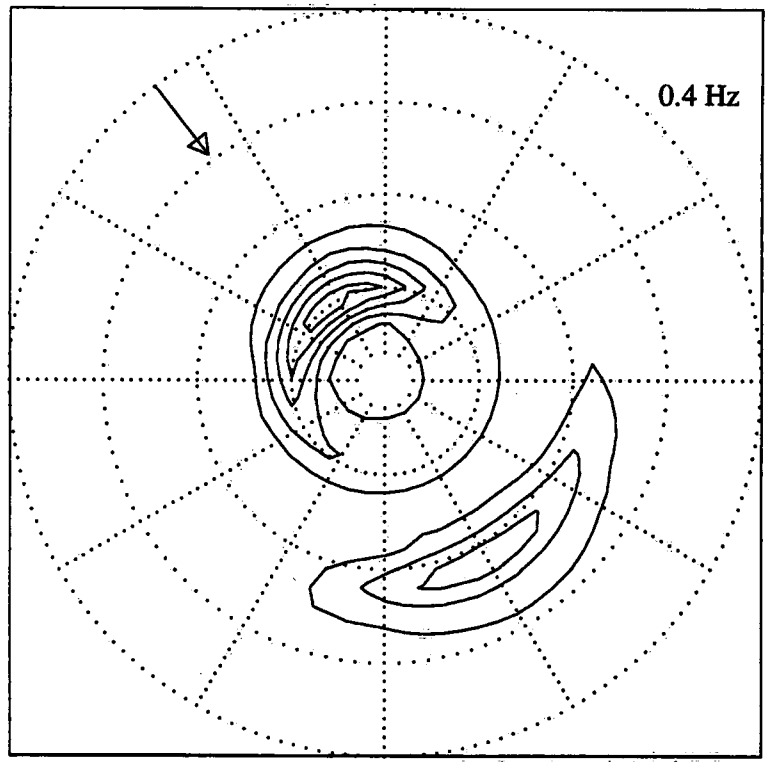
Wind speed 7 m/s from 307 degrees T

SWATH 30 Hs = 2.057 m



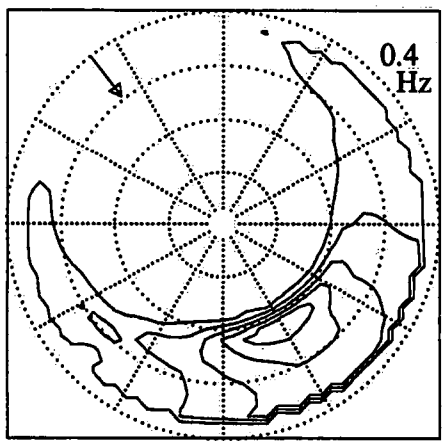
frequency [Hz]

SWATH 31 91.3.8 00:33Z @ 37 58 N 74 46 W. (68 mins)



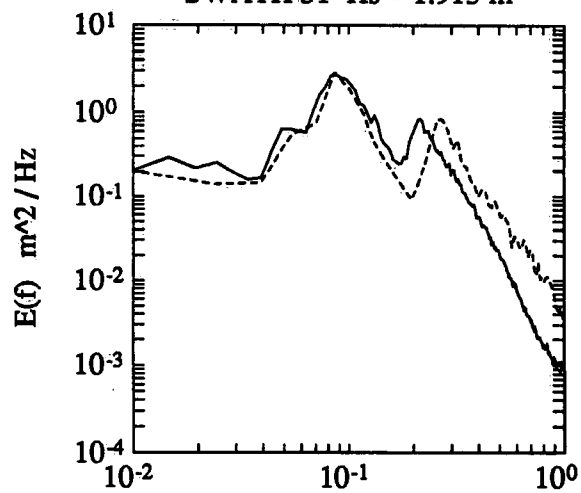
ship hdg: 316 @ 2.31 m/s. D = 30 m (3 staffs)

