

Current and Sea-Level Measurements in the Northwest Passage
Volume 3, March 1984 - April 1985.

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Les établissements des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports depuis décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du Rapport n° 1 en janvier 1982.

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CURRENT AND SEA-LEVEL MEASUREMENTS IN THE NORTHWEST PASSAGE
VOLUME 3, MARCH 1984 - APRIL 1985.

by

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ABSTRACT

Buckingham, W.R., R.A. Lake, and H. Melling, 1987. Current and Sea-Level Measurements in the Northwest Passage. Vol. 3, March 1984 - April 1985. Can. Data Rep. Hydrogr. Ocean Sci. No. 51:139pp.

A three-year program of current and sea-level measurements was undertaken between March 1982 and April 1985 in the Canadian Arctic Archipelago by the Institute of Ocean Sciences of the Department of Fisheries and Oceans. The measurements were in the form of time series, at fixed depths by self-recording instrument packages, of temperature, salinity, current speed, current direction and water pressure at the sea-floor pressure. The activities during each year of the study concentrated on a specific region of the Northwest Passage within the Archipelago. The emphasis in 1982 was on the western portion (M'Clure Strait, Prince of Wales Strait, and Viscount Melville Sound), in 1983 on the central portion (eastern Viscount Melville Sound and Barrow Strait), and in 1984 on the eastern portion (Barrow Strait and adjacent channels). This report discusses the aims of the project, the logistics of the 1984 field work, and summarizes the data acquired during that year in tabular and graphic form.

key words: Arctic Archipelago, Northwest Passage, temperature, salinity, current, tide.

RESUME

Buckingham, W.R., R.A. Lake, and H. Melling, 1987. Current and Sea-Level Measurements in the Northwest Passage, Vol. 3, March 1982 - April 1983. Can. Data Rep. Hydrogr. Ocean Sci. No. 51:139pp.

De mars 1982 à avril 1985, l'Institut des Sciences de la Mer du MPO a réalisé un programme triennal de mesures du niveau de la mer et des courants dans l'archipel arctique canadien. Ces mesures ont été prises sous forme de séries chronologiques, à des profondeurs déterminées, par des groupes d'instruments automatisés, de la température, de la salinité, de la vitesse et direction de courant et de la pression de leau au fond de la mer. Les activités annuelles ont porté sur une région déterminée du passage du Nord-Ouest de l'archipel. En 1982, l'accent a été mis sur la partie ouest (détroit de M'Clure, détroit de Prince-de-Galles, et détroit du Vicomte-Melville), sur la partie centrale en 1983 (parti est du détroit du Vicomte-Melville et détroit de Barrow), et en 1984, sur la partie est (détroit de Barrow et chenaux adjacents). Le présent rapport porte sur les buts du projet, le soutien logistique du travail sur le terrain en 1984 et résume les données recueillies cette année-là, qui sont présentées sous forme de tableaux et de graphiques.

Mots-clés: archipel arctique, passage du Nord-Ouest, température, salinité, courant, marée.

ACKNOWLEDGEMENTS

The authors wish to thank various members of the Institute of Ocean Sciences whose diligent efforts helped to make this project a success. In particular we thank electronics technician R.A. Cooke, support technician S. W. Moorhouse, and J.W. Green from the computing section. Logistic support, and accommodation at Resolute Bay was provided by the Polar Continental Shelf Project of the Department of Energy, Mines and Resources. Meals, radio and accommodations were also made available at Rae Point by Panarctic Oils, Ltd. We sincerely thank both organizations, and the particular individuals involved, for their cooperation and assistance. The considerable effort involved in the recovery in 1985 of year-long moorings in Penny Strait and Barrow Strait was provided by E.L. Lewis, R.G. Perkin, A.W. Koppel and G.A. Moonie of this Institute. This effort is gratefully acknowledged.

The funding for this project was provided by the Marine Transportation Research and Development Programme.

1. INTRODUCTION

A three-year physical-oceanographic study was undertaken between 1982 and 1985 in the Canadian Arctic Archipelago, centering on the complex of waterways known as the Northwest Passage. The study was carried out by the Department of Fisheries and Oceans at the Institute of Ocean Sciences (IOS). It extended from Amundsen Gulf in the west, through Prince of Wales Strait, M'Clure Strait, Viscount Melville Sound, Barrow Strait, and Lancaster Sound to Baffin Bay in the east (see Figure 1). The study also included the various passageways and basins bordering the Northwest Passage. The overall objective included the following goals:

- 1) the identification of the magnitude and direction of tidal and non-tidal currents,
- 2) the description of tidal propagation,
- 3) the identification of sources and destinations of various water-masses,
- 4) the identification of the relative importance of physical forces which determine currents and water-mass distribution (e.g. tidal forces, baroclinic forces related to horizontally inhomogeneous distribution of water density and non-tidal barotropic forces related to oceanic and atmospheric circulation),
- 5) the identification of temporal and spatial variability in current and water-mass distribution. Periods of particular importance are tidal (semi-diurnal and diurnal), seasonal, and interannual. Also of potential importance are singular or non-periodic events such as storm surges,
- 6) the estimation, to an order of magnitude, of the volume of water transport into and out of the study area and the partition of that transport.

The activities during each year of the study concentrated on a specific region of the Northwest Passage. The emphasis in 1984 was on the central portion. The field operations were undertaken during the early spring months, at which time the solid ice-cover made a stable platform from which to work.

This report describes the acquisition of water-current and sea-level information in 1984/85 as time series of current, temperature, salinity and sea-floor pressure and presents the data in final processed form. The main study area comprised the Barrow Strait and adjoining channels. The relevant mooring locations are indicated by square symbols and triple parallel lines (indicating transects) in Figure 2. The tide gauges are indicated by circular symbols. Tide gauges operated by other agencies are shown as diamond symbols. Data reports covering the activities during 1982 and 1983 may be found in Volumes 1 and 2 of this report series.

A related oceanographic investigation undertaken concurrently by the Institute of Ocean Sciences on the western periphery of the Arctic Archipelago was termed the Arctic Shelf Programme. The time series from this study are not included in this report. The mooring stations for the Arctic Shelf Programme are denoted in Figure 2 by star symbols. Relevant ocean measurements were acquired concurrently by the Canadian Hydrographic Service in the Gulf of Boothia (CHS-Central: seafloor pressures). The Canadian Hydrographic Service maintains tide stations at Cape Parry and Resolute Bay, and in 1984/85 maintained stations at Mould Bay, Isachsen and Auldhild Bay.

The study area has not previously been extensively investigated due to its remoteness and to the difficulty of ship operations. The sea surface is



Figure 1. A map of the Canadian Arctic Archipelago. The Northwest Passage shipping route will likely be through Lancaster Sound, Barrow Strait, Viscount Melville Sound, and Prince of Wales Strait.

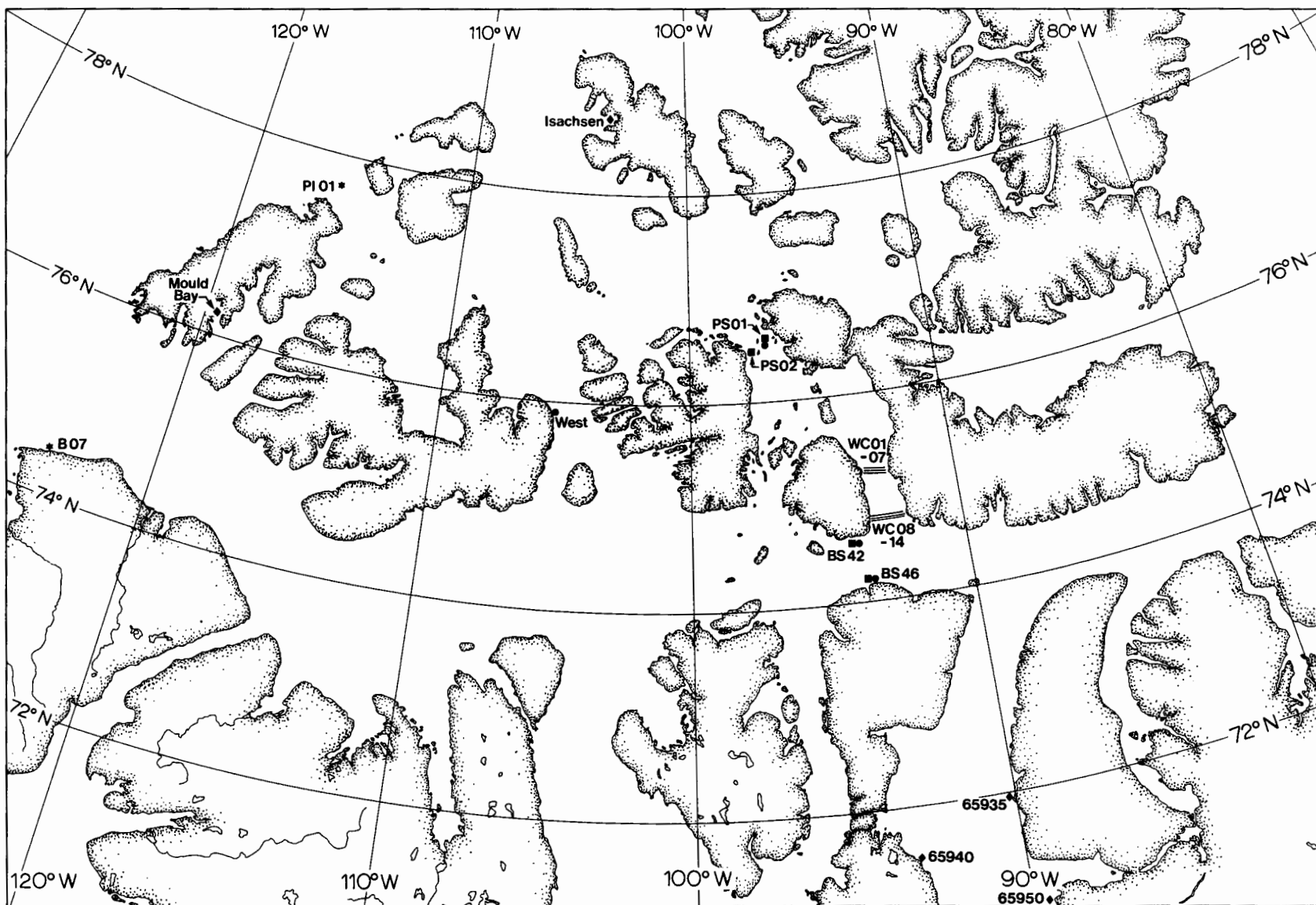


Figure 2. Location of recording instrumentation moorings throughout the Arctic Archipelago in 1984 (square and triple lines - current meters; dots - tide gauges; stars and diamonds - current meter and tide gauges from concurrent studies by other agencies).

completely frozen during most of the year, and is often ice-choked during the short navigation period. Previous oceanographic research in the Arctic Archipelago has been tabulated by Fissel, Knight and Birch (1984). The earliest significant collection of oceanographic data was accomplished from ships in summer during the 1950's and 1960's. These data were sufficient to delineate the regional water-mass characteristics. In 1976 and 1977, direct current measurements were made in Byam and Austin Channels and Crozier and Pullen Straits by the Institute of Ocean Sciences. In 1977 and 1978 investigators from the Physical Oceanographic Group of the Canada Centre for Inland Waters completed a number of current meter transects across Viscount Melville Sound, Prince of Wales Strait, and adjacent channels (Peck, 1978 and Prinsenberg, 1978). Current data across the western end of Viscount Melville Sound were gathered in 1979 as part of the Polargas Project (1979). A number of tidal height measurements were made during 1979 and 1980 as part of the Bridport Inlet studies by IOS. The Canadian Hydrographic Service made extensive tidal height measurements in 1977, and an additional tidal height record was obtained as a part of the Polargas program in 1979.

The present study involved measurements by CTD probe, recording current meters, tide gauges, and meteorological stations. This report deals with the recording instrument measurements. Section 2 describes the physical setting and bathymetry of the study area and the mooring locations during 1984/1985. Section 3 recounts the logistics, equipment used, and the timing of the measurements, while Section 4 deals with the data processing procedures. The data are presented as time-series plots in the Appendix.

2. PHYSICAL SETTING AND STATION LOCATIONS

2.1 Arctic Archipelago

The Canadian Arctic Archipelago consists of a large group of islands lying on the extensive polar continental shelf of North America (Figure 1). The Archipelago extends roughly 1500 kilometers between the 68° and 82° North latitude and about 2700 kilometers between 60° and 130° West longitude (at 70° North). These islands are bounded to the north and west by the Arctic Ocean and the Beaufort Sea respectively, to the south by the mainland of the North American continent and to the east and southeast by Nares Strait, Baffin Bay, Davis Strait, and Labrador Sea. For convenience, the Archipelago is often divided into three sections from north to south as follows: the Sverdrup Basin lying within the Queen Elizabeth islands (i.e., all islands north of Parry Channel); Parry Channel, consisting of M'Clure Strait, Viscount Melville Sound, Barrow Strait, and Lancaster Sound; and the "Southern Channels" comprising Amundsen Gulf, M'Clintock Channel, the Gulf of Boothia, and other, lesser waterways.

2.2 General Bathymetry

The channels and basins throughout the Archipelago are in general substantially shallower than the major adjoining oceanic basins. The continental shelf effectively limits free passage of water to maximum depths of about 450 meters into Sverdrup Basin, to about 380 metres into M'Clure Strait, and to about 360 meters into Amundsen Gulf. To the east, Baffin Bay has depths up to 2300 meters, but the sill in Davis Strait (to the south of Baffin Bay) limits deep water exchange with the North Atlantic to depths of less than 700 meters. Another shallow entrance (50 meters) to the Archipelago from the

North Atlantic exists through Hudson Strait, Foxe Basin, and Fury and Hecla Strait in the south. The deepest continuous passage through the Archipelago exists through Parry Channel and has a limiting sill of 125 meters in Barrow Strait. The passageways connecting Sverdrup Basin to the southern channels (M'Clure Strait, Viscount Melville Sound, Barrow Strait, etc.) are in general constricted by shallow sills on the order of 100 meters in depth. South of Parry Channel depths are characteristically shallow (mostly less than 200 meters) with the exception of some deeper areas of greater than 400 meters extending into Prince Regent Inlet from Lancaster Sound.

2.3 Mooring Locations and Local Bathymetry

The Northwest Passage field study in 1984 was concentrated on the region of the central sills of the Arctic Archipelago. The study area was bounded on the north by Penny Strait, on the east by the 91° West meridian in eastern Barrow Strait, on the south by Somerset Island, the northern end of Peel Sound and Prince of Wales Island, and on the west by the 106° West meridian in western Barrow Strait. Due to the large size of the area studied (about 50,000 square kilometres) currents were not measured systematically over the area. Only 2 transects were instrumented (in Wellington Channel) for the measurement of near-surface currents, and on these an attempt was made to achieve mooring spacing comparable to internal deformational, and topographic scales of variability. In anticipation of shoreline "hugging" baroclinic flows, meters were more closely spaced near shores (see Figure 2). As a result of confidence gained in the two preceding years of the project, four moorings were deployed for a 12-month period to measure seasonal variations in flow, and the vertical structure of current. Two were deployed in Barrow Strait, and two in Penny Strait. Recording pressure gauges were placed in the anchor buckets of 3 of these moorings. Two additional pressure gauges were deployed for a shorter period near the western shores of Byam Martin and Wellington Channels.

Concurrent measurements of current and seafloor pressure were acquired by the Canadian Hydrographic Service in the Gulf of Boothia. Farther afield the Canadian Hydrographic Service made sea-floor water pressure measurements at Mould Bay, Isaachsen, Auldild Bay and Pond Inlet, in addition to continuing longterm measurements at Cape Parry, Alert and Resolute Bay. Current measurements in Ballantyne Strait and western M'Clure Strait were acquired over 12 months by DFO staff as part of the Arctic Shelf Programme (R.G. Perkin, personal communication.) These locations are plotted, where possible, in Figure 2.

Instrument location, depth, type, serial number, recovery success and observational period are tabulated for this program and for concurrent studies in Table 1.

The bathymetry of the channels in the vicinity of the instrument moorings is shown in Figures 3 and 4. Figure 3 shows the waters surrounding Cornwallis Island. The principal sill of the Northwest Passage lies southwest of Lowther island near 98° W, 74.4° N (125 m). Other significant sills are found at the northern and southern ends of Wellington Channel, and at the southern end of Penny Strait. Figure 4 shows the topography of the latter strait to be complex. Waters within and immediately to the south of the strait are quite deep (~300 m). Waters in the Peel Sound also exceed 200 m.

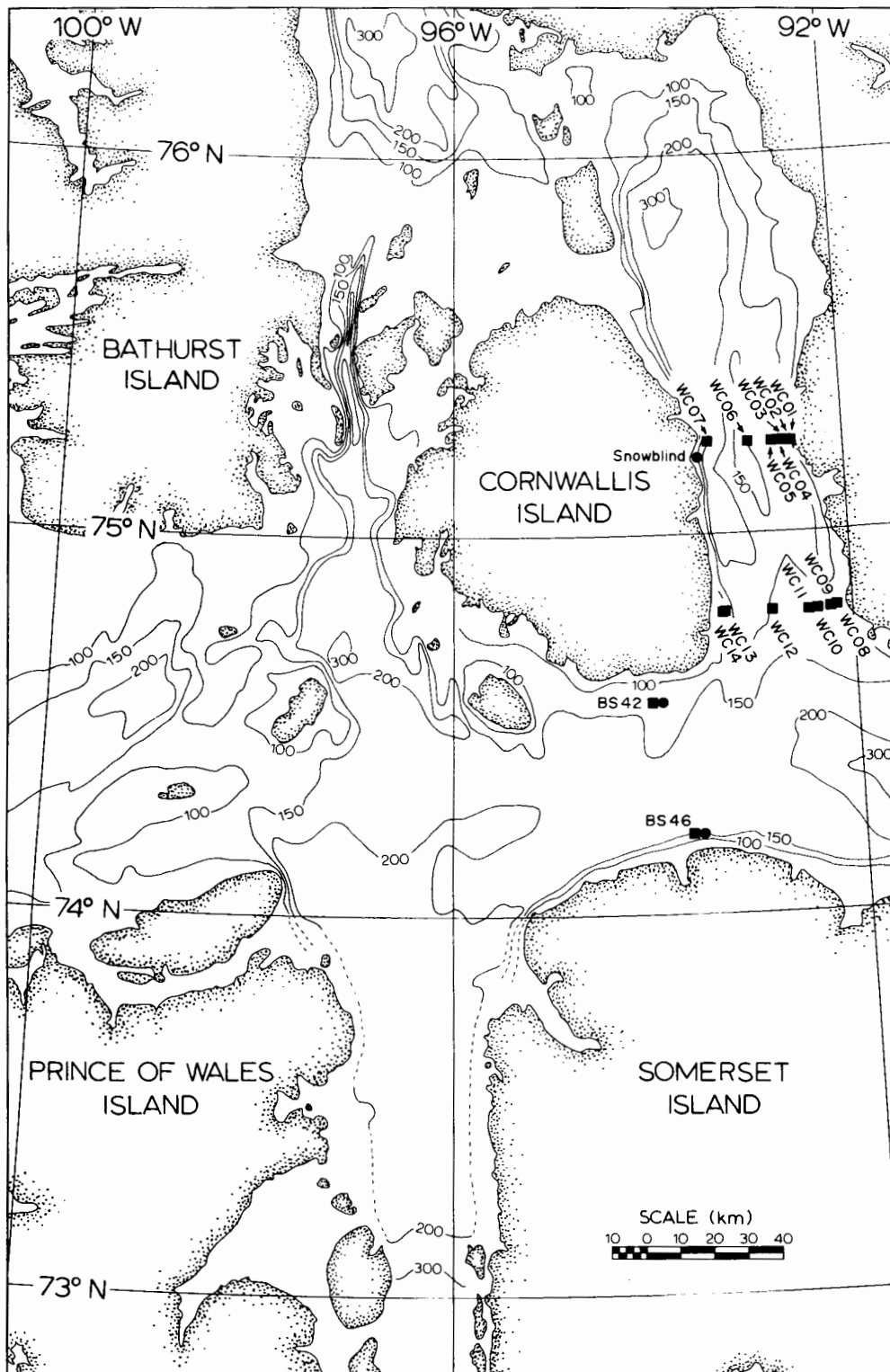


Figure 3. Bathymetry of the channels in the vicinity of Cornwallis Island (squares - current meters; dots - tide gauges).

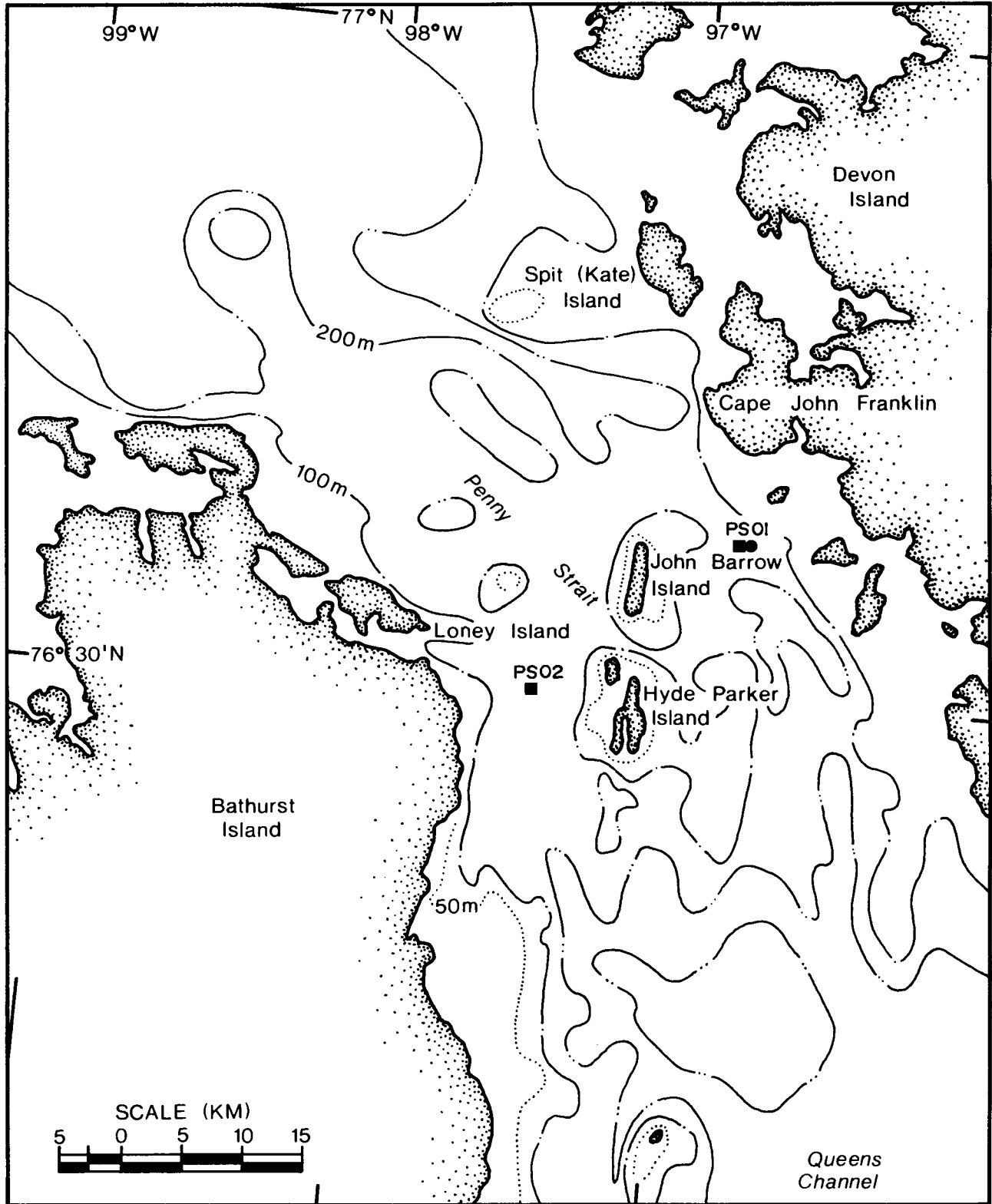


Figure 4. Bathymetry of Penny Strait (squares - current meters; dot - tide gauge).

In the following table, CCIW = Canada Centre for Inland Waters, T and C = Tides and Currents Section of Fisheries and Oceans, CHS = Canadian Hydrographic Service.

Table 1. Summary of Recording Instrument Records

Region	Site	S/N	Latitude	Longitude	Type	3 mos.	12 mos.	Depth (m)	Data Recovery/ Remarks
Wellington									
Channel	WC01	0801	75°13.3'	92°31.7'	RCM4	✓		18	✓
"	WC02	0972	75°14.1'	92°33.8'	RCM4	✓		18	✓ short record
"	WC03	1930	75°14.1'	92°35.4'	RCM4	✓		18	✓
"	WC04	1931	75°14.1'	92°40.0'	RCM4	✓		18	✓
"	WC05	2687	75°14.4'	92°44.4'	RCM4	✓		18	✓
"	WC06	2686	75°14.4'	92°59.6'	RCM4	✓		18	✓
"	WC07	3228	75°15.2'	93°22.8'	RCM4	✓		18	✓
"	WC08	3223	74°47.7'	92°09.2'	RCM4	✓		18	✓
"	WC09	1305	74°47.6'	92°12.7'	RCM4	✓		18	x instr. malf'n.
"	WC10	1932	74°47.5'	92°21.6'	RCM4	✓		18	✓
"	WC11	1939	74°47.8'	92°27.8'	RCM4	✓		18	✓
"	WC12	0218	74°47.7'	92°48.1'	RCM12	✓		18	✓
"	WC13	0217	74°47.7'	93°17.8'	RCM12	✓		18	✓
"	WC14	2695	74°47.7'	93°18.0'	RCM4	✓		18	x instr. malf'n.
Barrow Strait	BS42	0211	74°34.2'	94°01.2'	RCM12	✓		18	x exp'tl. AML RCM; malfunction.
"	BS42	0215			RCM12	✓		18	x exp'tl. AML RCM; malfunction.
"	BS42	0216			RCM12	✓		18	x speed missing
"	BS42	1386			RCM4	✓		18	✓
"	BS42	3388			RCM4		✓	51	✓
"	BS42	1935			RCM4		✓	100	✓
"	BS46	1936	74°12.5'	93°46.8'	RCM4	✓		18	✓
"	BS46	4960			RCM4		✓	52	x
"	BS46	0800			RCM4		✓	101	x lost
"	BS46	3395			RCM4		✓	149	x lost

Table 1. Summary of Recording Instrument Records (Continued)

Region	Site	S/N	Latitude	Longitude	Type	3 mos.	12 mos.	Depth (m)	Data Recovery/ Remarks
Penny Strait	PS01	5361	76°38.7'	96°54.6'	RCM4		✓	43	✓
"	PS01	5456			RCM4		✓	131	✓
"	PS02	5391	76°36.2'	97°25.2'	RCM4		✓	49	✓
"	PS02	5471			RCM4		✓	138	✓
Ballantyne Strait	PI01	5474			RCM4		✓	35	✓
"	PI01	5473			RCM4		✓	83	✓
M'Clure Strait	B07	4182			RCM4		✓	35	✓
"	B07	5472			RCM4		✓	96	✓
Byam Martin Channel	West	0087	75°54.9'	105°36.2'	TG12A	✓		27	✓ P _{max} = 30 dbar
Wellington Channel	Snowblind	0086	75°12.6'	93°29.6'	TG12A	✓		14	✓ P _{max} = 30 dbar
Penny Strait	PS01	0080			WLR5A		✓	186	✓ P _{max} = 270 dbar
Barrow Strait	BS42	0366			TG5		✓	129	✓ P _{max} = 270 dbar
"	BS46	0114			TG12A		✓	160	x lost
Auldhild Bay CHS					TG		✓		✓
Isachsen Bay CHS					TG		✓		✓

3. DATA COLLECTION

3.1 Instrumentation

In total, 28 recording current meters and 15 recording pressure gauges were deployed in April 1984 within the study area delineated in Section 2.3. Of the current meters, 19 were suspended from the ice for a deployment of between one and three months at shallow depth (~20 m). These meters were Aanderaa Instruments Ltd. RCM4's, modified at the Institute of Ocean Sciences to the 'vane-follower' configuration described below, or Applied Microsystems Ltd., CM12's (5 units). Three of these were deployed for engineering purposes and their records will not be discussed here. The remaining 9 current meters were also Aanderaa RCM4's deployed in the 'vane follower' configuration, and were used on the 12-month deployments in Barrow and Penny Straits, where stable ice for suspension could not be expected throughout the deployment. Mesotech acoustic releases (Model 501AR) were used to secure the subsurface moorings in Barrow and Penny Straits. Recording pressure gauges were manufactured by Aanderaa Instruments, Ltd. (Model WLR5A) or by Applied Microsystems, Ltd. (TG12A). All gauges use the Paroscientific, Inc. Digiquartz pressure transducers, with a full-scale pressure ranges as indicated in Table 1.

Special modification to the RCM4's was as follows: Two or more of the resistors in each of the bridge circuits for temperature and conductivity ratio were exchanged for values yielding 10-bit resolutions of about 0.005°C and 0.00016 respectively, and ranges centred on those of interest. For temperature this range was typically (-2.5°C, +2.5°) and for salinity approximately (29, 35). Resolution in salinity was about 0.006. Aanderaa current meters were deployed in lengthened pressure cases which permit the installation of two batteries, desirable for long records at low water temperature. In the 'vane follower' configuration, a small (8.7 cm high by 5.8 cm wide) vane was suspended beneath the pressure case in mounts held by 3 stainless steel rods about 6 mm in diameter. The vane was neutrally buoyant in seawater. The field from two magnets mounted above the vane and free to turn with it was adequate to orientate the compass within the case. In this way current direction relative to the case was measured, while geographic orientation of the case was established at deployment and maintained until recovery.

Three methods were used for positioning moorings. Pressure gauge moorings near shore were sited by sextant relative to natural landmarks, or to markers set up for the purpose. Moorings more than a few hundred meters from shore were positioned using a GNS-500A VLF/Omega navigation system installed on the aircraft and initialized at nearby geodetic survey points. This allowed positioning to within a 500 m radius. The bottom-founded moorings in Barrow and Penny Straits were positioned to an accuracy of a few meters using microwave transponders (a DelNorte system) deployed at known locations for this purpose. Sites where moorings were to be recovered before the break-up of fast ice in summer were marked by 4-foot square by 1-foot high aluminum marker boxes painted red, and by radio beacons operating at 130 MHz (Novatech Designs Ltd., Model RF200). Sites where moorings were to be recovered one year later were marked by underwater acoustic beacons operating at 37 kHz (Johnson Laboratories, Inc., Model JL1).

3.2 Mooring Design, Deployment and Recovery

'Vane-follower' current meters were suspended from the sea ice on 1-inch hydraulic hose (see Figure 5). The hose was chosen because of its high torsional rigidity despite reasonable bending flexibility. Resistance to twisting was essential for maintaining a direction reference for current measurement. Meter depth was 18.5 m below the upper ice surface for all near-surface instruments. The hose was terminated and bolted to a 1-inch aluminum pipe just below the ice. This 12-foot pipe, and a vinyl-coated cable within it passed through the ice inside a 10-foot pipe of polyvinyl chloride plastic (PVC). A rubber seal between the metal and PVC pipes at the lower end of the latter permitted the space between the pipes to be filled with a 50/50 ethylene-glycol/water solution. A crossbar at the top of the metal pipe held the weight of the mooring and allowed mooring orientation (and that of the current meter) to be established. The assembly was deployed through an 8-inch-diameter hole augered in the ice and allowed to freeze in. The plastic-coated cable was bolted to the square site marker as a security measure. At the time of recovery, an 8-inch hole was augered beside the mooring and the crossbar on the mooring removed. The metal pipe was then lowered on the cable until well clear of the ice. At this point, the cable was hooked by a pole manipulated through the adjacent hole and the assembly pulled through this hole to the surface. The PVC pipe (still frozen in the ice) was abandoned. Simulation of the mooring response to flow using the model of Bell (1979) indicated that the vertical displacement of the current meter was only 0.2m with a 50 cm/s current.

Current meters in 'vane-follower' configuration were also used at sites BS42 and BS46 in Barrow Strait and PS01 and PS02 in Penny Strait on the bottom-founded moorings (see Figure 6). Flotation was provided by a single 28" diameter steel float (Ocean Research, Inc., Model SS28). The principal mooring "line" was assembled on site from aluminum tubing (12-foot lengths) of 1" diameter. Current meters were mounted in load-bearing frames made from two 1/2"-diameter stainless steel rods spread to a separation of 8" to allow inclusion of the RCM4. Frames were about 4 feet in length and were bolted in line with the tubing. The anchor consisted of steel chain lengths contained in a 45-gallon drum with a harness of steel flat stock to reinforce it. Steel feet penetrated the sediment to discourage anchor movement. The mooring was attached to the anchor via a universal joint from an automobile which permitted bending in any plane, but no twisting. The overall intent of the design was to achieve a high degree of torsional rigidity while allowing bending. Magnetic compasses could not be used at these sites for direction reference due to the weak horizontal geomagnetic field. Orientation of the moorings was determined at deployment using a gyrocompass. A single acoustic transponding release was used on each mooring. Current meters were positioned at depths near 50 m, 100 m and 150 m. Pressure records from the uppermost RCM4's indicated that 2 of the 3 moorings recovered were somewhat lacking in buoyancy. The east and west moorings in Penny Strait were depressed by 26 m and 50 m at spring tide, respectively. At BS42, depression was 5 m. The deployment winch, quadripod, ice-hole melter and other mooring gear were designed and built at the Institute of Ocean Sciences to meet the requirements of the task, and yet be aircraft transportable.

