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Flow at the Cootes Paradise Fishway

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Management Perspective

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The Hamilton Harbour Remedial Action Plan (Can-US GLWQA)

Background:

A fish control structure (fishway) was built at the outlet of Cootes Paradise to control the entrance of carp into the wetlands. Understanding of the flow conditions at the fishway will assist in the development of an operational plan for the fishway. The flow was monitored during 1997 and analyzed, in conjunction with the local meteorological conditions and water level records at the west end of Lake Ontario. Furthermore, an understanding of the sediment discharge at the fishway is needed to help delineate the sediment loading of the wetlands. Documentation of the cumulative discharge of the water from the wetlands will assist in addressing this issue.

Next Steps

The results of the monitoring programme are being forwarded to the Dept. of Fisheries and Oceans, so that the information can be incorporated with data on fish movement and sediment load.

Abstract

The flow through the Cootes Paradise fishway was monitored from April until December 1997. The flow was highly variable, and typically changed direction several times each day. Comparison with local meteorological and water level data revealed several interesting features. Outflow events of four hours or greater in duration were typically preceded by wind events with an easterly component usually lasting at least six hours. Similarly inflow events longer than four hours were typically preceded by westerly winds for at least six hours. There was a tidal component to the flow as well as evidence of Helmholtz resonance between Hamilton Harbour and Lake Ontario, and resonance due to the exchange between the harbour and Cootes Paradise. The estimates of the cumulative discharge clearly show that there was net outflow to Hamilton Harbour during each deployment of the instruments.

Flow at the Cootes Paradise Fishway

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Introduction

A fish passage control structure or fishway was built at the outlet of Cootes Paradise into Hamilton Harbour, and became fully operational in 1997. The purpose of the fishway is to prevent carp from entering the wetlands and destroying aquatic vegetation. However, many other fish species use the marsh as spawning, nursery and feeding habitat and an operational plan is needed to facilitate their movement past the fishway. During 1997, the fishway was instrumented to monitor the flow and other relevant variables. Fish movement was also monitored (independently) at the fishway during the same period, so that the flow data will be available to correlate with that data. The documentation of the flow conditions will be of use in developing an operational plan for the fishway. In addition the amount of sediment loading of the Cootes Paradise is an issue. The cumulative discharge of water from Cootes Paradise, estimate from the flow data, will assist in addressing the sediment loading issue. This report describes the findings of the flow monitoring program.

Instrument Deployment

The flow through the fishway and canal connecting Cootes Paradise and Hamilton Harbour is not controlled. That is to say, there is no structure, natural or man-made, that constrains the flow in such a manner that conventional discharge measurements can be made. It was decided to use a two-axis (horizontal) current meter that would simultaneously measure magnitude and direction of the flow. In addition to the flow, temperature and optical backscatter (to obtain a measure of turbidity) were also monitored. The three instruments were deployed from April until November 1997, approximately in the middle of the fishway. The two axis electromagnetic current meter with its sensing volume at 0.6 times the depth below the water surface, a temperature sensor and an optical backscatter sensor were co-located as indicated in figure 1. The current meter and temperature sensor were logged every 20 minutes; each value represented a five-minute average of data collected at one sample per second. The optical backscatter was logged once every 20 minutes. Because of the high level of biological activity in the water, the sensors were cleaned once every week.

The whole deployment was broken up into 9 individual deployments, usually separated by a day or two to service the current meter. For the first, second and part of the third deployments, the meter was suspended by cable between the fishway deck and an anchor on the bottom. For the last part of the third and the reminder of the deployments, the meter was supported by a rigid frame attached to the fishway deck. The second part of the third deployment was terminated when it was discovered that the current meter was damaged. It was repaired and returned to service. The time periods of the deployments are summarized in table 1.

Near the end of the measurement period a portable Marsh McBirney electromagnetic current meter was used to take current profiles once each day for about three weeks. Fourteen stations across the fishway were monitored (see figure 1). At each horizontal station one measurement was taken 0.5 m below the surface, one at 0.5 m above the bottom, and one approximately in the middle of the water column. The flow was monitored for about 20 seconds for each measurement and a representative value recorded manually.

Other Data Sources

To complement the flow measurements, meteorological data from the NWRI meteorological station at the Burlington Pier and Lake Ontario water level data from the Canadian Hydrographic Service station, also at the Burlington Pier, were obtained. Summary rainfall data were obtained from the weather station at the Hamilton Airport. The meteorological data were available every 10 minutes and the water level data every 15 minutes or every hour.

Results

Histograms of Flow Direction

To get an overview of the flow in the fishway, histograms of the number of flow occurrences, as a function of direction, were plotted for each deployment. The approximate orientation of the fishway is 20° True, so that inflow normal to the fishway axis would be at -70° True and outflow at 110° True. Because the fishway is not lined up with the axis of the channel connecting Cootes Paradise with Hamilton Harbour, it is to be expected that the flow directions will deviate somewhat from these two directions. The first and fourth deployment histograms are shown in figure 2 (all histograms are shown in the appendix). It is clear from these plots that the current was strongly bipolar. In deployment #1 the peak directions were -60and 137° True; in #4 they were -19 and 187° True. The peak directions for deployment #1 are reasonably close to the directions normal to the fishway and may be taken as representative of inflow and outflow respectively. The shift in the recorded peak directions between deployments #1 and #4 occurred sometime during deployment #3. The direction results of deployment #3 showed two peaks in each direction that could not be resolved in terms of time, so that data were not used in the remainder of the analysis. The shift in direction response is believed to be a result of the change in the meter mount, but is not totally resolved. There is, however, no doubt that the peaks at less than 100°T were inflow and at greater values were outflow. In the subsequent analysis of the data all flows with angle less than 50° were assumed inflow for deployments 1 and 2 and less than 100° for deployments 4 to 9; angles greater are assumed to be outflow. The mean flows, in and out, were computed for each deployment, and are summarized along with the mean directions in table 2.

Time Series

The time series plots of variables for all deployments have been prepared and are show in the appendix. An example of the beginning of deployment #1 is show in figure 3. The most noticeable feature is the frequent reversal of the current direction at the Fishway (this segment happens to be one of the clearest of all the time series in terms of the regularity of the flow reversals). For example, during Day 109 there are 8 incidents of outflow and 7 inflows. The wind was moderate out of the north. There were numerous small (less than 3 cm) variations in the water level at the Burlington Canal and upon close examination it appears that most occurrences of outflows were linked to falling water level or a decrease in the rate of rise of water level. Outflow events appeared to lag the water level drop events by up to about half an hour, with considerable variability. Water temperature data (shown on the plots in the appendix) showed indications of flow reversals.

The optical backscatter sensor (OBS) was operational from deployment #3a through #9. Examination of the time series (see appendix) for this sensor shows clearly that the sensor was adversely affected by fouling. It, along with the current meter, was cleaned on a weekly basis. Nevertheless, its output typically reached saturation level within a few days, rendering it useless expect for the most qualitative analysis during the short periods the output was not saturated (saturation corresponds to complete backscatter, attributed to heavy fouling of the lens).

Extended Outflow and Inflow Events

Extended outflow events were extracted from the time series and are listed in table 3. In this exercise events that had outflows for more than four hours were identified and information on water levels, wind, and rainfall were recorded. The information in table 3 was extracted from the time series plots visually so are descriptive rather than precise. An important feature that emerges from this summary is that the water level at the Burlington pier was usually dropping during an outflow event (about 80% of the events). The water level was steady for 20% of the events. The wind conditions were more variable. Broadly speaking, the wind was out of an easterly direction for about 62% of the events and out of a westerly direction the remainder. However, the wind conditions <u>before</u> events had an easterly component for 80% of the events, often for more than 12 hours beforehand. This level of occurrence was the same as that of falling water level. Rainfall during an event was not typical, occurring only for about one quarter of the

events. The time of day when the events started show a pattern in that less than 10% started during the daytime.

Extended inflow events were similarly extracted from the time series and are listed in table 4. Typically the events were less numerous than the extended outflow events and were of shorter duration. The strongest correlation is with water level rising at the Burlington pier. Of the 20 events the water level was rising for 19, and steady for the other one. The wind direction during an event did not show a strong pattern, but the wind for at least six hours before the event was westerly for 15 of the 20 events (75% of the events). A striking feature was that the events typically started around mid-day (12 times at about 1600 GMT and 3 times at about 1800 GMT: 75% of the events).

Frequency Domain

From figure 3 it is apparent that there were frequent quasi-regular reversals of the flow at the fishway. The time series of the flow and the water levels were analyzed in the frequency domain to investigate any links to know driving processes. The flow spectra are presented in the form of rotary spectra (Gonella, 1972; Rao et al., 1977). The rotary spectrum technique is used here to try to detect rotation that could be attributed to a large eddy or eddies in the fishway area. If the peaks in the two directions were of different magnitude it would indicate the preference for one direction of rotation over the other, and hence the likely occurrence of a persistent eddy. The spectra for deployment #1 are shown in figure 4a (all others are in the appendix). Both clockwise and counterclockwise spectra have peaks of the same magnitude at periods of about 14.3, 5.3 and 3.1 hours. There is no indication of a preferred direction of rotation in the flow reversals for this or all the other deployments, indicating that there were no large eddies detected.

The peak velocity reversal periods and water level periods for all the deployments are summarized in tables 5 and 6. Both flow and water level clearly show what appear to be semi-diurnal oscillations, and the first harmonic of the semi-diurnal. The flow has several other shorter periods, most notably around 3.2 hours.

Cross-spectra were calculated between the water level at the Burlington Pier and the outflow at the fishway. This analysis shows where, in the frequency domain, the energy is concentrated (similar to the rotary spectrum). It also shows, through the coherence, whether or not pairs of variables are related. Deployment #1 is shown in figure 5. The periods where the coherence was high are listed in table 7. The predominant periods are the semi-diurnal tide and the first harmonic of the tide. Two additional driving mechanisms which might cause periodic flow reversals were investigated: Helmholtz resonance (Freeman et al., 1974) and exchange flows (Hamblin, 1997). Freeman et al. reported the period of Helmholtz resonance for Hamilton Harbour and the open lake to be 2.5 hrs. The method of Hamblin allows the estimation of the period of exchange flows between two enclosed bodies of water. In this case Hamilton Harbour, Cootes Paradise, and the connecting channel geometries were used, and the period of oscillation was estimated to be about 1.8 hrs. The flow data shows some evidence of both phenomena, but most of the energy is in the tidal components.

Cumulative Discharge

The time series of the velocity, taken with the cross-sectional area of the water at the fishway can be used to estimate the cumulative discharge at the fishway. The flow was only measured at one point in the cross-section, and the flow is assumed to be normal to the plane of the fishway, so that there is considerable uncertainty in the estimates. Nevertheless, the estimates give some guidance as to the discharge. Both the outflow and inflow cumulative discharge, as well as the net cumulative discharge, are plotted versus time for the first deployment in figure 6. This plot graphically depicts the oscillatory nature of the flow at the fishway, and shows that, although there is considerable flow in both directions, there is substantially more outflow than inflow. The plots for the other deployments are in the appendix.

Comparison with the Portable Current Meter

During the latter part of the field season, staff of the Royal Botanical Gardens used a portable Marsh McBirney current meter to measure the flow at three elevations at 14 stations across the fishway. The elevations were at 0.5 m above the bottom, 0.5 m below the water surface, and approximately the middle of the water column (estimated visually at the time of measurement). Table 8 shows the flow measured by the portable meter at the mid-depth at the two stations (9 and 10) that bracketed the fixed current meter and the flow measured by the fixed meter. These stations were in about 4.3 m of water so that the hand held meter would have been about half a meter above the fixed current meter. Thus the meters were close enough that the flow could be expected to be roughly the same at the two mid-depth locations for the portable meter and the fixed meter location, given steady flow. The fixed meter time that was closest to the estimated portable meter time was used. When the readings at station 9 and station 10 differed by more than 50 % of the smaller reading, two more fixed meter values are tabulated which bracketed in time the portable meter readings. The possibility of flow reversals at the time of the measurements can thus be examined.

In general there is relatively poor correspondence between the two readings taken with the portable meter at station 9 and 10, even though the readings were taken within a minute or two of each other. Out of the fourteen sets of portable meter readings at stations 9 and 10, the two differed in seven cases by more than 50% of the value of the smaller reading (In one case the flow was in the opposite direction!).

The agreement is even worse between the fixed meter and the portable meter. Of the twelve comparisons between the two meters, the flow was in the same direction ten times, eight times the portable meter read high, and twice the fixed meter read high. Of the eight, three showed large differences between station 9 and 10 suggesting varying flow conditions and possible flow reversal, this was not supported by the fixed meter readings in two of the cases, but some variation in the third was observed. Of the two with the fixed meter reading high, one suggested flow reversal from the portable meter and was not confirmed with the fixed meter. Of the two cases were the two meters indicated flow in opposite directions, the fixed meter data indicated a flow reversal in one case.

Calibration of the Meters

The National Calibration Service, NWRI, calibrated both the fixed Neil Brown meter and the portable Marsh McBirney meter. The pre-field calibration for the Neil Brown meter was used for this report. The post-field calibration indicated that the meter was reading up to 10% high at the end of the season, but there was no indication that the direction sensitivity had changed. The portable meter calibration equation was found to be:

$$V = 0.974(\text{Indicated Reading}) + 0.0127 \text{ m/s},$$

where V is the actual velocity of the calibration carriage. This equation indicates that the meter reading gives the correct velocity within about 3%. It was noted that there is an offset of –0.01 m/s when the meter was at rest. **It should be noted that the calibration is only valid when the meter is properly oriented into the flow. When the meter was turned so that it was facing away from the flow the indicated reading was only about one-half of the true velocity.**

Discussion

The flow at the Fishway was predominantly bi-directional. The histogram plots show that the flow was in and out of the fishway and that there are more outflow occurrences than inflow. That this should be so can be understood by realizing that the meter takes a record every 20 minutes and many outflow events last longer than that so they are recorded as multiple occurrences.

Examination of the time series provided a useful tool in analysing the data from all the sensors and in delineating events. It is evident from these plots that the relationship of the flow with possible dominant processes was complex. While major rainfall events did appear to have an effect (primarily in prolonging

outflow events), wind direction and water levels clearly played the major roles in the extended events. The temperature data may be of some use in identifying water from the wetlands or the harbour. For example, short inflow or outflow events may simply return water to its previous location and would be indicated by minor or no temperature changes. Exchanges of water would be marked by significant temperature changes.

Tabulation of the extended outflow events showed that they were well correlated to the occurrence of easterly wind events. About 80% of outflow events longer than 4 hours duration were preceded by winds with an easterly component for at least six hours, and were accompanied by falling water levels. The latter appear to be due to wind direction changes at or during the event (usually to a westerly component). In simple terms it appears that long wind events with an easterly component set up the west end of the lake and harbour. A shift in wind direction to a westerly component causes the lake and harbour levels to drop, promoting a significant outflow event at the fishway. Only 10% of the events occurred in the daytime.

A similar observation can be made for inflow events longer than four hours. In this case, 75% of the events are preceded by winds with a westerly component for more than six hours. It appears that the westerly wind set down the western end of the lake, helping to drive water out of Cootes Paradise. When the westerly wind relaxes (either by a drop in speed or change in direction) the water in the lake and harbour rises forcing water into the wetlands. Most (75%) of the events occurred around mid-day.

The wind direction at the Burlington pier can be used as a guide for predicting outflow and inflow events longer than four hours. When the wind has an easterly component for six hours or more, it can be expected that, when the wind shifts to contain a westerly component, an outflow event of four hours or longer may occur (80% of the extended outflow events had these wind conditions). Similarly westerly winds for six hours or more may lead to a prolonged inflow event (75% of such events had these wind conditions). A quick way to check the previous 24 hours of wind records is to access the Environment Canada site at: <http://www.tor.ec.gc.ca/forecasts/retro.cgi?city=Burlington&province=Ontario> Alternatively, the meteorological data from the Royal Botanical Gardens could be used, but a comparison of the flow data with the RBG meteorological should be made to ensure that there are no biases compared to the Burlington pier data.

To put the frequency of the occurrence of these extended events into perspective, note that the total deployment was about 186 days long. There were 46 outflow events and 20 inflow events of four hours duration or longer. Therefore on average either one or the other only occurred about once every three days.

Shorter period flow reversals do not appear to be related directly to any obvious causes, rather they are likely free oscillations set up by the larger wind driven events. The frequency domain analysis revealed that there was a tidal component to the oscillations as well as a harmonic of the tide. Some evidence of both Helmholz resonance and of exchange flow resonance was noted in the flow spectra, but the energy in these oscillations was usually quite small compared to the tide and first harmonic of the tide. Use of the rotary spectrum analysis indicated that there was no preferred direction of rotation and hence the meter was not likely in a persistent gyre or eddy within the fishway. The high coherence between the water level and the flow at the tidal periods indicates the water level in the lake is an important factor in the flow reversals at these periods.

The cumulative discharge figures provide a dramatic illustration of the flow reversals at the fishway. They also indicate that the net flow during each deployment was out of the wetlands into the harbour. The net outflow was significantly greater in the spring and fall than it was during the summer, when the flow was more balanced. While the discharge data can be used with suspended sediment data to estimate the net discharge of sediment, caution must be exercised. Firstly the discharge data are based on only one flow measurement in the cross section (albeit the most appropriate location was chosen), so that the variation in flow across the channel and hence accurate estimates of discharge cannot be made.

Furthermore there is a question of dilution of the sediment because of mixing of inflowing harbour water with the wetlands water, which then flows out after a reversal. Finally, to use any sediment samples that were taken at the fishway, the time of the sediment samples must be correlated with inflow and outflow events to determine if the samples represent harbour water or wetlands water.

There was poor correspondence between the portable and the fixed meter. Indeed, there was also poor correspondence between half of the readings of the portable meter at adjacent stations taken within a minute or two of each other. It is clear that the portable meter must be used with great caution because of the rapid and frequent reversals in flow direction at the fishway. It is quite possible that the flow may reverse between the time a profile is started and when it is finished. **The meter must be properly facing the flow when taking a reading, and if the flow direction changes while the meter is being used, the operators must retake the reading ensuring the meter is correctly facing the flow for the full duration of the measurement.**

Conclusions

The flow conditions at the Cootes Paradise Fishway were monitored from April to November 1997. The flow was characterized by many reversals each day. Extended periods (greater than 4 hours) of outflow were preceded in 80% of the cases by at least six hours of winds with some easterly component (NNE through SSE). Furthermore 80% of the extended outflow cases (not always the same cases as the wind) were also accompanied by water level decreases at the Burlington Pier. The outflow events usually occurred at night (90%). Extended inflow events (more than four hours) were preceded by westerly winds for more than 6 hours and almost always with rising water levels at the Burlington pier, and usually happened around mid-day (75%). It would appear that the wind direction could be used as a predictor of extended outflow and inflow events. Shorter period reversals were related to the tide, Helmholtz resonance and exchange flow resonance, although the energy in these reversals was small. The discharge data can be used to get rough estimates of sediment discharge from the wetlands. Caution must be exercised when interpreting spot readings taken with a portable current meter.

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Tables

Table 1. Cootes Paradise Fishway current meter deployment summary.

Deployment	Start Date (Julian Day); Time (GMT)	Stop Date (Julian Day); Time (GMT)	Comments
12381	1997-4-18 (108); 1625	1997-4-24 (114); 2045	
12382	1997-5-2 (122); 1625	1997-5-28 (148); 1505	
12383	1997-5-30 (150); 1425	1997-6-18 (169); 1405	Direction uncertainty
12383a	1997-6-20 (171); 1625	1997-6-27 (178); 1425	Direction uncertainty
12384	1997-6-27 (178); 1625	1997-7-16 (197); 1345	
12385	1997-7-17 (198); 1625	1997-8-13 (225); 1345	
12386	1997-8-14 (226); 1425	1997-9-8 (251); 1405	
12387	1997-9-10 (253);1925	1997-9-29 (272); 1225	
12388	1997-9-30 (273); 1425	1997-10-28 (301); 1245	
12389	1997-10-31 (304); 1425	1997-11-28 (332); 1245	

Table 2. Mean flows at Cootes Paradise during 1997 deployments. The decision as to whether an occurrence was an inflow or outflow was based on inspection of the occurrence histograms: for A12381 and 2 angles less than 50°T and for A1234-9, angles less than 100°T were considered inflows. The means are vector averages for all occurrences of inflow or outflow respectively. The net flow weighting is based on the number of occurrences in each direction (inflow and outflow).