DS * f^4



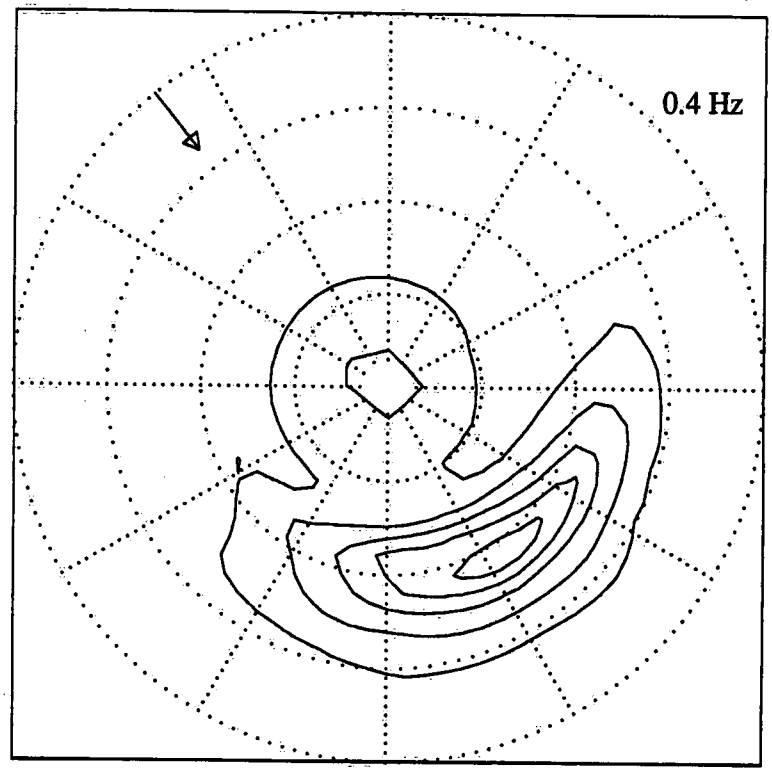
Wind speed 9.3 m/s from 322 degrees T

SWATH 31 Hs = 1.913 m



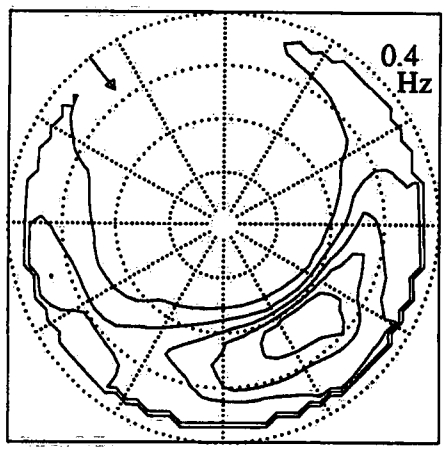
frequency [Hz]

SWATH 32 91.3.8 21:23Z @ 37 32 N 74 42 W. (60 mins)



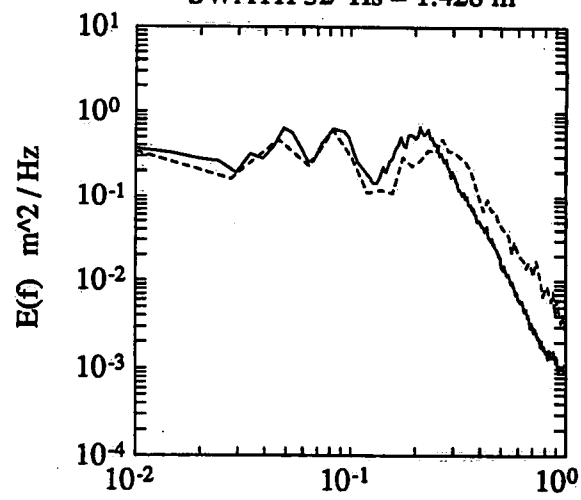
ship hdg: 326 @ 2.44 m/s. D = 50 m (3 staffs)