Recording pressure gauges were moored in two ways. Those gauges required for tidal description, and short-term (1-3 month) deployment were strapped above a steel or lead ballast weight and lowered to an upright position on the seafloor (see Figure 7). Sufficient slack was left in the

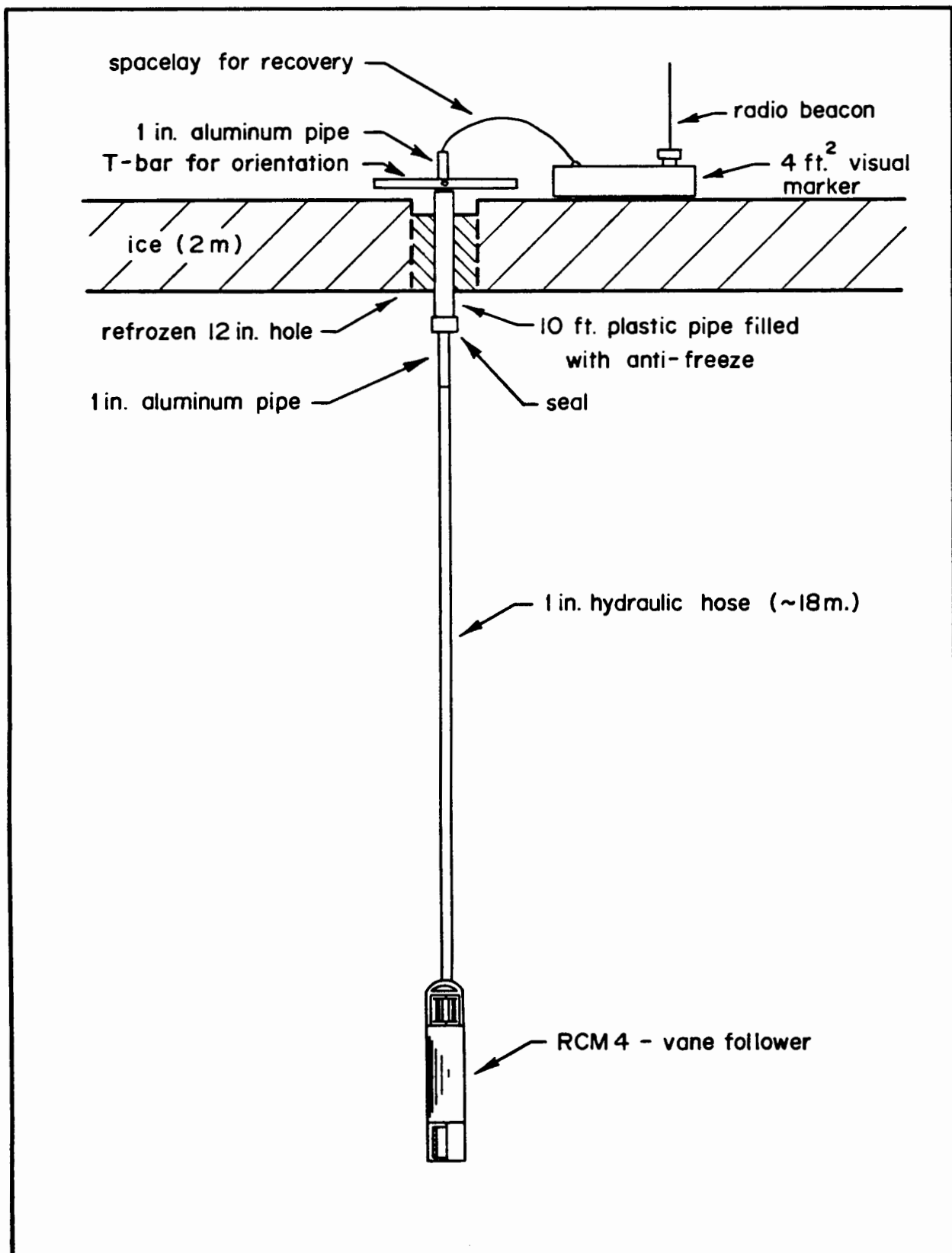


Figure 5. Vane-follower current meters suspended from the sea-ice on hydraulic hose.

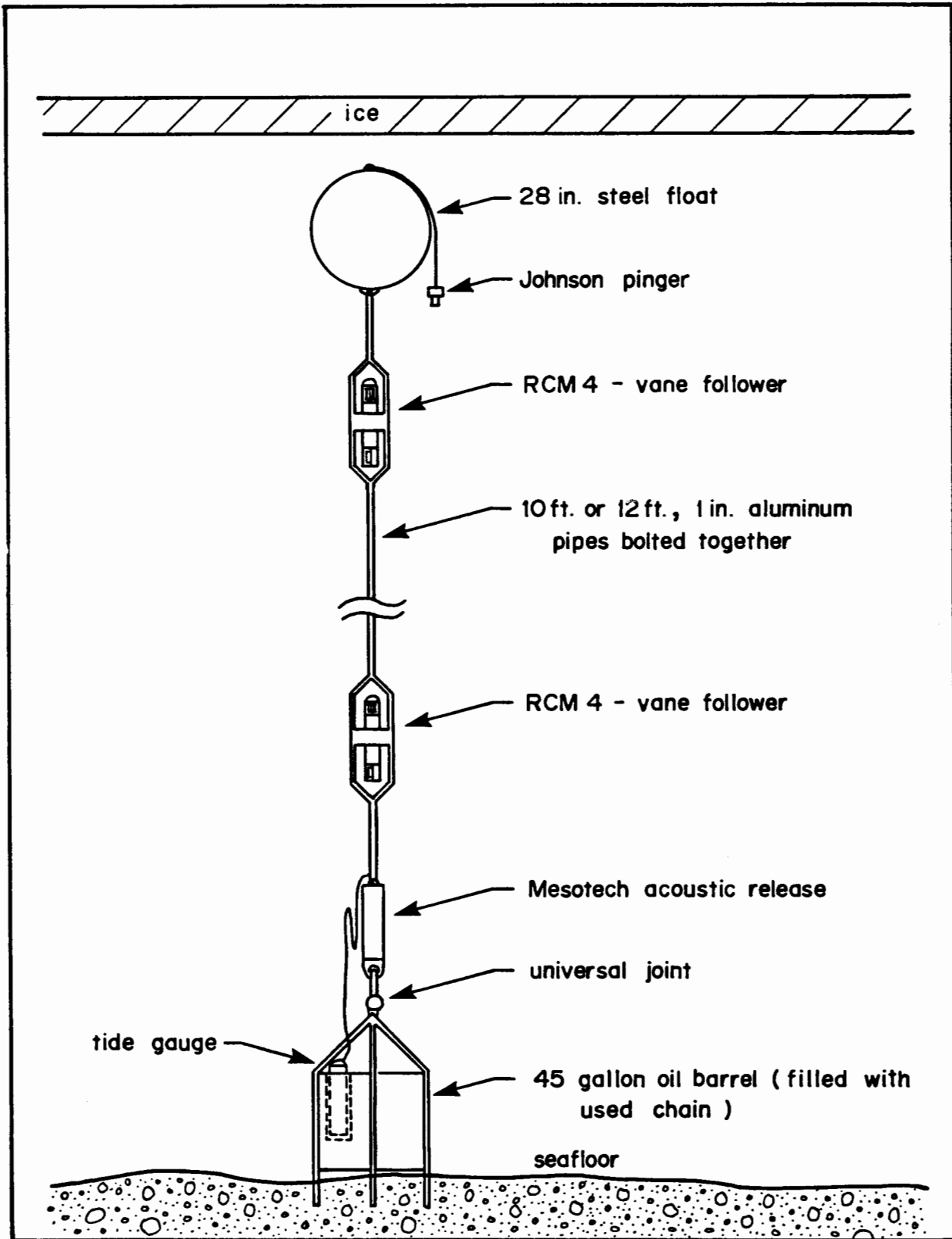


Figure 6. Bottom founded mooring with vane-follower current meters.

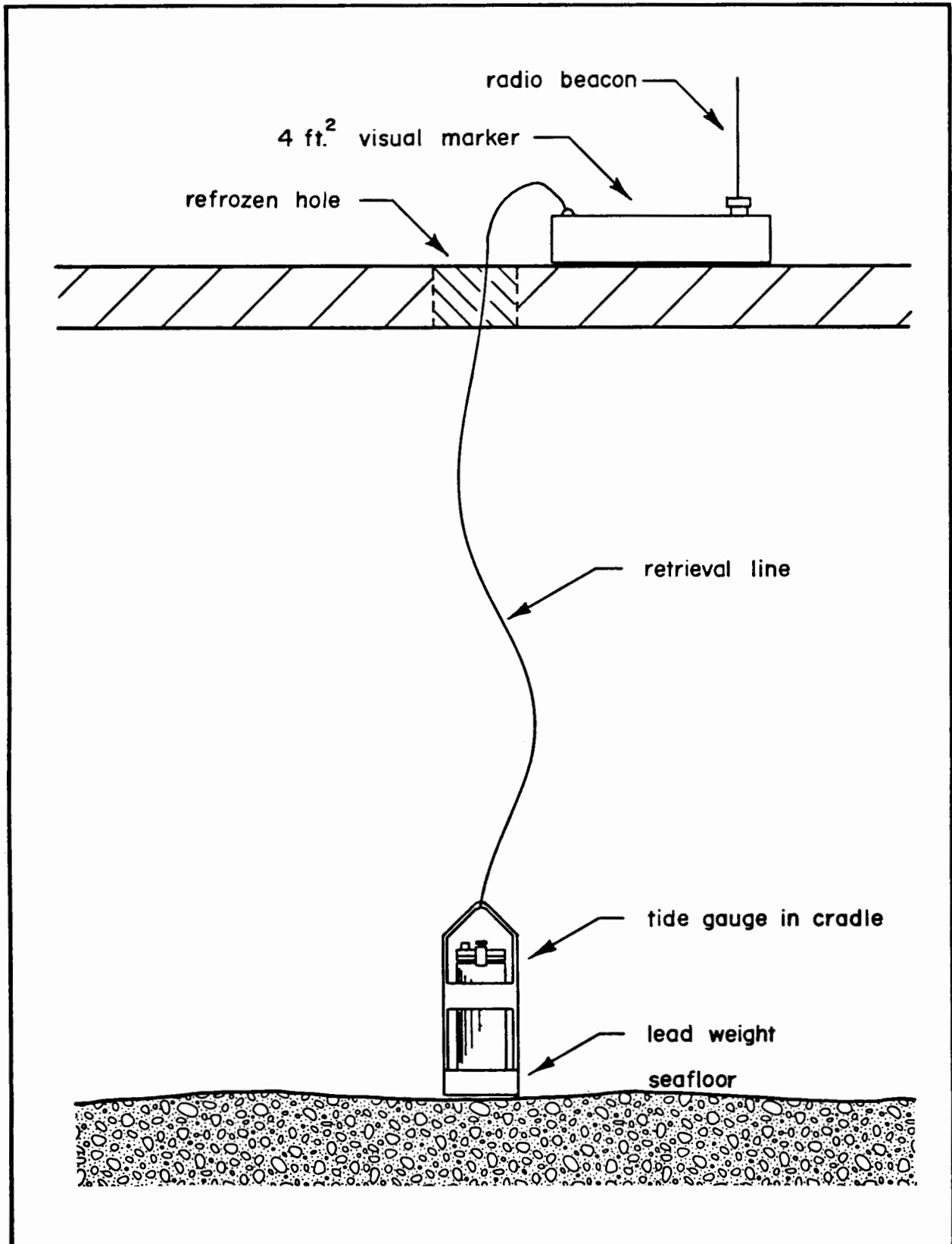


Figure 7. Mooring for short-term tide gauge deployment.

polypropylene rope to accommodate sea-level variations, and the rope was secured to the marker barrel on the ice. For recovery, a hole was augered in the ice adjacent to the in-frozen rope, the rope hooked and the instrument raised from the seafloor. For the gauges moored in Barrow and Penny Straits over 12 months, a cradle was welded to the anchor bucket of the RCM mooring. A slack line connected the mooring to the gauge in order that the mooring, when released, would also raise the gauge to the surface.

Mooring operations were conducted, interspersed with CTD work, during the month of April 1984. Activity was supported out of a base camp run by the Polar Continental Shelf Project of the Department of Energy, Mines and Resources at Resolute Bay. Most operations were carried out from a chartered Bell 206L-1 helicopter, while caches of fuel and equipment were established in the working areas by deHavilland DHC-6 Twin Otter on ski/wheel gear.

Recovery of ice-secured instruments was accomplished during the first week of June 1984, again using a Bell 206L-1 with Twin Otter support.

Retrieval of bottom-mounted instruments was attempted in mid-April 1985, using a Twin Otter assisted by a Bell 206B helicopter for transport. A search for the release transponder was conducted in the vicinity of each mooring by lowering a hydrophone through an augered ice hole and transmitting an interrogation message. Once the transponder was heard, and was verified to be a suitable range (less than a few hundred metres), the appropriate release code was transmitted. The exact location of the released mooring was then determined by triangulation on the signal from the Johnson acoustic pinger, now close beneath the ice, and verified by physical contact on the mooring with a pole manipulated through a small augered ice hole. At this time, equipment for melting a 30-inch diameter hole through the ice, and for raising the mooring was flown to the site, by helicopter sling if necessary. Recovery then proceeded in a straightforward fashion. Unfortunately, the mooring in the southern side of Barrow Strait (BS46) could not be located. Erroneous positioning on deployment, a defective release/transponder or drift of the mooring from the site are possible explanations for its apparent disappearance. The latter explanation gains credence from the fact that the three recovered moorings were noted to be severely corroded in the vicinity of the release hook. In fact, at the mooring on the west side of Penny Strait, the hook corroded completely and the mooring floated to the surface and lodged beneath the fast ice six days before recovery was attempted. Complete corrosion of the hook may also have occurred at BS46, and current and drift ice could subsequently have moved the free-floating mooring far from its deployment position. Lack of adequate electrical isolation of the steel anchor from the aluminum release was the cause of the excessive corrosion observed. Three current meters and one tide gauge were lost at BS46.

The timing of successful operational periods of the recording instrumentation is shown in the bar chart of Figure 8.

3.3 Calibration

Current meters were deployed with sensors for current speed, direction, water temperature and conductivity. The speed sensors were not calibrated for this deployment, since experience has shown the calibration to be stable provided that rotor bearings are well maintained. Rotor thresholds were verified to be within tolerance by testing for rotation in response to a minimum torque specified by Aanderaa Instruments. It should be noted that in the 'vane follower' configuration, flow may approach the meter from any direction. (In the standard configuration flow is always at right angles to the

CURRENT METERS — Short Term

STN.	APRIL	MAY	JUNE
WC01	_____	_____	_____
WC02	_____		
WC03	_____	_____	_____
WC04	_____	_____	_____
WC05	_____	_____	_____
WC06		_____	_____
WC07		_____	_____
WC08		_____	_____
WC10		_____	
WC11		_____	_____
WC12		_____	_____
WC13		_____	_____
BS 42		_____	_____
BS 46		_____	_____

CURRENT METERS — Long Term

STATION	1984										1985			
	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	
BS 42 (51 m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
BS 42 (100m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
PS 01 (43m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
PS 01 (131 m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
PS 02 (49m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
PS 02 (138 m)		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	

TIDE GAUGES

STATION	1984										1985			
	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	
BYAM MARTIN CH. WEST	_____	_____	_____											
SNOWBLIND BAY	_____	_____	_____											
PS 01		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	
BS 42		_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	

Figure 8. Bar chart of operational periods for recording instrumentation.

rotor support yoke). It has recently been established (Pite, 1986) that in some directions, the support interferes significantly with the rotor response to flow. As a result the rotor sensitivity is azimuthally non-uniform (see Figure 9). Further anisotropy is contributed by the presence of the load-bearing rods of the RCM mounting frame. Since no correction for these effects were made in processing these data, they contribute an imprecision of about $\pm 7\%$.

In the 'vane-follower' configuration uncertainties in direction measurement arise from the following sources: nonlinearity in vane response to current; non-linearity in encoded compass reading to vane position; inaccuracy in carrying the reference direction up the 20 m of hydraulic hose and aluminum pipe from the instrument case to the crossbar at the surface; and inaccuracy in referencing the crossbar orientation to geographic north. The nonlinearity in vane response to current arises from the interaction of the flow with the 3 rods supporting the vane bearing and the thicker rods supporting the current meters (Pite, personal communication). Vane orientations aligned with a downstream support rod are avoided. Since no correction has been made for this effect in processing these data, an imprecision of about $\pm 7^\circ$ in direction is thereby contributed. The non-linearity in compass response to vane position arises from the interference of the geomagnetic field and any remnant magnetism in the instrument case with the magnetic coupling between the vane magnets and the compass, from any departure in concentricity between the vane and the compass pivots and from nonlinearities in the compass potentiometer. The combined effect of these factors was measured near the mooring sites before deployment (at Resolute Bay), and appropriate corrections (as large as 13° peak-to-peak) were made during processing. The uncertainty in these corrections contributes a further imprecision of $\pm 3^\circ$ to direction measurement. Difficulties in carrying the direction reference from the current meter to the crossbar produce an inaccuracy of about $\pm 5^\circ$, while those in referencing the crossbar orientation to geographic north produce a further inaccuracy of about $\pm 3^\circ$. (Crossbar orientation was determined by measuring the angle between the crossbar and the sun with an astrocompass, and by determining the solar azimuth from sun tables, knowing the measurement time and position). For the long pipe moorings, accuracy and precision are less good. A mooring in 150 m of water contains about 32 lengths of tubing. It is not unreasonable to assume that bolt holes at opposite ends of each length are misaligned with a root-mean-square misalignment of 5° . If these misalignments are random, then the uncertainty over 32 lengths grows to about $\pm 30^\circ$. In addition the mooring may be subject to elastic torsional deformation. An investigation of this possibility over a 30 m length of mooring at mid-latitude where direction could be measured independently by magnetic compass gave a root-mean-square discrepancy between the 2 methods of $\pm 5^\circ$ for currents peaking at 50 cm/s. If this discrepancy scales linearly with the length of mooring, then an imprecision of $\pm 15^\circ - 20^\circ$ from this source may be estimated for the pipe moorings deployed in 1984-85.

Temperature sensors on the current meters were calibrated in a large insulated seawater bath whose temperature was controlled to within one or two millidegrees Celsius. Sensor output was determined at 6 or 7 temperatures spanning the range, and a cubic polynomial equation for temperature fitted. Bath checks before and after deployment, and *in situ* comparisons with output from a profiling CTD have verified that accuracy and precision equal the resolution of 0.005°C .

Conductivity sensors on the current meters were calibrated in the same bath at two or three different conductivities and a linear equation for

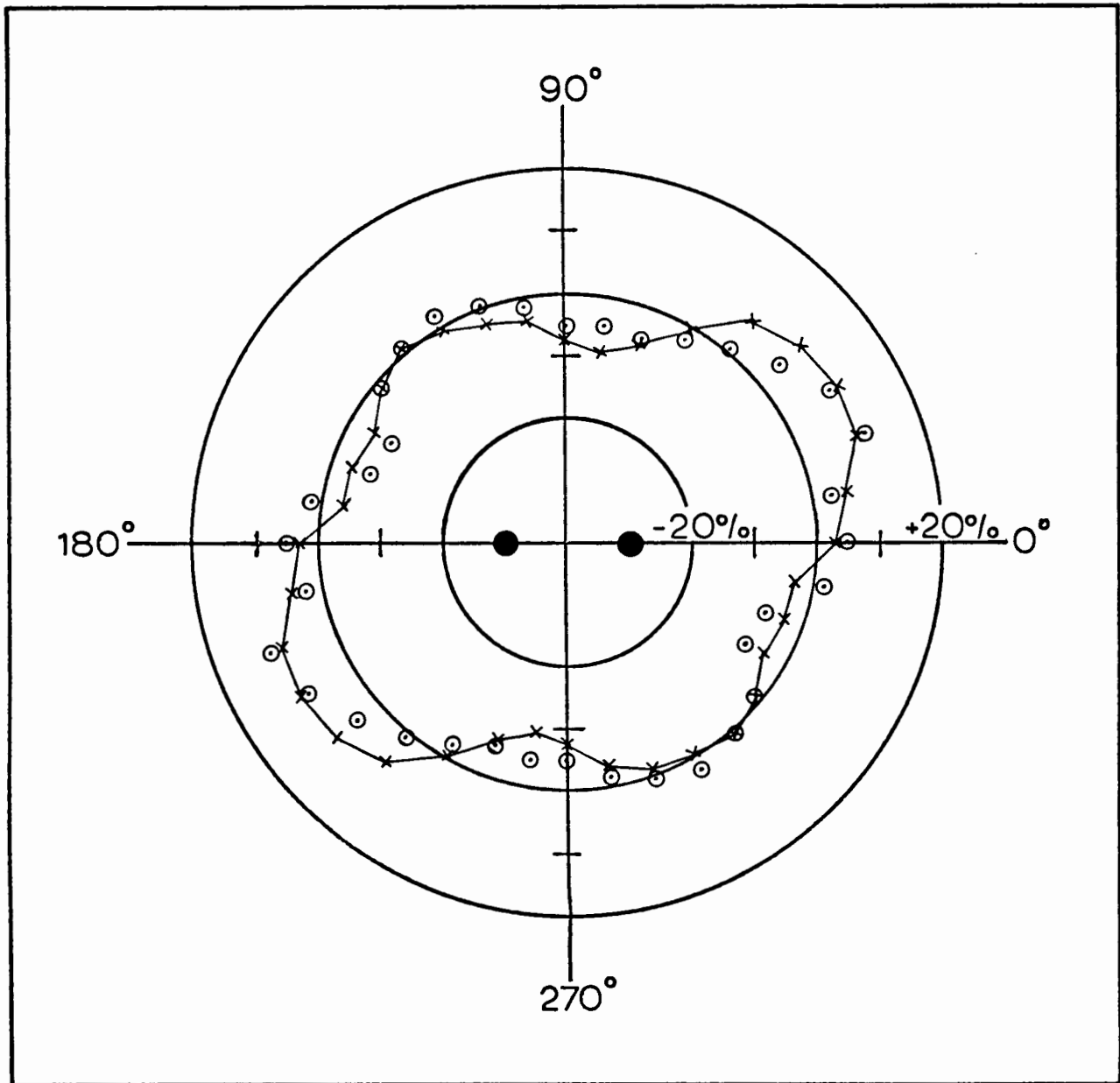


Figure 9. Plot of current meter rotor sensitivity versus azimuth for a two rod support configuration.

conductivity ratio was fitted. Bath salinity was determined by analysis of samples on a Guildline AutoSal salinometer. Experience has shown that bath calibrations are not reliable predictors of *in situ* performance, for reasons which are not well understood. *In situ* comparisons with output from a profiling CTD at the moorings in Prince of Wales Strait in 1982 showed RCM salinity offsets ranging as far as +0.13 from laboratory calibrations, with an average departure of +0.06. *In situ* comparisons at the other moorings were not as well controlled, but yielded similar values. Calibration equations for measurements in 1984 were not, however, adjusted in accordance with the *in situ* calibrations. Accuracy and precision in salinity measurements are thus estimated to be ± 0.1 and ± 0.03 , respectively.

Digiquartz pressure gauges were calibrated by Aanderaa Instruments Ltd., at a single fixed temperature (generally 0°C) by applying known pressures with a dead-weight tester (Ruska Model 2465-751-00). Output values at 10-20 different pressures were fitted to a polynomial equation with a precision of approximately 0.01% fs. Reproducibility of deadweight pressures was about 0.01 dbar. Their absolute accuracy depends on the care used in operation and on the attention paid to such factors as hydraulic heads and air bubbles in connecting tubing. A realistic estimate is 0.03 db.

Digiquartz pressure gauges were calibrated by Aanderaa Instruments Ltd., at a single fixed temperature (generally 0°C) by applying known pressures with dead-weight tester (Ruska Model 2465-751-00). Output values at 10-20 different pressures were fitted to a polynomial equation with a precision of approximately 0.01%fs. Reproducibility of dead-weight pressures was about 0.05 dbar. Their absolute accuracy depends on the care used in operation and on the attention paid to such factors as hydraulic heads and air bubbles in connecting tubing. A realistic estimate is 0.03 db.

The estimated accuracy and precision of the current meter and tide-gauge sensors are tabulated in Table 2.

Table 2

Estimated Accuracy and Precision of Measurement

<u>Instrument</u>	<u>Parameter</u>	<u>Accuracy</u>	<u>Precision</u>	<u>Resolution</u>
RCM4	Speed (cm/s)	$\pm 2\%$	$\pm 7\%$.05 cm/s
RCM4 (hose)	Direction ($^{\circ}$ T)	$\pm 3^{\circ}$	$\pm 7^{\circ}$	0.4 $^{\circ}$
RCM4 (pipe)	Direction ($^{\circ}$ T)	$\pm 30^{\circ}$	$\pm 20^{\circ}$	0.4 $^{\circ}$
RCM4	Temperature ($^{\circ}$ C)	$\pm .005$	$\pm .005$	0.005
RCM4	Conductivity Ratio	$\pm .0025$	$\pm .0008$	0.00016
WLR5A	Pressure (db)	$\pm 0.03\text{db}$	$\pm .005\text{db}$	0.001%fs
TG12A	Pressure (db)	$\pm 0.03\text{db}$	$\pm 0.005\text{db}$	0.001%fs
TG12A	Temperature ($^{\circ}$ C)	$\pm .005$	$\pm .005$	$\pm .005$

4. DATA PROCESSING

The first stage in processing the current meter data was the translation of the information from the original one-quarter inch magnetic tape onto a computer-compatible nine-track magnetic tape. This process was done at the

Institute of Ocean Sciences using an HP2100 computer. The data were then read into the Institute's Univac 1100/60 computer for editing. The editing procedure involved timing checks, the truncation of irrelevant pre- and post-deployment data, and the replacement of occasional spurious measurements, or "spikes". Calibration formulae were then applied to the "N" numbers to produce values of the designated parameters, usually speed (cm/sec), direction (degrees True), conductivity ratio, temperature, and sometimes pressure. Salinity and density were then calculated. Salinity was calculated using the Practical Salinity Scale 1978 (Lewis, 1981). Density was presented as sigma-t, from the relationship,

$$(\sigma_t = (\text{density (gm/cm}^3) - 1) \times 10^3)$$

After the data had been converted to real values, they were stored on magnetic tape. Each file on a tape contains information from one instrument. The files begin with a header which indicates such things as instrument number, station location, and station designation. These are followed by up to eleven channels of calibrated data as follows:

channel 1 - time
 2 - speed
 3 - direction
 4 - high resolution temperature
 5 - salinity
 6 - pressure
 7 - conductivity ratio
 8 - sigma-t
 9 - low resolution temperature
 10 - time code generator
 11 - voltage reference

Not all channels were used in each instance.

Similar procedures were used to process the tide gauge and meteorological station data.

5. DATA PRESENTATION

The calibrated and corrected current meter data are presented in the Appendix as time series plots of current speed, direction, temperature, and salinity. Superimposed on the speed and direction traces with a heavier pen are low-pass filtered values of the same (tidal signal removed). One month of data is displayed per page.

For the tide-gauge measurements, only one month of representative data is shown.

LIST OF REFERENCES

- Bell, W.H., 1979. A three-dimensional subsurface mooring model. Pacific Marine Science Report 79-20, Institute of Ocean Sciences, Sidney, B.C., 48p.
- Fissel, D.B., D.N. Knight, and J.R. Birch, 1984. An oceanographic survey of the Canadian Arctic Archipelago, March 1982. Can. Contr. Rep. Hydrogr. and Ocean Sci. 15, Institute of Ocean Sciences, Sidney, B.C., 415p.
- Lewis, E.L., 1981. The practical salinity scale 1978 and its antecedents. In: Background Papers and Supporting Data on the Practical Salinity Scale 1978, UNESCO Technical Papers in Marine Science 37, UNESCO, Paris, 13-18.
- Peck, G.S., 1978. Arctic Oceanographic Data Report 1977. Western Viscount Melville Sound. Data Report Series No. 78-3. Canada Centre for Inland Waters, Burlington, Ontario, 150p.
- Pite, H.D., 1986. The influence of support rods on the rotation speed of Savonius rotors. Journal of Atmospheric and Oceanic Technology, Vol. 3, No. 3, 487-493.
- Polargas Project, 1979. M'Clure Strait Marine Geophysical Investigation - April 1979. By Polargas Project, Toronto, for Combined Pipeline System Study, 73p.
- Prinsenbergh, S.J., 1978. Arctic Oceanographic Data Report 1978, Vol. 1, Data Report Series No. 78-4. Canada Centre for Inland Waters, Burlington, Ontario, 211p.

APPENDIX

Recording instrument data index and time-series plots.

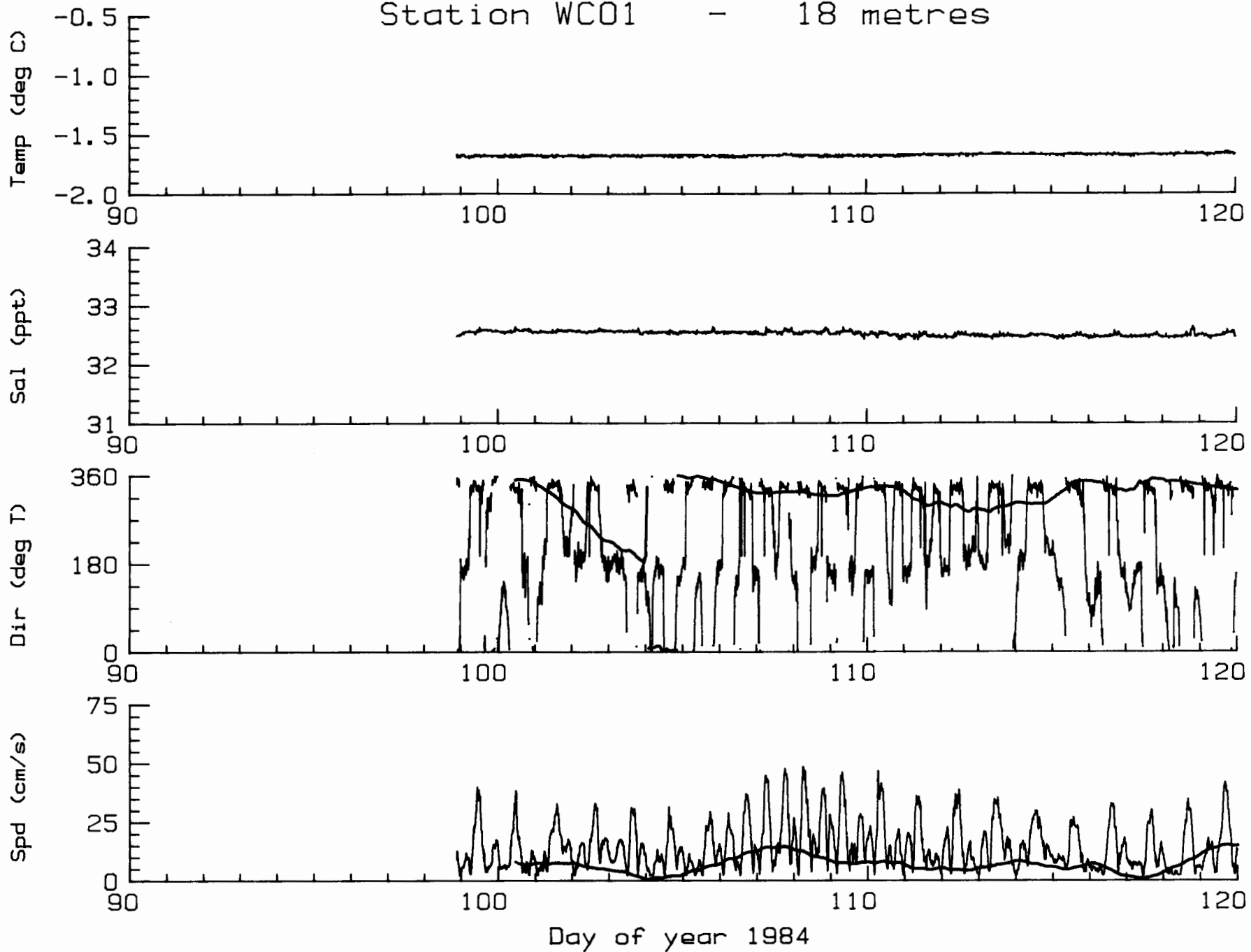
RECORDING INSTRUMENT DATA INDEXCURRENT METERS

<u>STATION</u>	<u>PAGE</u>	<u>STATION</u>	<u>PAGE</u>	<u>STATION</u>	<u>PAGE</u>
WC01	24	WC08	43	BS42 - 100m	71
WC02	27	WC10	46	BS46	83
WC03	28	WC11	48	PS01 - 43m	86
WC04	31	WC12	51	PS01 - 131m	99
WC05	34	WC13	53	PS02 - 49m	112
WC06	37	BS42 - 18m	55	PS02 - 138m	125
WC07	40	BS42 - 51m	58		