Deployment File	Inflow			Outflow				
	Mean Velocity [m/s]	No. of Occurrences	Mean Dir'n [°T]	Mean Velocity [m/s]	No. of Occurrences	Mean Dir'n [°T]	Net Weighted Mean Vel [m/s]	Dir'n Difference [°T]
A12381	0.078	157	-60	0.109	289	137	0.043	197
A12382	0.082	539	-58	0.115	1328	149	0.058	207
A12384	0.066	635	-19	0.086	714	187	0.014	206
A12385	0.070	980	-10	0.105	961	189	0.017	199
A12386	0.086	679	-11	0.147	1121	197	0.059	208
A12387	0.072	468	1	0.116	880	189	0.051	188
A12388	0.090	719	-10	0.143	1293	195	0.060	205
A12389	0.079	627	3	0.124	1384	196	0.061	191

Table 3. Extended outflow events (more than four hours) at the Fishway in 1997.

Date (Julian Day), Start Time (GMT)	Event Duration, hrs	Water Level	Wind Direction[1]	Wind Direction before Event[2]	Rainfall, mm/day	Maximum Outflow[3], m/s
3 May (123), 1500	12	[redacted]	ENE → NW	[redacted]	18.6	0.4
6 May (126), 0800	8	[redacted]	W → NNW	[redacted]	0	0.3
9 May (129), 1200	6	steady	ENE → WNW	W for 6	0	0.4
12 May (132), 0900	8	[redacted]	W	W> 12	0	0.3
15 May (135), 0900	8	[redacted]	ENE → W	[redacted]	15.6	0.3
16 May (136), 0600	6	[redacted]	W → NW	W> 12	2.4	0.4
28 June (179), 0300	6	[redacted]	SSE → WNW	[redacted]	0	< 0.1
30 June (181), 1800	6	[redacted]	NE → W	[redacted]	0	0.1
31 July (212), 0400	8	[redacted]	SSE → WNW	[redacted]	0	0.2
13 Aug (225), 0200	8	[redacted]	ENE → NW	[redacted]	18.2	0.3
15/16 Aug(227/228) 1800/0100	6 / 8	[redacted]	NE → WNW	[redacted]	15.2 / 0	0.5
18 Aug (230), 0900	6	[redacted]	NNE	[redacted]	0	0.3
19/20 Aug (231/232), 2200	6	[redacted]	E → NE	[redacted]	0 / 11.2	0.3
21 Aug (233), 0600	12	[redacted]	ESE	[redacted]	0	0.3
23 Aug (235), 0000	8	[redacted]	NE → NW	[redacted]	0	0.3
25 Aug (237), 2200	12	[redacted]	NW → E	[redacted]	0	0.2
26 Aug (238), 1800	8	[redacted]	E	[redacted]	0	0.2
27 Aug (239), 1700	8	[redacted]	E → W	[redacted]	0	0.3
28 Aug (240), 0000	6	[redacted]	W	W> 12	0	0.3
1 Sept (244), 1600	8	[redacted]	SE → W	[redacted]	0	0.2
2 Se pt (245), 0600	8	[redacted]	W	[redacted]	0	0.2
6 Sept (249), 0000/1200	6 (X2)	[redacted]	W	W> 12	10.5	0.2
7 Sept (250), 0100	6	[redacted]	W	W> 12	0	0.3
11 Sept (254), 0400	6	[redacted]	SE → NW	[redacted]	0	0.2
13 Sept (256), 0500	6	[redacted]	NW	W> 12	0	0.2
15 Sept (258), 0800	6	[redacted]	NW	[redacted]	0	0.3
4 Oct (277(1)), 0000	6	steady	NE	[redacted]	0	0.3
4 Oct (277(2)), 0900	6	steady	W → NE	[redacted]	0	0.2
14 Oct (287), 0600	8	[redacted]	NE → NW	[redacted]	0	0.4
15/16 Oct (288/9), 1900	8	[redacted]	N → S → NE	[redacted]	0	0.3
17 Oct (290), 0600	8	[redacted]	S→NE	[redacted]	0	0.3
17/18 Oct (290/1), 1900	8	steady	NE → S	[redacted]	0	0.2
18 Oct (291), 0900	8	steady	NW	[redacted]	0	0.3
18/19 Oct (291/2), 2200	8	[redacted]	SSE→NW	[redacted]	0	0.3
27 Oct (300), 0300	24	[redacted]	SE →NW	[redacted]	35.1(299); 11.6	0.8
1/2/3 Nov (305/6/7), 2200	30	[redacted]	E → W	[redacted]	24.6(305)	0.6
3 Nov (307), 1200	8	steady	SSW → WNW	W> 12	24.6(305)	0.3
12 Nov (316), 0400	8	[redacted]	W → NW	W> 12	0	0.3
14/15 Nov (318/9), 1800	8	[redacted]	SE→ NE	[redacted]	20.2	0.2
16 Nov (320), 2200	8	[redacted]	NW → W	W> 12	0	0.2
22 Nov (326), 1400	8	[redacted]	E → NE	[redacted]	0	0.2
24 Nov (328), 0300	8	steady	NW	W> 12	0	0.1
26 Nov (330), 1500	8	steady	W	W> 12	0	0.2

[1] Direction during the event, or the arrow indicates the wind direction changed from the first to the second direction before or during the event.
[2]Direction conditions before event ('E' means with an easterly component, 'W' means with a westerly component).
[3]Approximate: determined visually from the time series plots.

Table 4. Extended inflow events (more than four hours) at the Fishway in 1997.

Date (Julian Day), Time (GMT)[1]	Event Duration, hrs	Water Level	Wind Direction	Wind Direction before Event[2]	Rainfall, mm/day	Maximum Inflow[3], m/s
29 June (180), 1600	4	[illegible]	E	[illegible]		0.1
1 July (182), 1600	4	[illegible]	E	NE for 6		0.2
2 July (183), 1600	7	[illegible]	E	[illegible]	8.5	0.2
5 July (186), 1600	6	[illegible]	W	[illegible]		0.2
7 July (188), 1800	4	[illegible]	SE	N>6	3.4	0.1
18 July (199), 0400	4	[illegible]	WNW	[illegible]		0.2
18 July (199), 1300	4	[illegible]	W	[illegible]		0.2
18 July (199), 1800	4	[illegible]	NW	[illegible]		0.2
1 Aug (213), 1800	7	[illegible]	W	[illegible]		0.2
2 Aug (214), 1600	5	[illegible]	W	[illegible]		0.2
3 Aug (215), 1600	4	[illegible]	S	[illegible]		0.3
8 Aug (220), 1600	5	[illegible]	W	[illegible]		0.2
12 Aug (224), 1100	8	[illegible]	NE	NNE>6		0.2
17 Aug (229), 1600	4	[illegible]	ESE	[illegible]	0.9	0.2
19 Aug (231), 0400	4	[illegible]	NE	S→NE		0.2
19 Aug (231), 1600	5	[illegible]	E	N		0.2
2 Sept (245), 1600	4	[illegible]	W	[illegible]		0.2
14 Sept (257), 1600	4	[illegible]	W→S	[illegible]		0.3
14 Oct (287), 1600	4	[illegible]	W	[illegible]	0.6	0.3
15 Oct (288), 0200	5	steady	NW	[illegible]		0.2

[1] Approximate start time of inflow event.
[2]Approximate: determined visually from the time series plots.

Table 5. Periods of the spectral peaks in the rotary spectra of the 20 minute velocity time series at the Cootes Paradise Fishway, April to November 1997. One or the other of the columns marked with * was the biggest peak (other than semi-diurnal tides).

Deployment	Period, Hours						
			*	*			
1		14.3	5.3	3.1		1.3	1.0
2	26.3	12.3	4.5	3.2			
4		13.9	5.0	3.1	2.3	1.7	1.4
5	26.3	12.2	5.0	3.4	2.5		
6	25.0	12.5	4.8	3.2			
7		13.9	5.0	3.2	2.3	1.7	1.4
8		12.5	5.0	3.2		1.7	
9							

Table 6. Periods of the spectral peaks of the 15-minute water level time series at Burlington Pier (Lake Ontario). The second highest peak after the semi-diurnal tides was always at approximately 5 hours.

Deployment	Period, Hours				
1		13.3	5.4		1.8
2		11.5	5.9/4.8	3.1	
4	21.3	11.4	5.3		
5		13.2			
6		10.2	4.8		1.8/1.3/1.1
7		12.5	5.6		1.4/0.83
8		11.5	5.3	3.3	
9					

Table 7. Periods of high coherence (typically >0.95) between the water level at the Burlington Pier and the outflow at the fishway.

Deployment	Periods of high coherence, hours			
1	12.9	5.4		1.3
2	12.1			1.7
4		4.5		
5	12.6	4.6	3.3	
6	21.8/11.6	6.6/5.1		1.4
7	12.7	4.9		1.4
8	13.0	5.1		1.7
9	18.9/11.2			

Table 8. Velocities measured by the portable current meter at stations either side of the fixed meter, and by the fixed current meter, at approximately the same time. The shaped portable meter times denote that the readings from the two stations are different by more than 50% of the smaller reading; the fixed meter readings that bracket these readings have been included so that any trend in time will be shown.

Date (Julian Day)	Time[1], GMT (portable meter)	Velocity[2], m/s, at Stn 9 (S of fixed meter)	Velocity[2], m/s, at Stn 10 (N of fixed meter)	Time, GMT (fixed meter)	Velocity, m/s, fixed meter	(Mean(Stn9 &10)-fixed meter)/mean (Stn9&10), m/s
11 Nov 97 (315)				1625	0.06	
	[illegible]	0.43	0.28	1645	0.16	0.55
				1705	0.14	
12 Nov (316)	1427	0.55	.056	1445	0.24	0.57
13 Nov (317)				1325	0.33	
	[illegible]	1.09	0.20	1345	0.33	0.49
				1405	0.32	
17 Nov (321)	1452	.038	0.40	1505	0.08	0.63
18 Nov (322)	1338	0.01	0.01	1345	0.02	-1.00
19 Nov (323)				1325	0.15	
	[illegible]	0.04	0.13	1345	0.15	-1.24
				1405	0.11	
20 Nov (324)	1428	0.41	0.30	1425	0.07	0.80
21 Nov (325)				1805	0.17	
	[illegible]	0.40	0.25	1825	0.14	0.57
				1845	0.07	
24 Nov (328)				1325	-0.10	
	[illegible]	0.20	0.02	1345	-0.04	1.36
				1405	0.03	
25 Nov (329)				1325	0.26	
	[illegible]	0.57	0.23	1345	0.21	0.48
				1405	0.16	
26 Nov (330)	1335	0.36	0.42	1345	-0.18	1.46
27 Nov (331)	1404	0.45	0.39	1405	0.21	0.50
28 Nov (332)	[illegible]	0.05	-0.04	-	-	-
1 Dec (335)	1344	0.18	0.25	-	-	-

[1] The time reported here is 7 minutes later than the reported start time of each profile measurement set. Each set of all the stations took about 15 minutes, and stations 9 and 10 are about in the middle of the stations, and so the two were measured within a minute or two of each other.

[2] These velocities are spot readings: as soon as the reading appeared reasonably steady, the value was recorded.

Figures

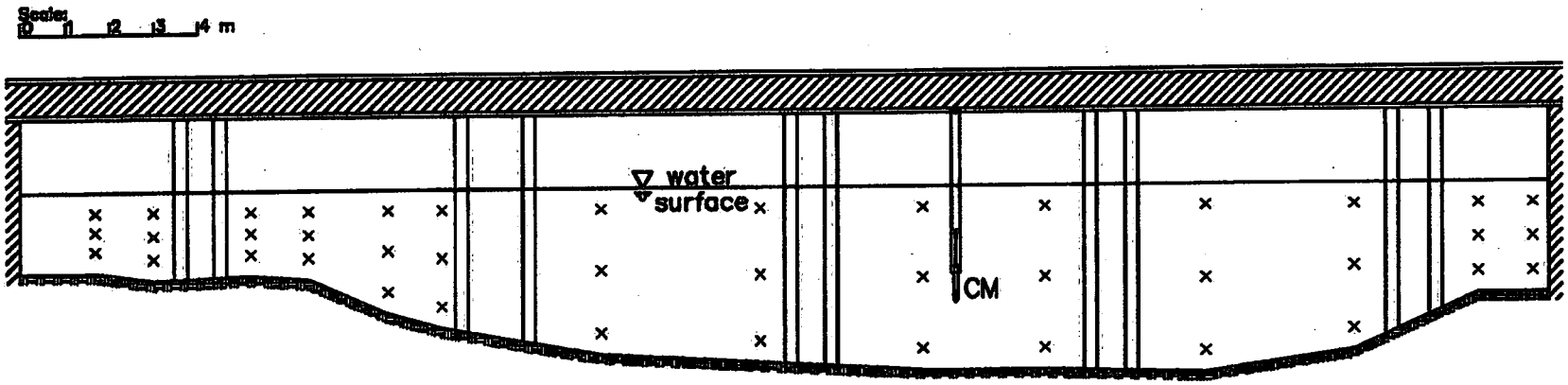


Figure 1. View of the fishway looking towards Cootes Paradise showing the location of the Neil Brown current meter (CM), and the 14 stations (x) used for the portable current meter.

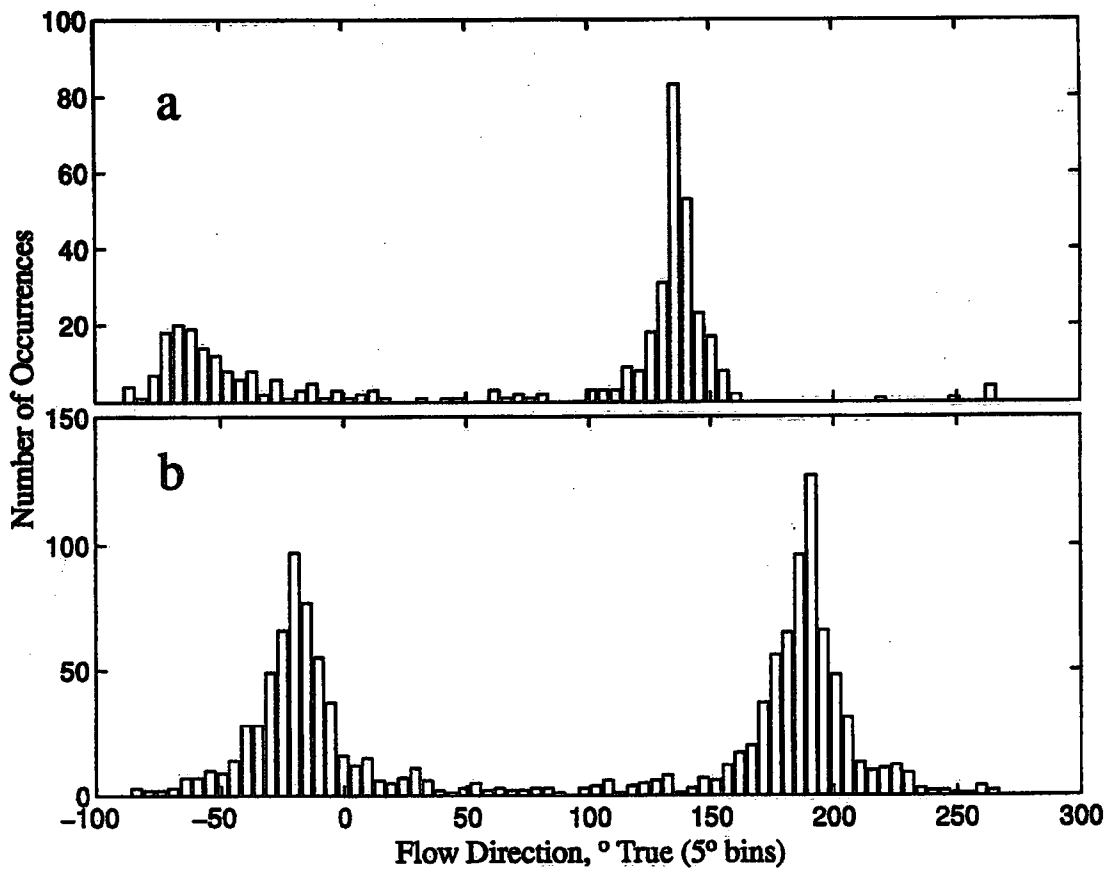


Figure 2. Occurrences of flow greater than 1 cm/s by direction: a) Deployment 1, b) Deployment 2.

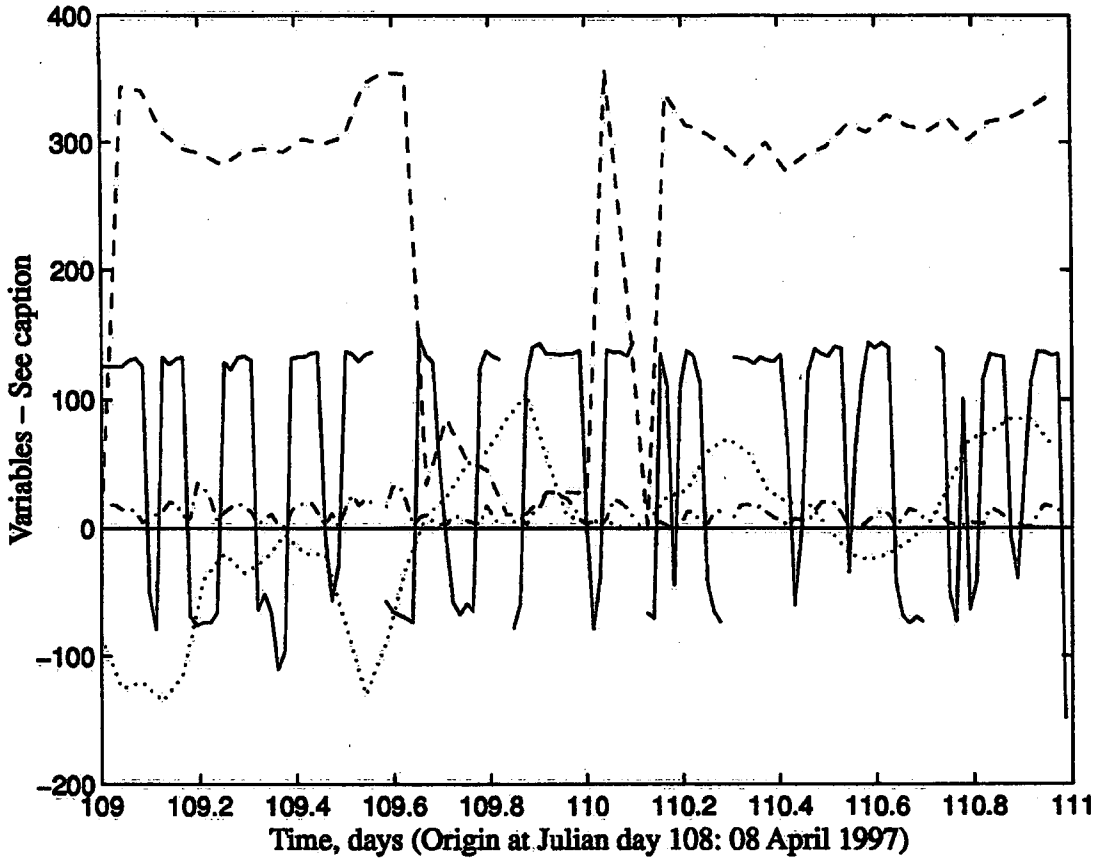


Figure 3. Time series of the flow magnitude (—, cm/s) and direction (—, °T), water level (···, multiplied 50 times and mean removed, cm), and wind direction (– –,°T) for a portion of record for deployment #1. Gaps in the flow magnitude and direction plots occur when the flow is less than 1 cm/s.