DS * f^4

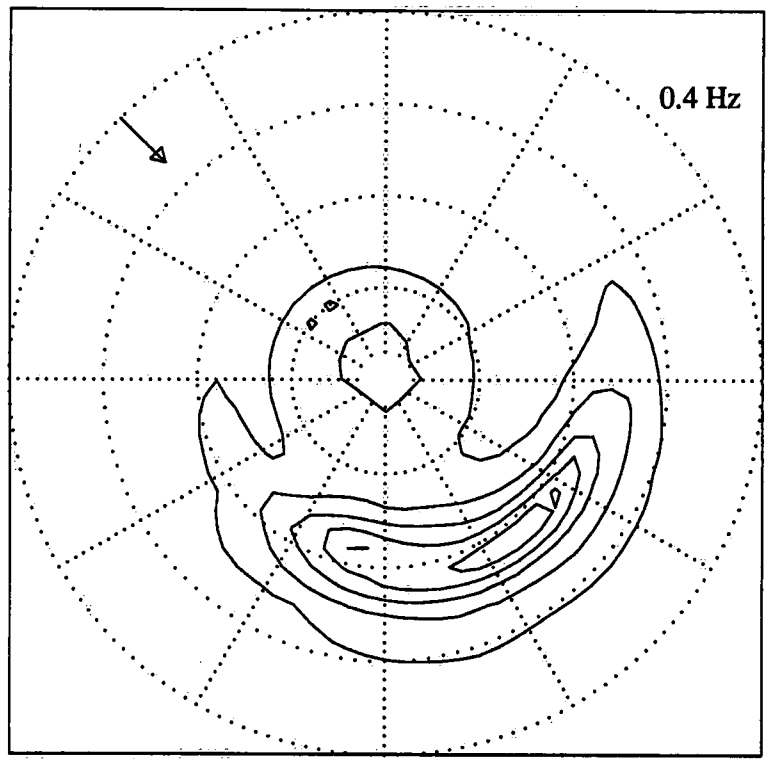


Wind speed 7.6 m/s from 321 degrees T

SWATH 32 Hs = 1.428 m

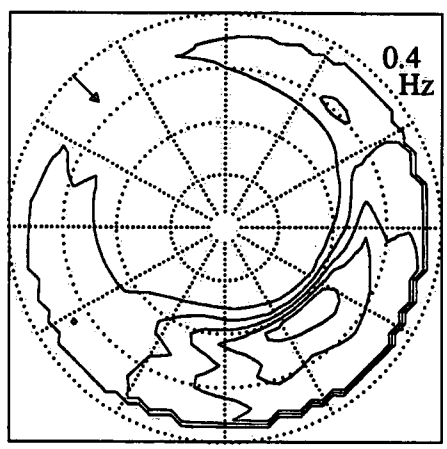


SWATH 33 91.3.8 22:23Z @ 37 36 N 74 44 W. (60 mins)



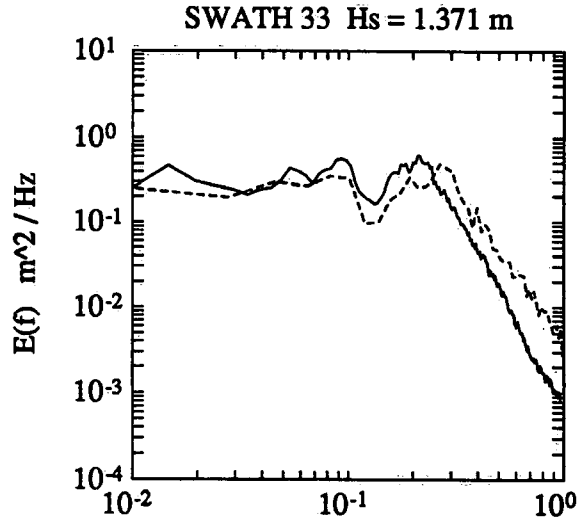
ship hdg: 326 @ 2.44 m/s. D = 50 m (3 staffs)