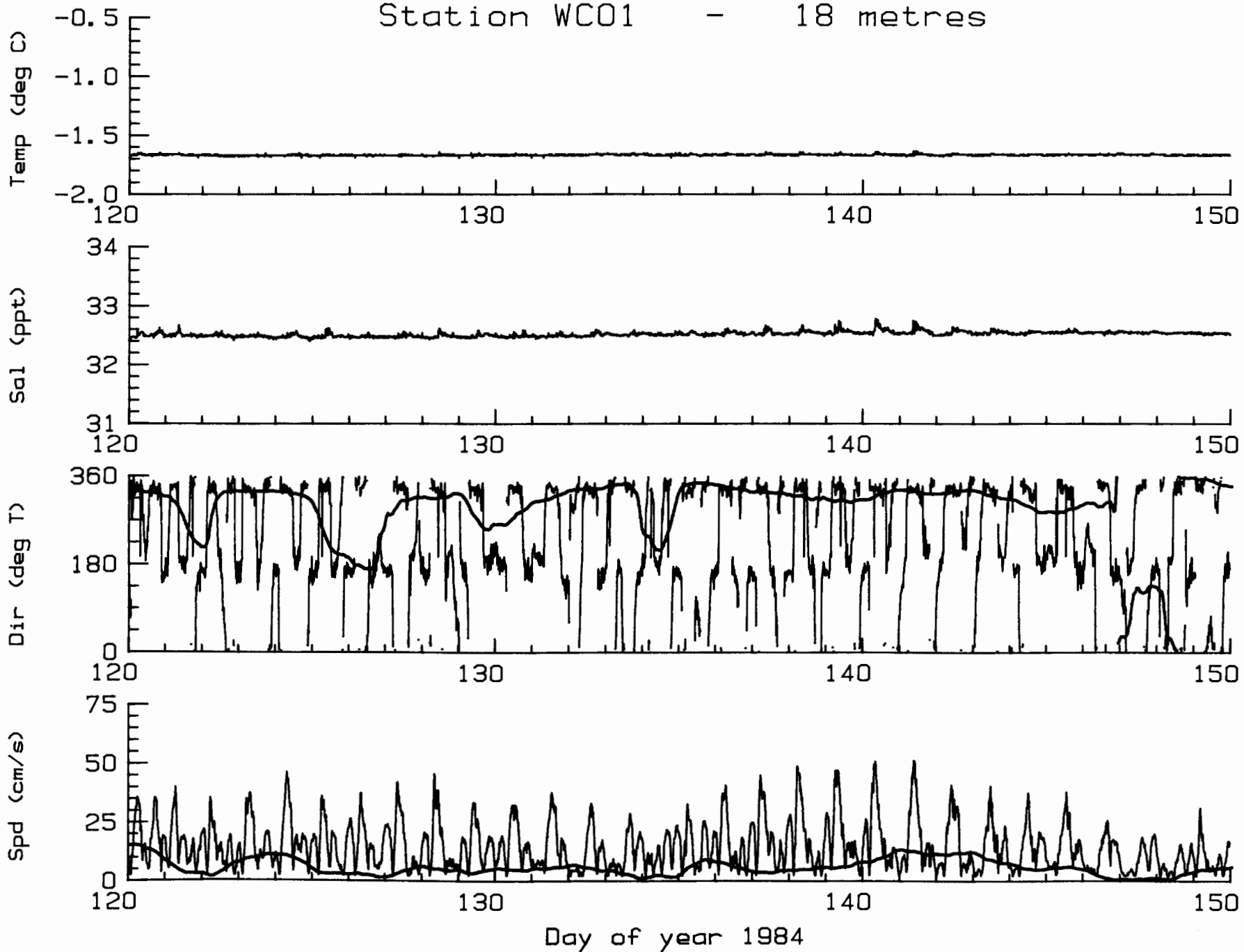
TIDE GAUGES

<u>STATION</u>	<u>PAGE</u>
Byam Martin	
Channel West	138
Snowblind Bay	138
PS01	139
BS42	139

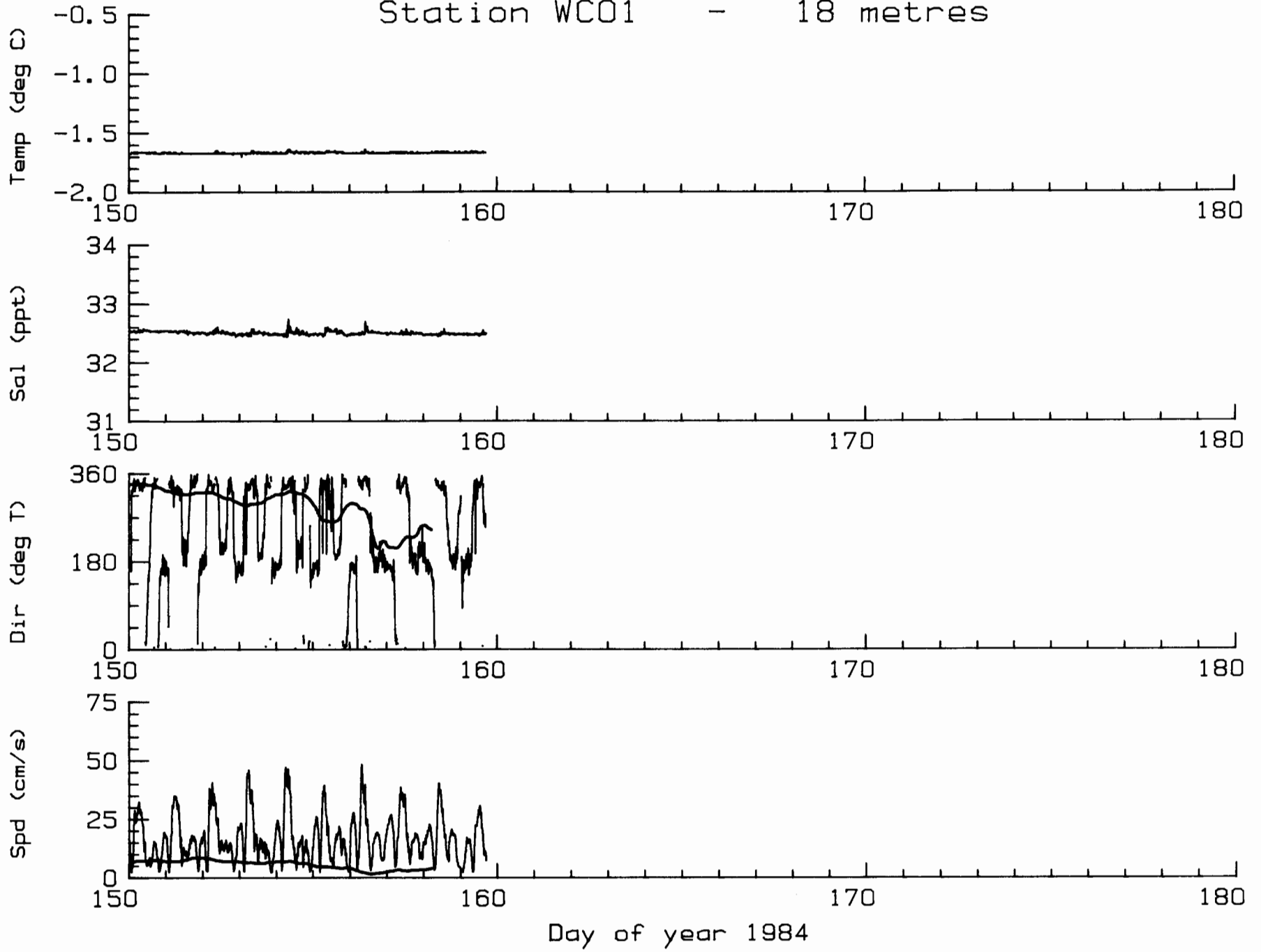
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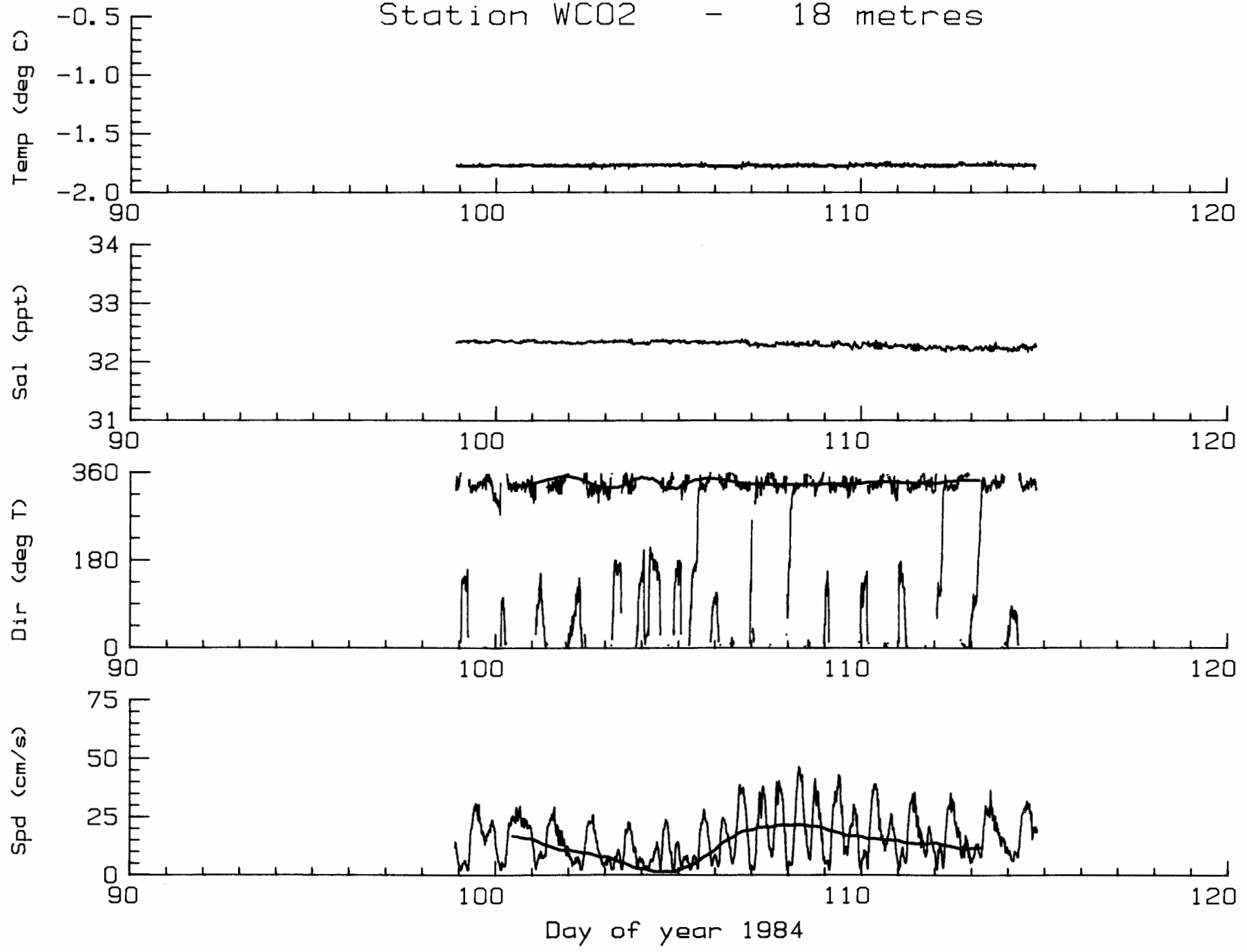
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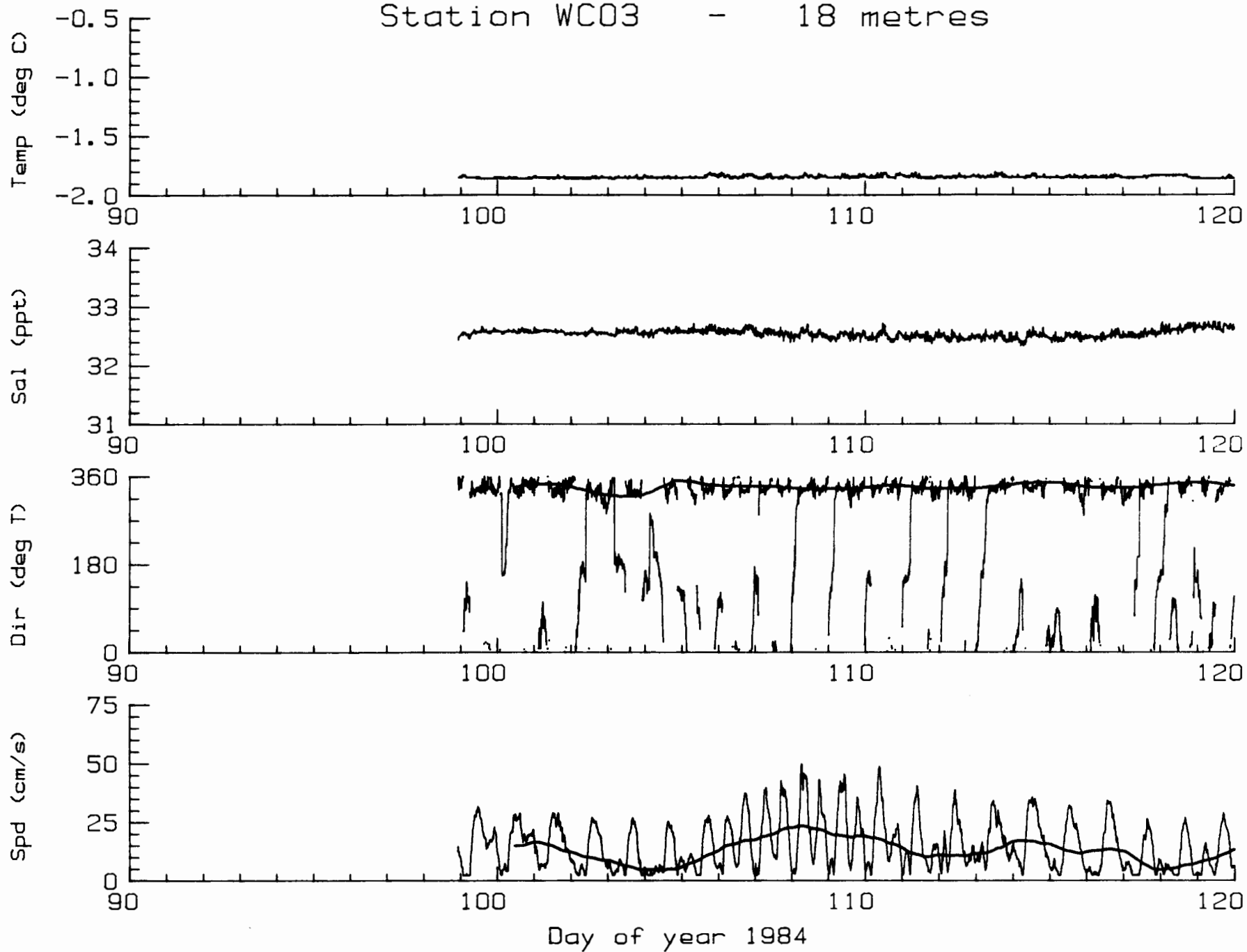
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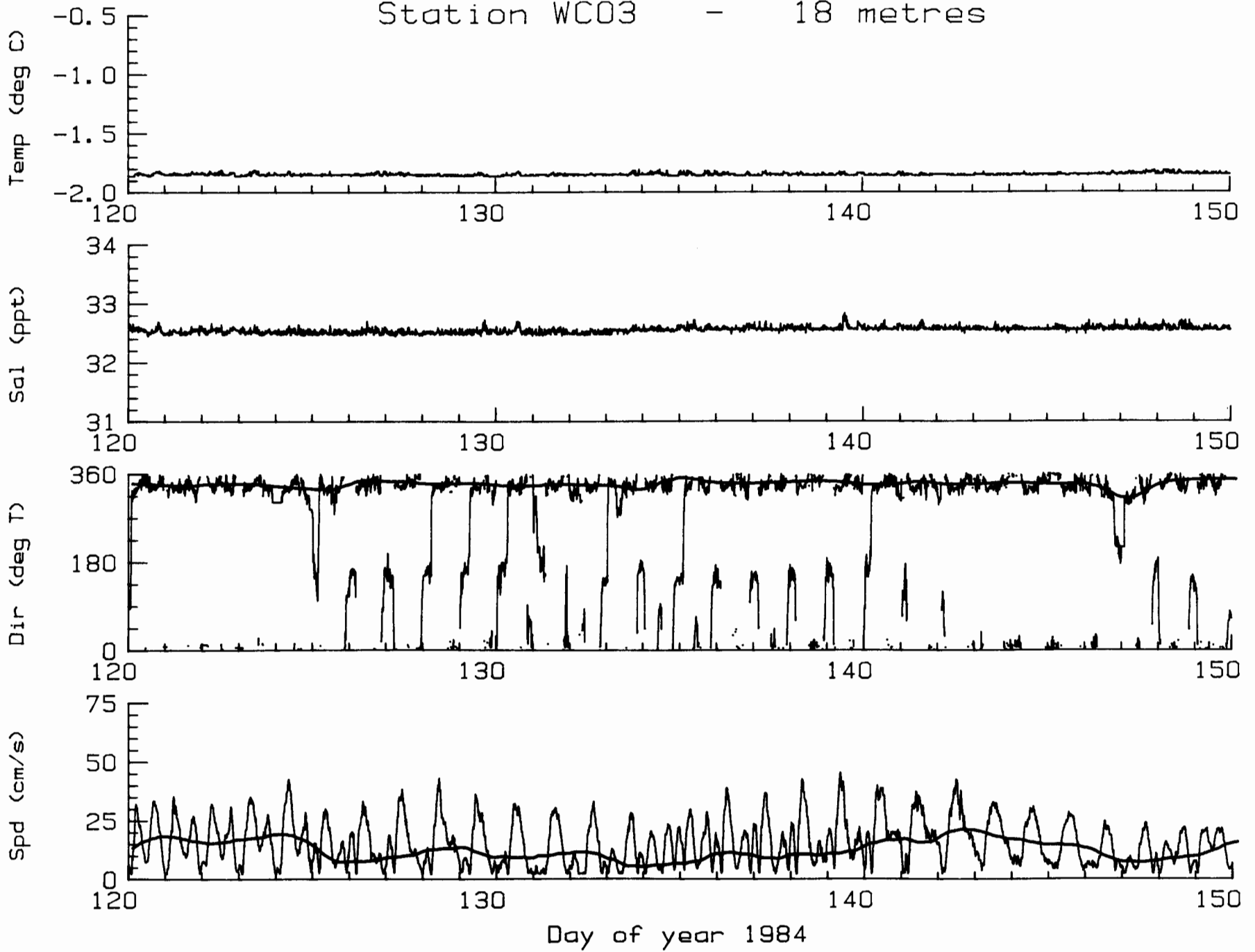
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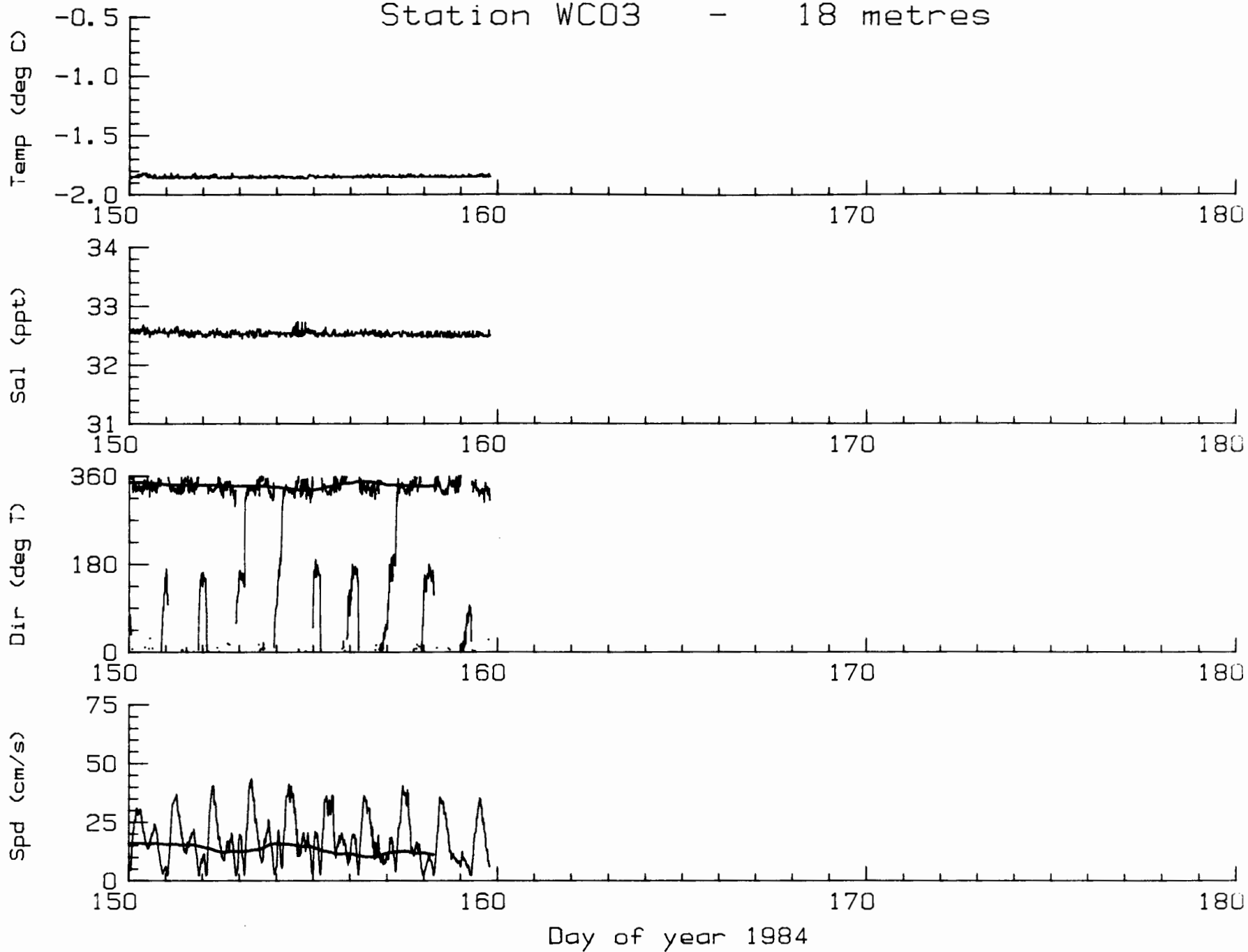
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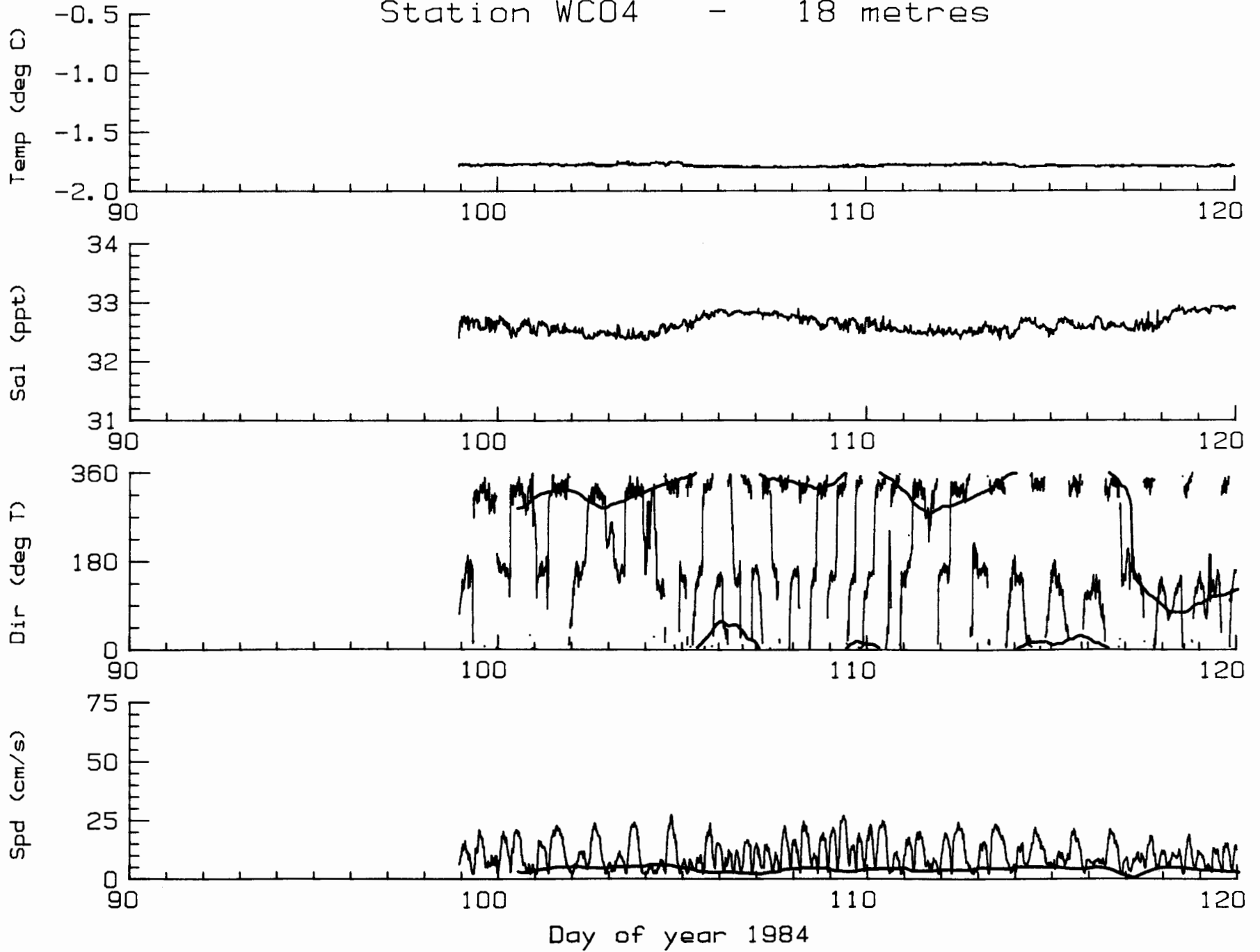
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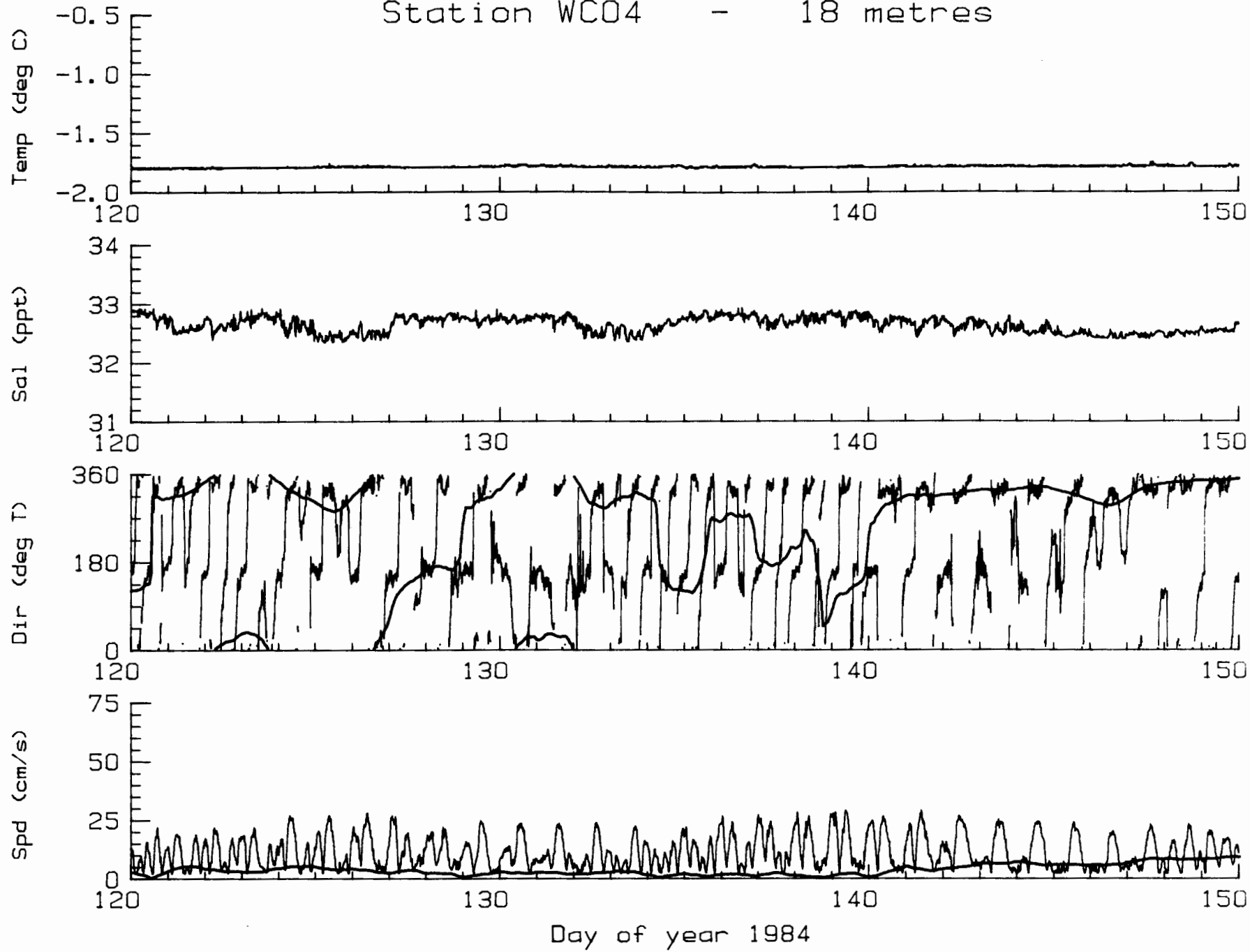
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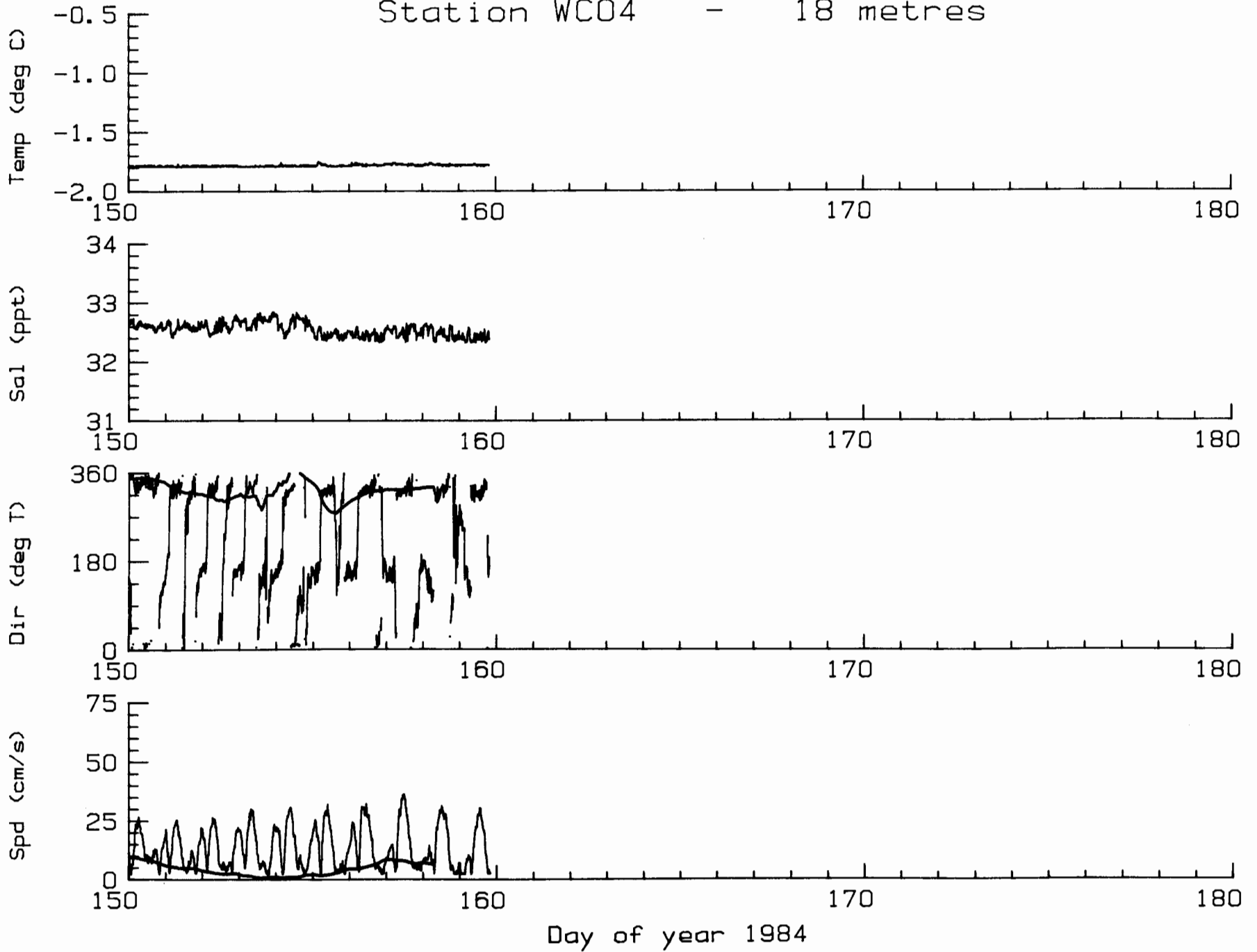
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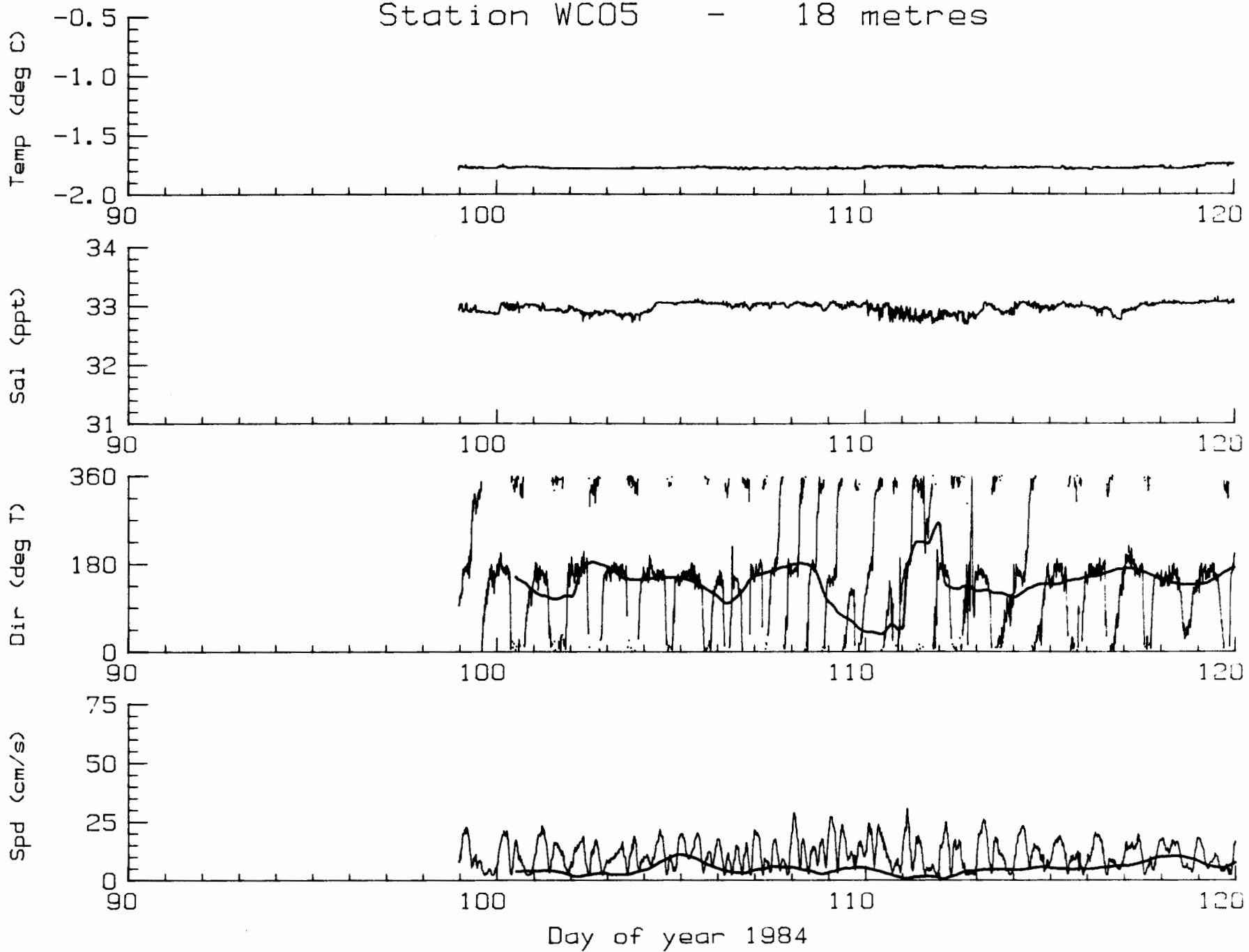
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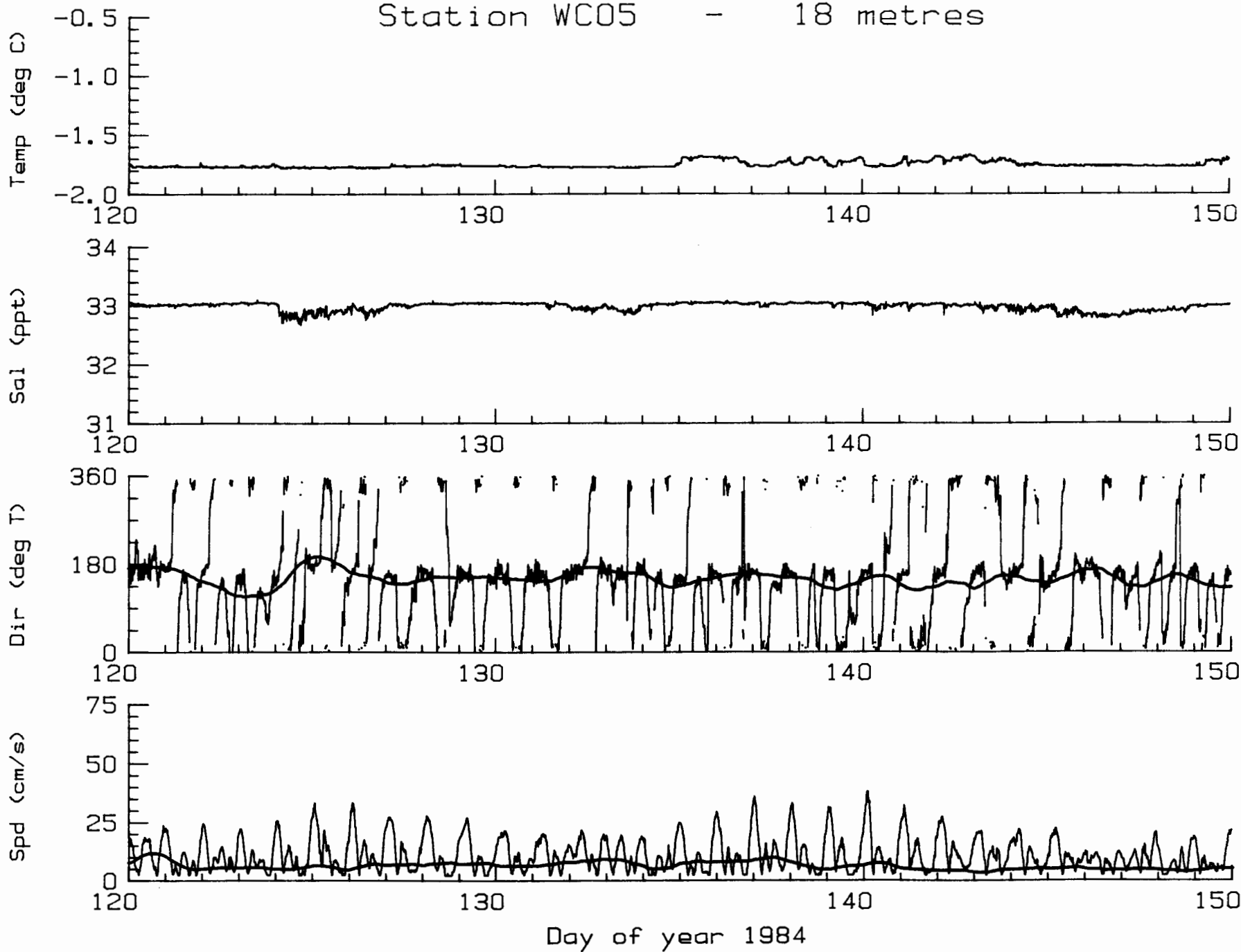
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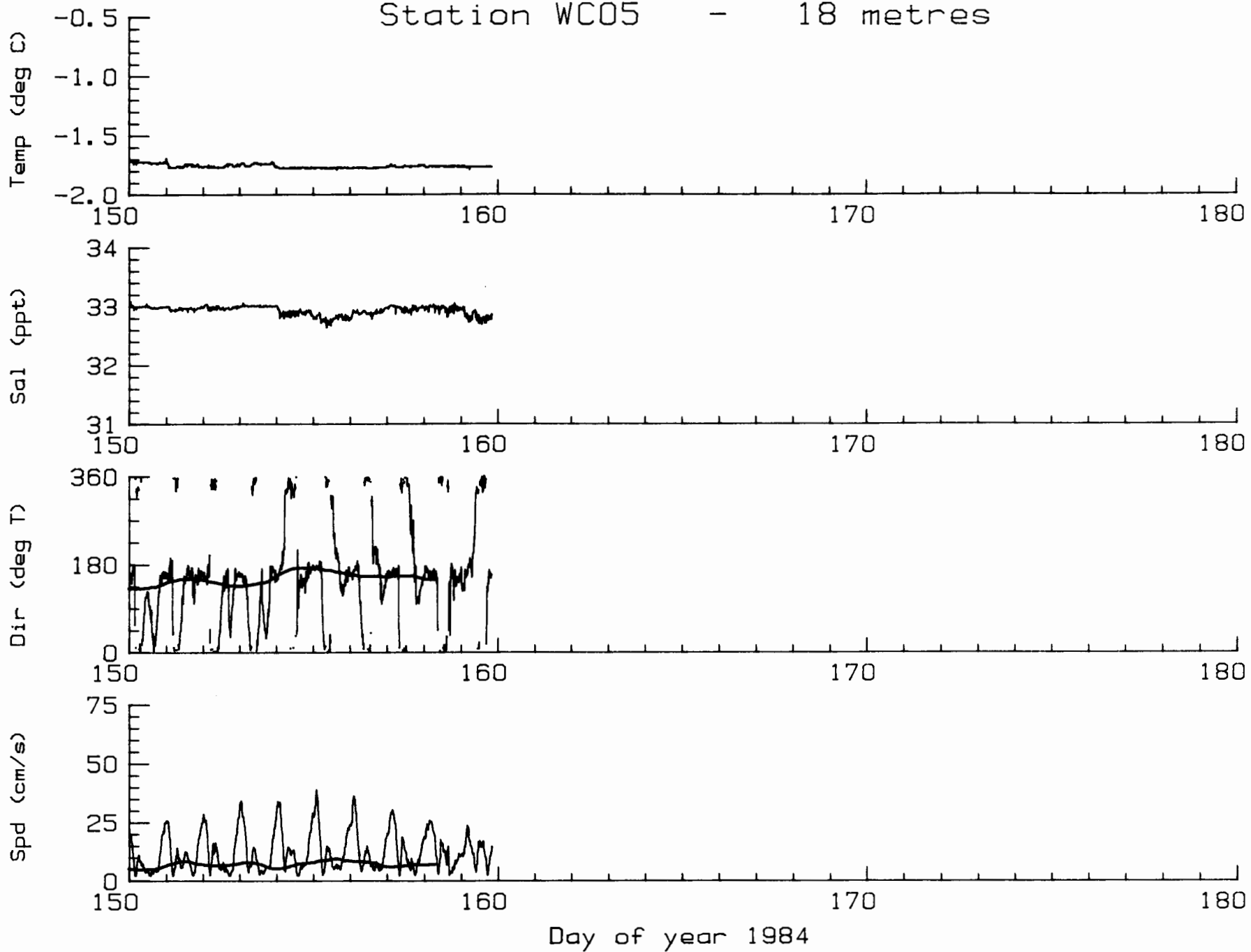
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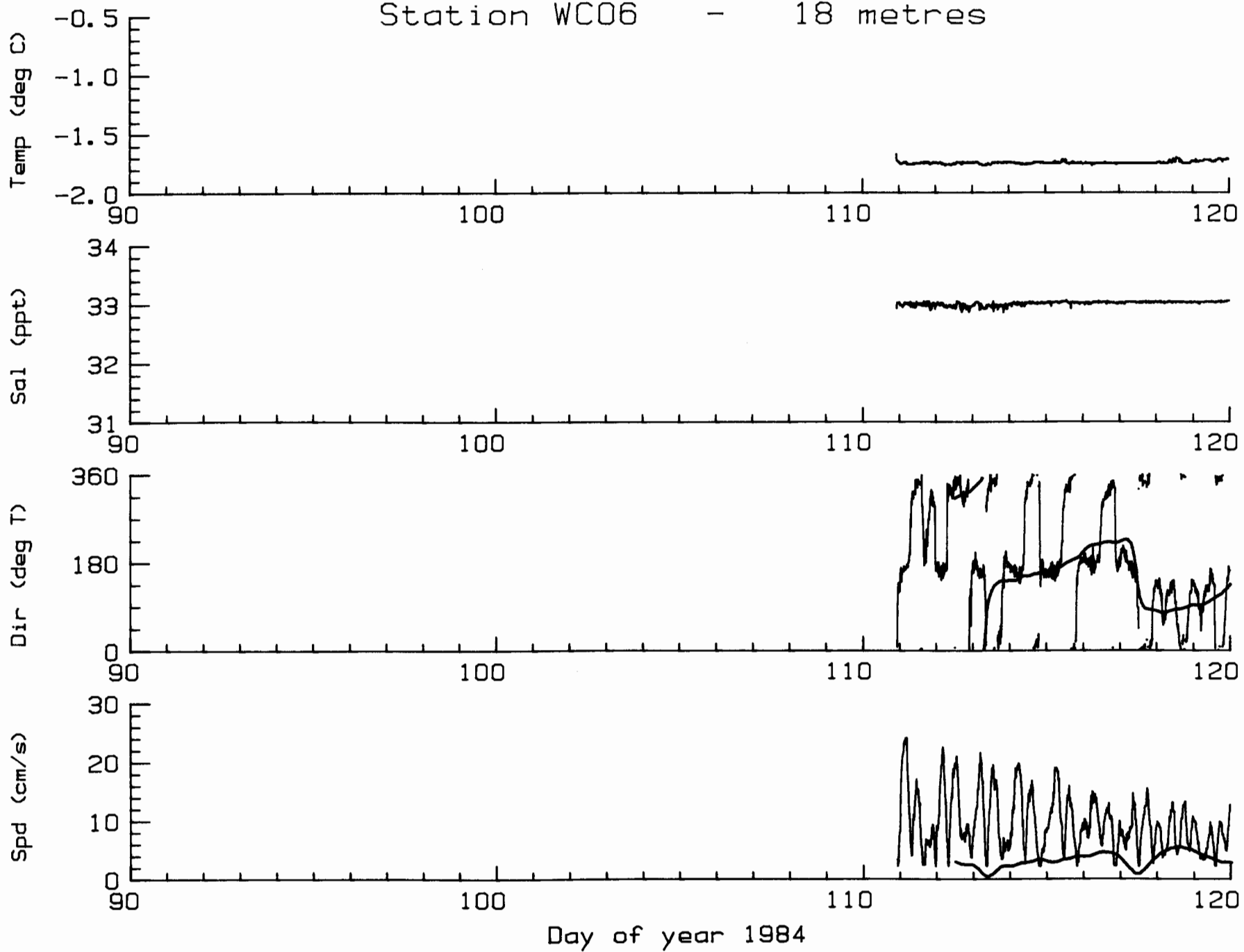
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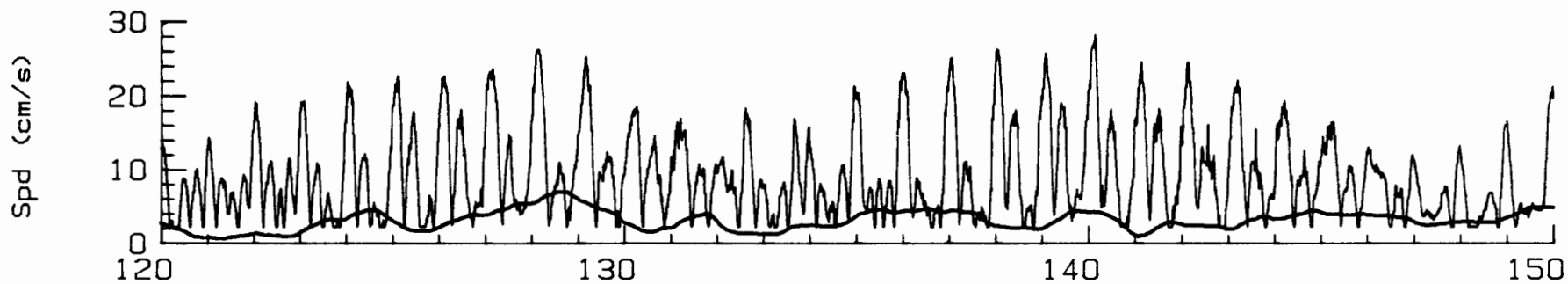
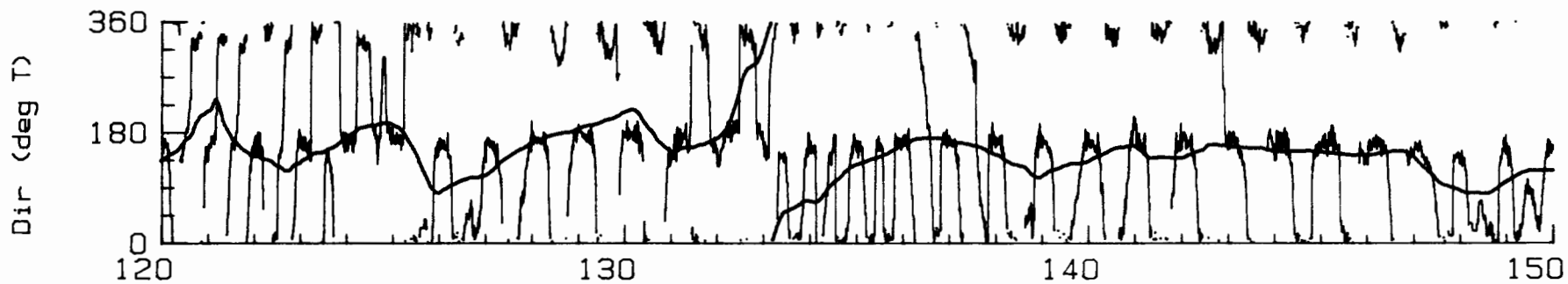
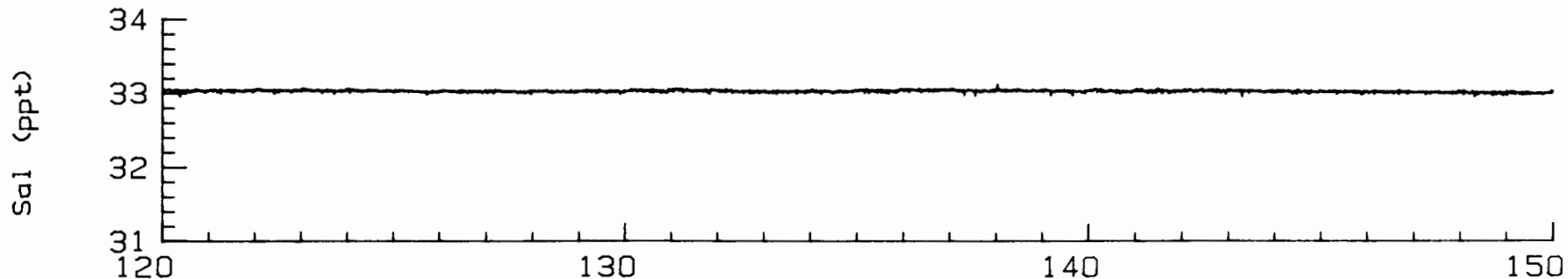
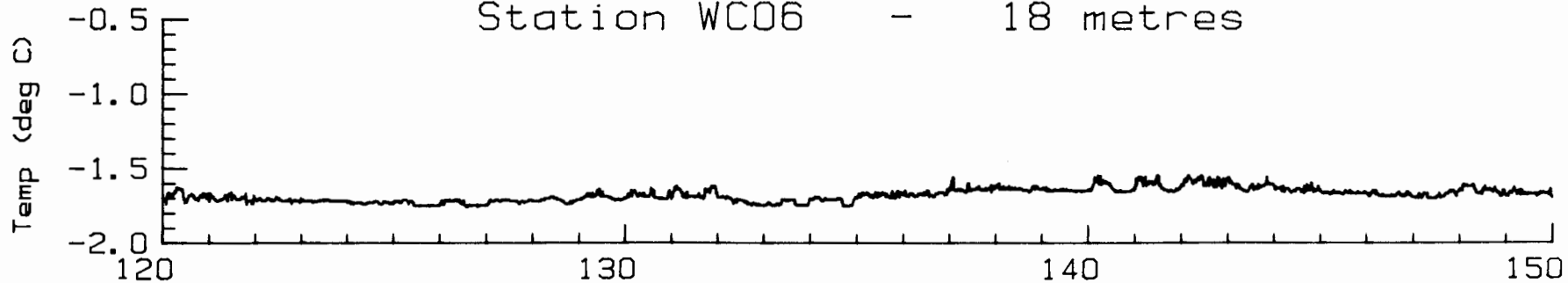
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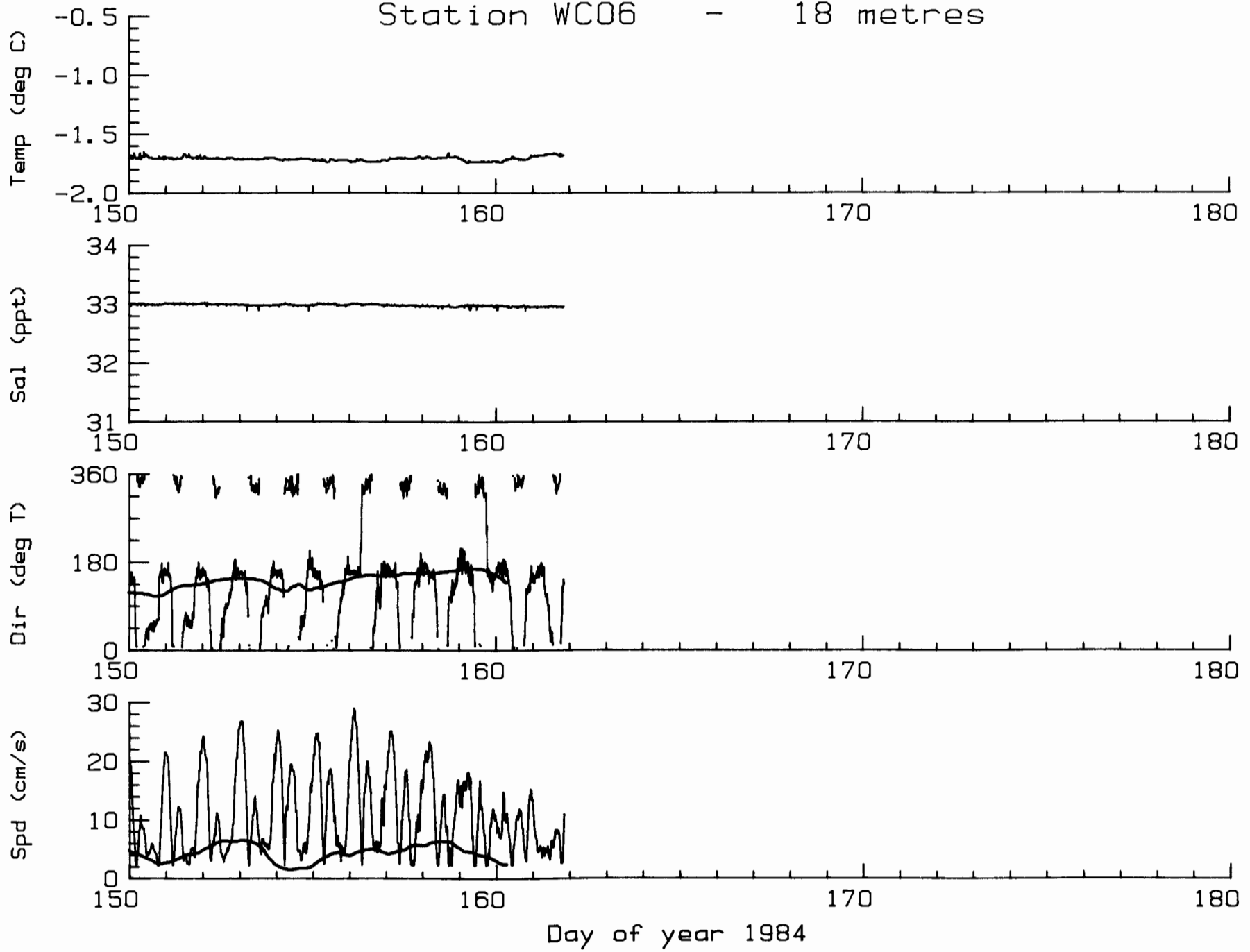