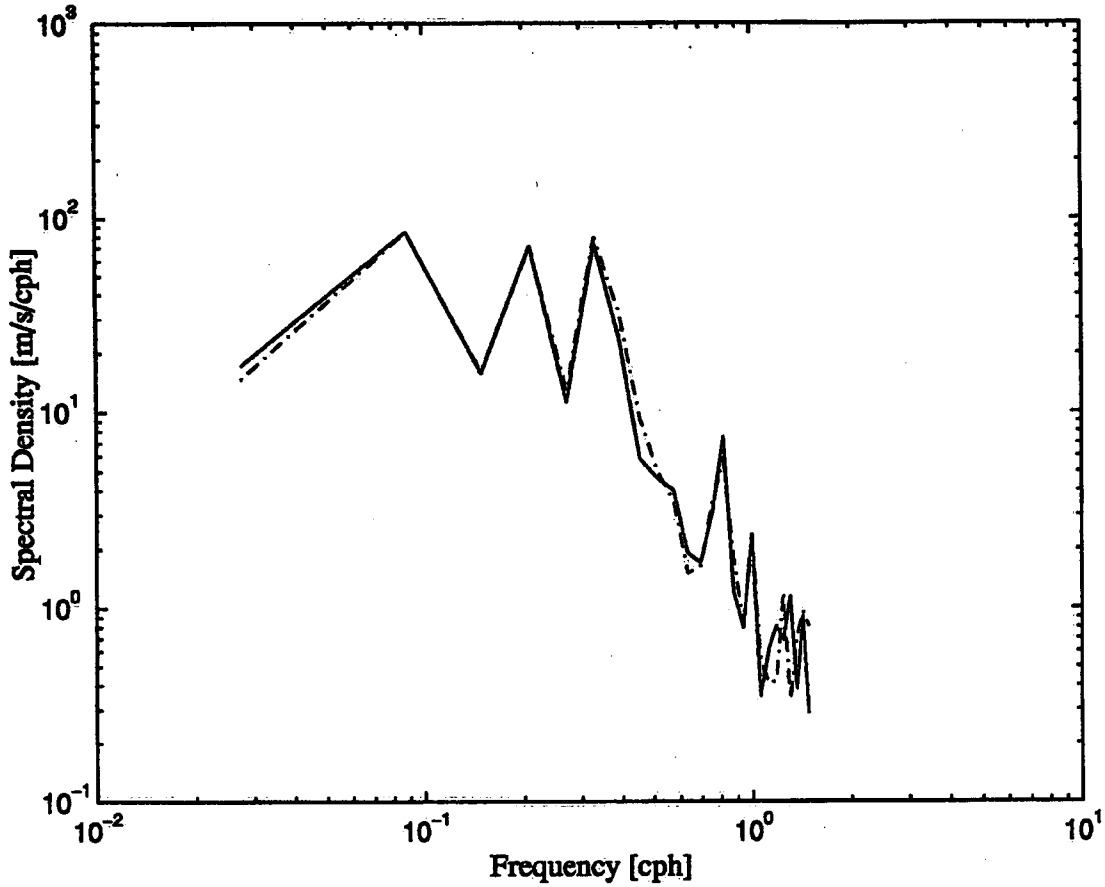


Figure 4. Rotary spectra for deployment #1: CW(—); CCW(-·-).

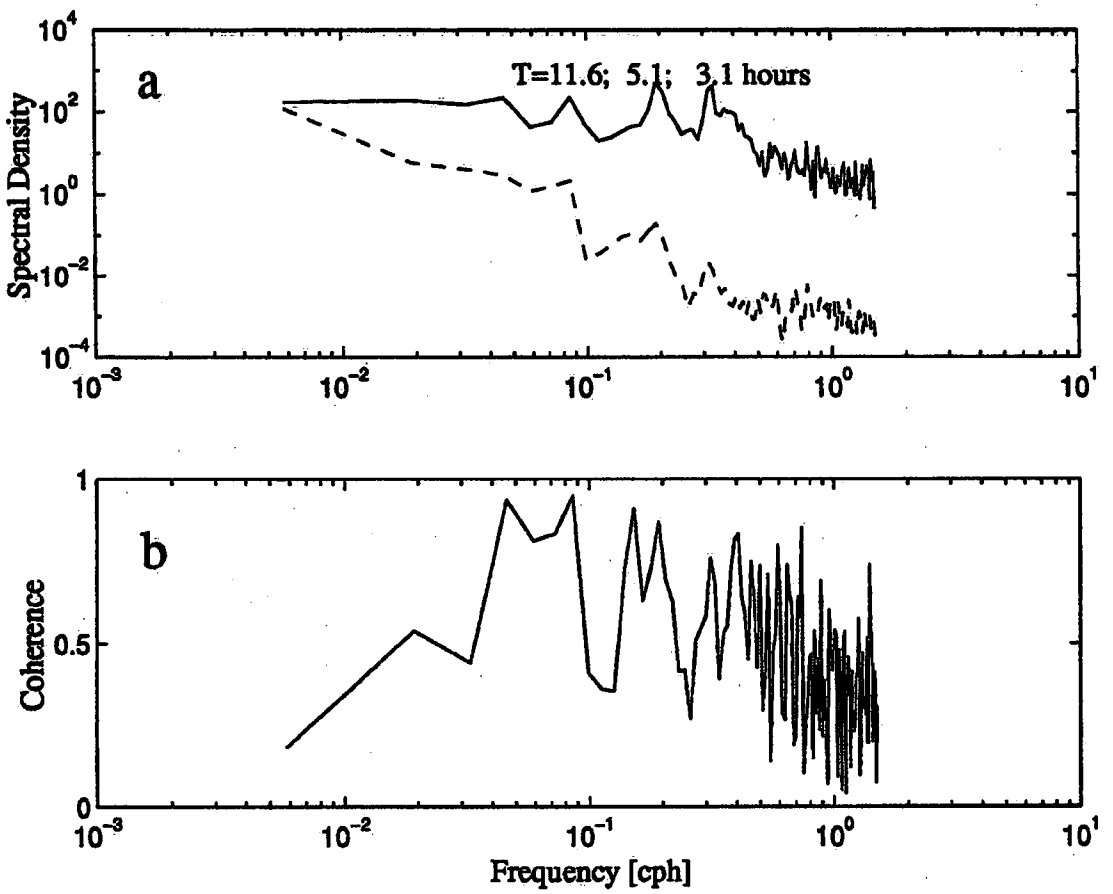


Figure 5. a) Co- Spectra of the outflow (—: [(m/s)^2/cph]) and water level (– –: [m^2/cph]); b) Coherence.

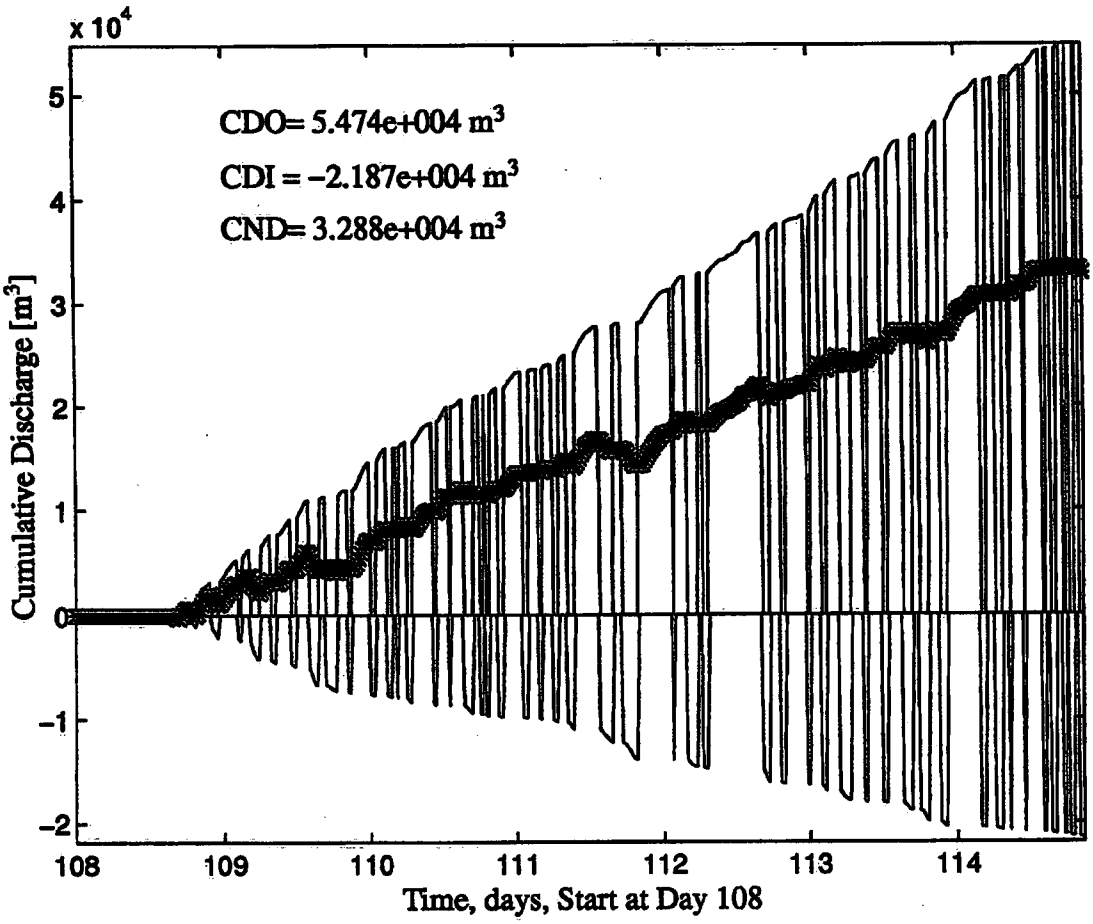
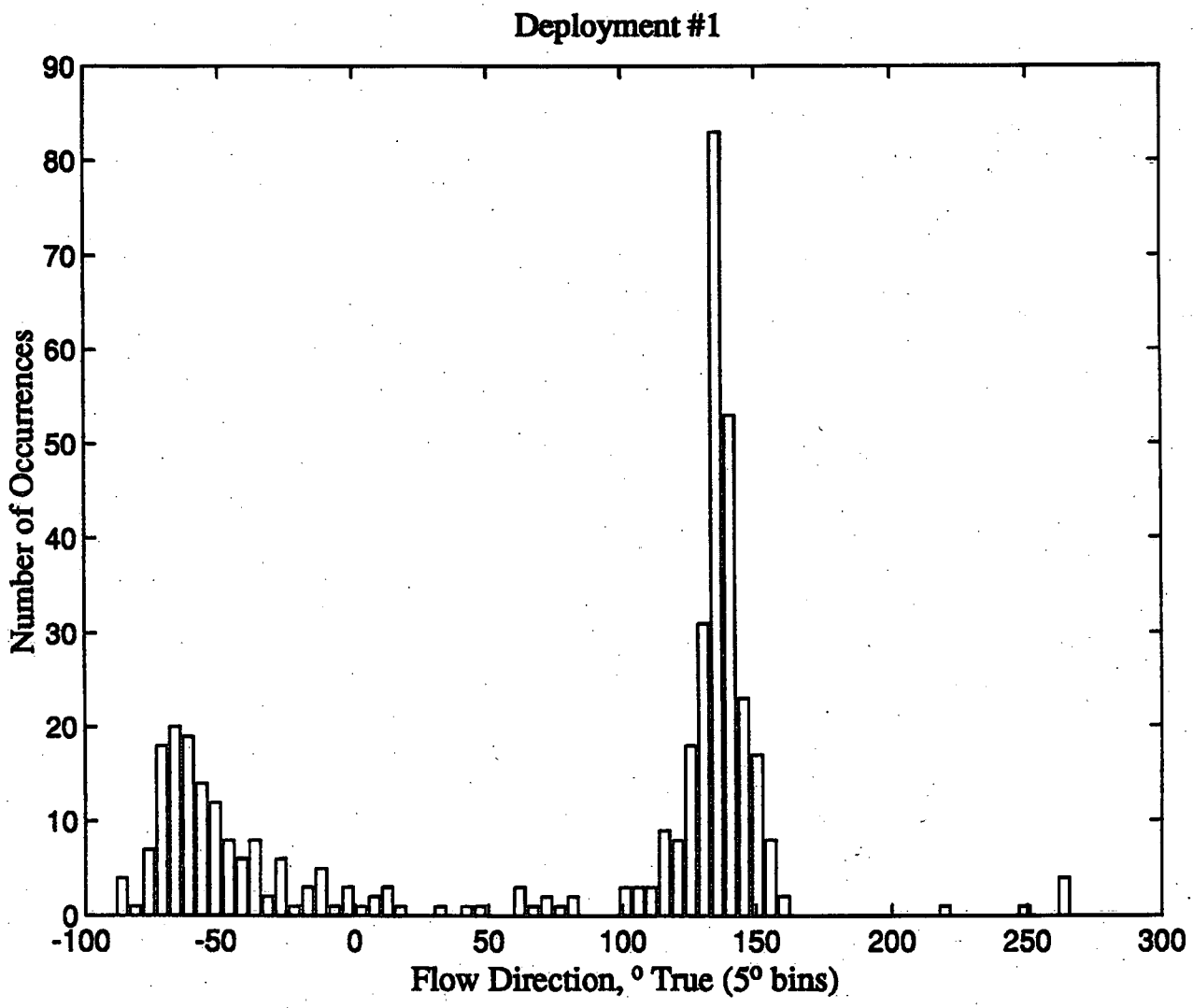


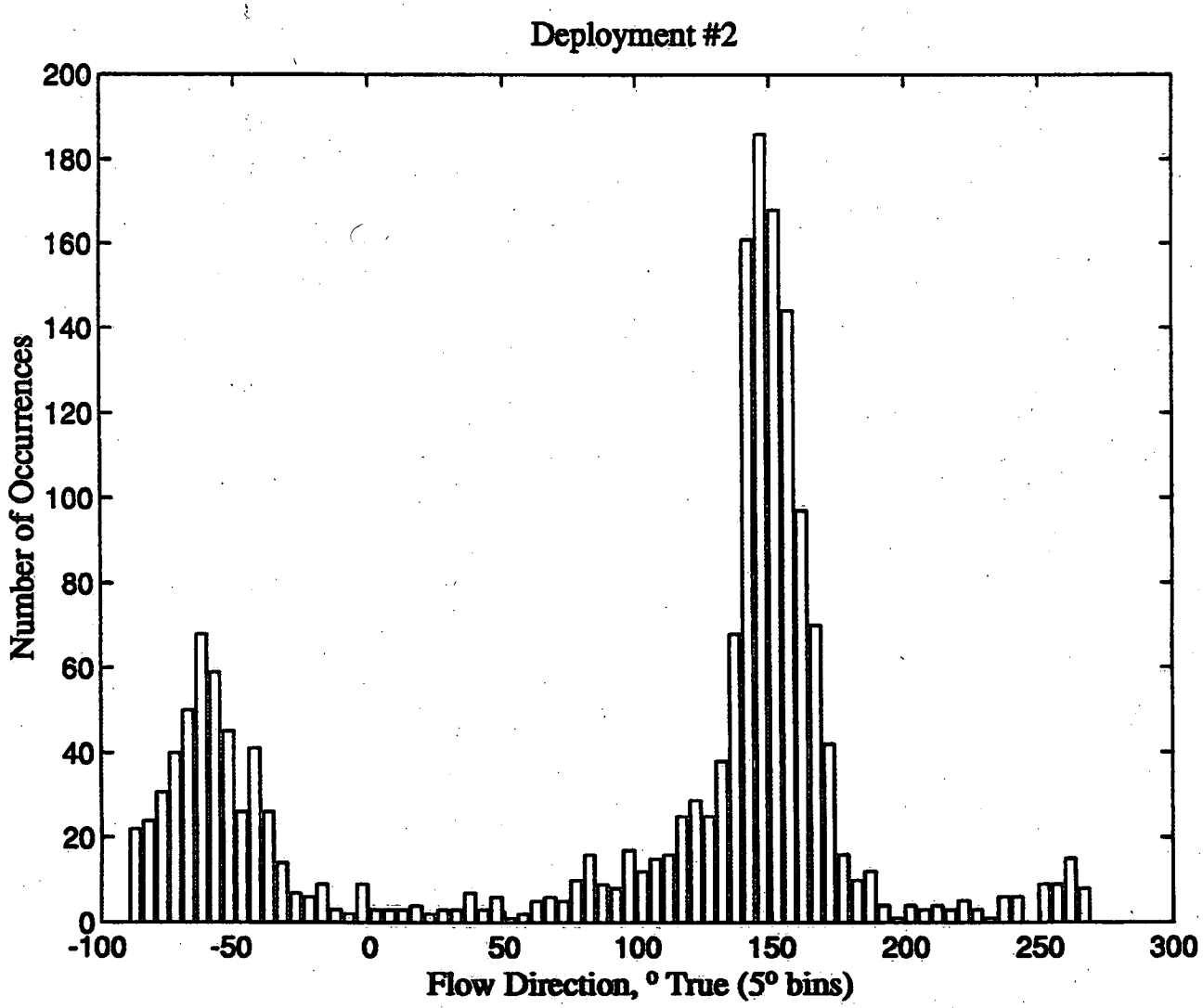
Figure 6. Cumulative discharge for deployment #1: CDO (positive - outflow); CDI (negative - inflow); CND (***, net).