DS * f^4



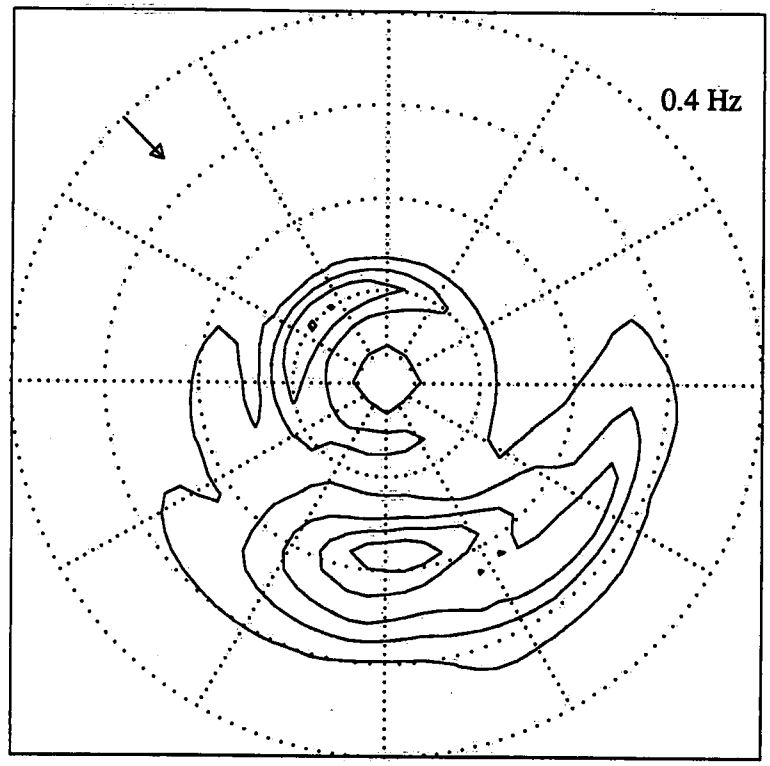
Wind speed 6.8 m/s from 315 degrees T

SWATH 33 Hs = 1.371 m



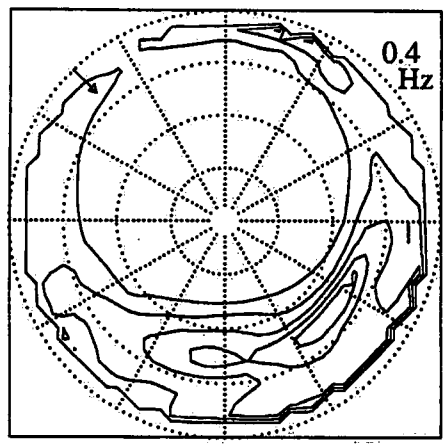
frequency [Hz]

SWATH 34 91.3.8 23:36Z @ 37 42 N 74 37 W. (26 mins)



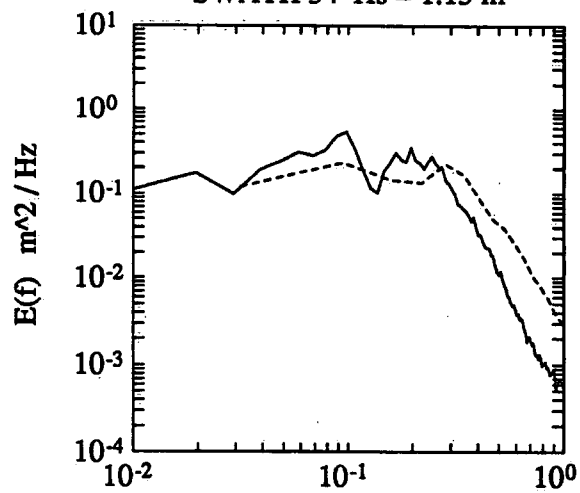
ship hdg: 322 @ 2.57 m/s. D = 55 m (3 staffs)