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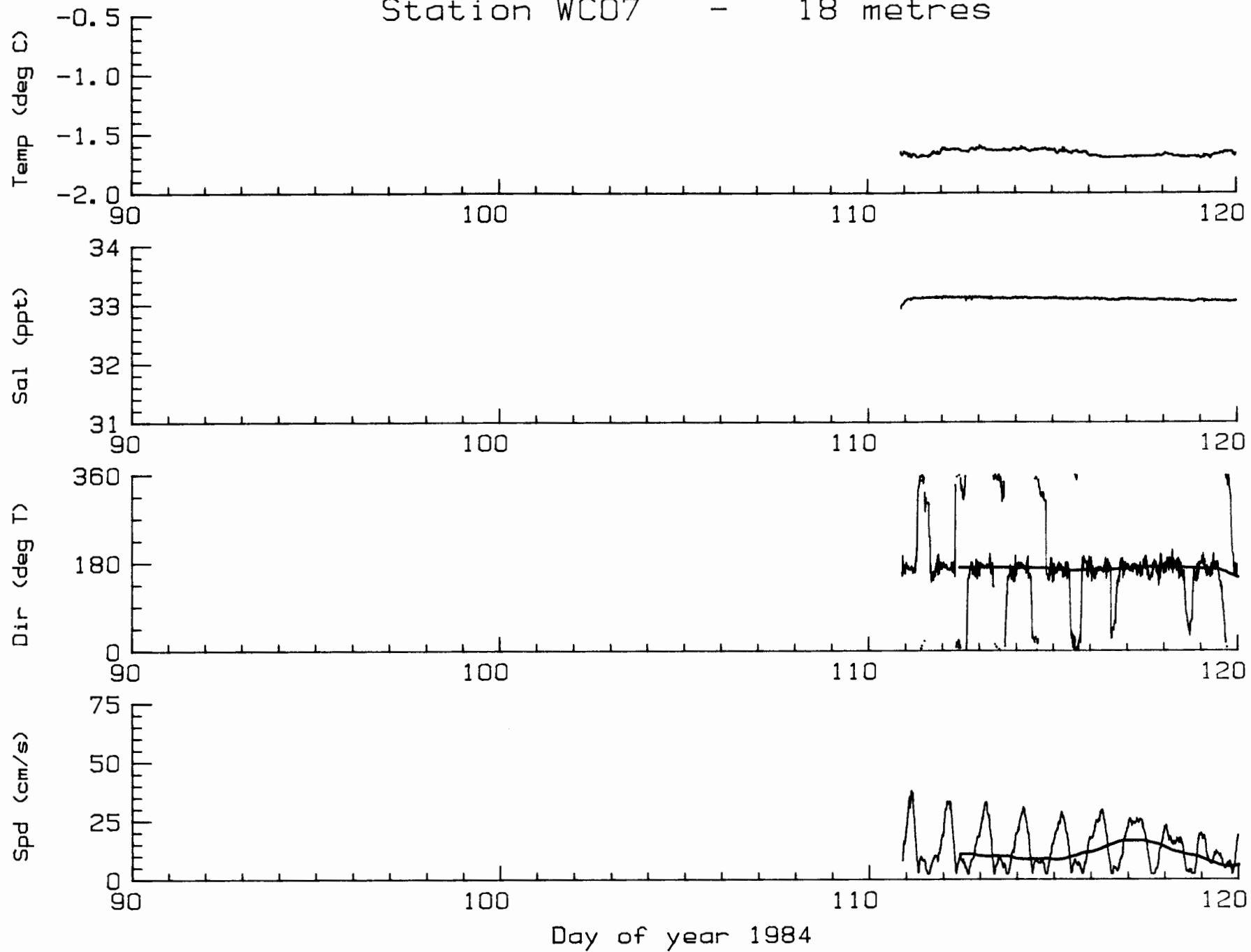