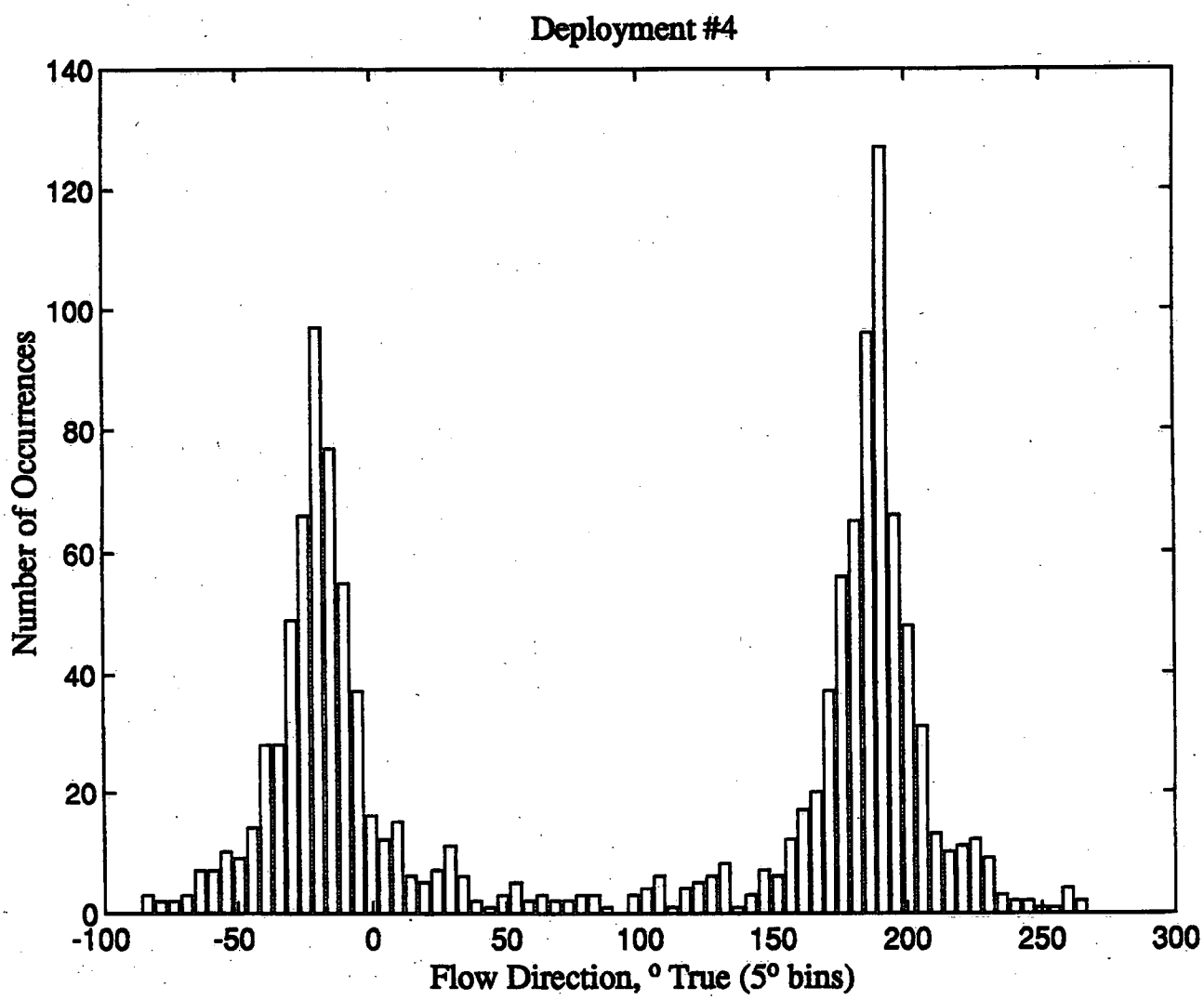
Appendix

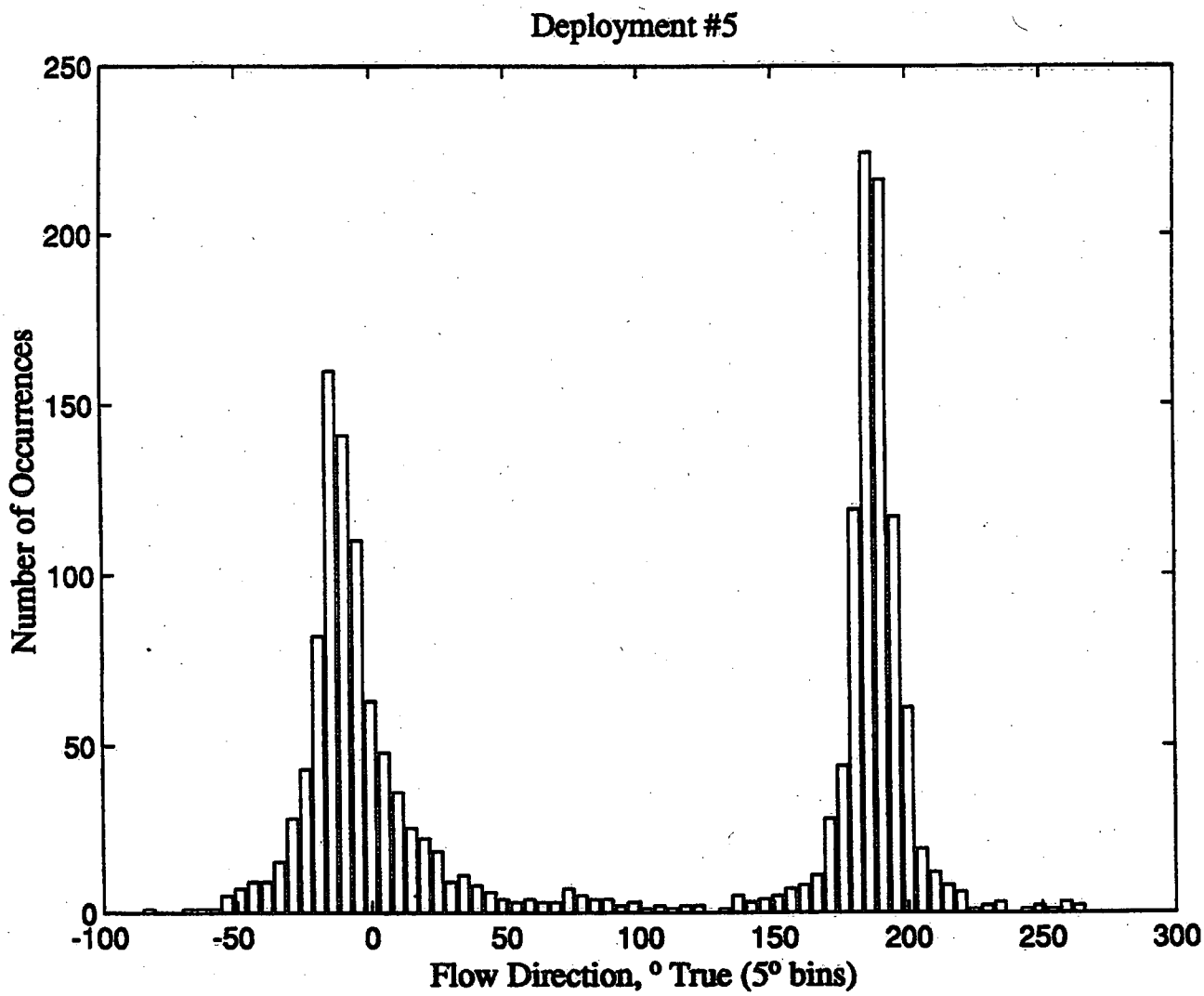
The appendix contains the complete set of figures for all the deployments: histograms of flow direction; time series data from all the sensors; rotary spectra; cospectra of the outflow and the water level; cumulative discharge.

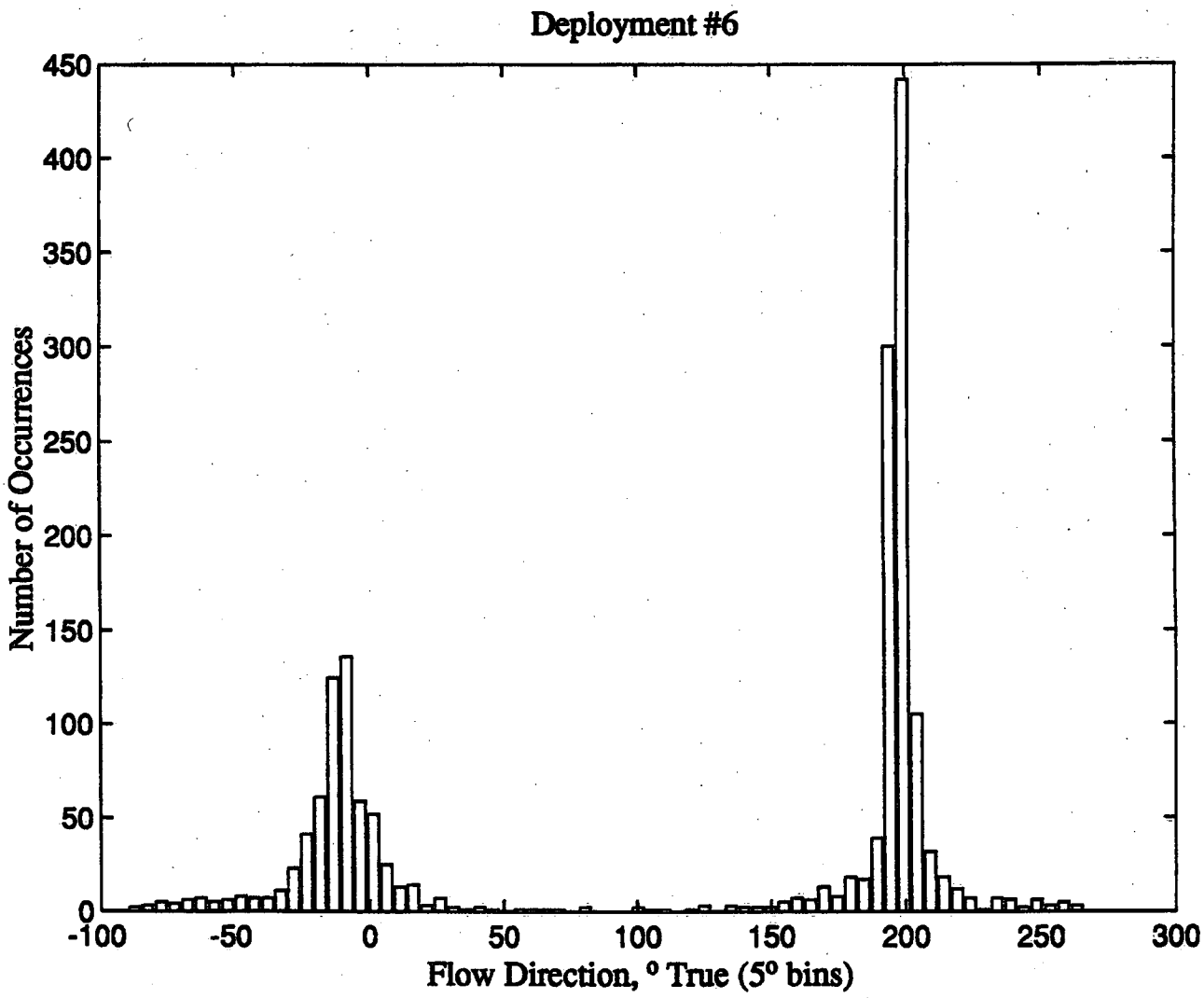
The figures that follow next are the histograms of flow direction for each deployment.

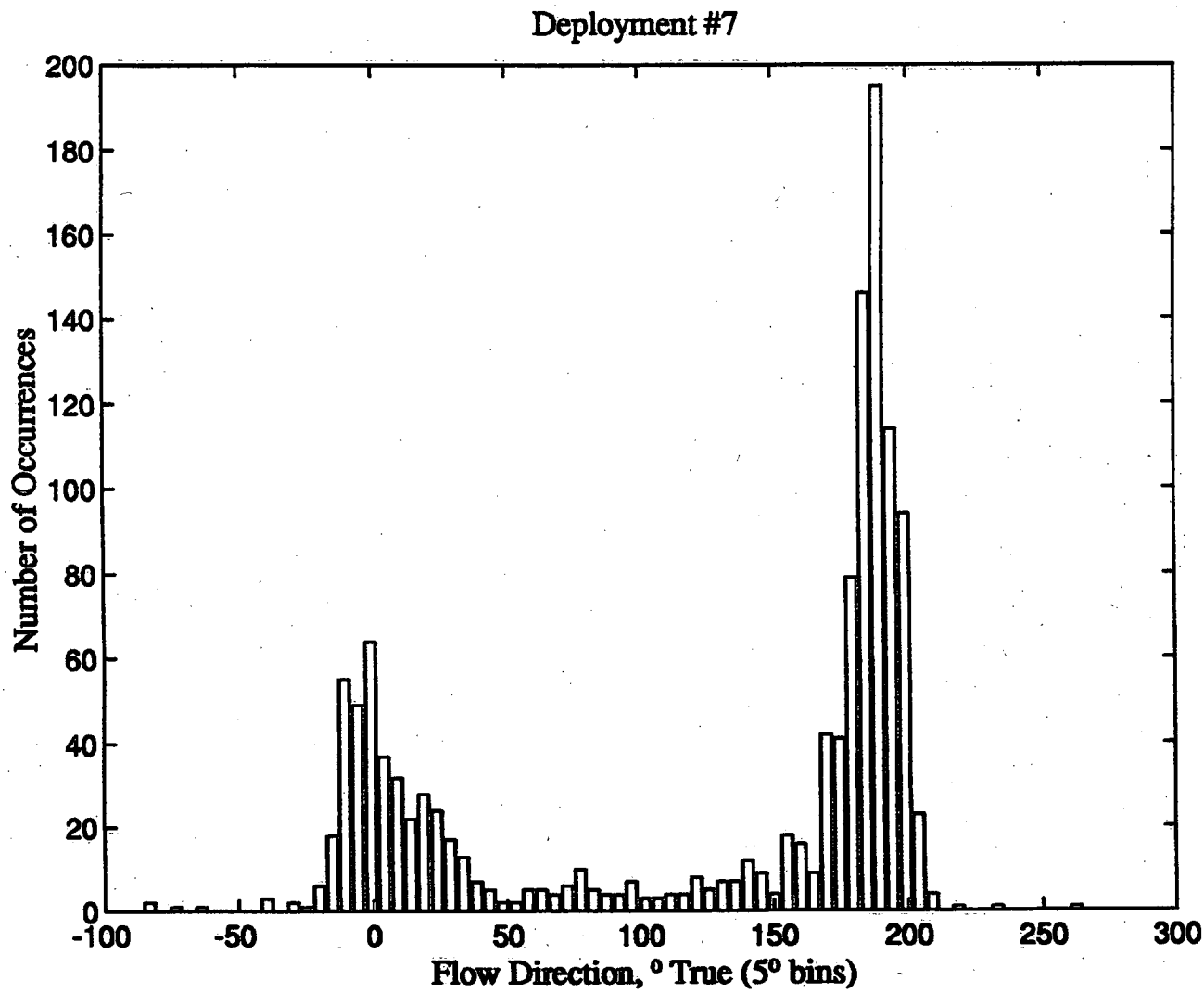

Deployment #1
Number of Occurrences
90
80
70
60
50
40
30
20
10
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

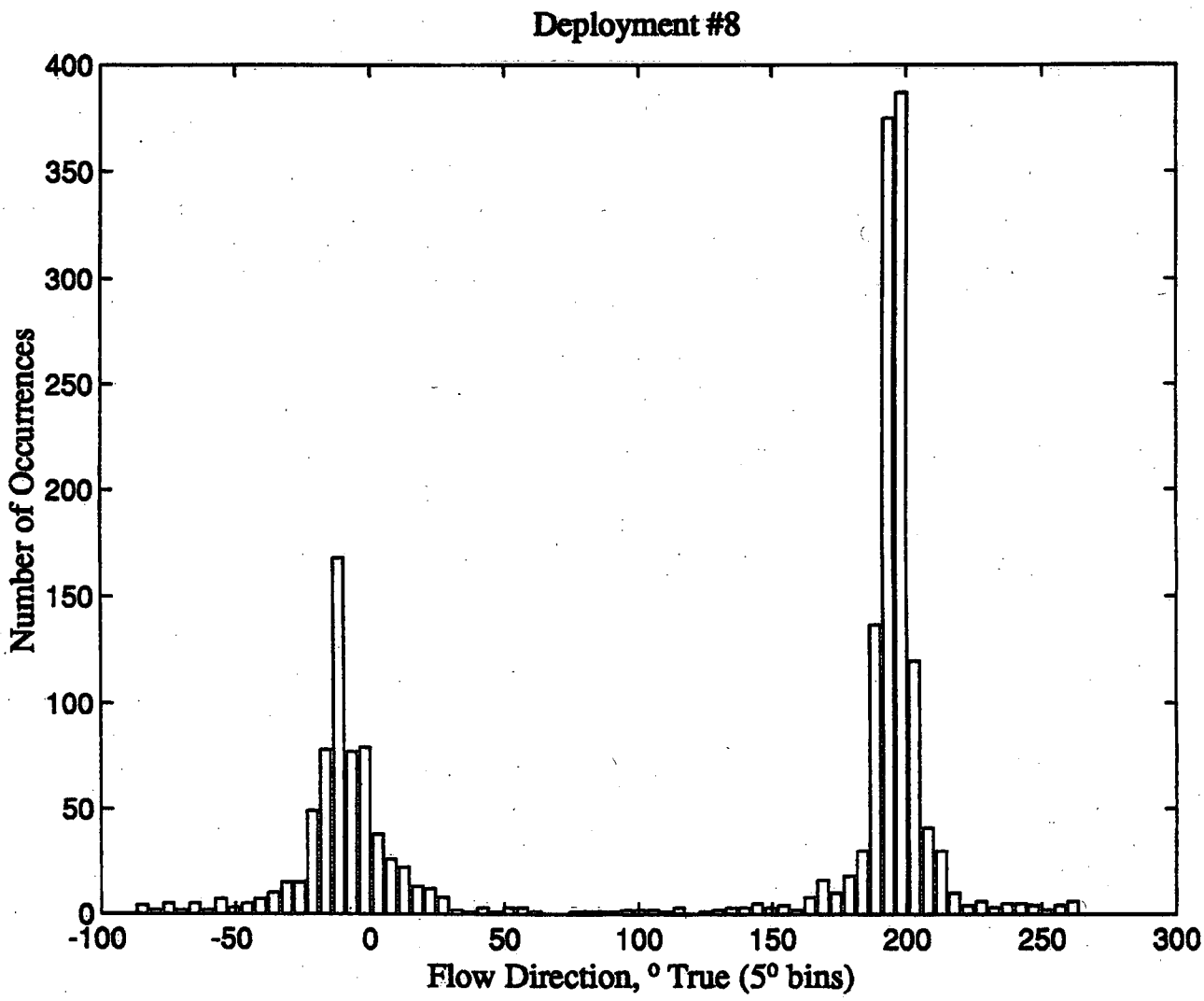

Deployment #2
Number of Occurrences
200
180
160
140
120
100
80
60
40
20
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

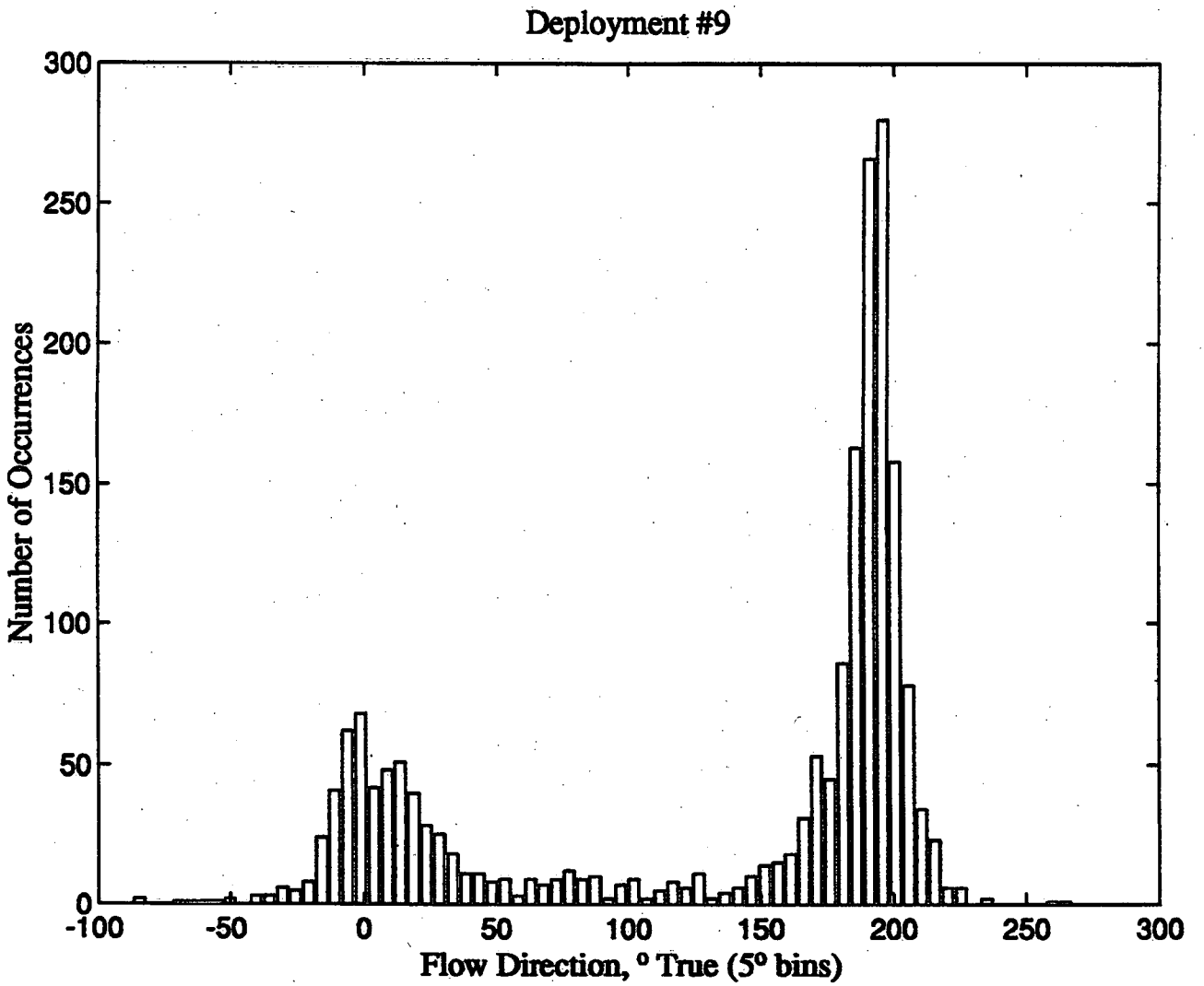

Deployment #4
Number of Occurrences
140
120
100
80
60
40
20
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)


Deployment #5
Number of Occurrences
250
200
150
100
50
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