DS * f^4



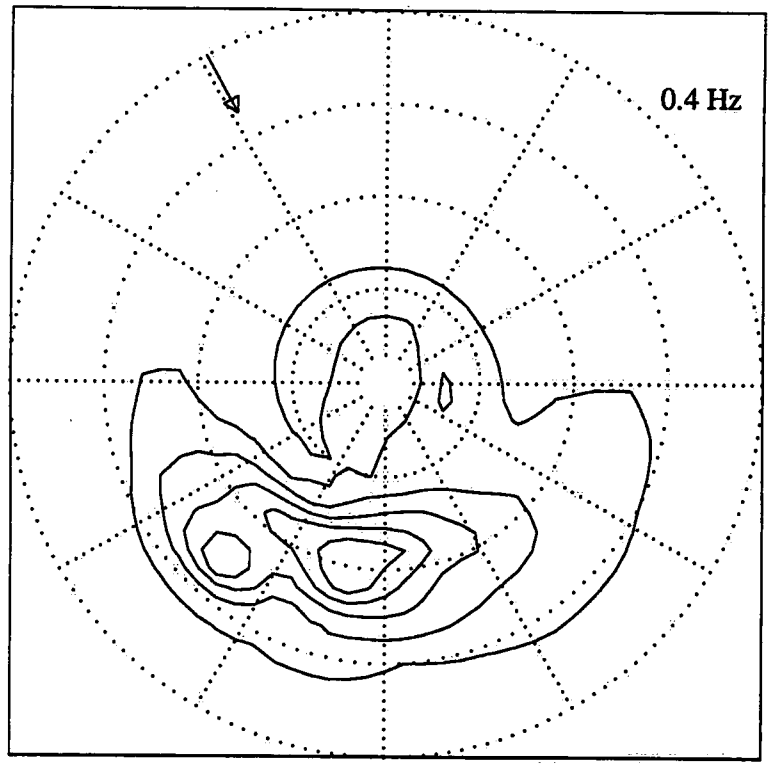
Wind speed 6.1 m/s from 315 degrees T

SWATH 34 Hs = 1.13 m



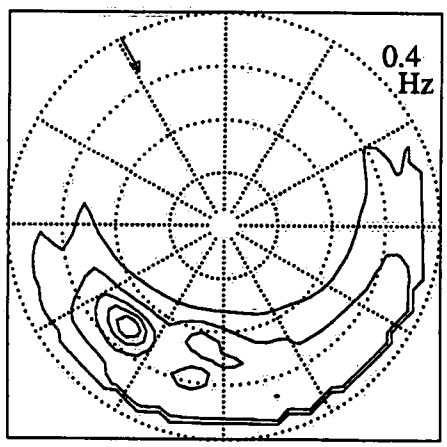
frequency [Hz]

SWATH 35 91.3.9 00:06Z @ 37 44 N 74 38 W. (22 mins)



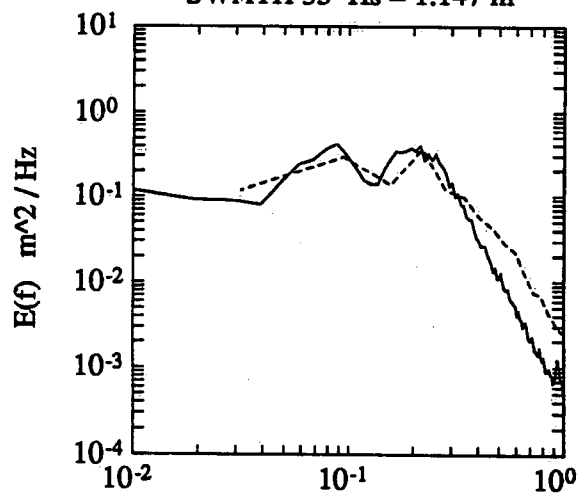
ship hdg: 297 @ 2.57 m/s. D = 55 m (3 staffs)