Day of year 1984

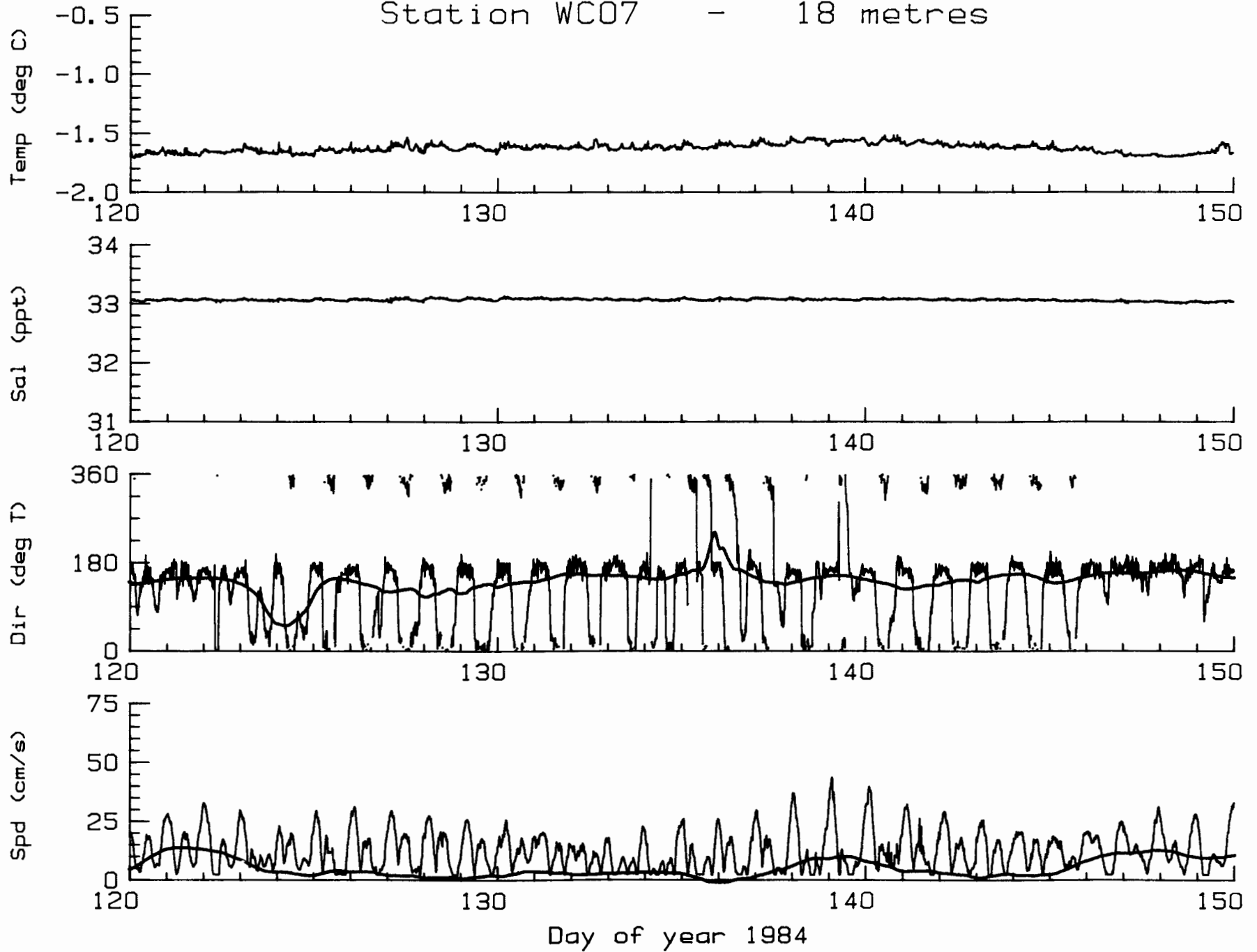
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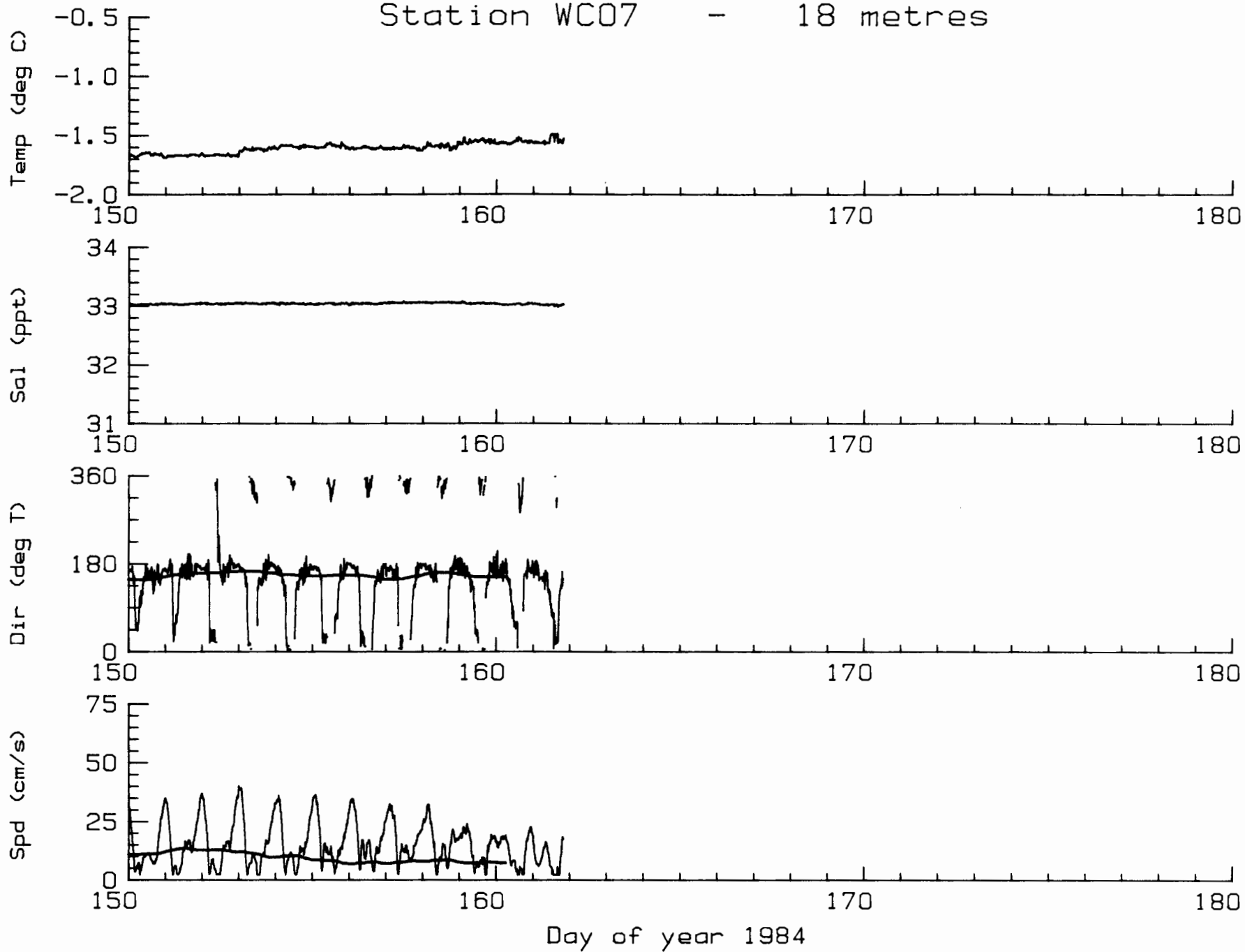
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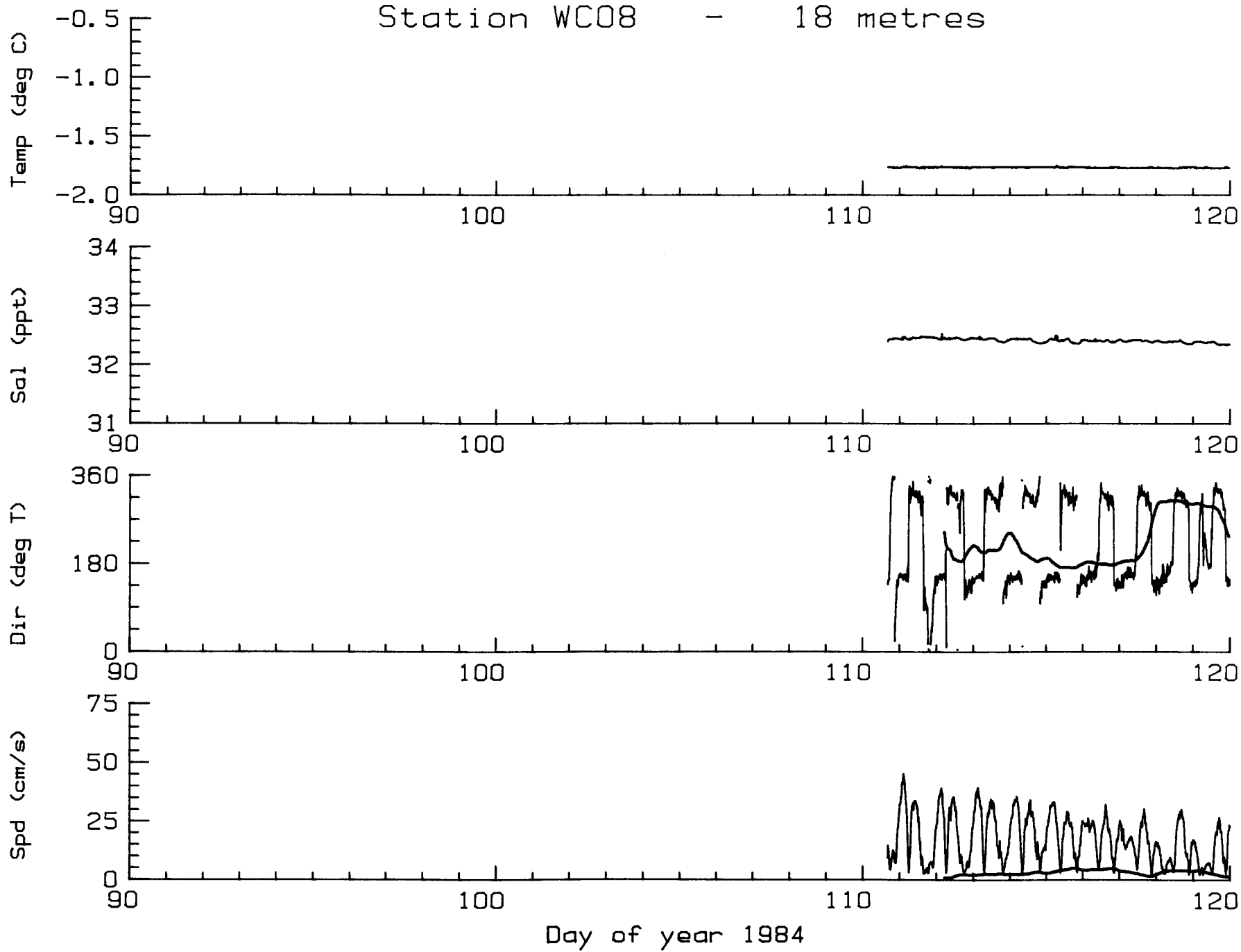
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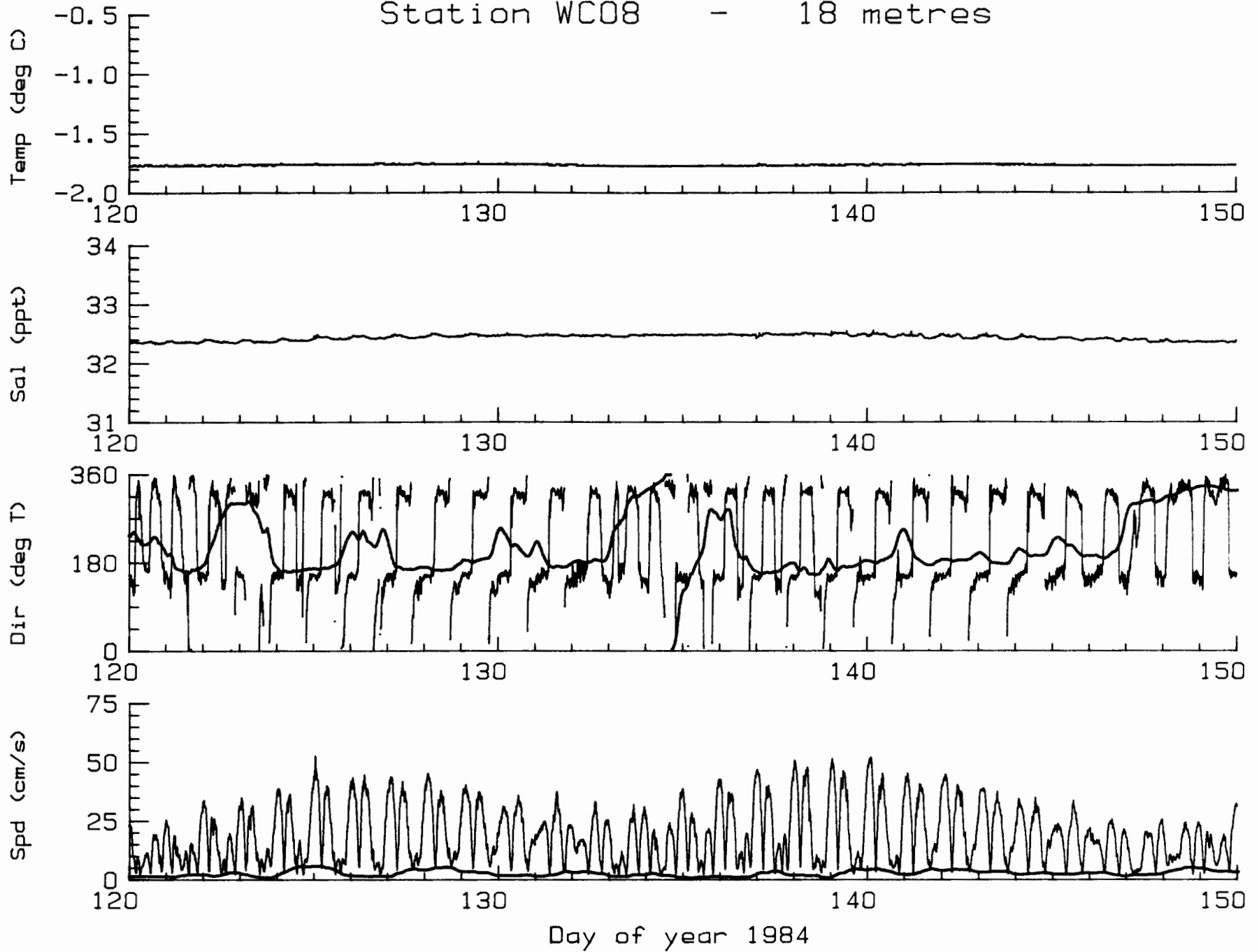
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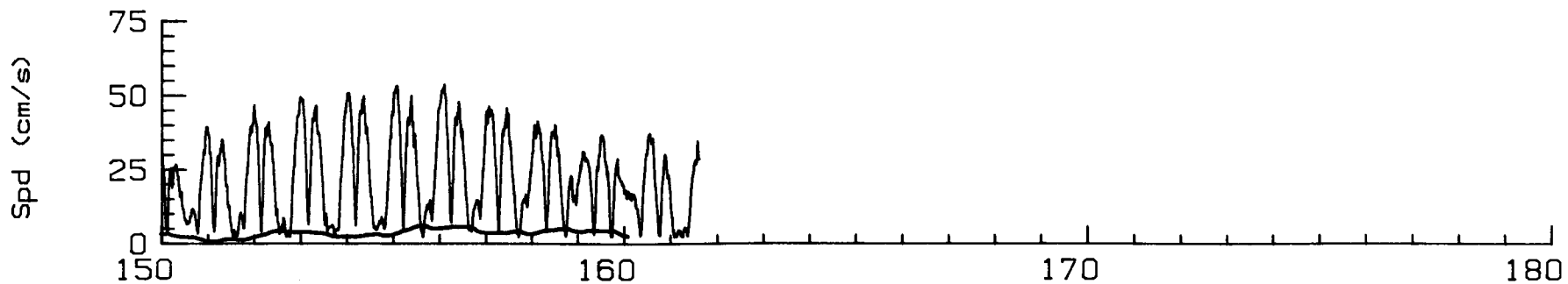
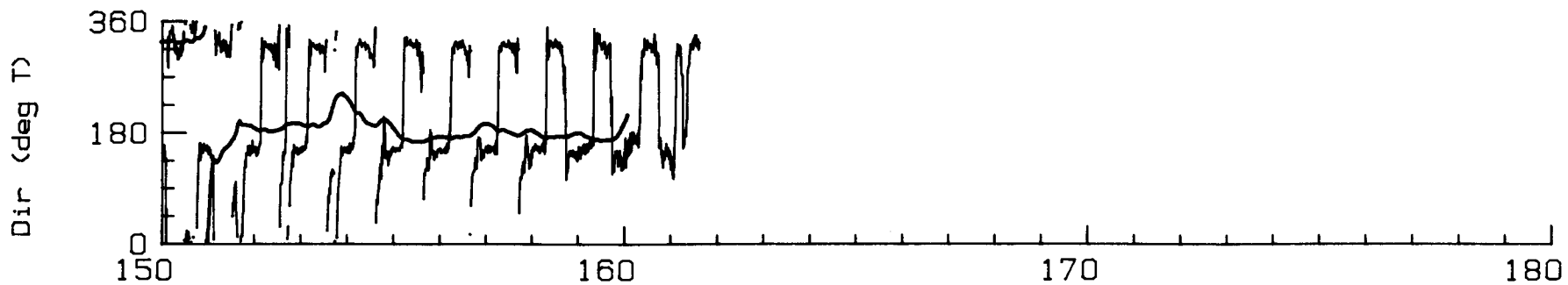
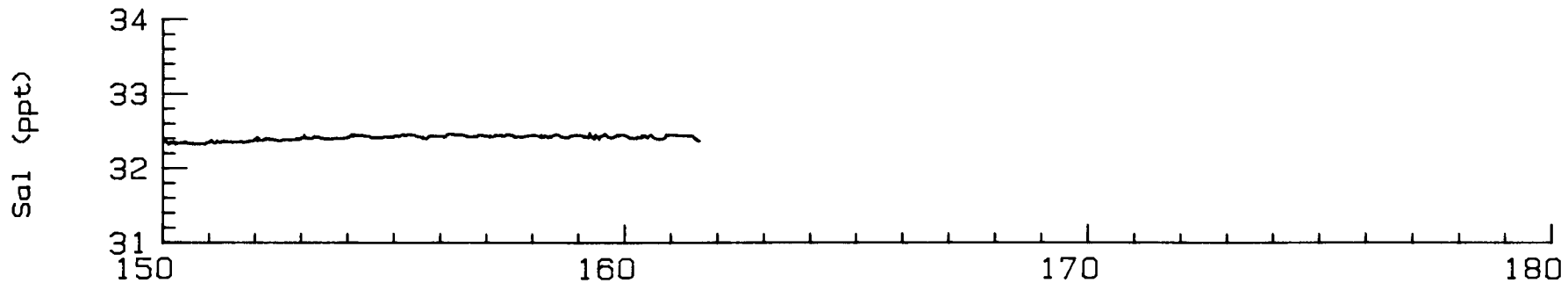
Station WCO8 - 18 metres



Station WCO8 - 18 metres

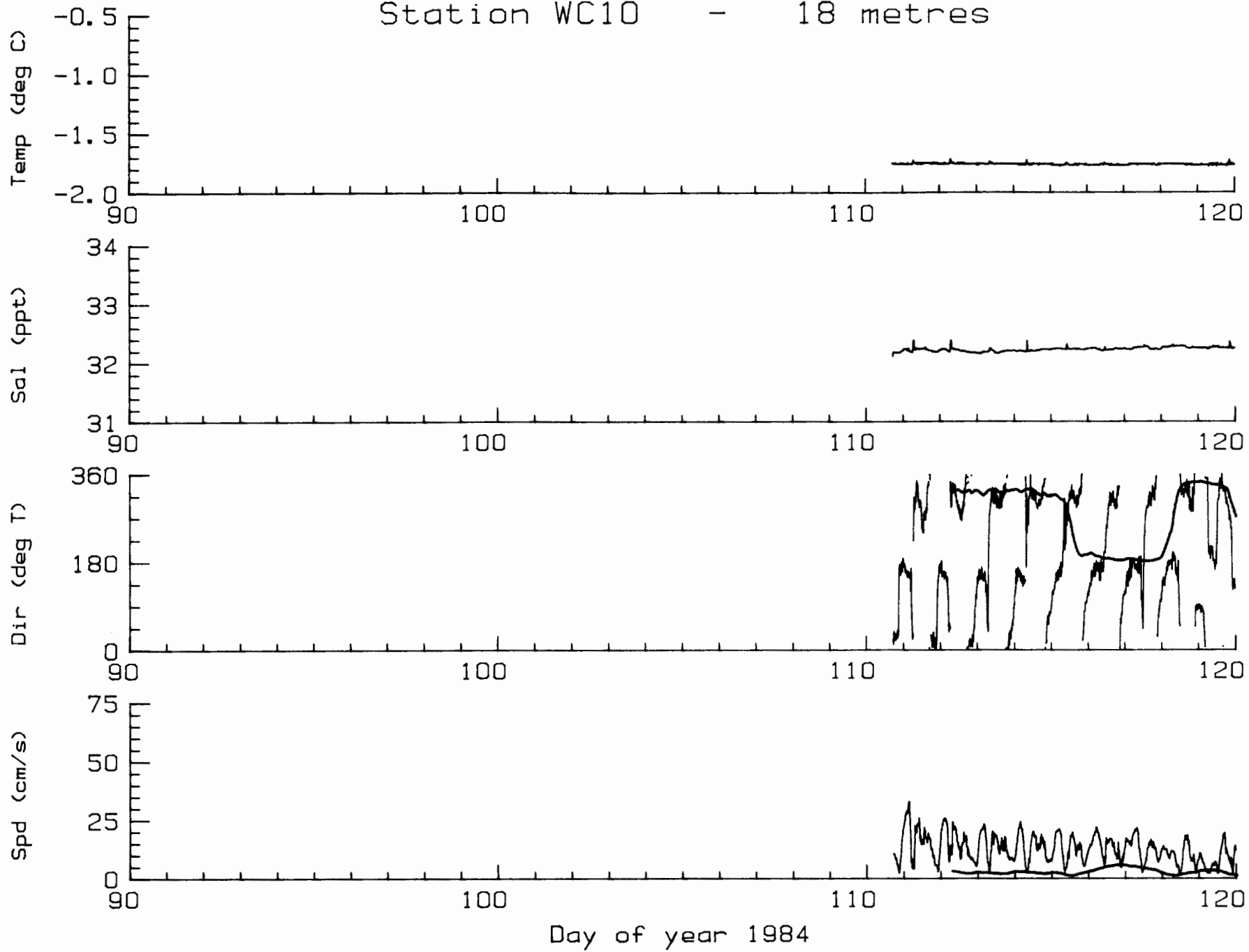


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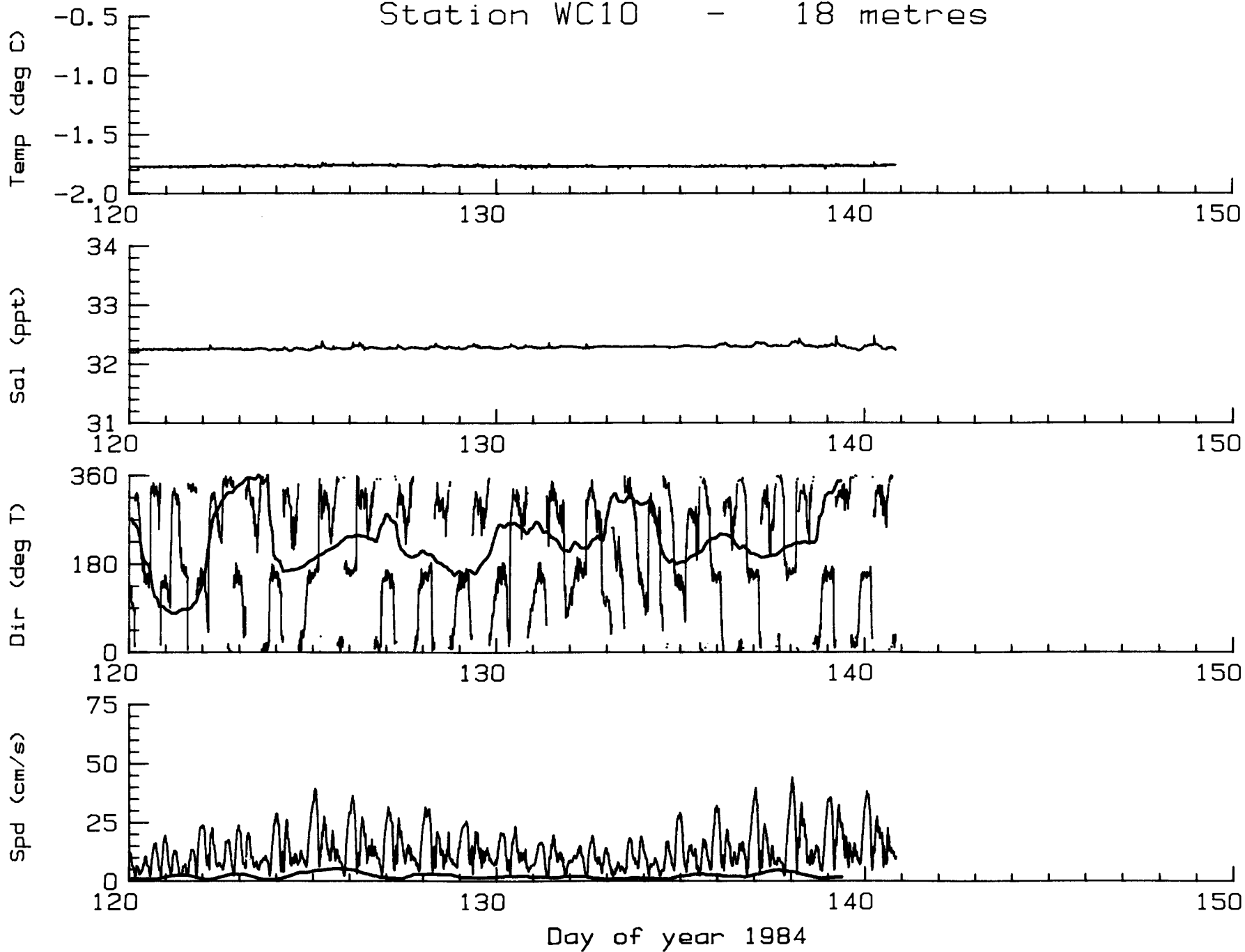