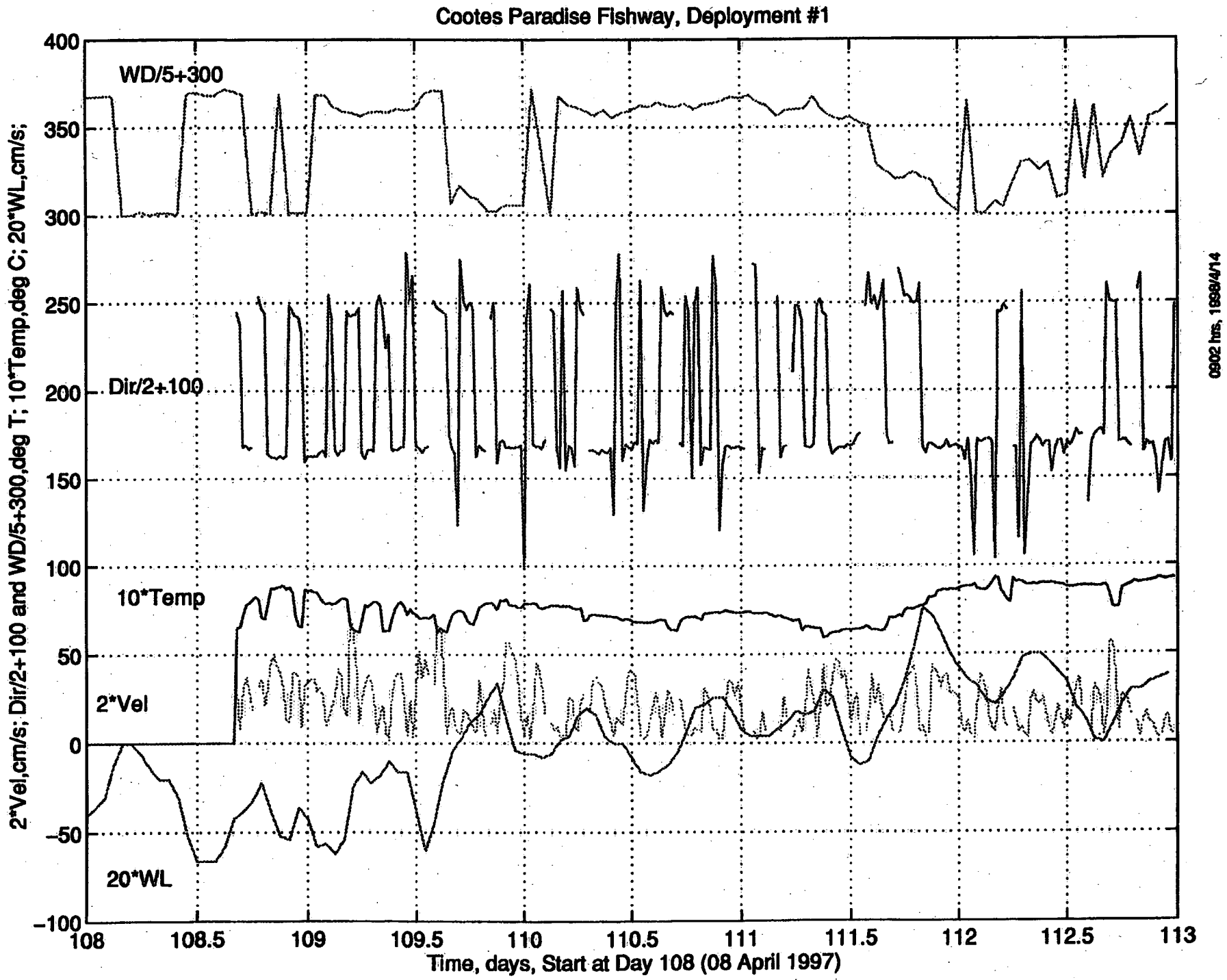

Deployment #6
Number of Occurrences
450
400
350
300
250
200
150
100
50
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

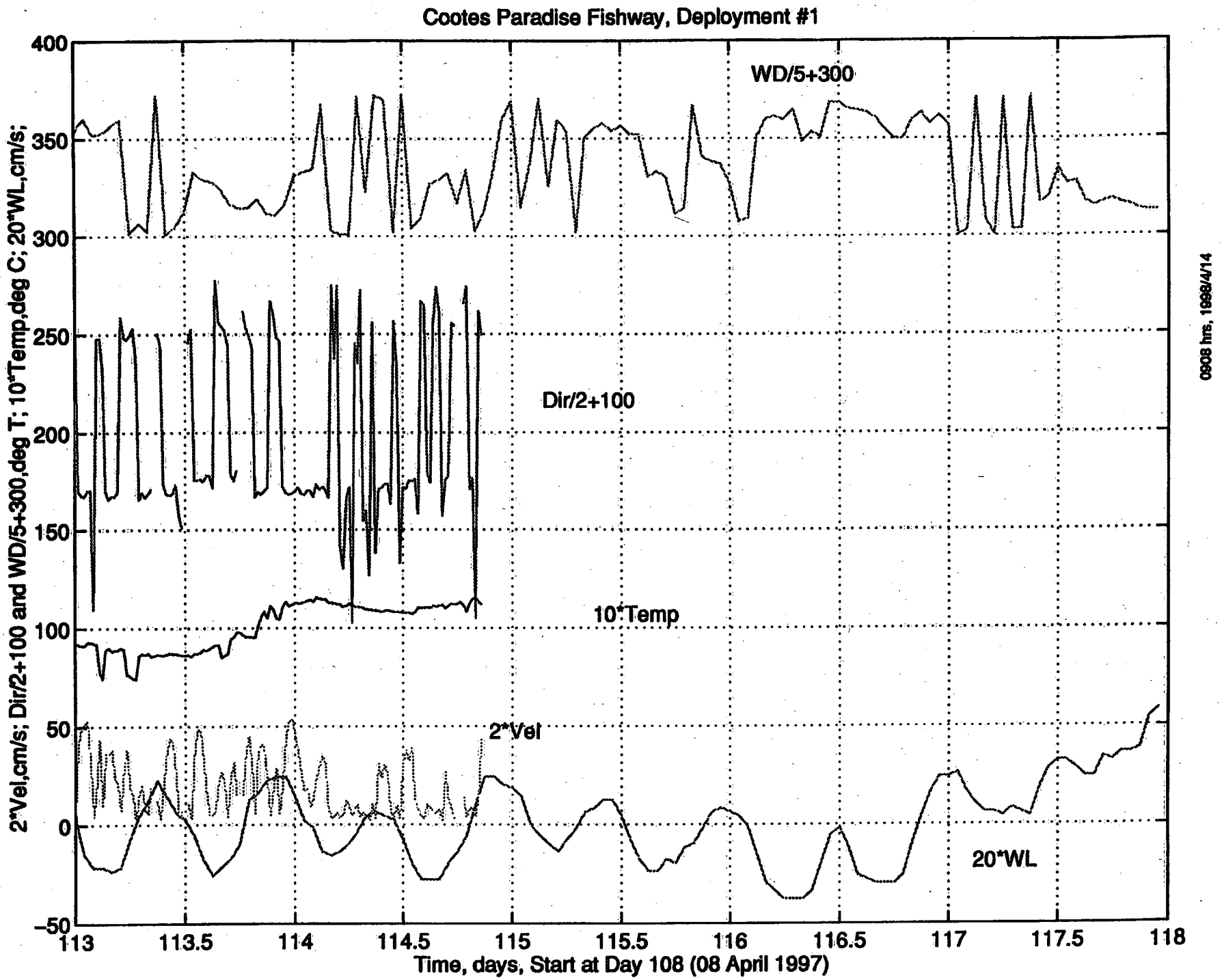

Deployment #7
Number of Occurrences
200
180
160
140
120
100
80
60
40
20
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

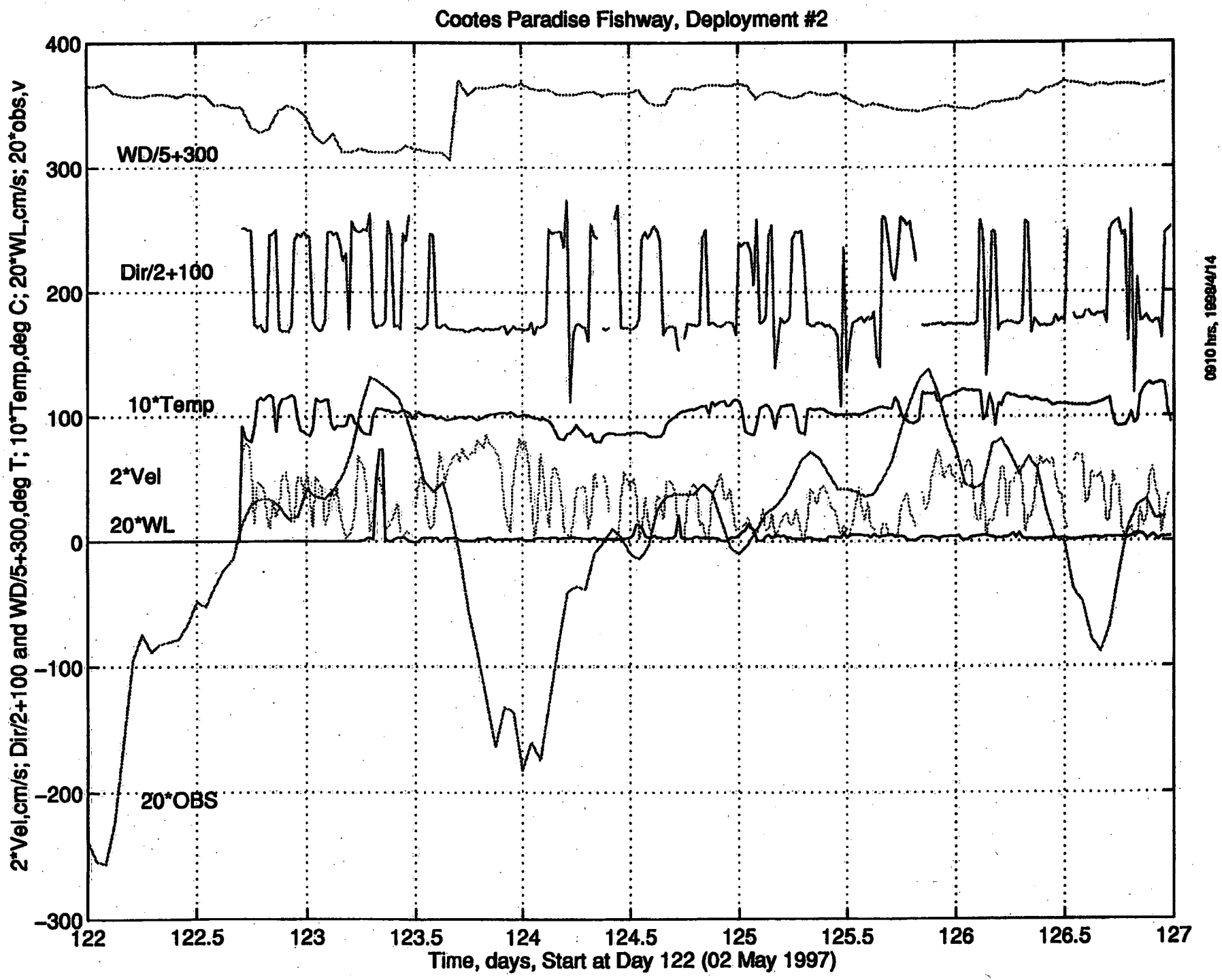

Deployment #8
Number of Occurrences
400
350
300
250
200
150
100
50
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

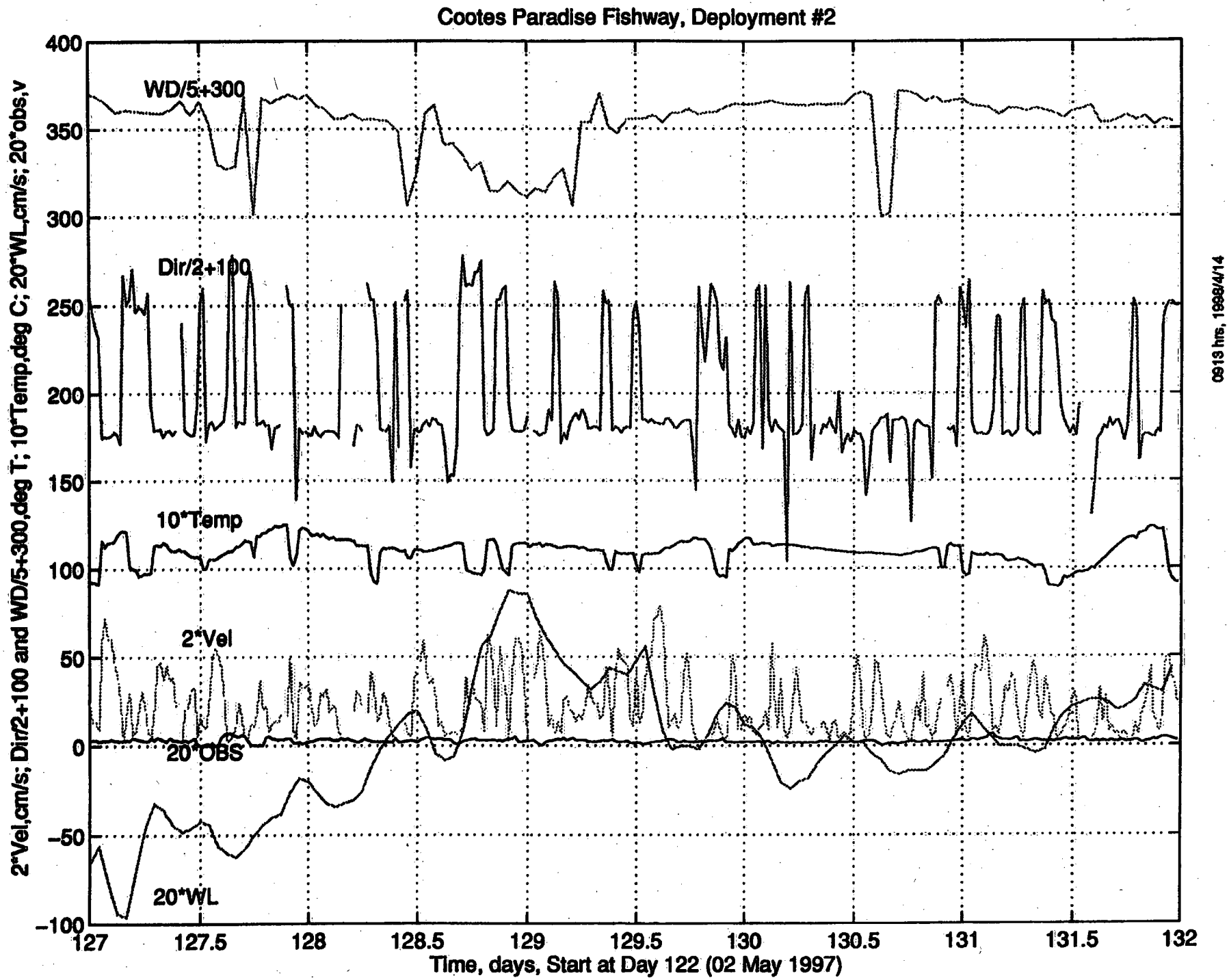

Deployment #9
Number of Occurrences
300
250
200
150
100
50
0
-100
-50
0
50
100
150
200
250
300
Flow Direction, ° True (5° bins)

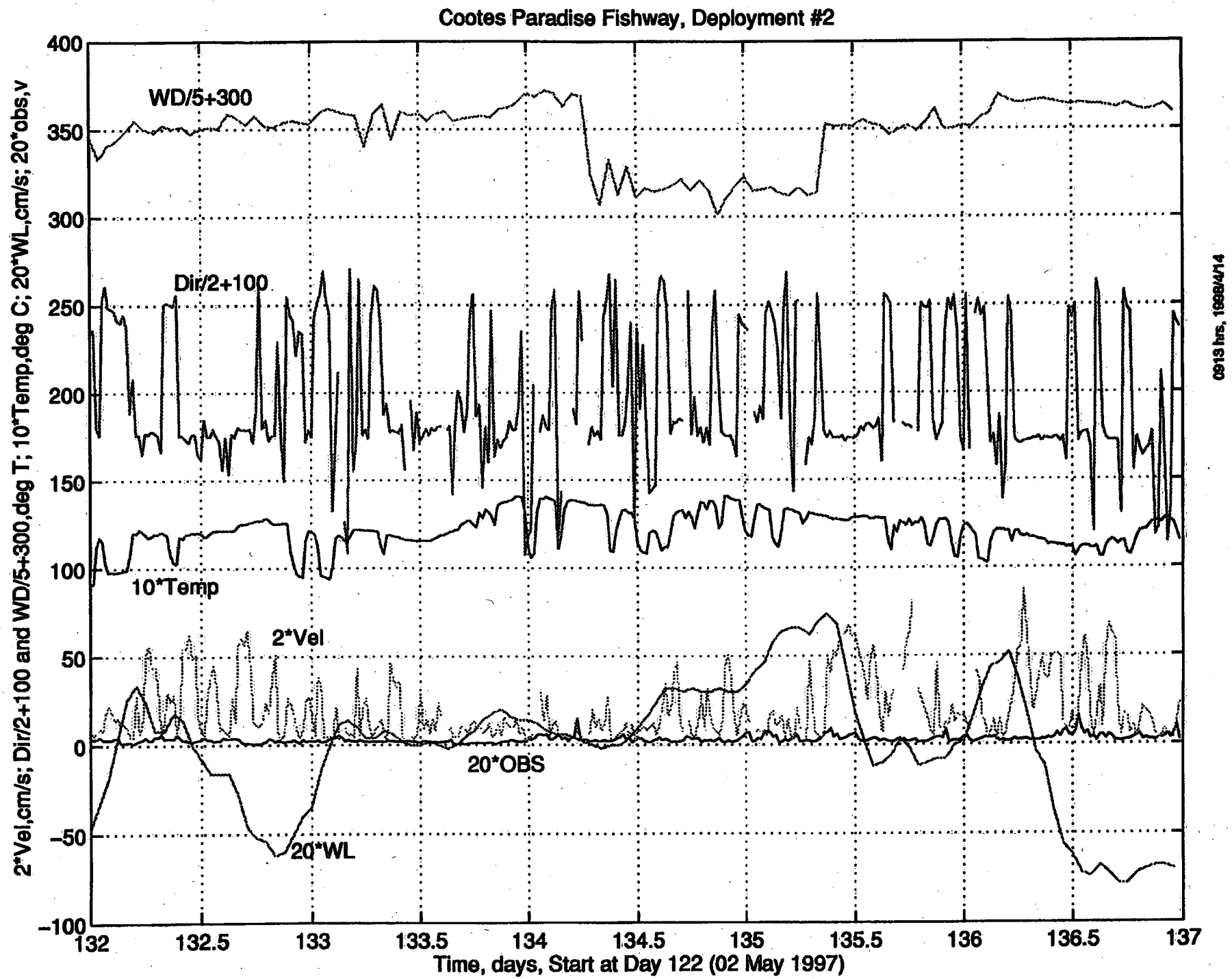
The figures that follow next are the time series data from the sensors. 'Vel' is the magnitude of the velocity from the Neil Brown current meter. 'Dir' is the flow direction. 'WD' is the wind direction. 'Temp' is the water temperature. 'WL' is the water level with the mean removed. The units of each are indicated in the ordinate label. 'deg' is short for degrees. The times series have been multiplied and shifted by constants as indicated to separate them in the figures.