DS * f^4

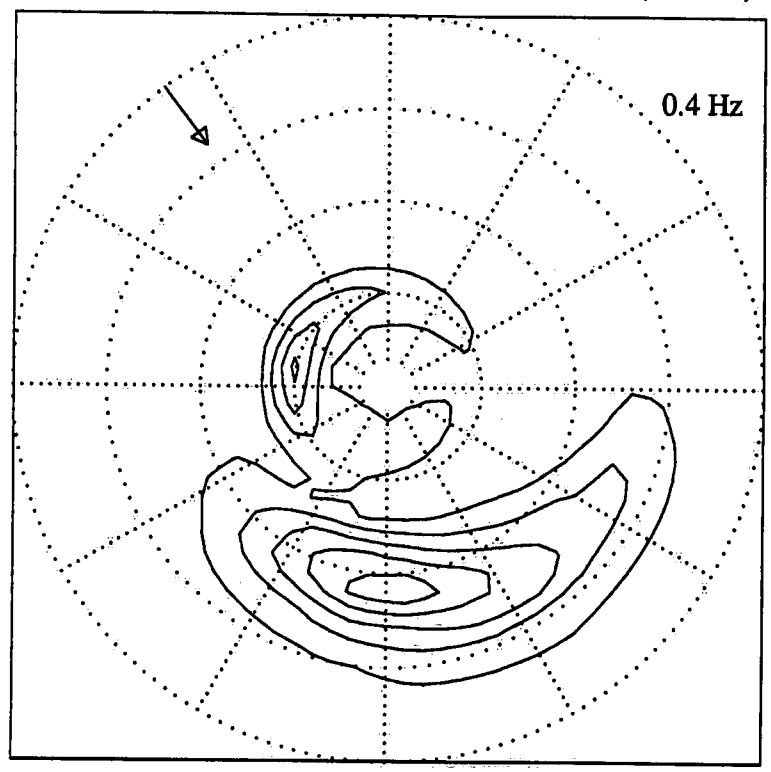


Wind speed 7 m/s from 331 degrees T

SWATH 35 Hs = 1.147 m

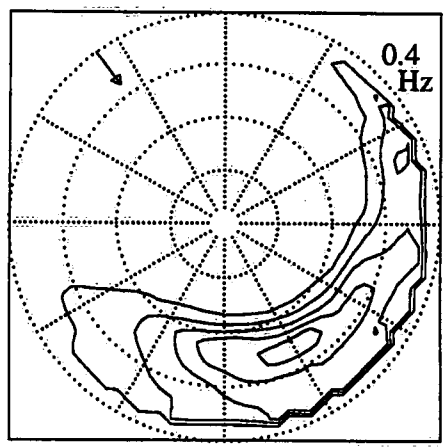


SWATH 36 91.3.9 00:33Z @ 37 45 N 74 40 W. (19 mins)



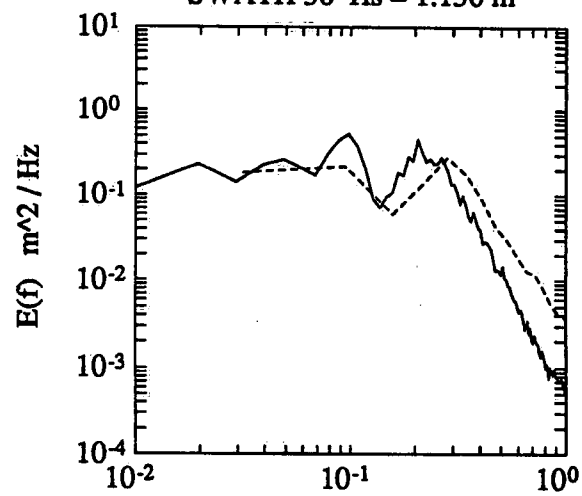
ship hdg: 354 @ 2.57 m/s. D = 55 m (3 staffs)