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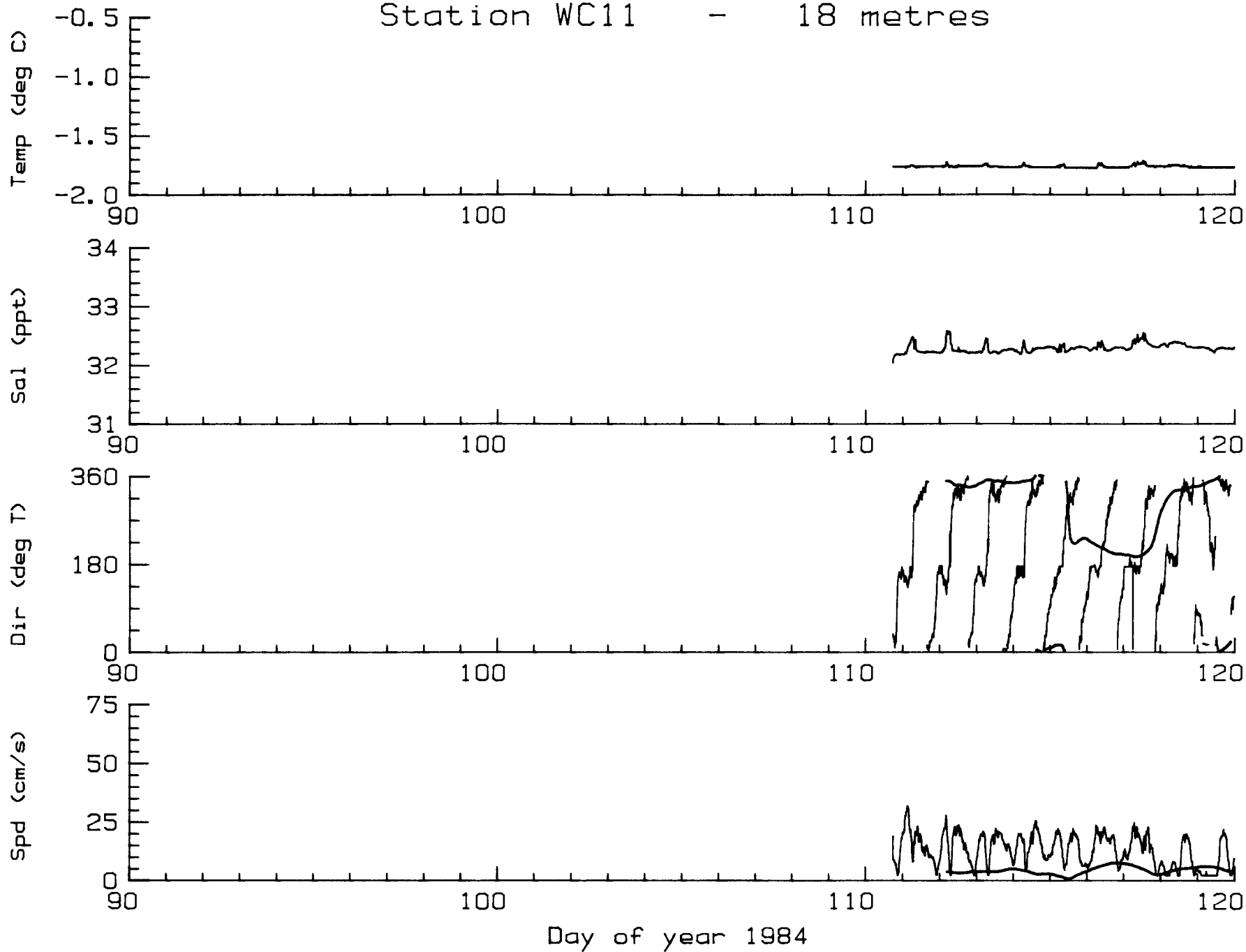
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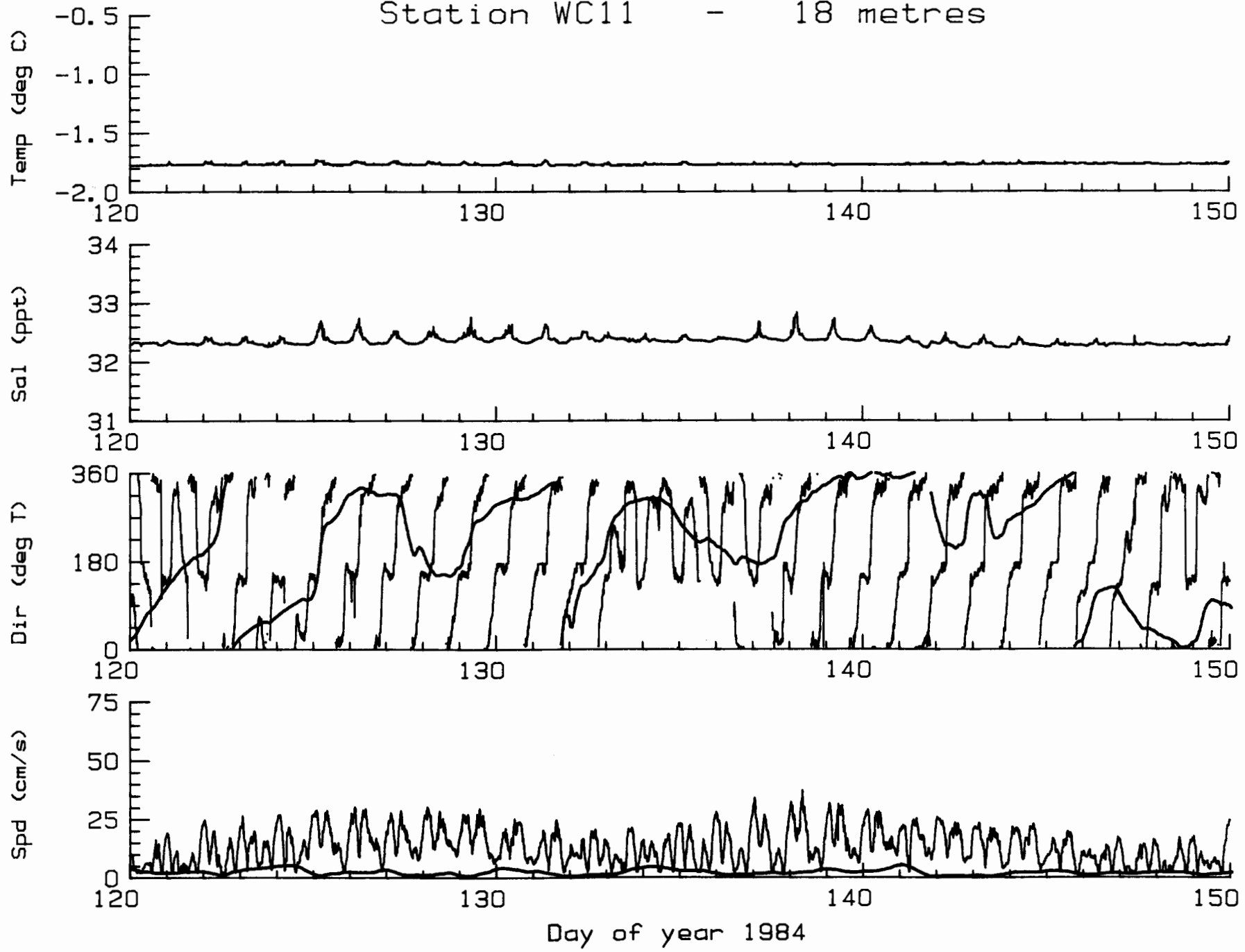
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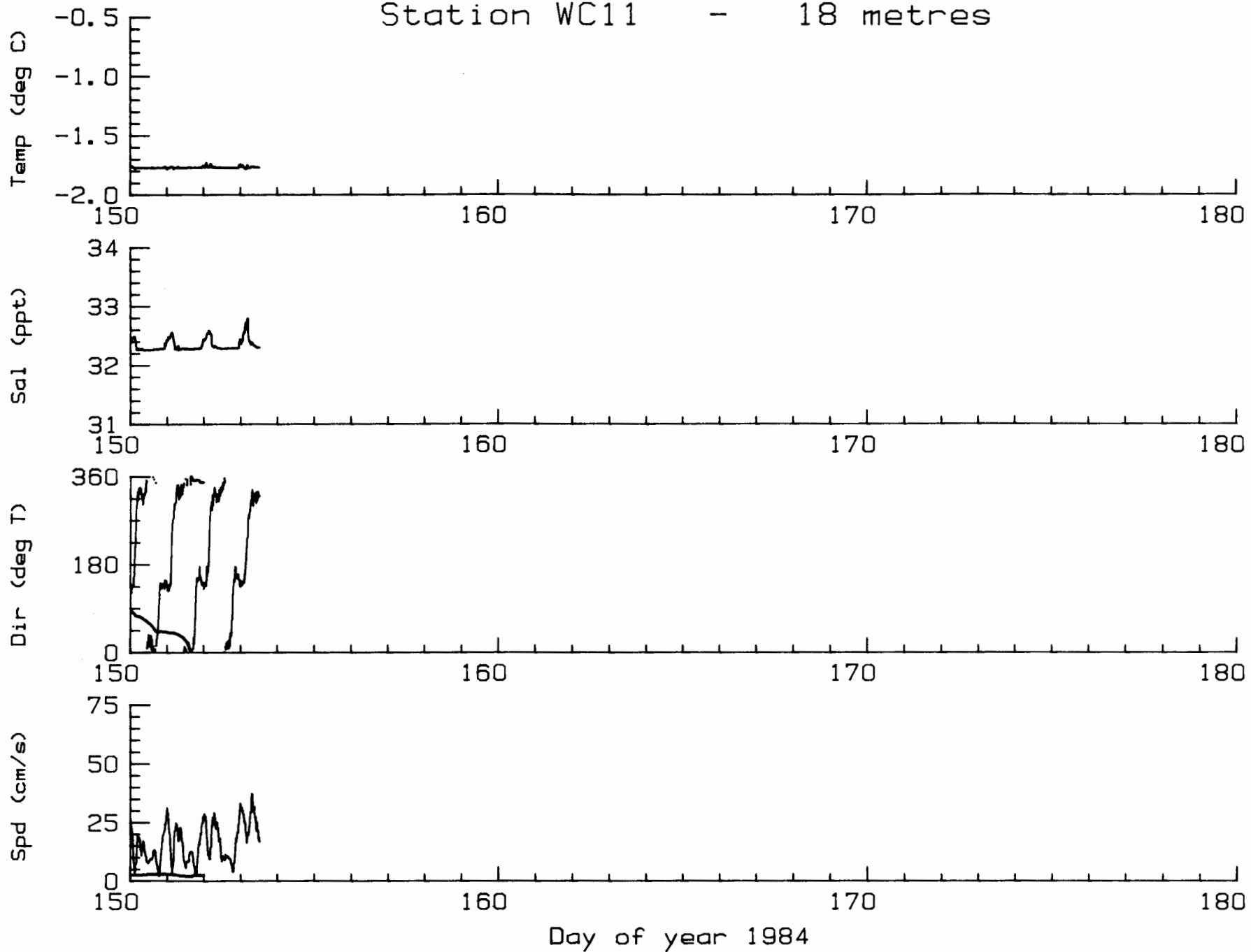
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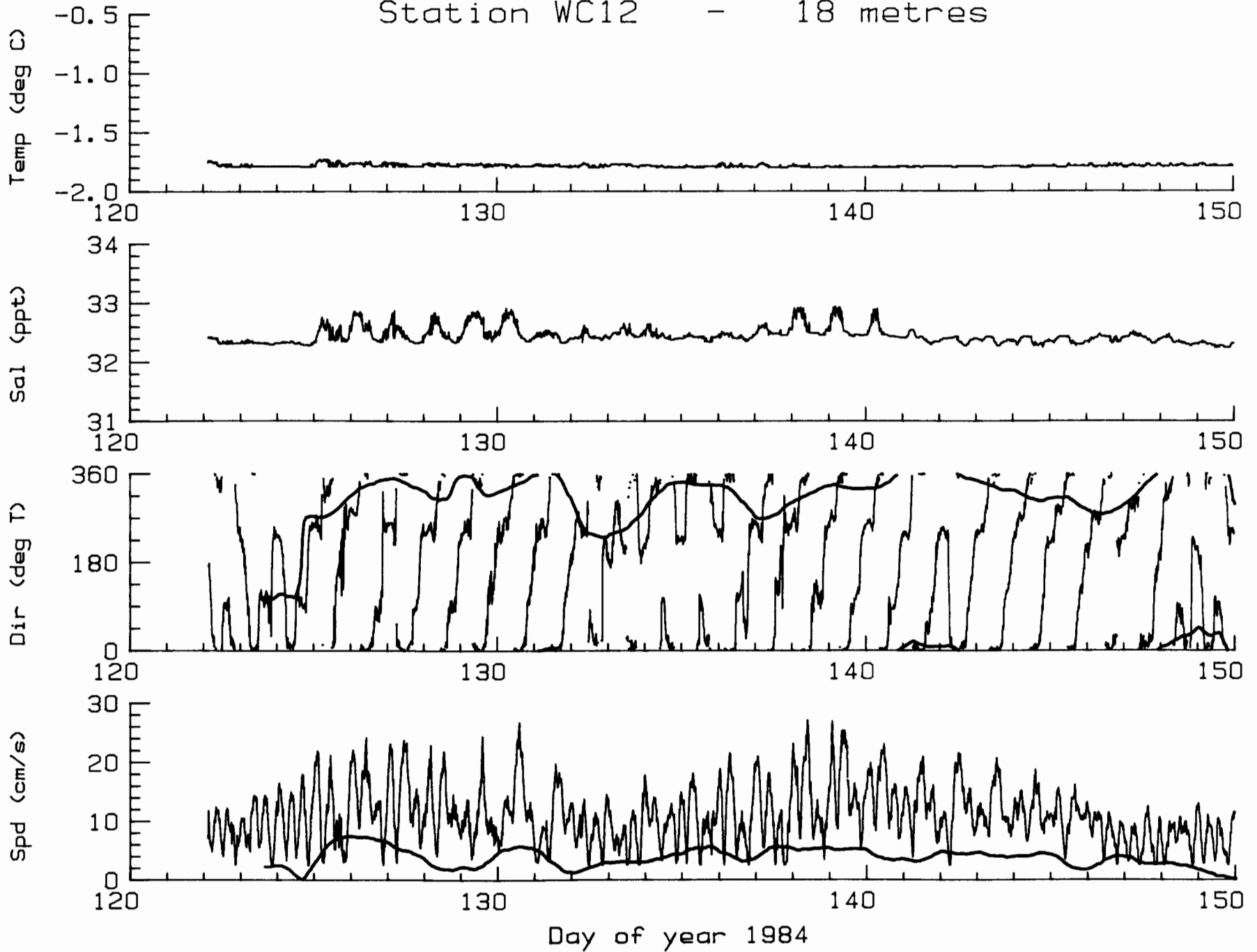
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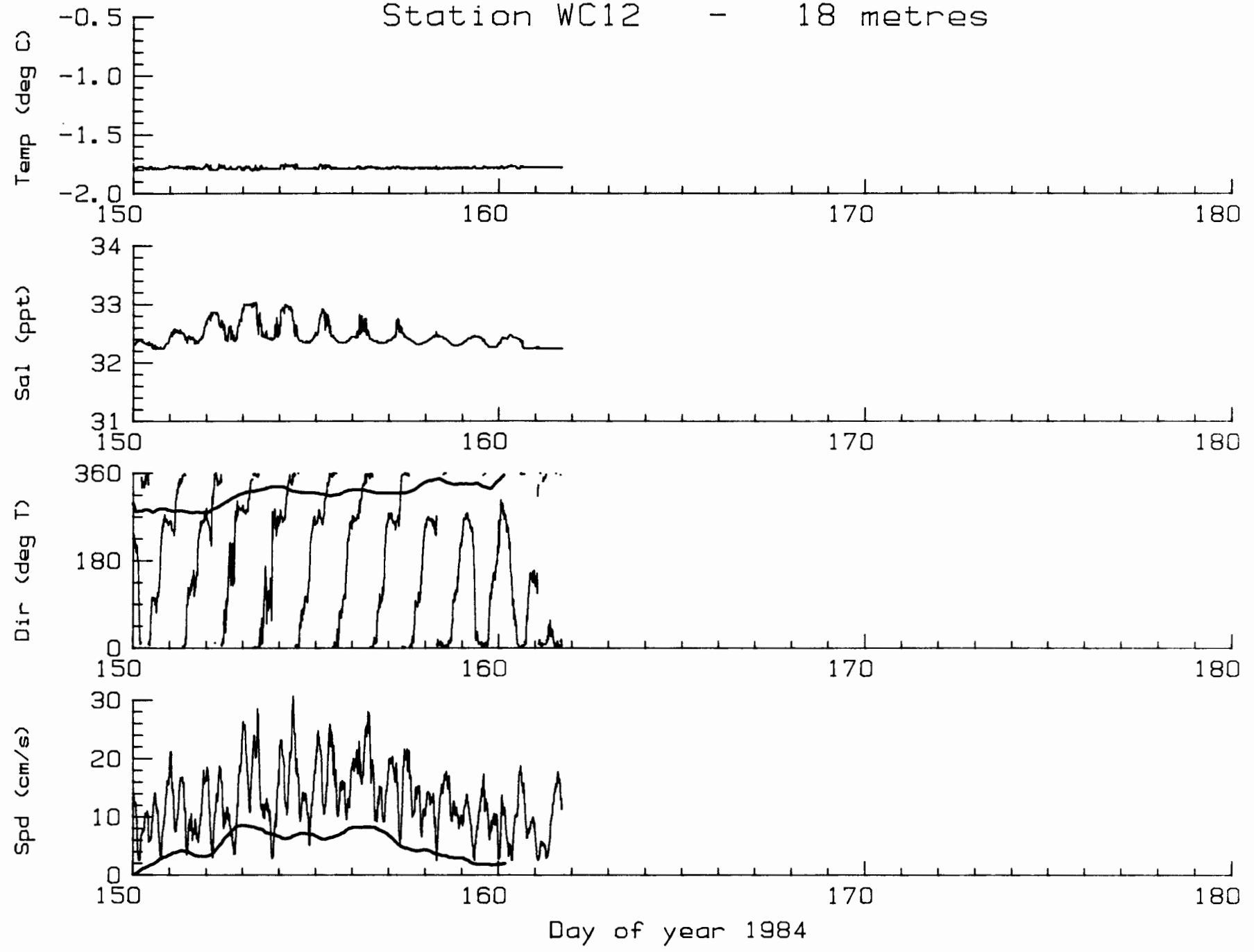
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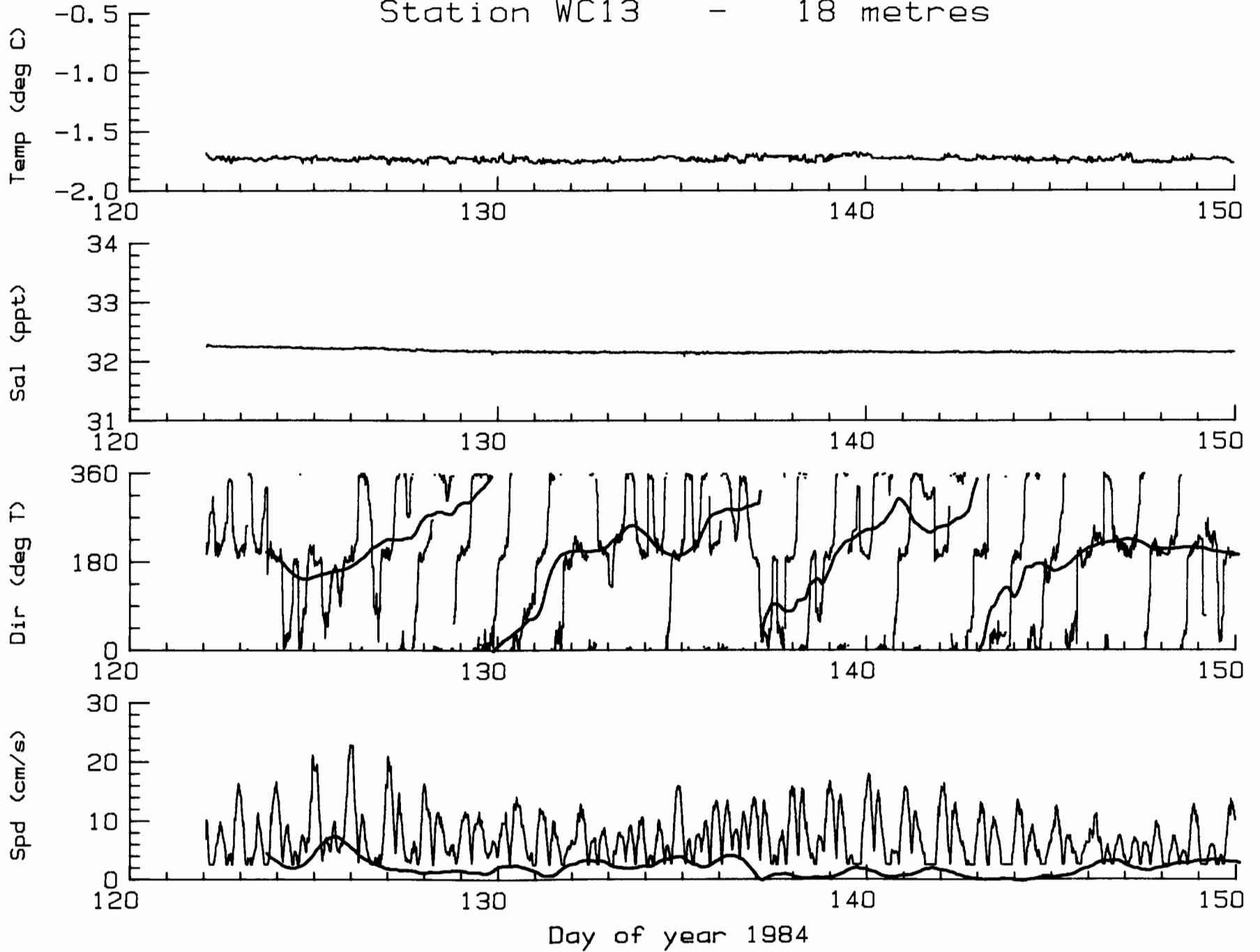
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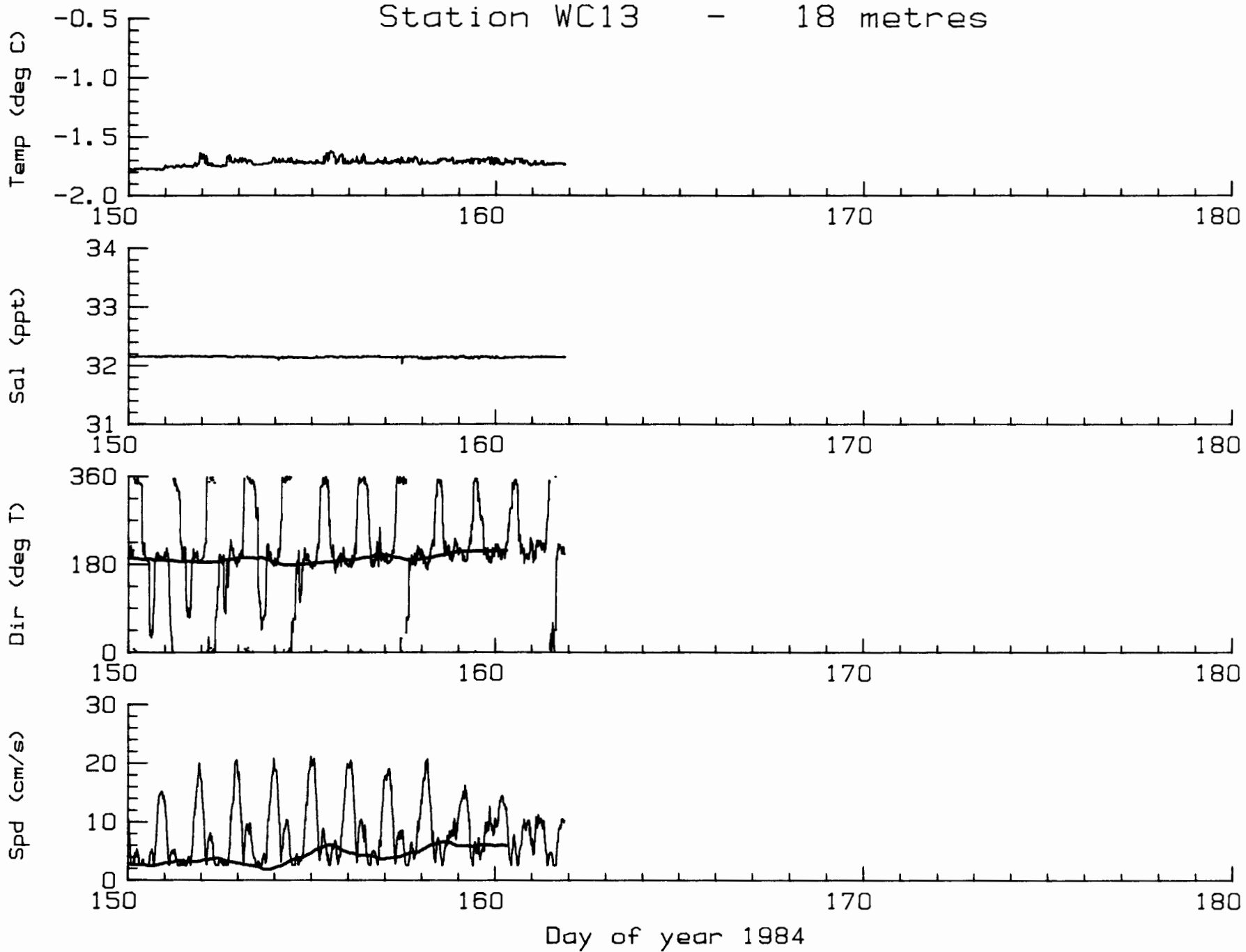
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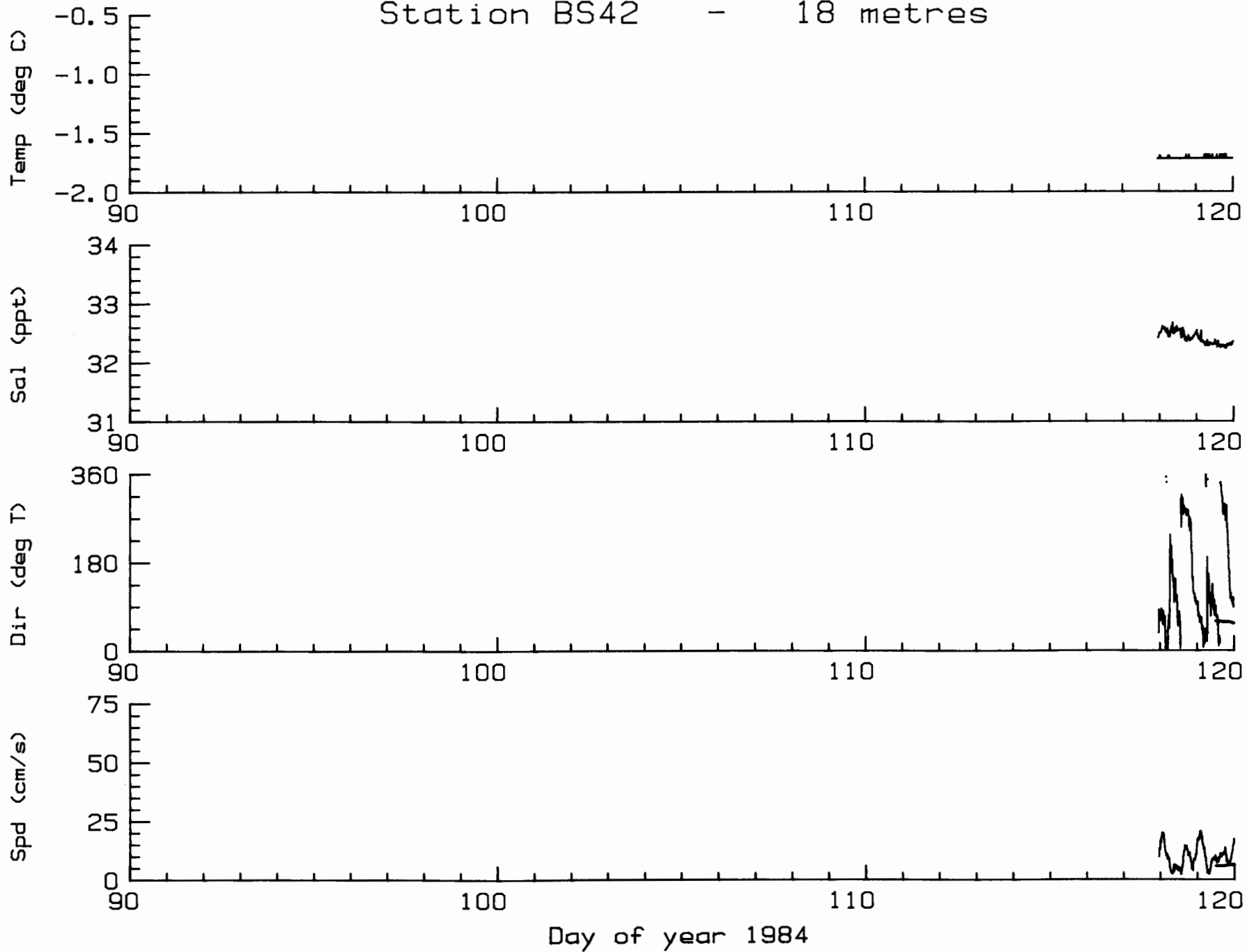
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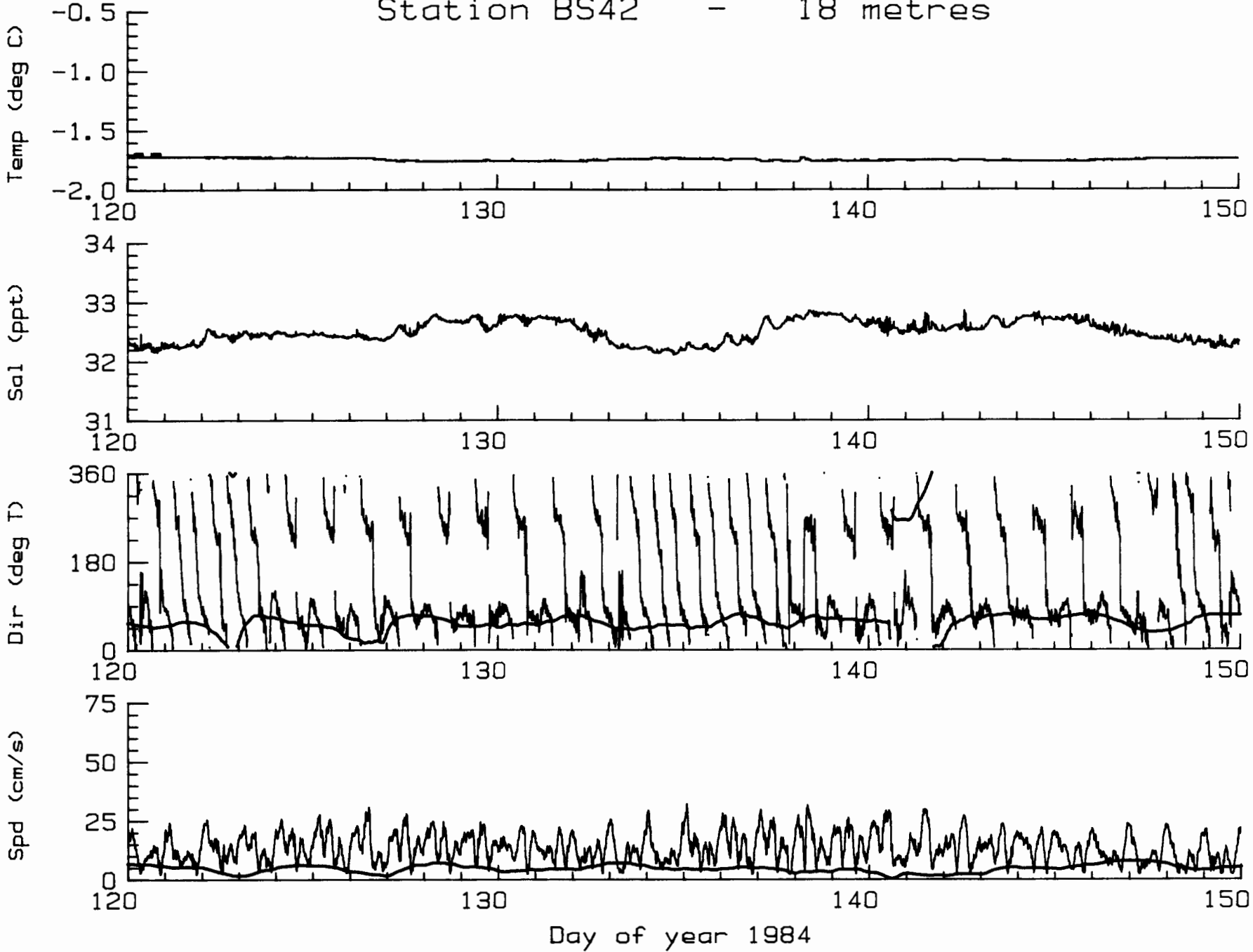
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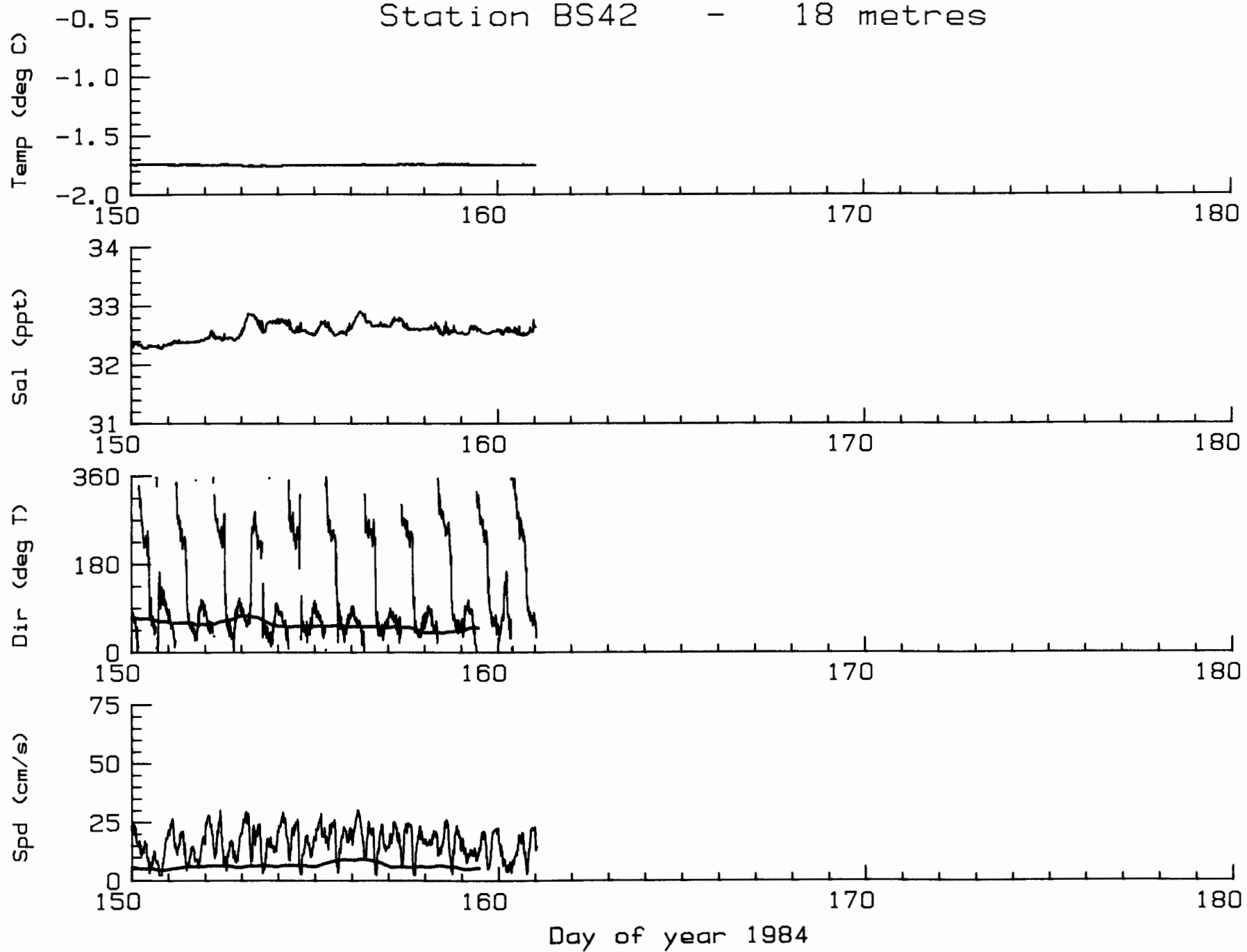
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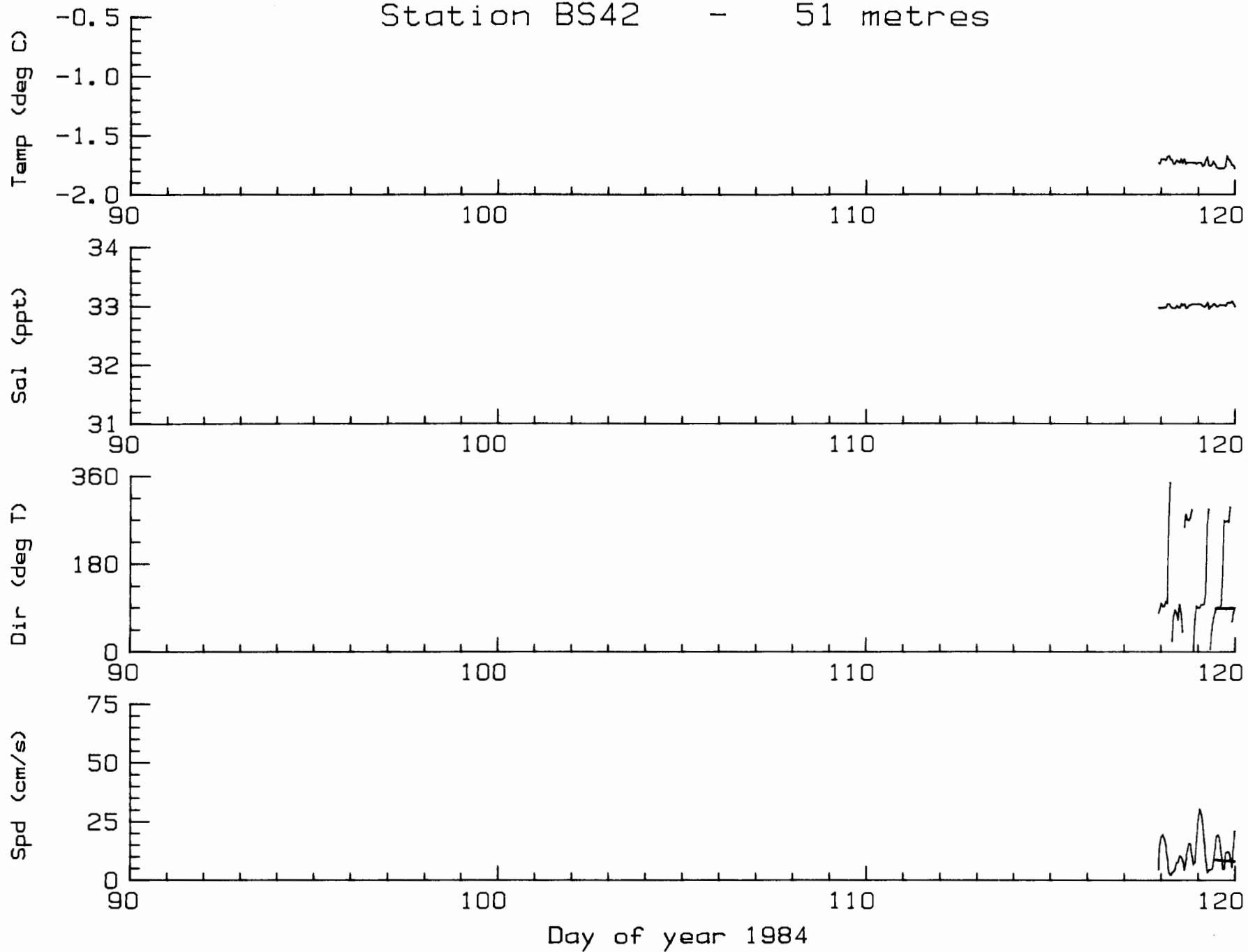
Station BS42 - 18 metres