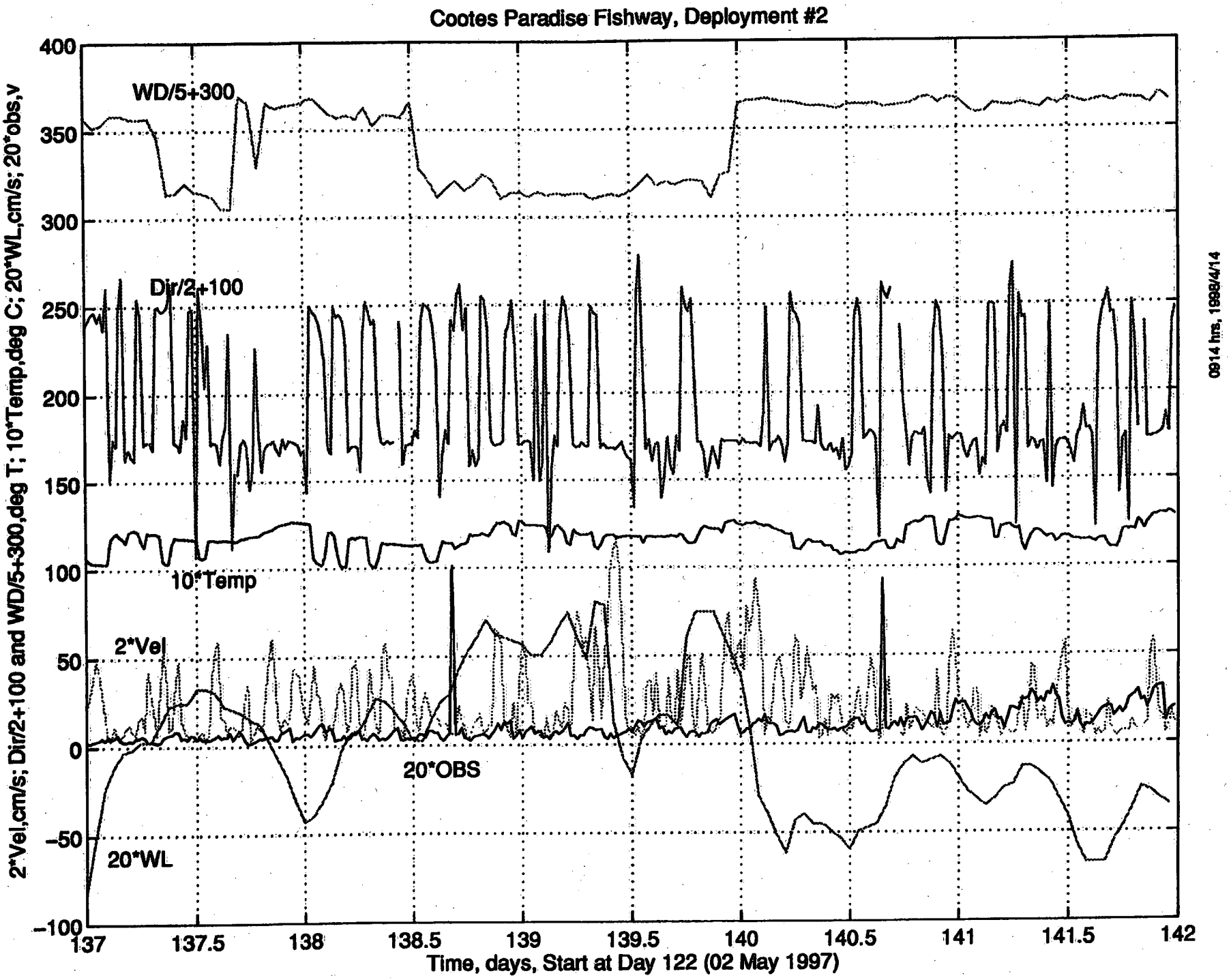

Cootes Paradise Fishway, Deployment #1
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s;
400
350
300
250
200
150
100
50
0
-50
-100
108
108.5
109
109.5
110
110.5
111
111.5
112
112.5
113
Time, days, Start at Day 108 (08 April 1997)
0902 hrs, 1998/4/14

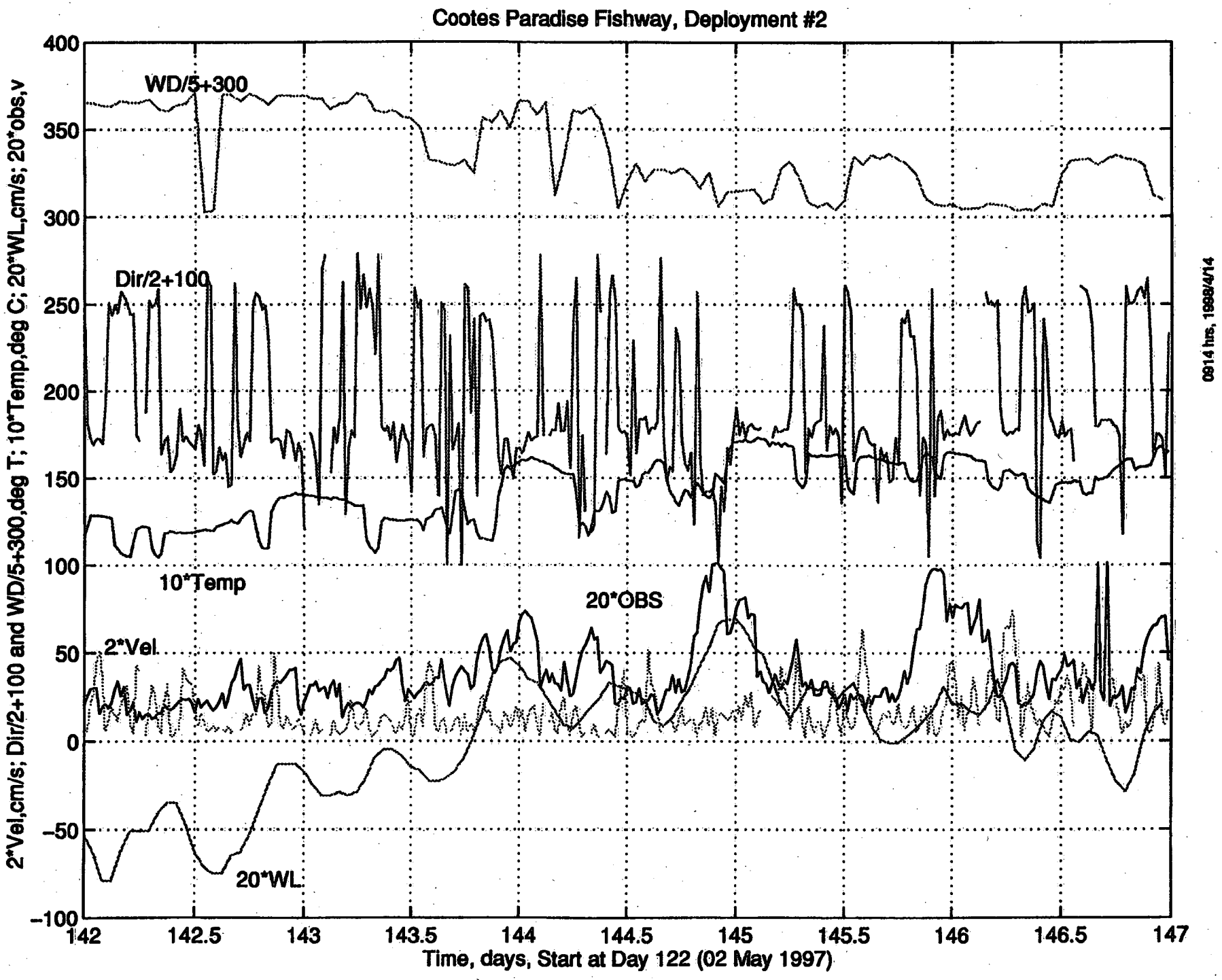

Cootes Paradise Fishway, Deployment #1
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s;
400
350
300
250
200
150
100
50
0
-50
113
113.5
114
114.5
115
115.5
116
116.5
117
117.5
118
Time, days, Start at Day 108 (08 April 1997)
0908 hrs, 1998/4/14

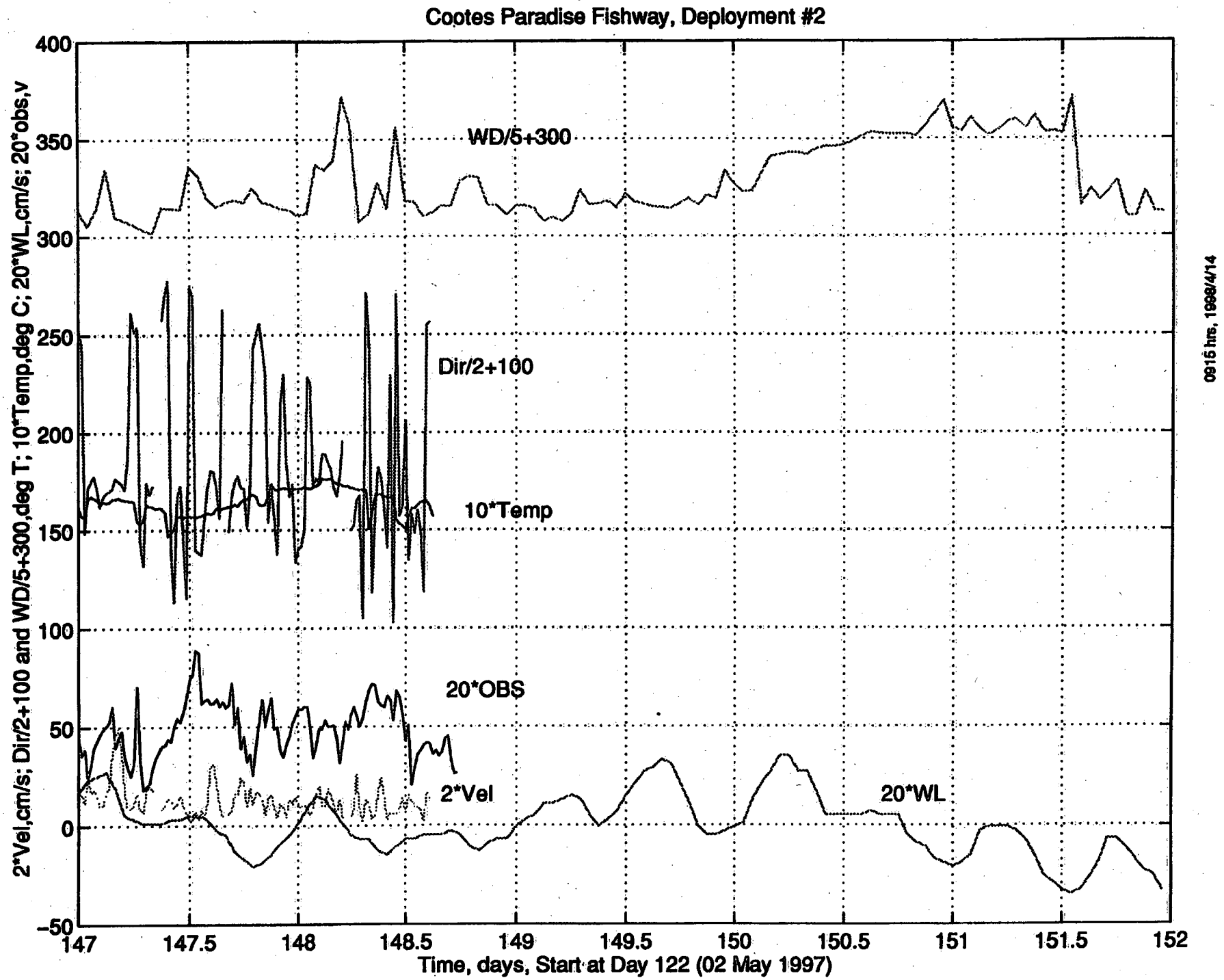

Cootes Paradise Fishway, Deployment #2
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
400
300
200
100
0
-100
-200
-300
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*WL
20*OBS
122
122.5
123
123.5
124
124.5
125
125.5
126
126.5
127
Time, days, Start at Day 122 (02 May 1997)
0910 hrs, 1998/4/14

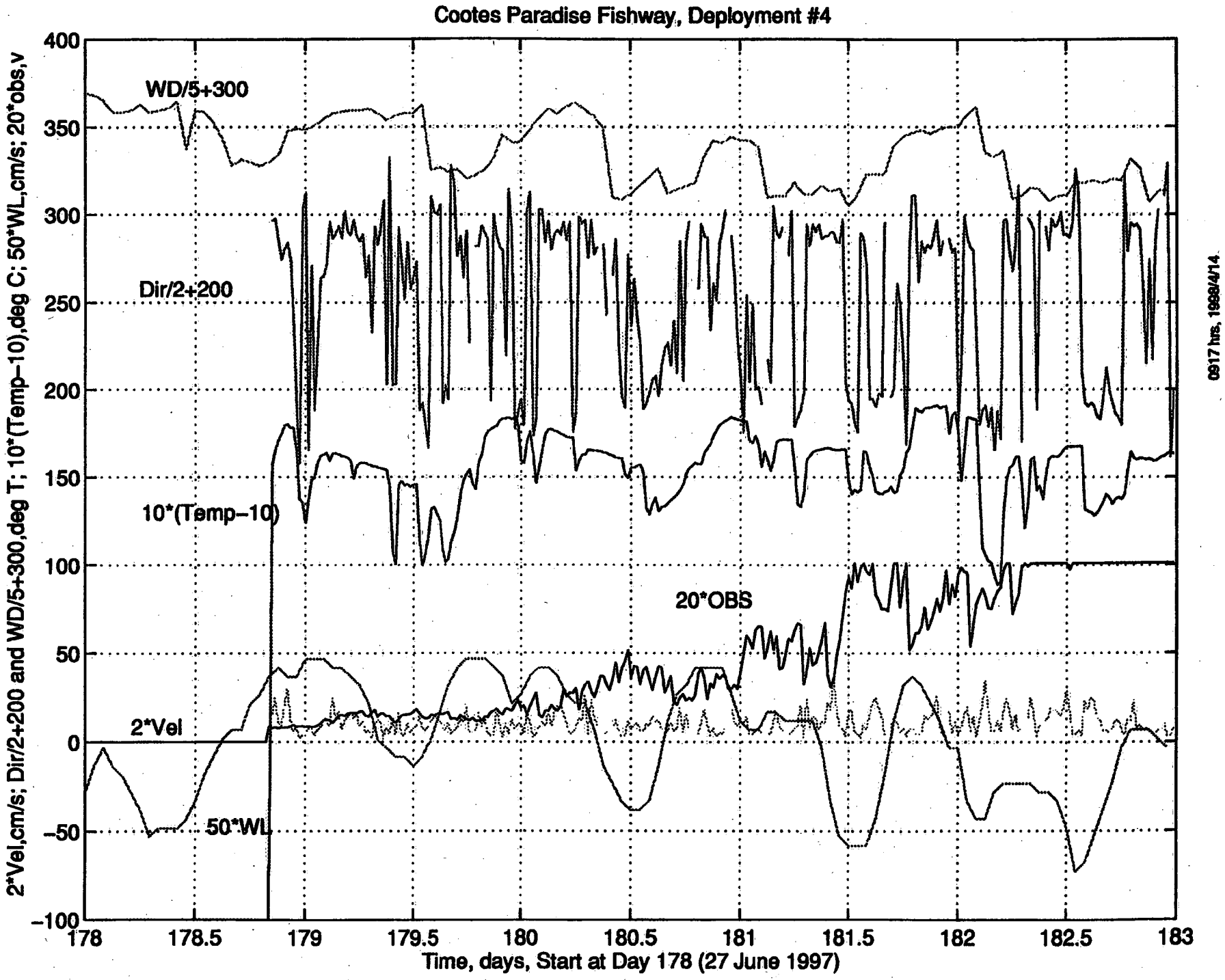

Cootes Paradise Fishway, Deployment #2
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*OBS
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
-100
127
127.5
128
128.5
129
129.5
130
130.5
131
131.5
132
Time, days, Start at Day 122 (02 May 1997)
0913 hrs, 1998/4/14

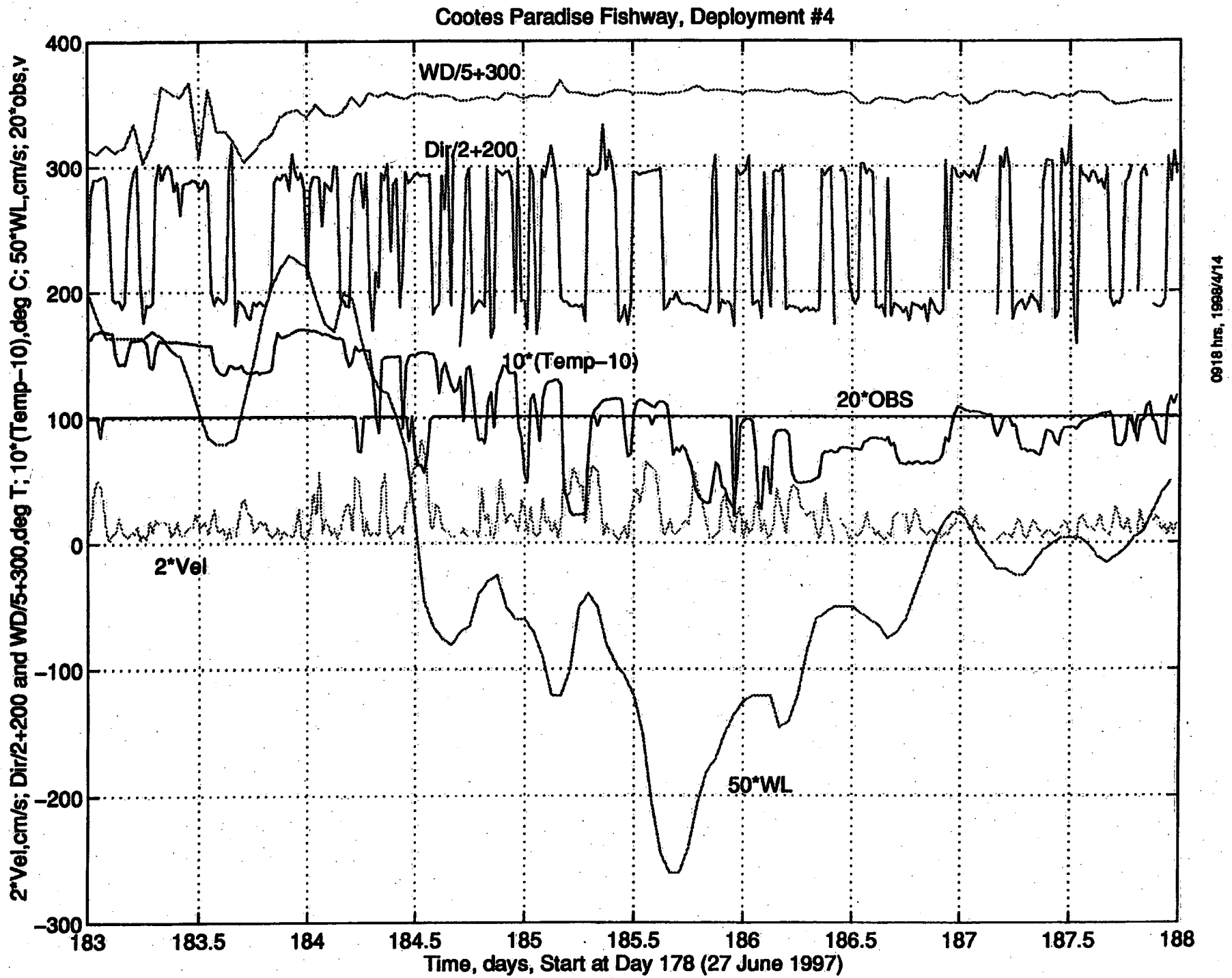

Cootes Paradise Fishway, Deployment #2
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*OBS
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
Time, days, Start at Day 122 (02 May 1997)
400
350
300
250
200
150
100
50
0
-50
-100
132
132.5
133
133.5
134
134.5
135
135.5
136
136.5
137
0913 hrs, 1998/4/14