DS * f^4



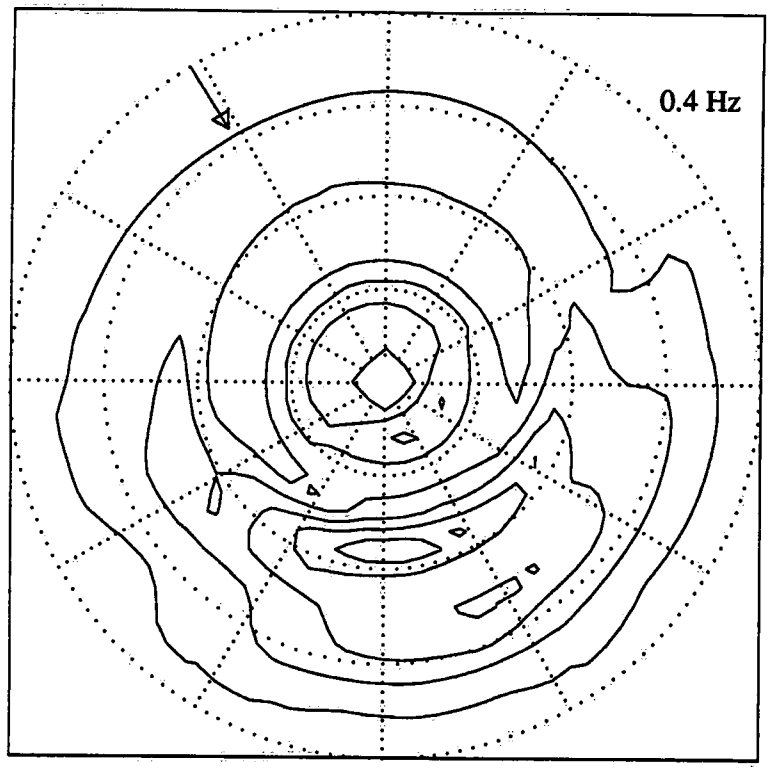
Wind speed 7.7 m/s from 323 degrees T

SWATH 36 Hs = 1.136 m



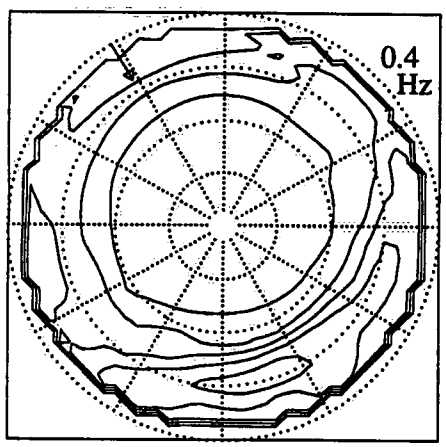
frequency [Hz]

SWATH 37 91.3.9 01:00Z @ 37 47 N 74 40 W. (17 mins)



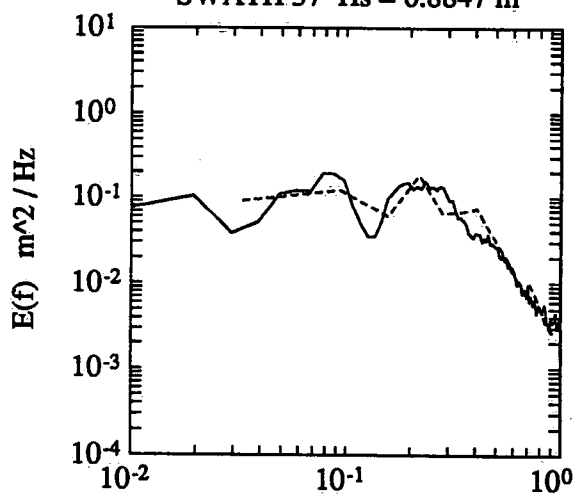
ship hdg: 323 @ 2.57 m/s. D = 50 m (3 staffs)