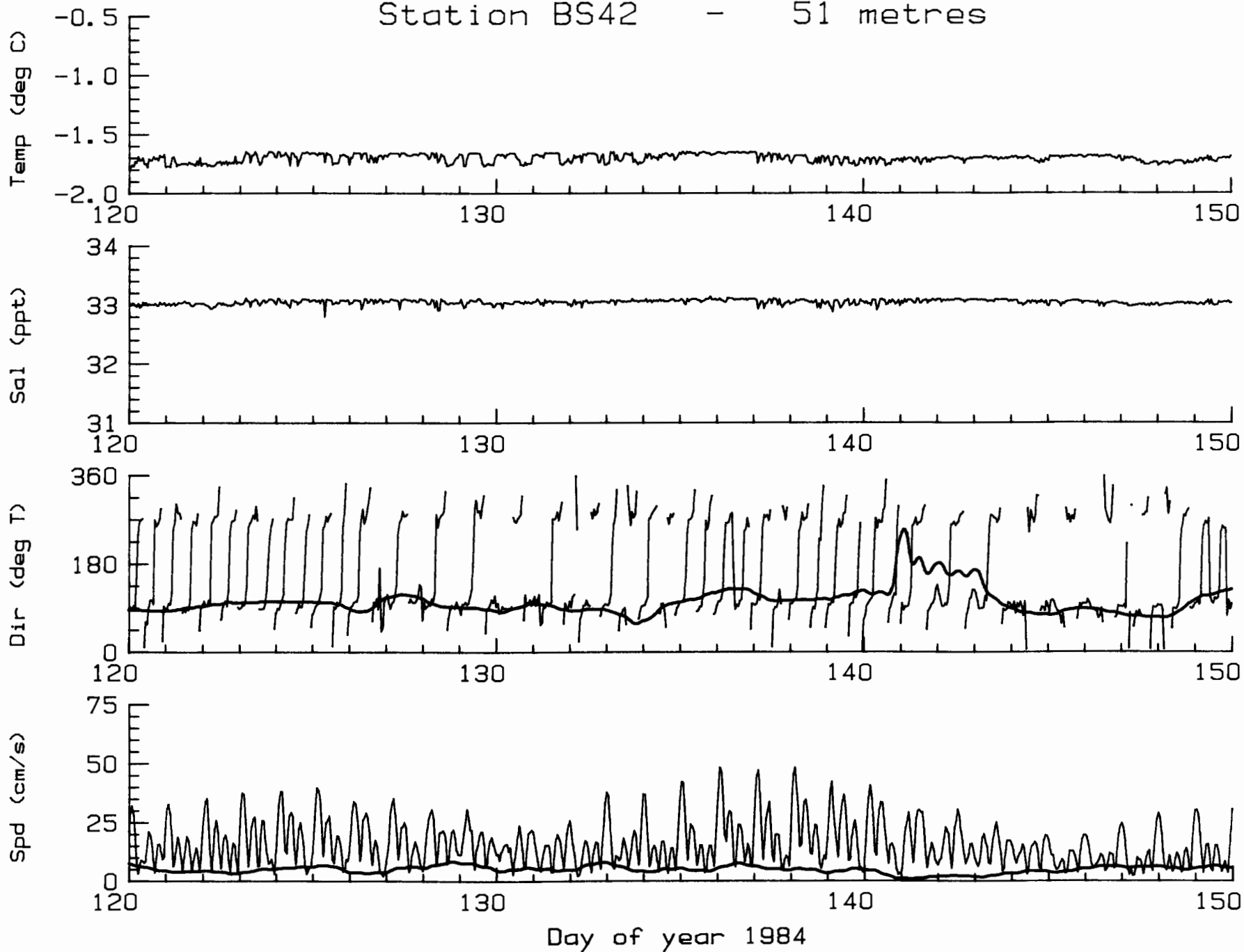
Station BS42 - 18 metres



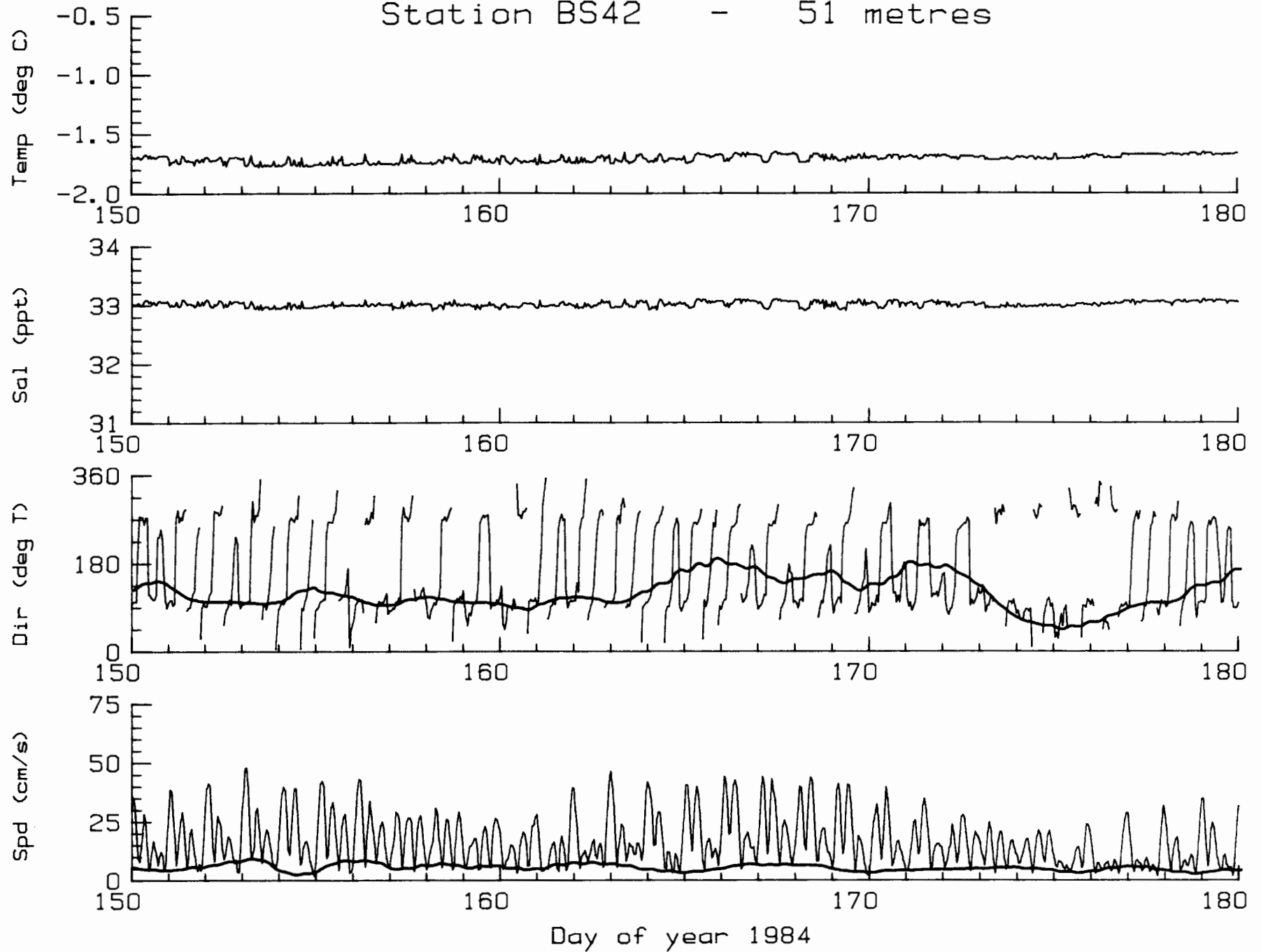
Station BS42 - 51 metres



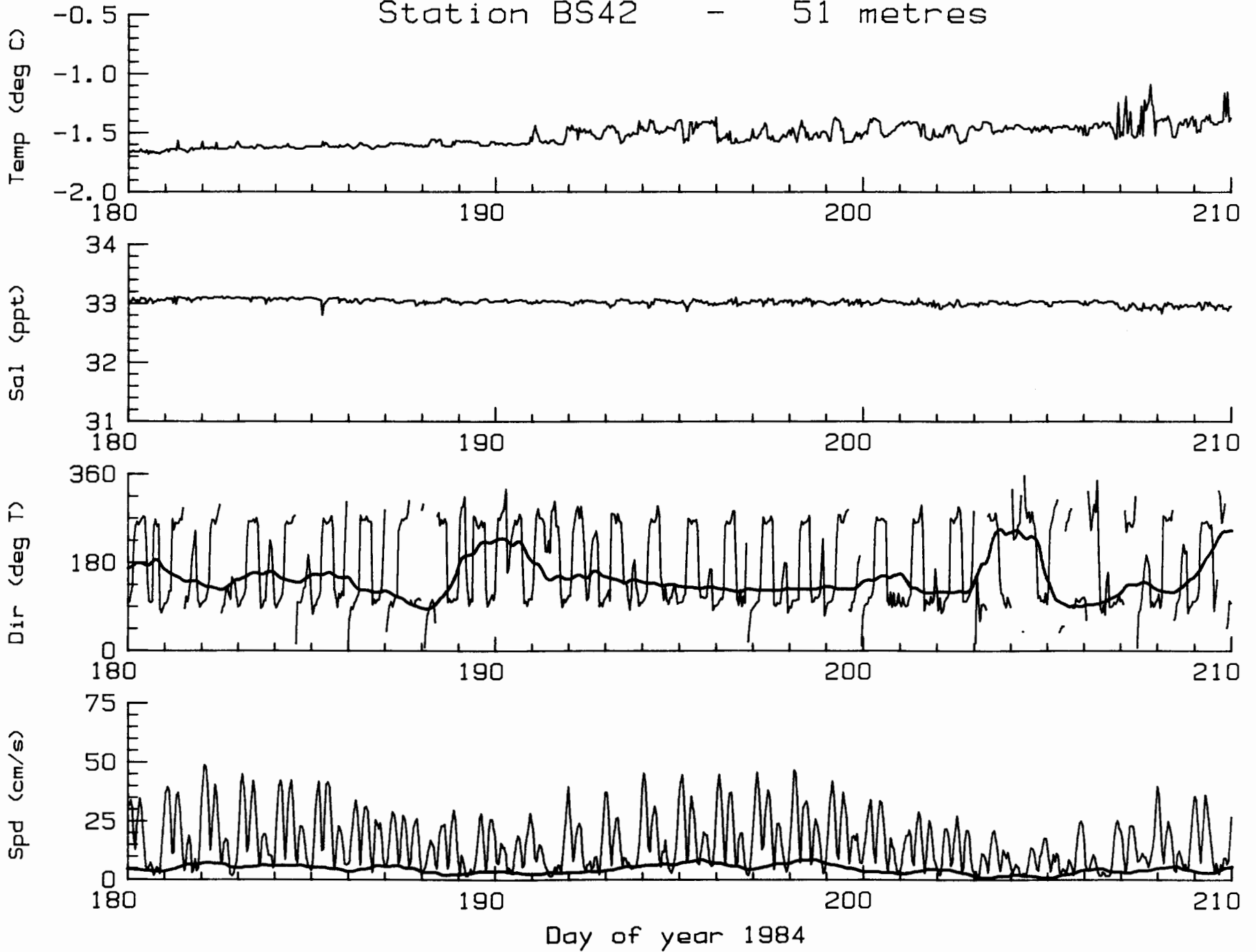
Station BS42 - 51 metres

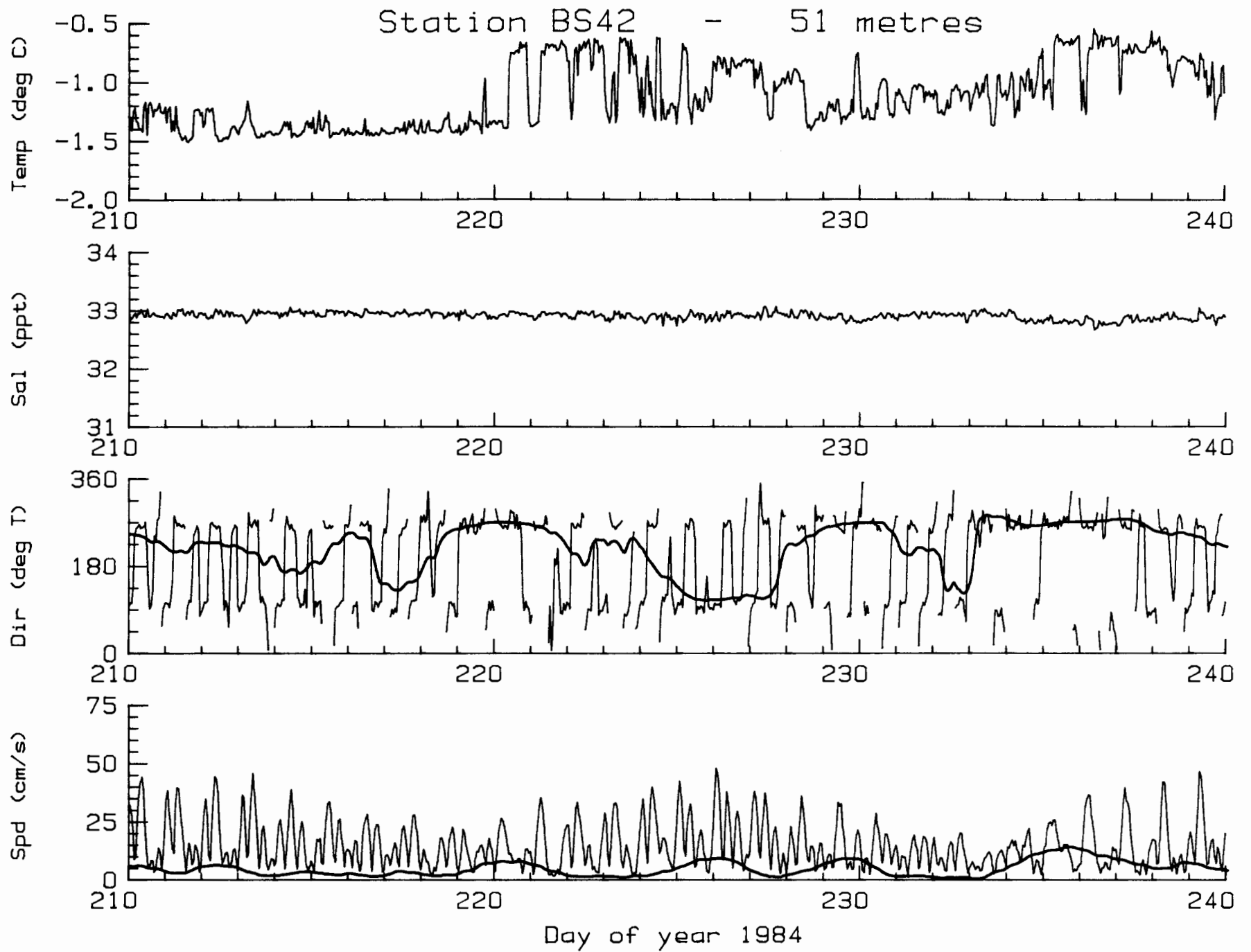


Station BS42 - 51 metres

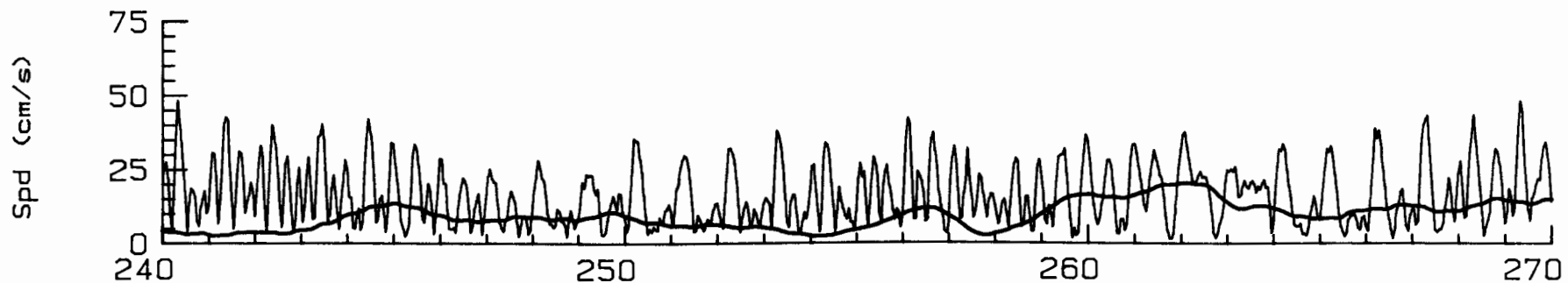
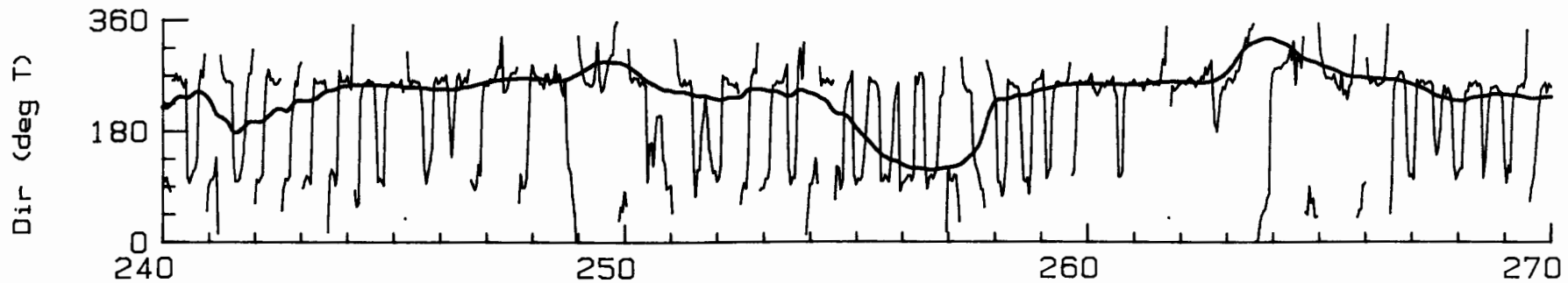
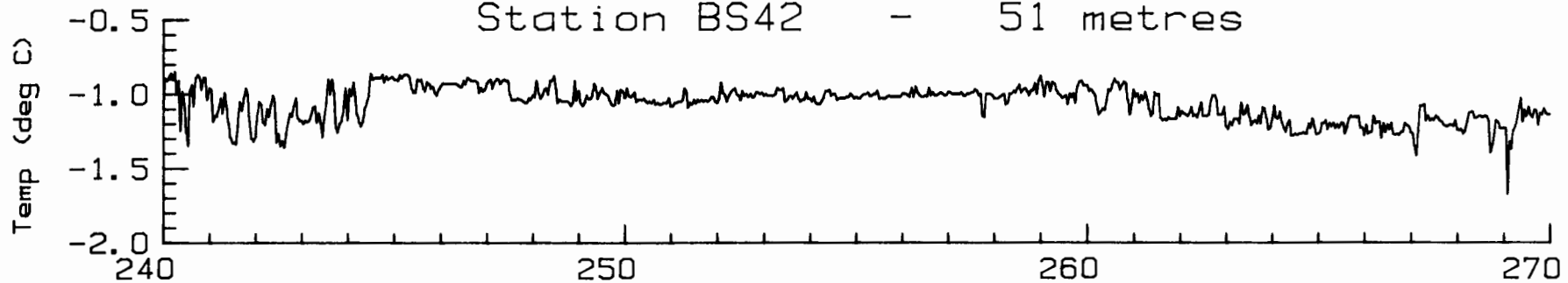


Station BS42 - 51 metres



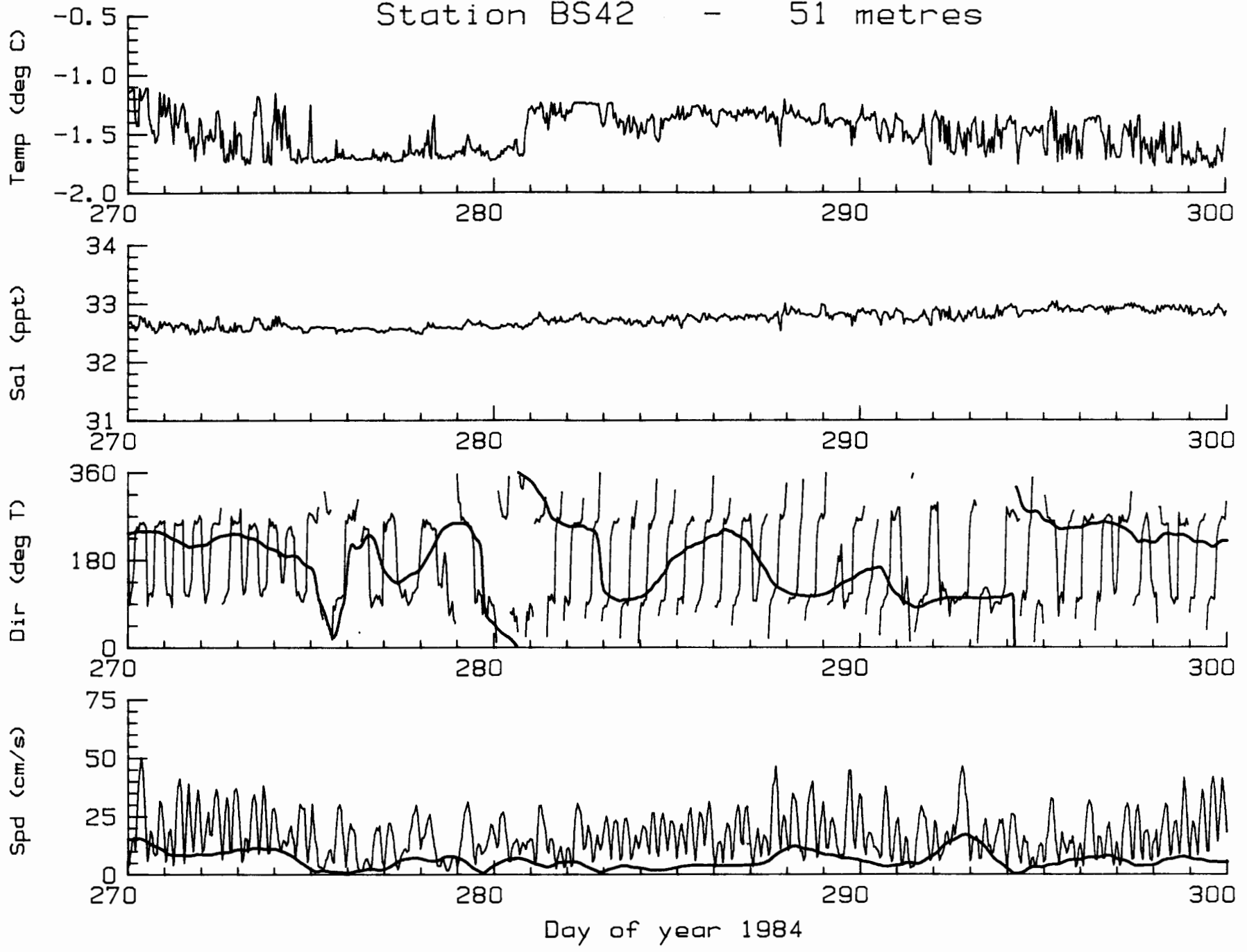


Station BS42 - 51 metres

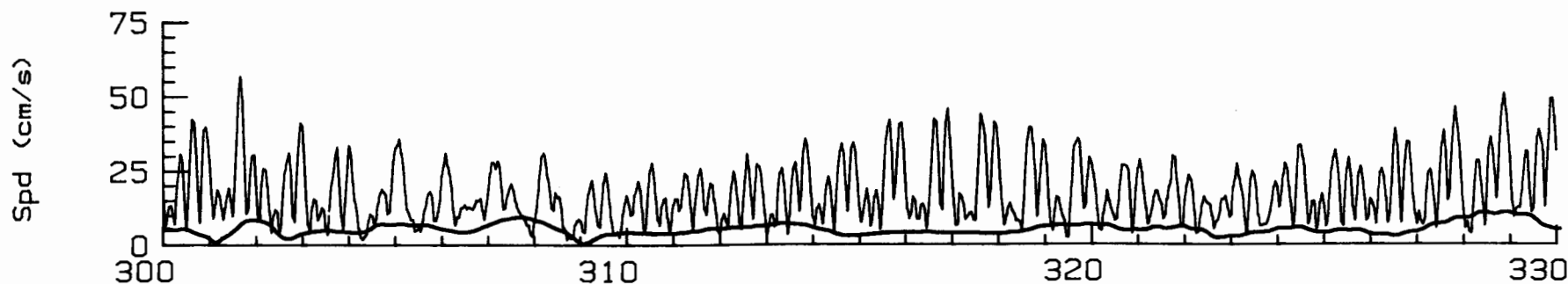
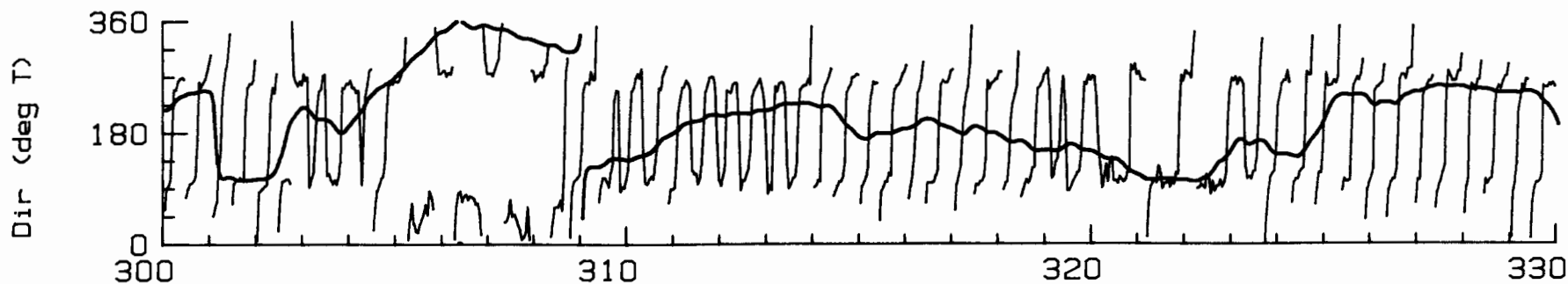
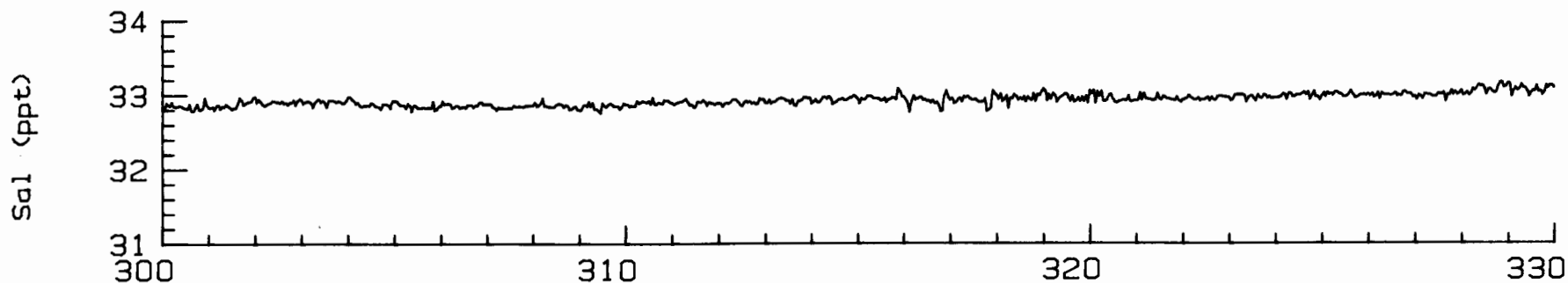
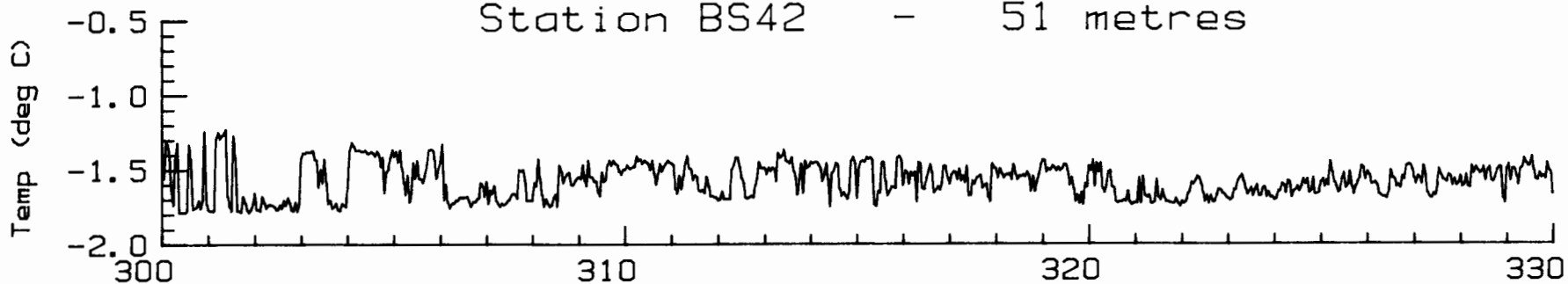