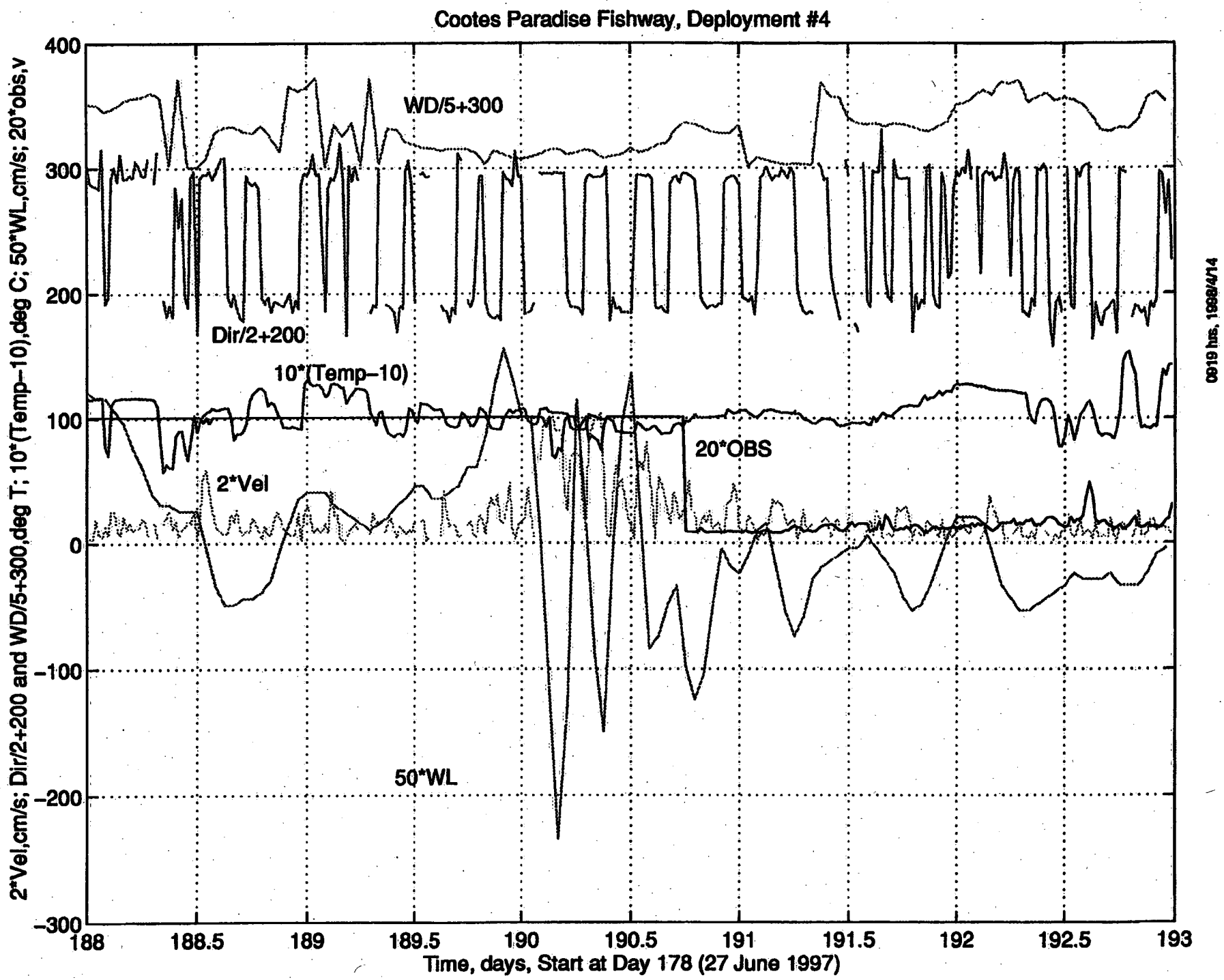

Cootes Paradise Fishway, Deployment #2
WD/5+300
Dir/2+100
10*Temp
2*Vel
20*OBS
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
-100
137
137.5
138
138.5
139
139.5
140
140.5
141
141.5
142
Time, days, Start at Day 122 (02 May 1997)
0914 hrs, 1998/4/14

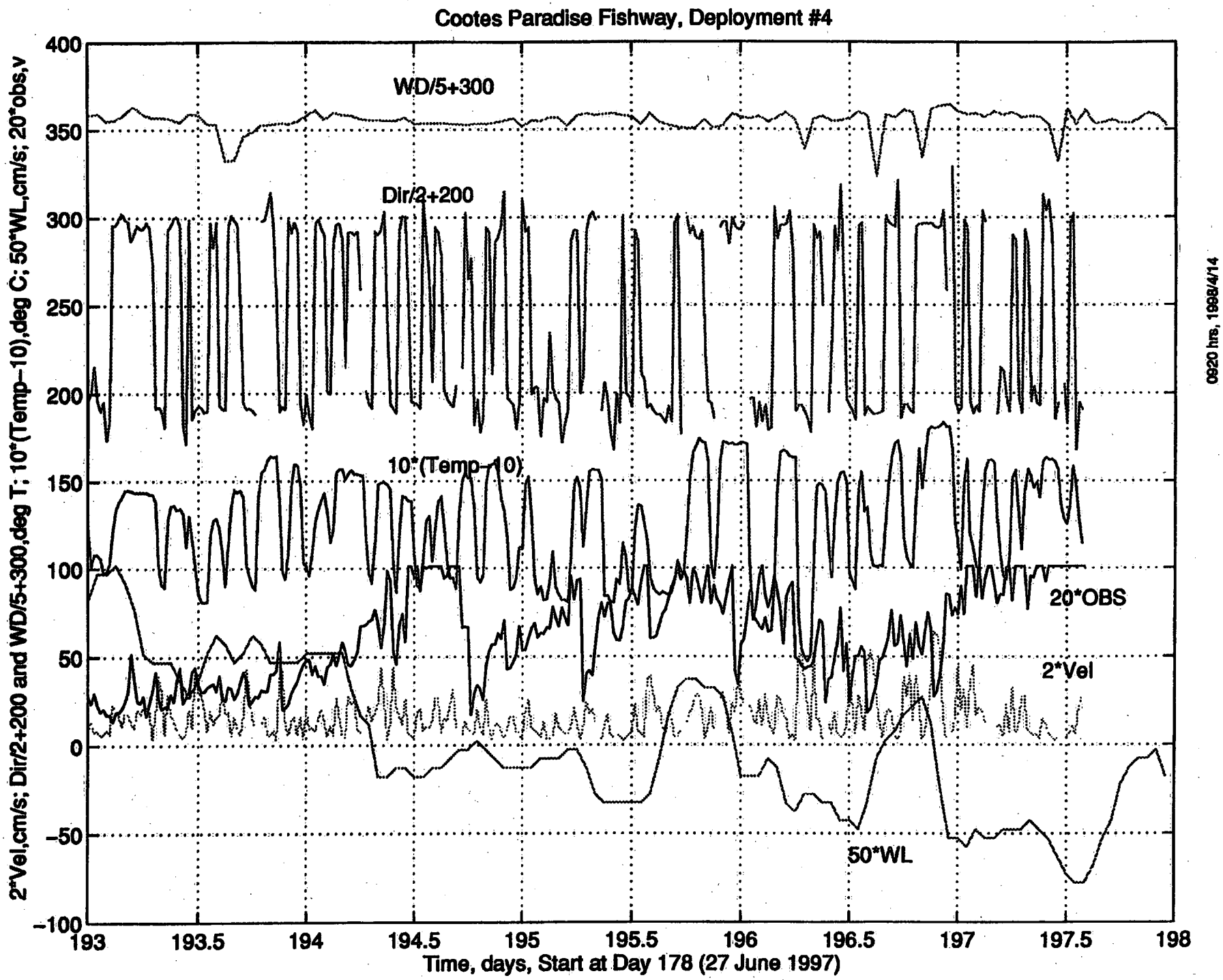

Cootes Paradise Fishway, Deployment #2
WD/5+300
Dir/2+100
10*Temp
20*OBS
2*Vel
20*WL
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
-100
142
142.5
143
143.5
144
144.5
145
145.5
146
146.5
147
Time, days, Start at Day 122 (02 May 1997)
0914 hrs, 1998/4/14

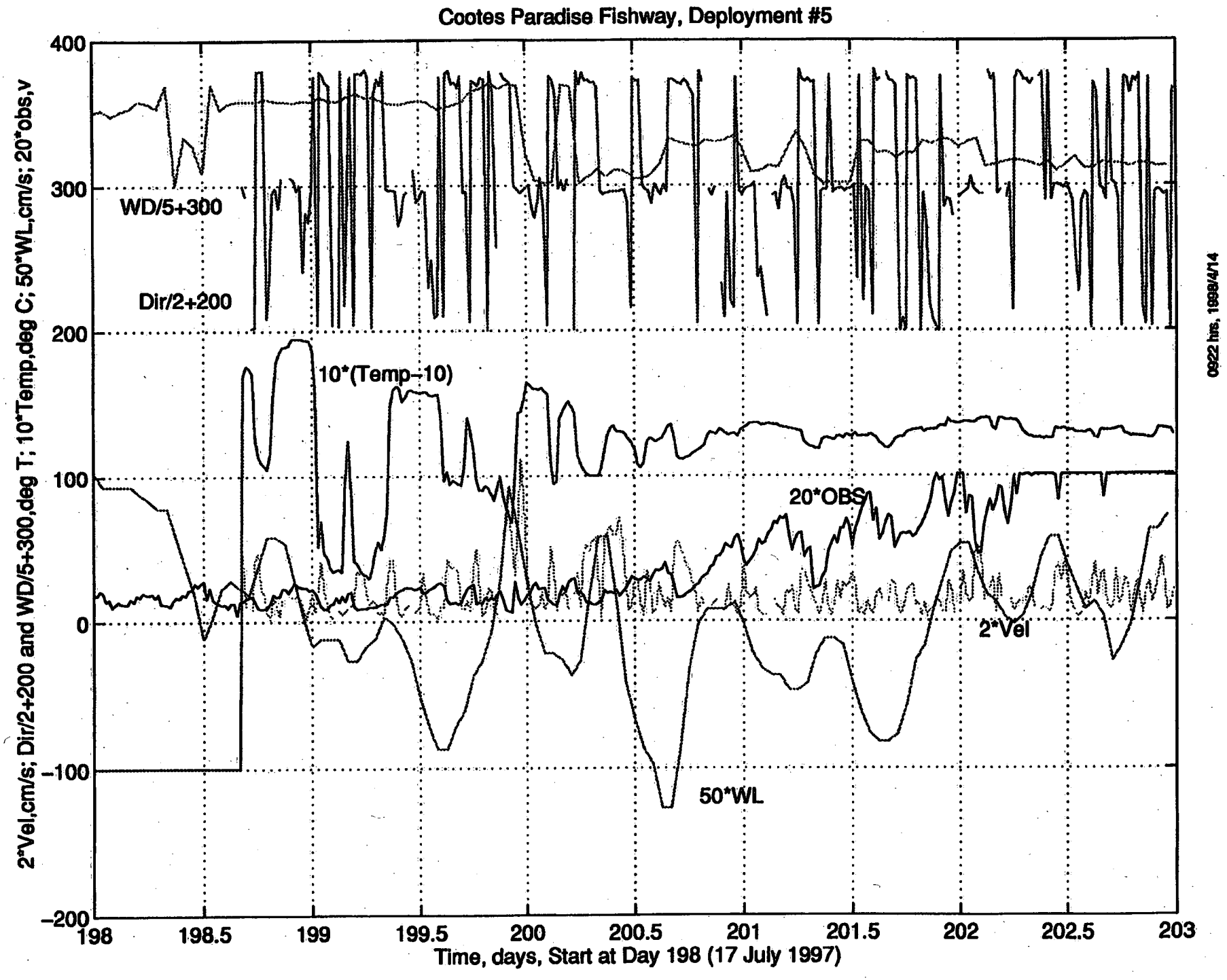

Cootes Paradise Fishway, Deployment #2
2*Vel,cm/s; Dir/2+100 and WD/5+300,deg T; 10*Temp,deg C; 20*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
147
147.5
148
148.5
149
149.5
150
150.5
151
151.5
152
Time, days, Start at Day 122 (02 May 1997)
WD/5+300
Dir/2+100
10*Temp
20*OBS
2*Vel
20*WL
0915 hrs, 1998/4/14

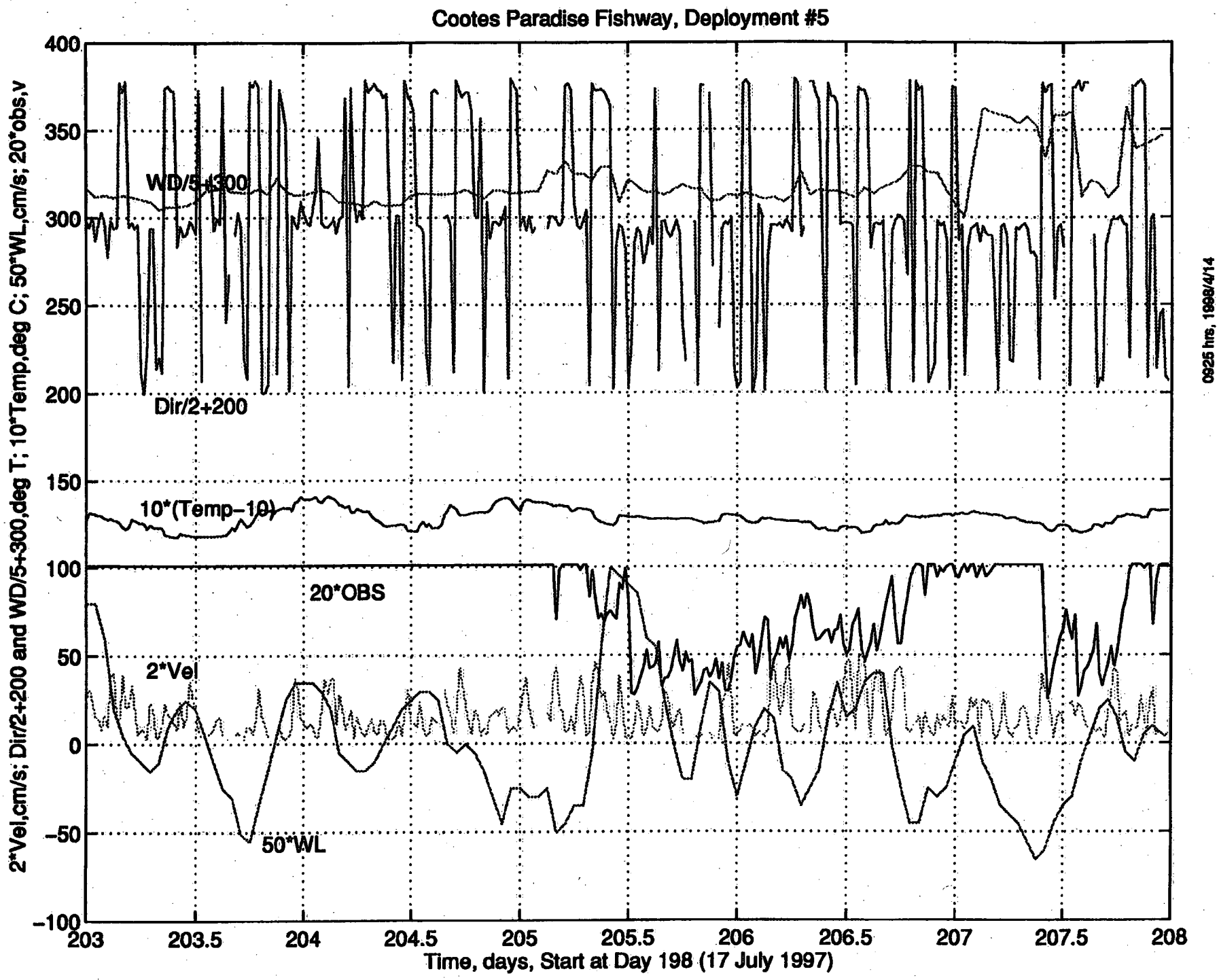

Cootes Paradise Fishway, Deployment #4
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp−10),deg C; 50*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
−50
−100
178
178.5
179
179.5
180
180.5
181
181.5
182
182.5
183
Time, days, Start at Day 178 (27 June 1997)
0917 hrs, 1998/4/14

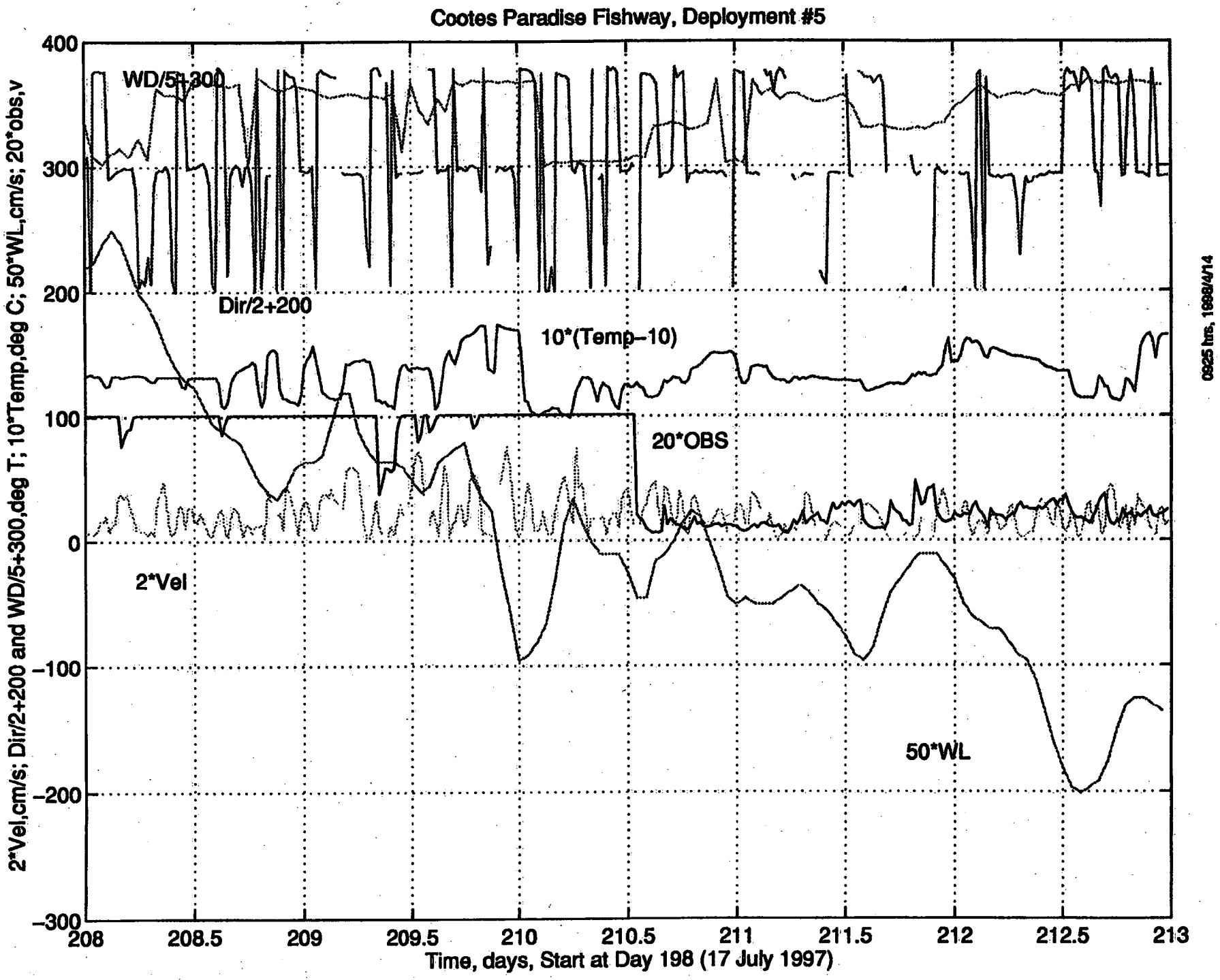

Cootes Paradise Fishway, Deployment #4
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp−10),deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
−300
183
183.5
184
184.5
185
185.5
186
186.5
187
187.5
188
Time, days, Start at Day 178 (27 June 1997)
0918 hrs, 1998/4/14