DS * f^4



Wind speed 7.9 m/s from 328 degrees T

SWATH 37 Hs = 0.8847 m



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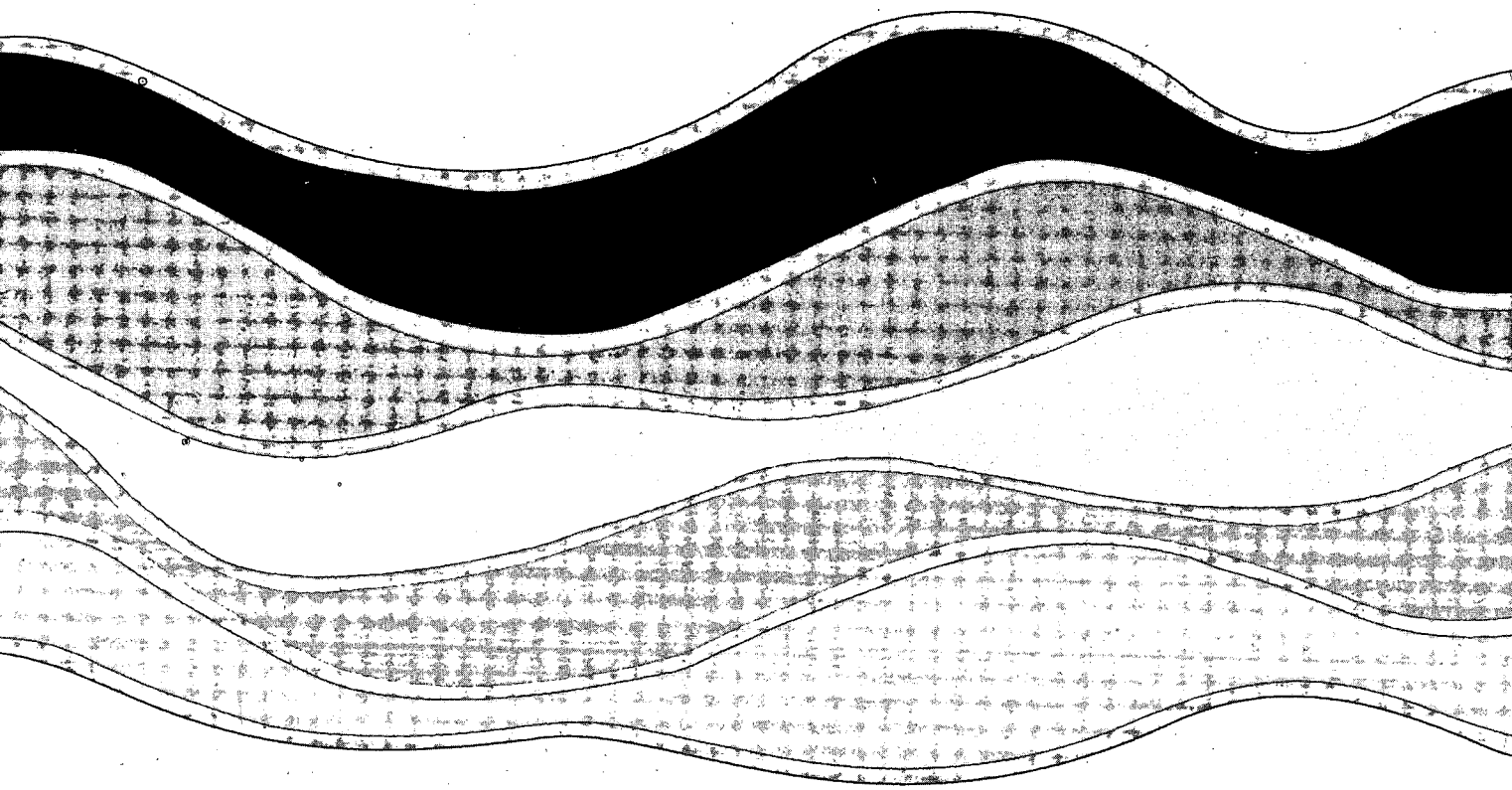

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