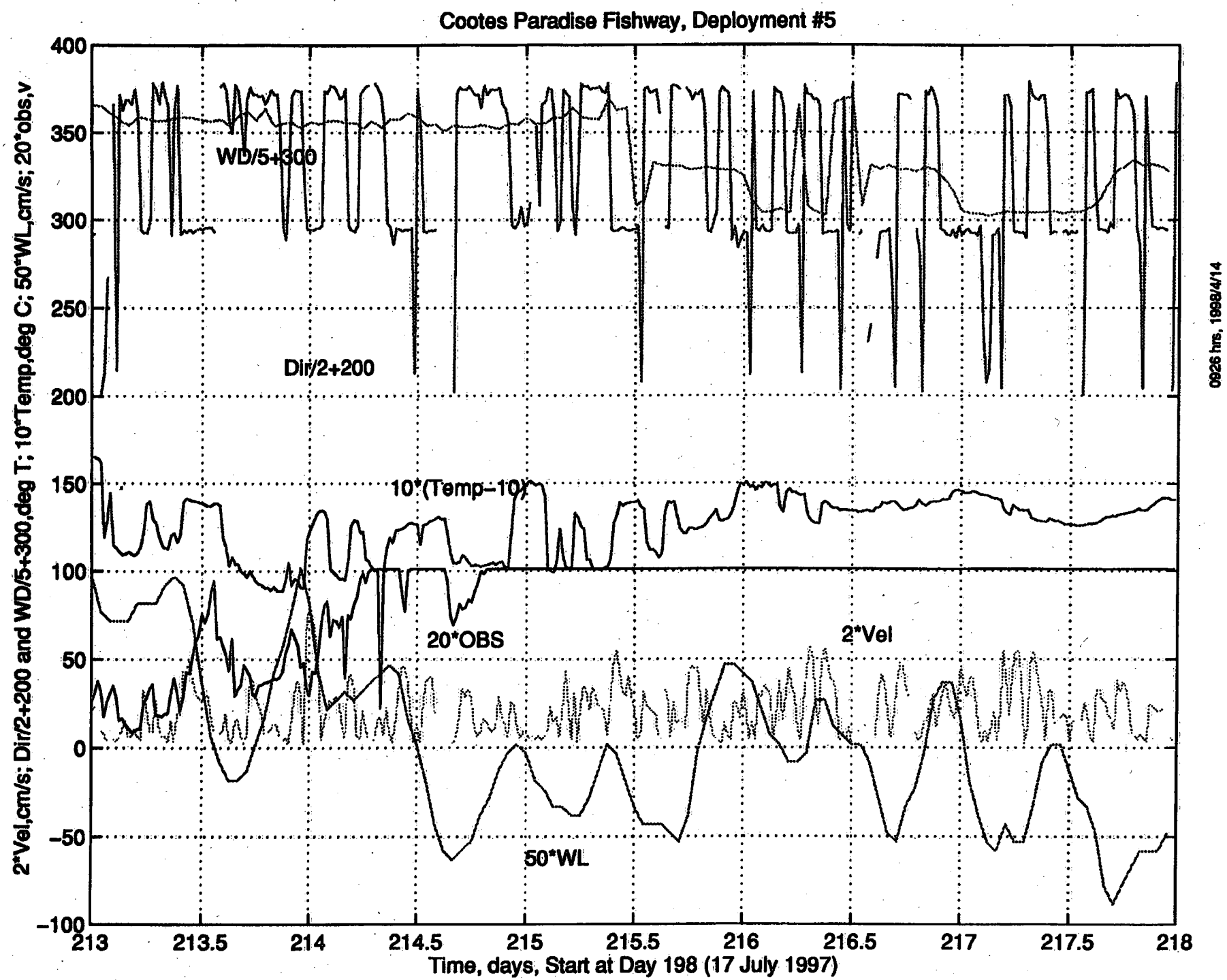

Cootes Paradise Fishway, Deployment #4
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp−10),deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
−300
188
188.5
189
189.5
190
190.5
191
191.5
192
192.5
193
Time, days, Start at Day 178 (27 June 1997)
0919 hrs, 1998/4/14

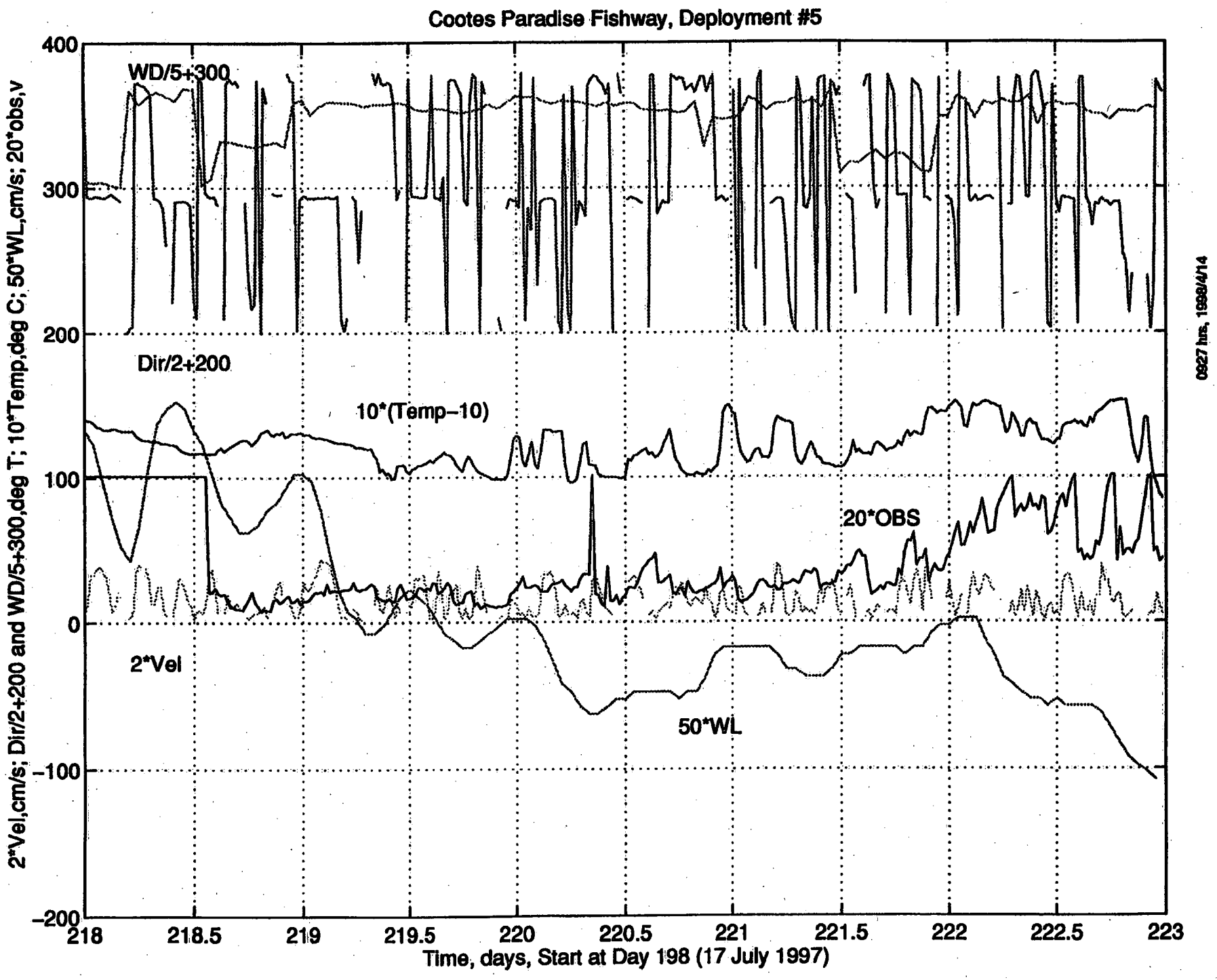

Cootes Paradise Fishway, Deployment #4
WD/5+300
Dir/2+200
10*(Temp-10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp-10),deg C; 50*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
-100
193
193.5
194
194.5
195
195.5
196
196.5
197
197.5
198
Time, days, Start at Day 178 (27 June 1997)
0920 hrs, 1998/4/14

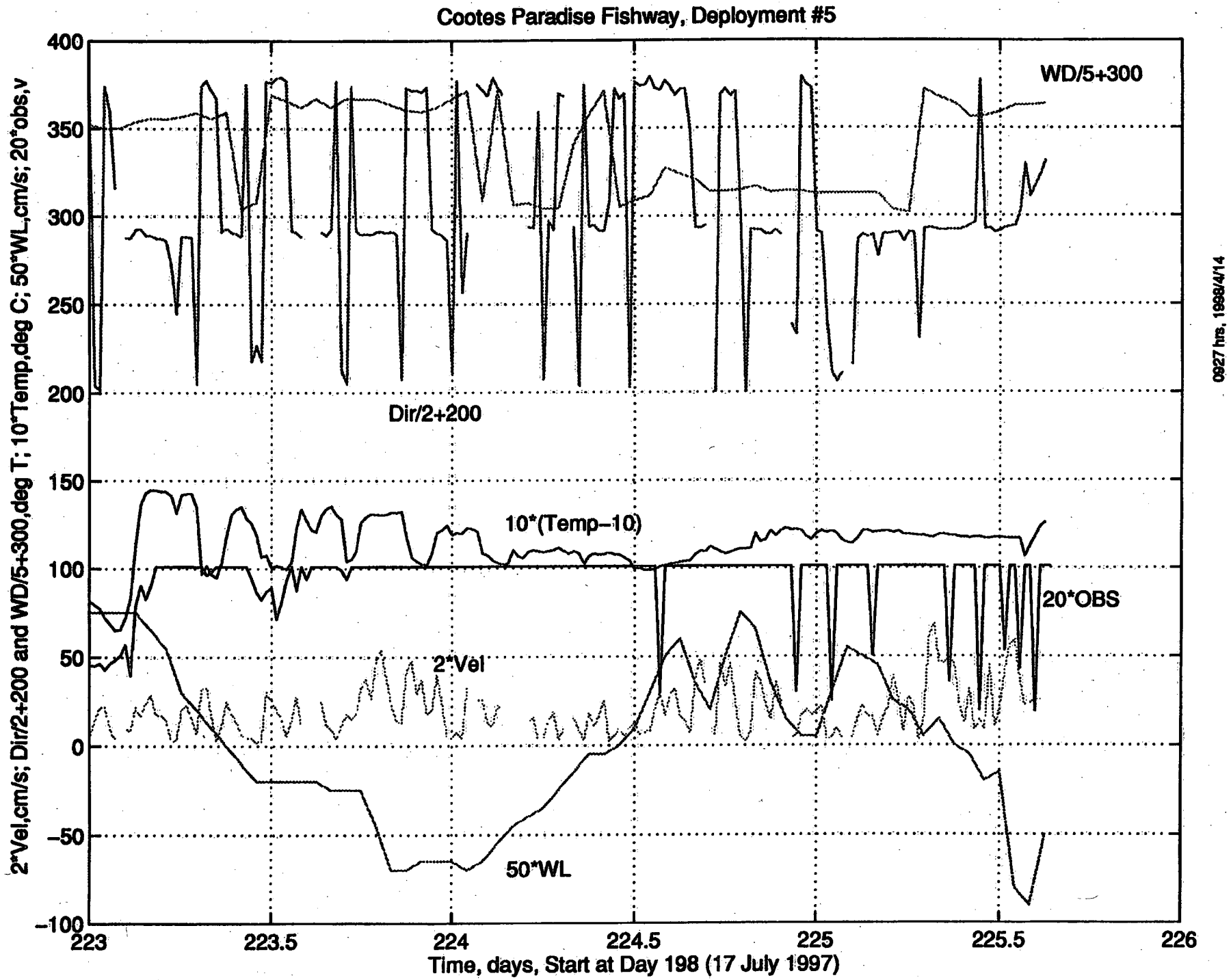

Cootes Paradise Fishway, Deployment #5
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
-100
-200
WD/5+300
Dir/2+200
10*(Temp-10)
20*OBS
2*Vel
50*WL
198
198.5
199
199.5
200
200.5
201
201.5
202
202.5
203
Time, days, Start at Day 198 (17 July 1997)
0922 hrs, 1998/4/14

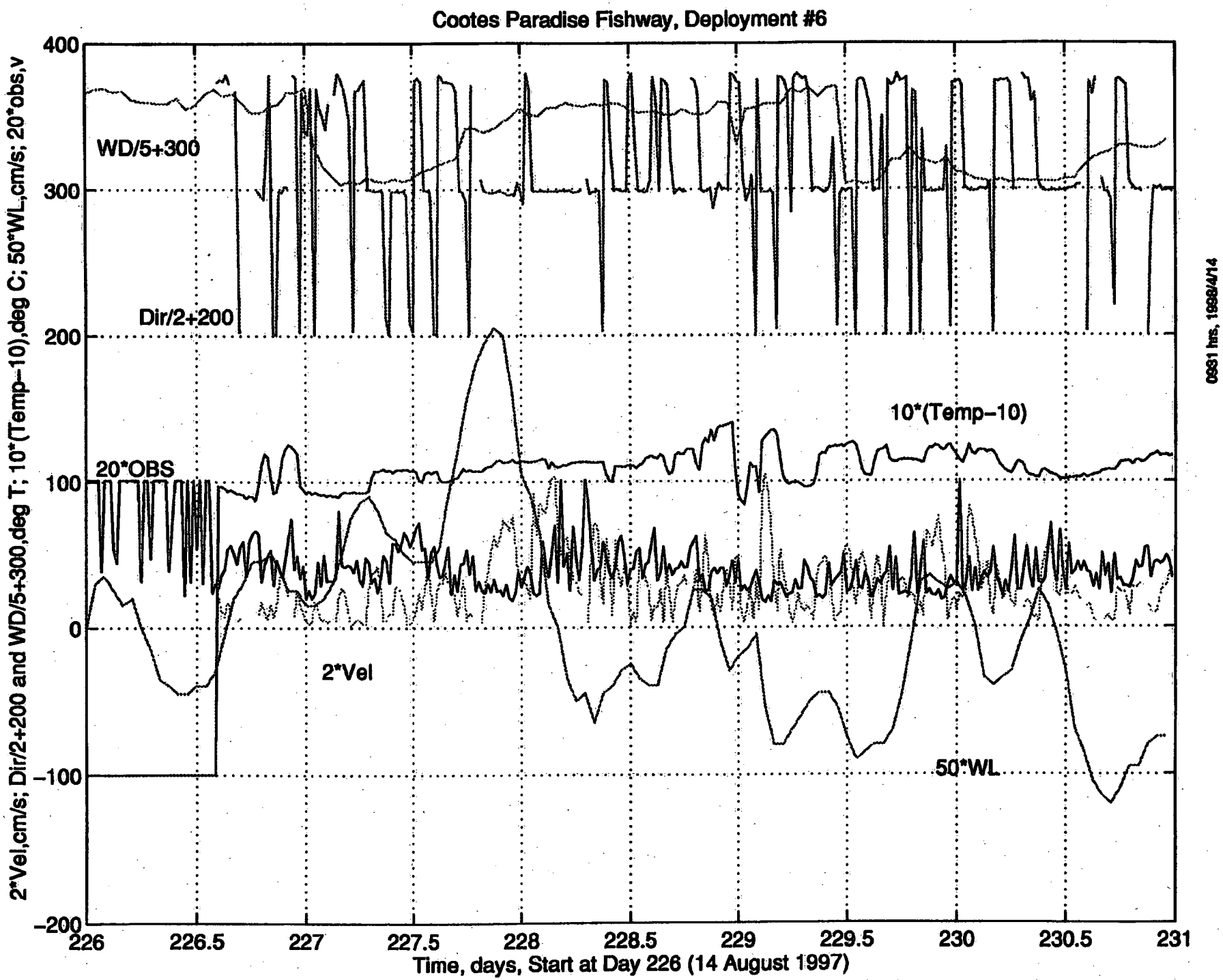

Cootes Paradise Fishway, Deployment #5
WD/5+300
Dir/2+200
10*(Temp-10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
Time, days, Start at Day 198 (17 July 1997)
400
350
300
250
200
150
100
50
0
-50
-100
203
203.5
204
204.5
205
205.5
206
206.5
207
207.5
208
0925 hrs, 1998/4/14

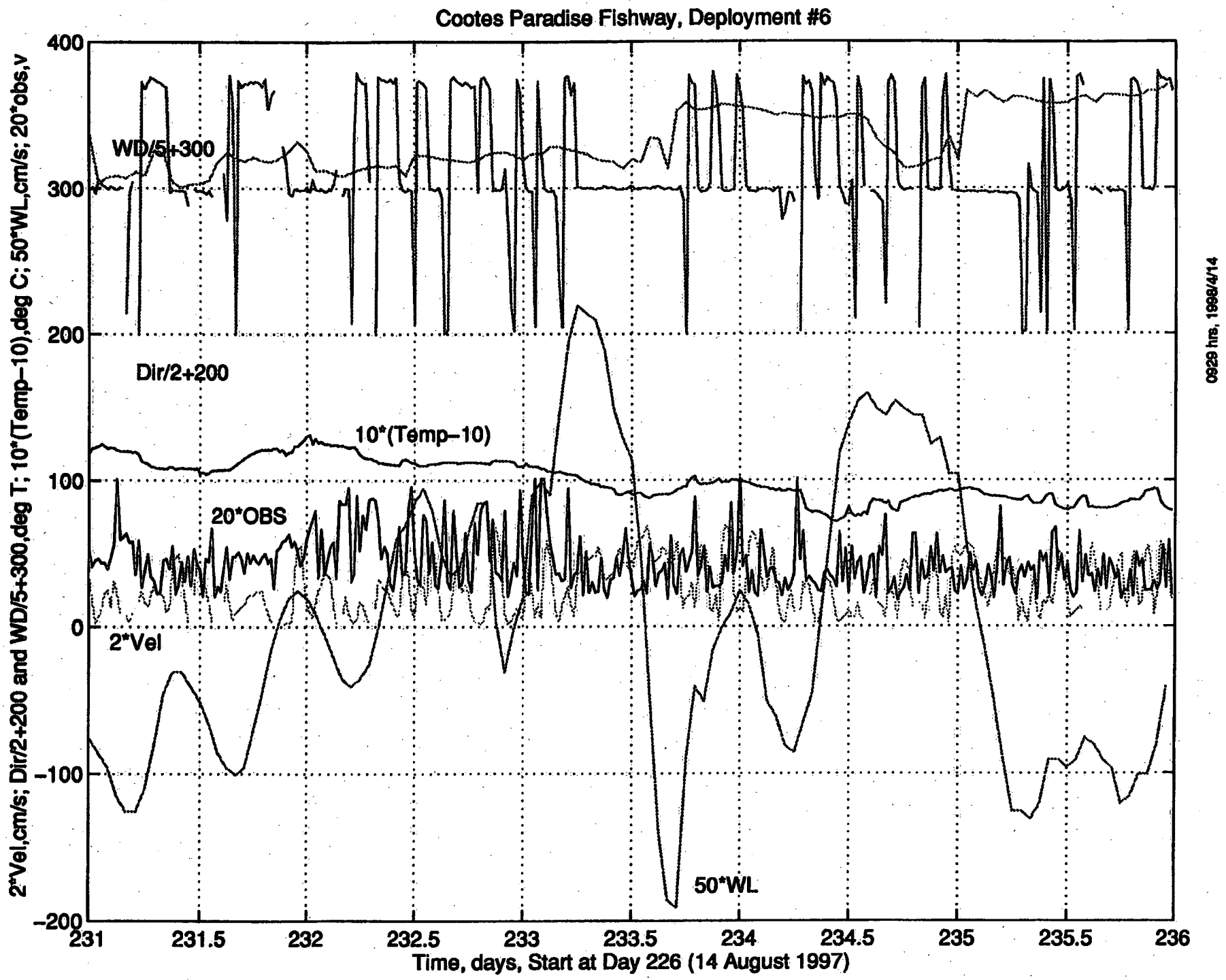

Cootes Paradise Fishway, Deployment #5
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
−300
208
208.5
209
209.5
210
210.5
211
211.5
212
212.5
213
Time, days, Start at Day 198 (17 July 1997)
0925 hrs, 1998/4/14


Cootes Paradise Fishway, Deployment #5
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
-50
-100
WD/5+300
Dir/2+200
10*(Temp-10)
20*OBS
2*Vel
50*WL
213
213.5
214
214.5
215
215.5
216
216.5
217
217.5
218
Time, days, Start at Day 198 (17 July 1997)
0926 hrs, 1998/4/14


Cootes Paradise Fishway, Deployment #5
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
218
218.5
219
219.5
220
220.5
221
221.5
222
222.5
223
Time, days, Start at Day 198 (17 July 1997)
0927 hrs, 1998/4/14


Cootes Paradise Fishway, Deployment #5
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*Temp,deg C; 50*WL,cm/s; 20*obs,v
400
350
300
250
200
150
100
50
0
−50
−100
223
223.5
224
224.5
225
225.5
226
Time, days, Start at Day 198 (17 July 1997)
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
0927 hrs, 1998/4/14


Cootes Paradise Fishway, Deployment #6
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp−10),deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
226
226.5
227
227.5
228
228.5
229
229.5
230
230.5
231
Time, days, Start at Day 226 (14 August 1997)
0931 hrs, 1998/4/14


Cootes Paradise Fishway, Deployment #6
2*Vel,cm/s; Dir/2+200 and WD/5+300,deg T; 10*(Temp−10),deg C; 50*WL,cm/s; 20*obs,v
400
300
200
100
0
−100
−200
WD/5+300
Dir/2+200
10*(Temp−10)
20*OBS
2*Vel
50*WL
231
231.5
232
232.5
233
233.5
234
234.5
235
235.5
236
Time, days, Start at Day 226 (14 August 1997)
0929 hrs, 1998/4/14

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