Day of year 1984

Station BS42 - 51 metres

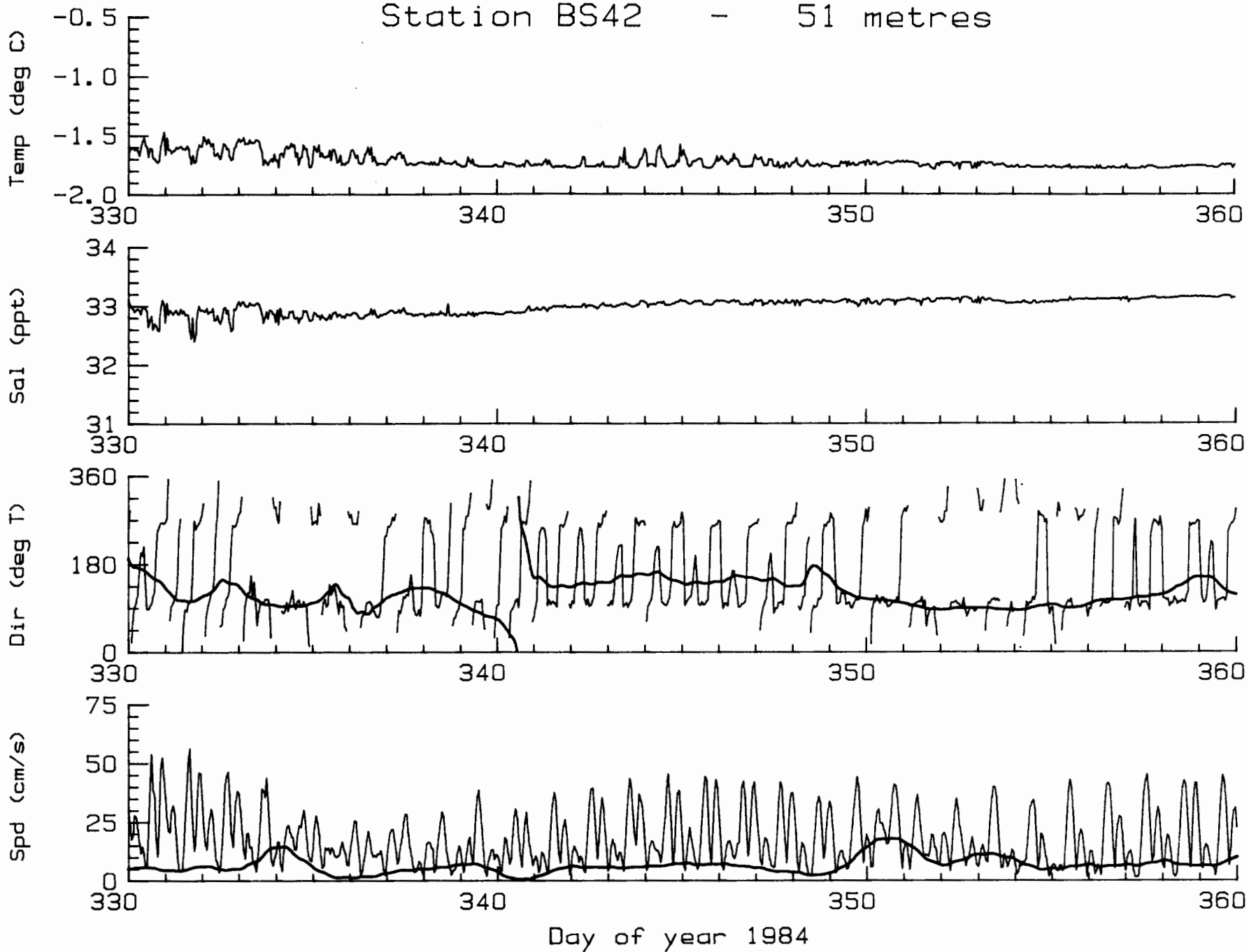


Station BS42 - 51 metres

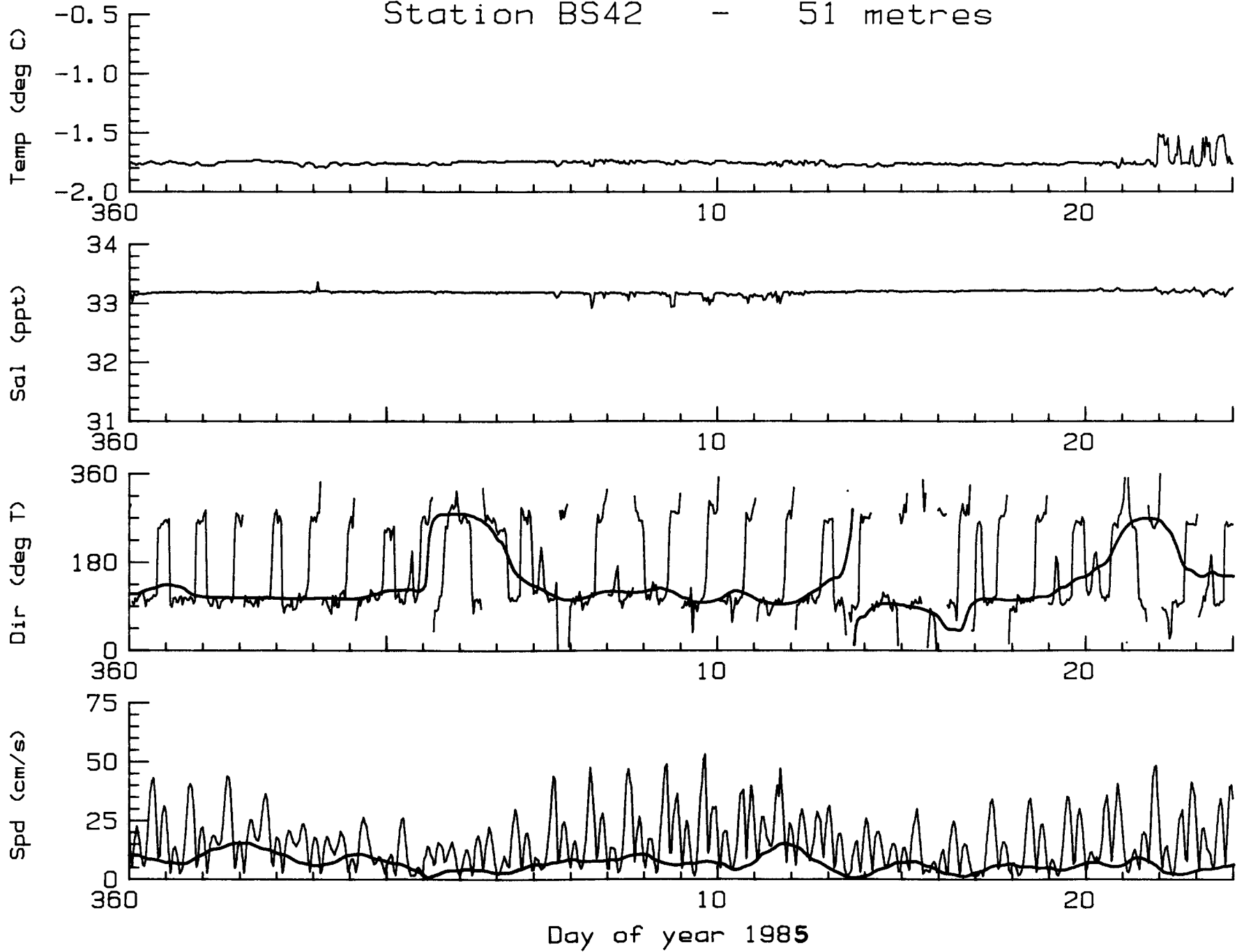


Day of year 1984

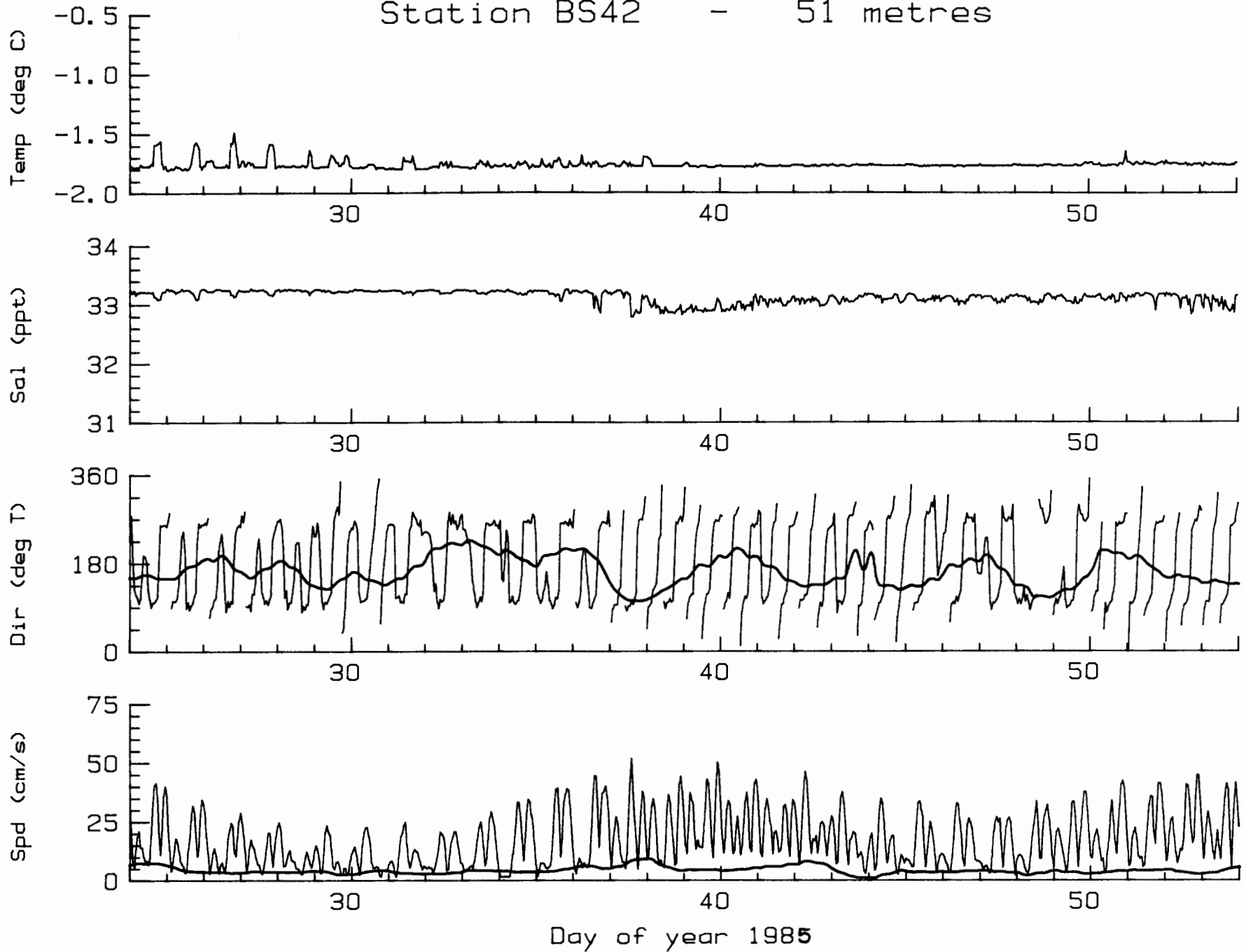
Station BS42 - 51 metres



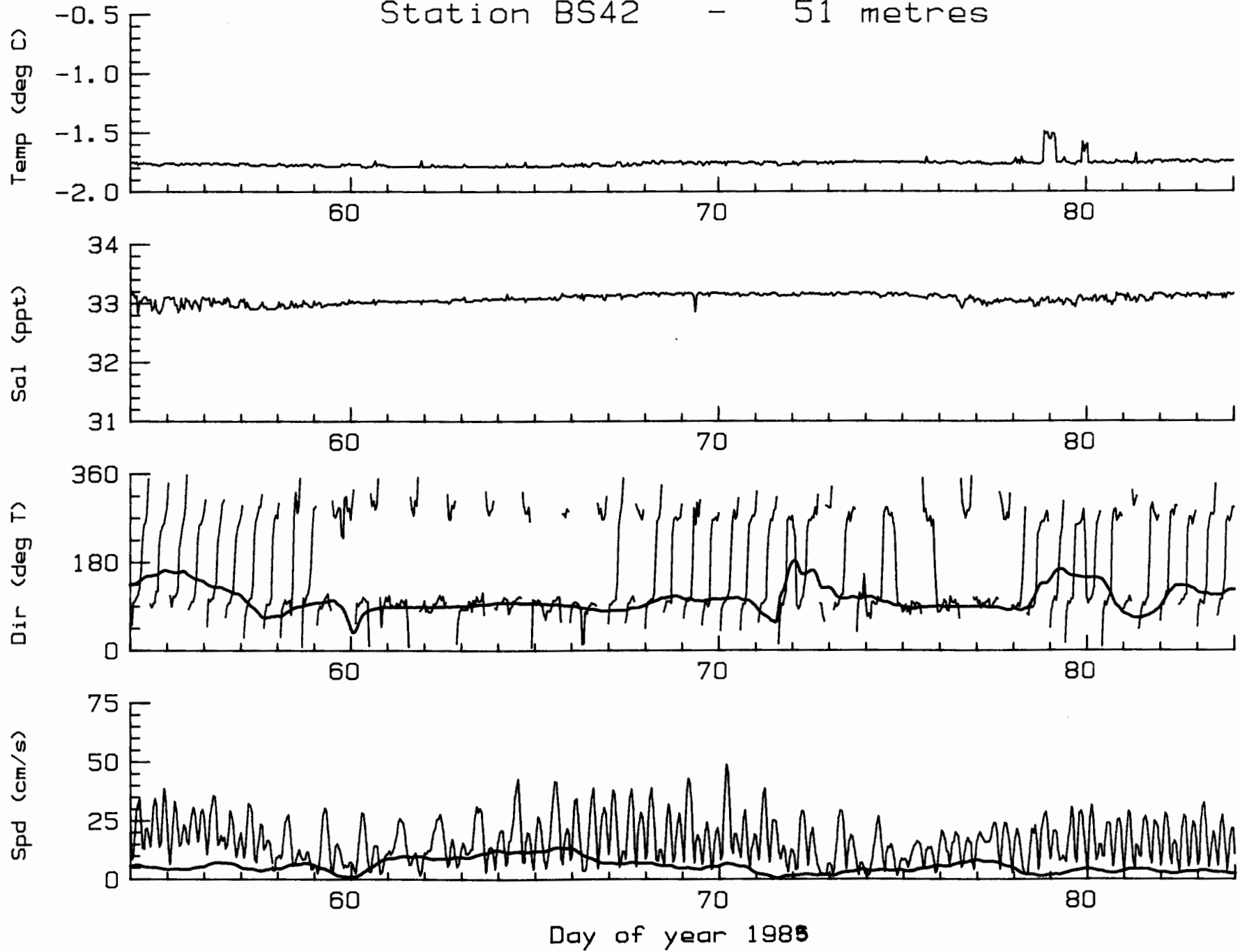
Station BS42 - 51 metres



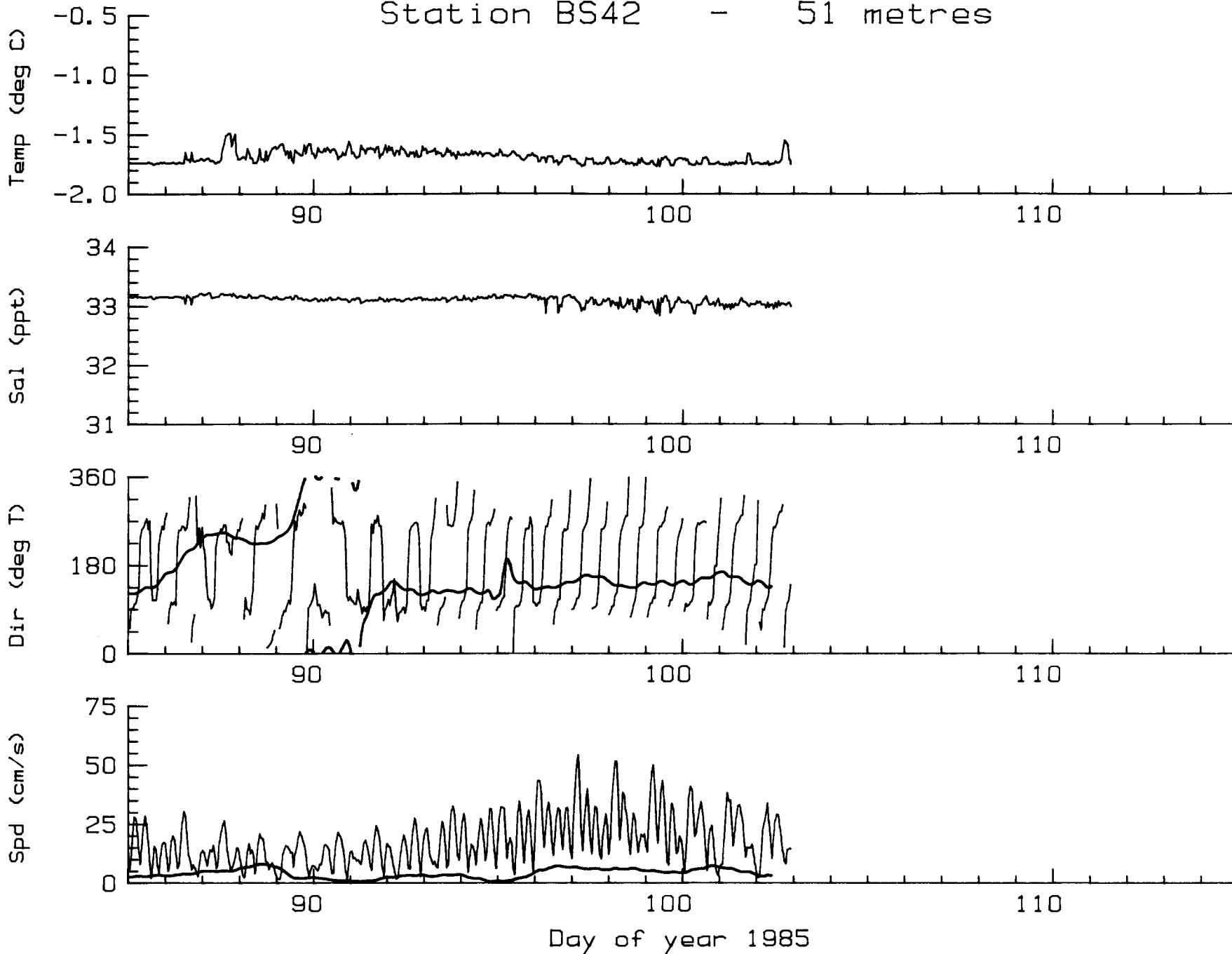
Station BS42 - 51 metres



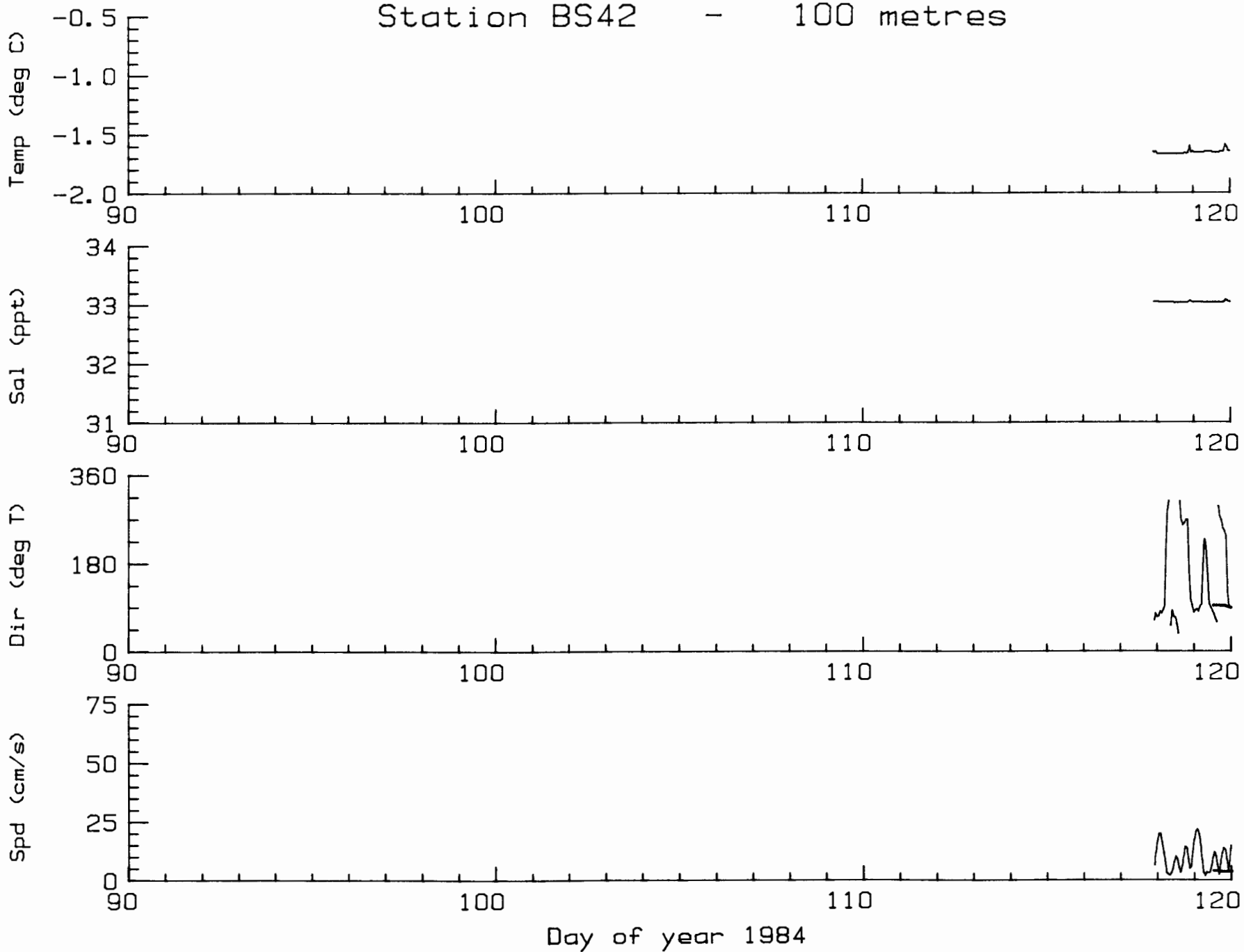
Station BS42 - 51 metres



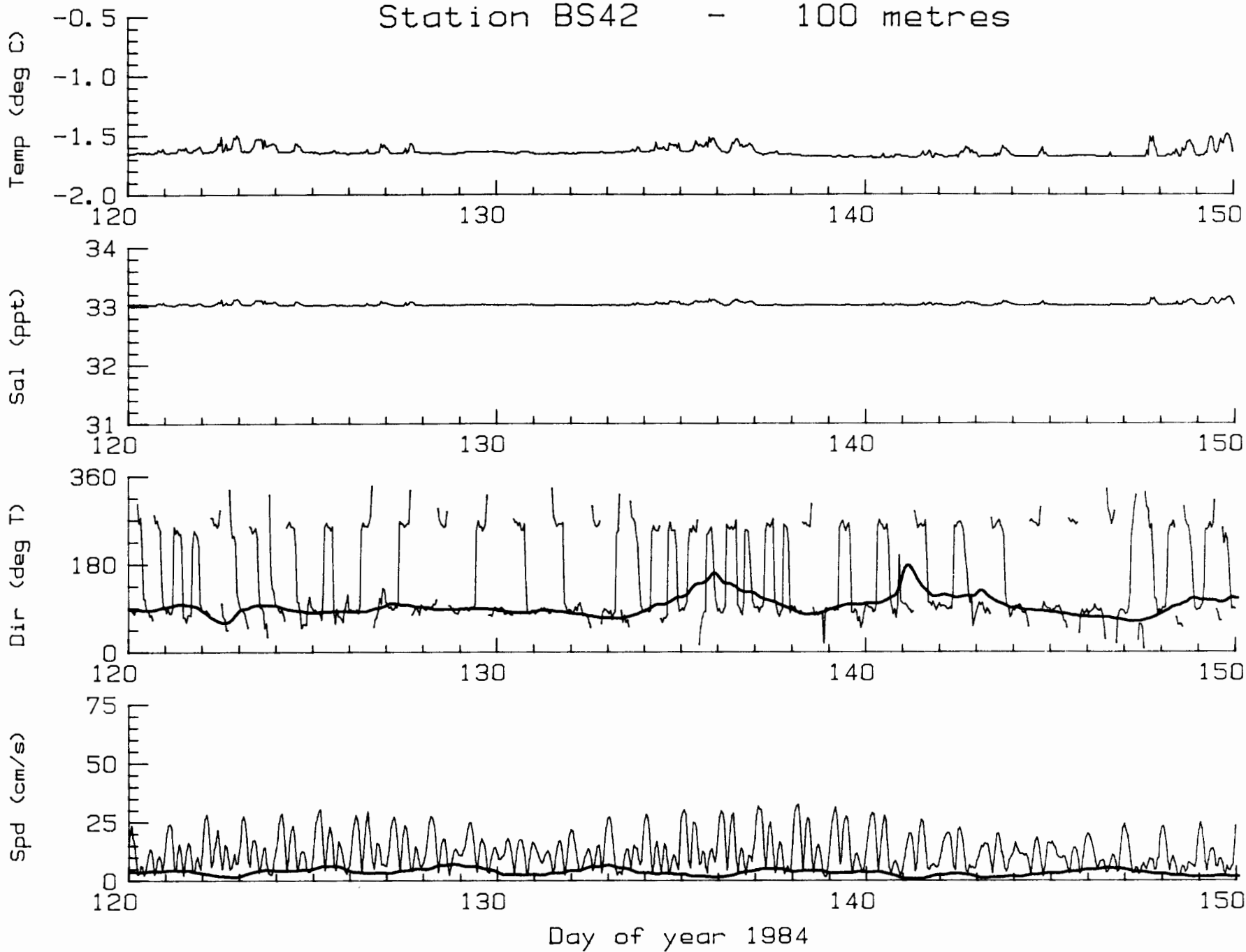
Station BS42 - 51 metres



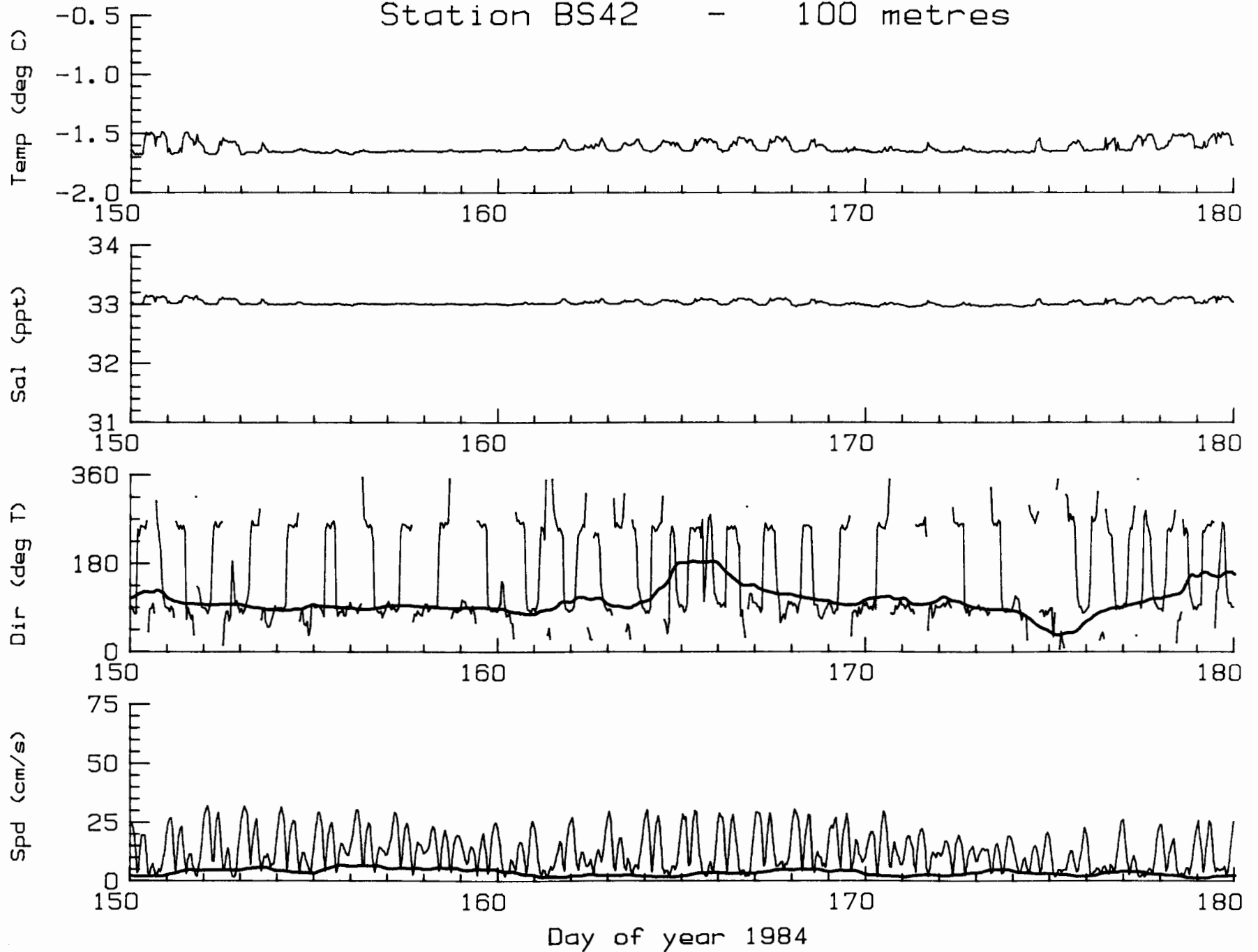
Station BS42 - 100 metres



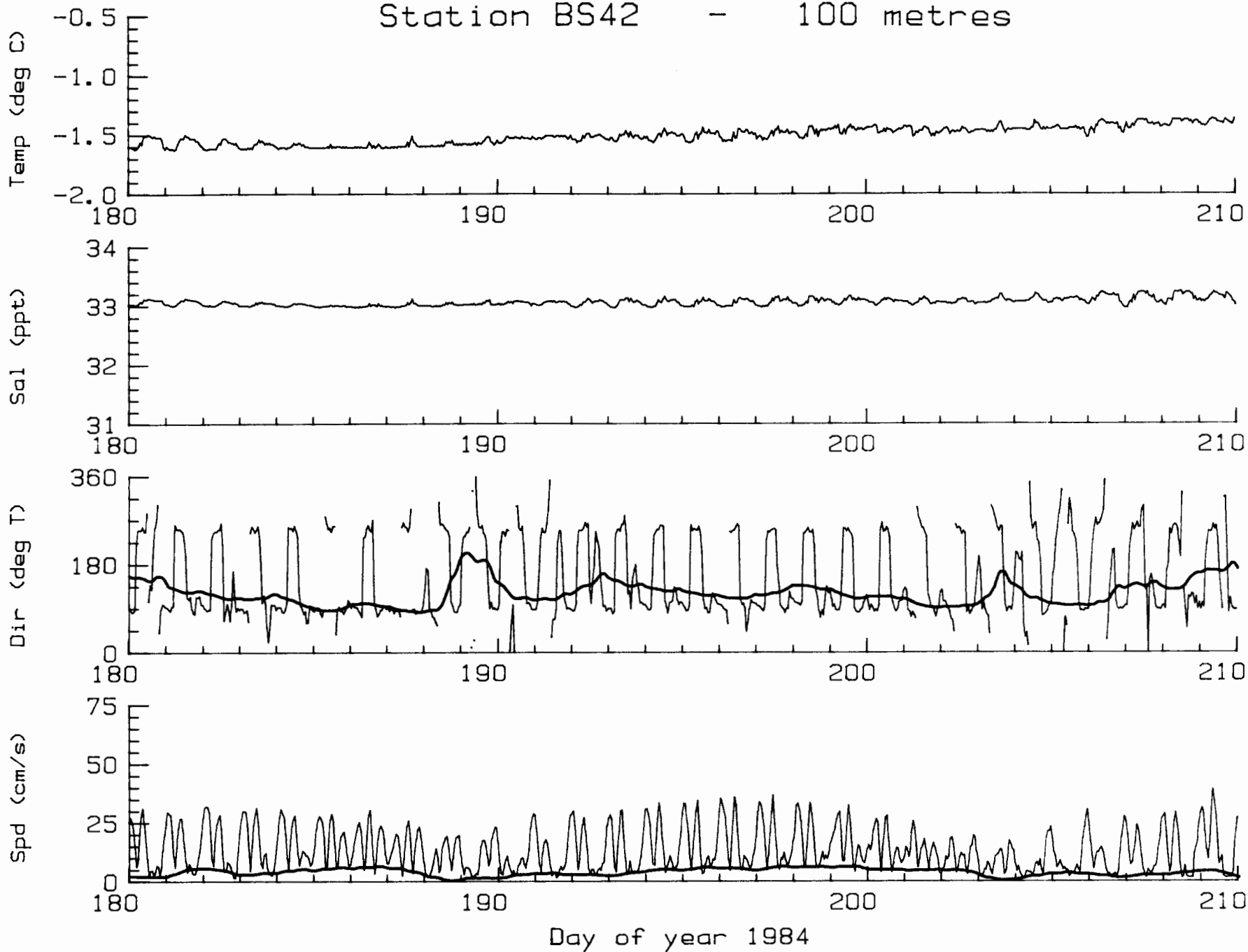
Station BS42 - 100 metres



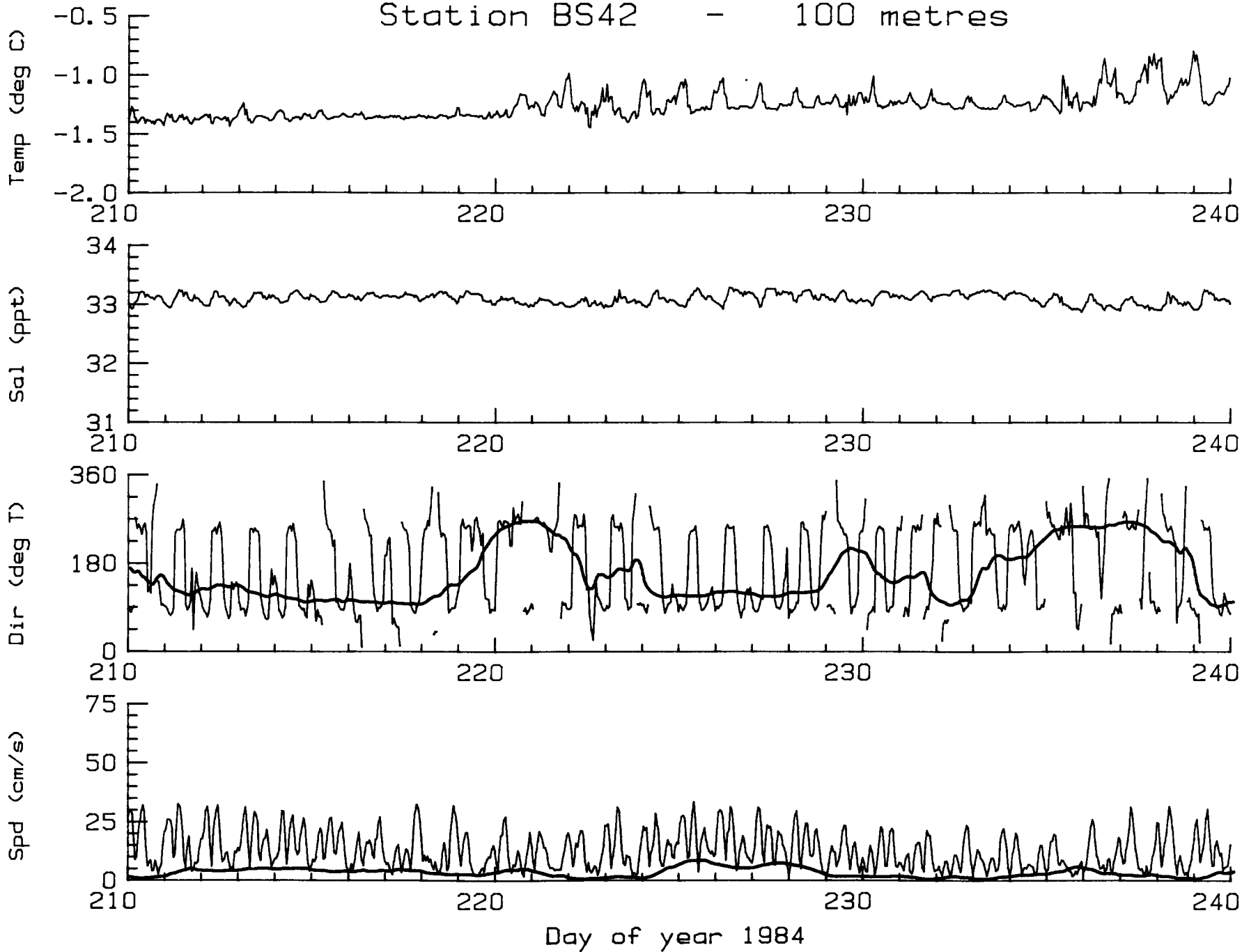
Station BS42 - 100 metres



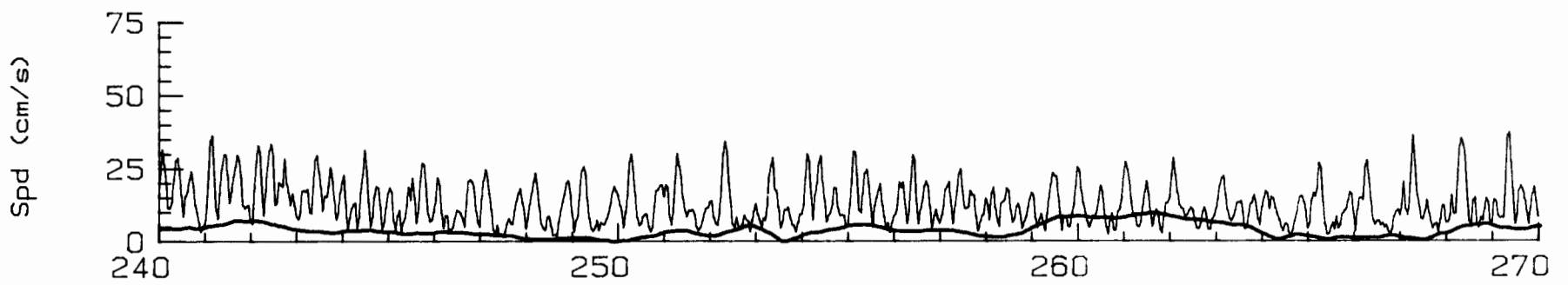
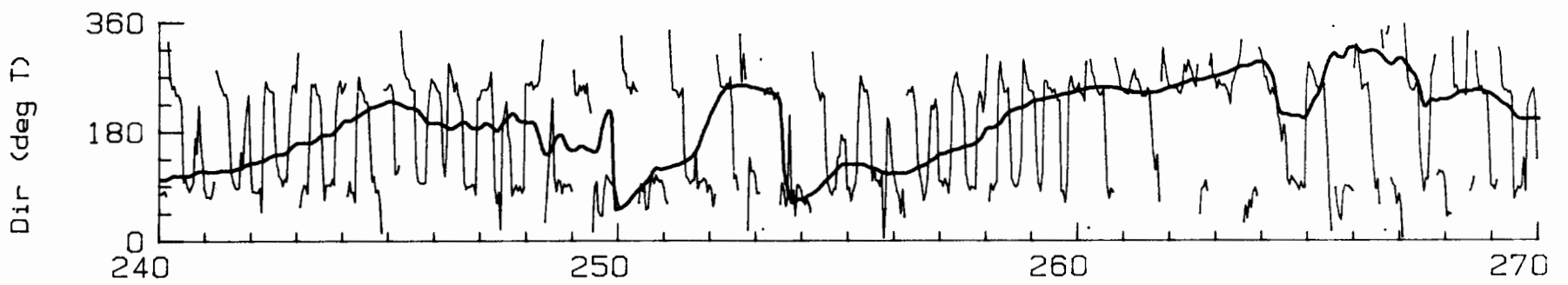
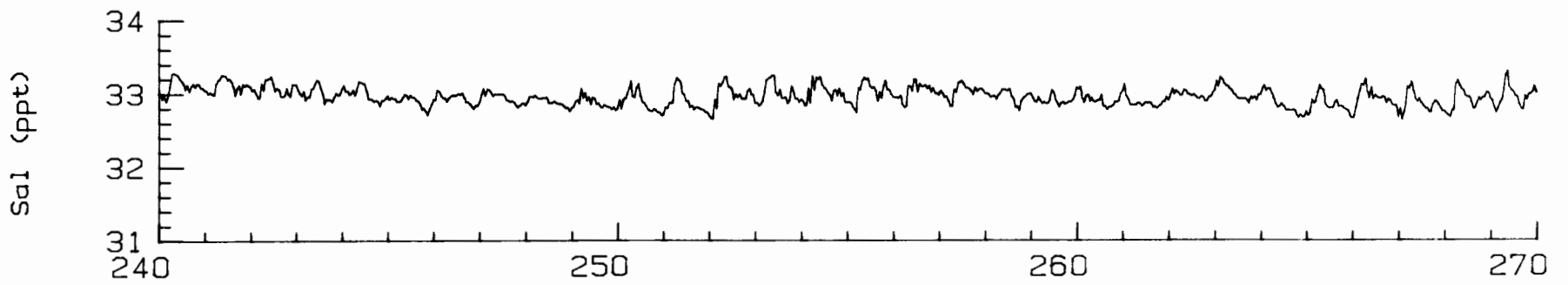
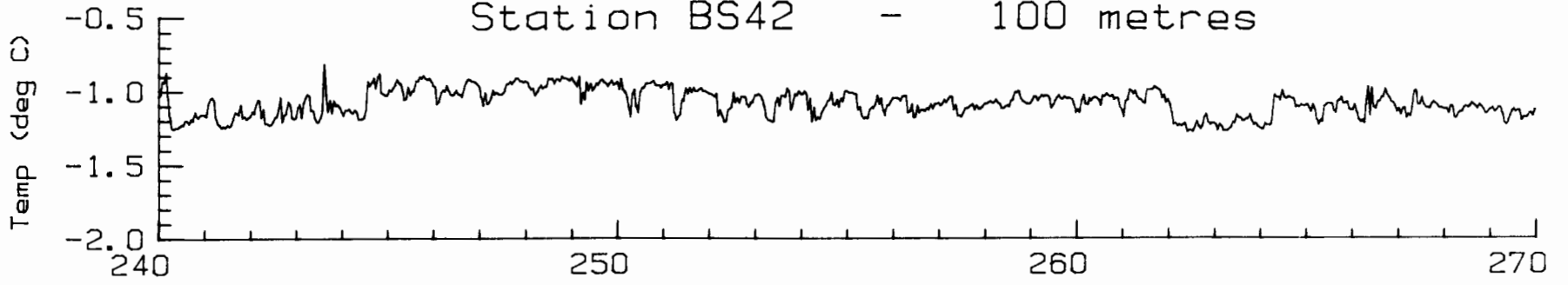
Station BS42 - 100 metres



Station BS42 - 100 metres

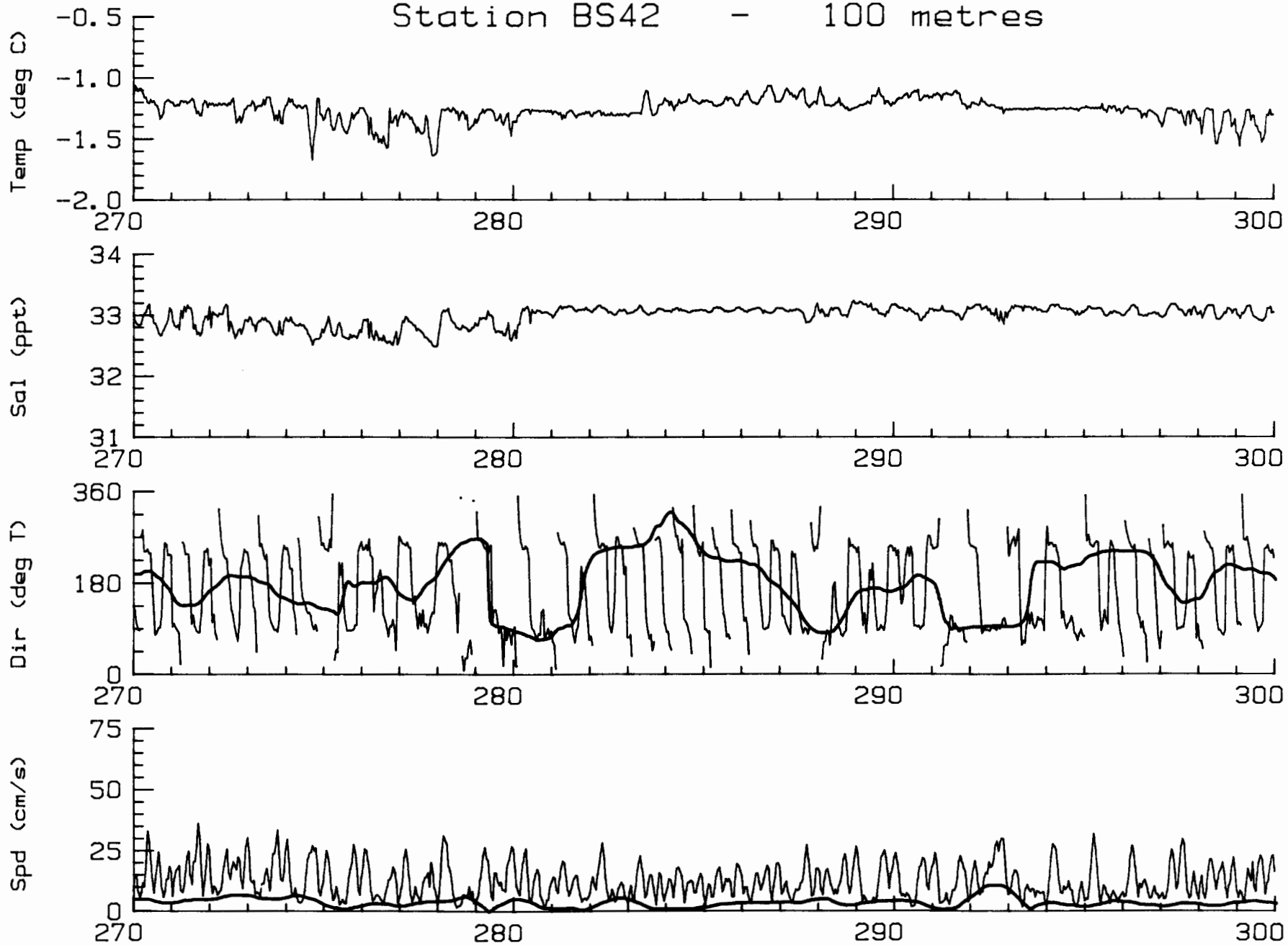


Station BS42 - 100 metres



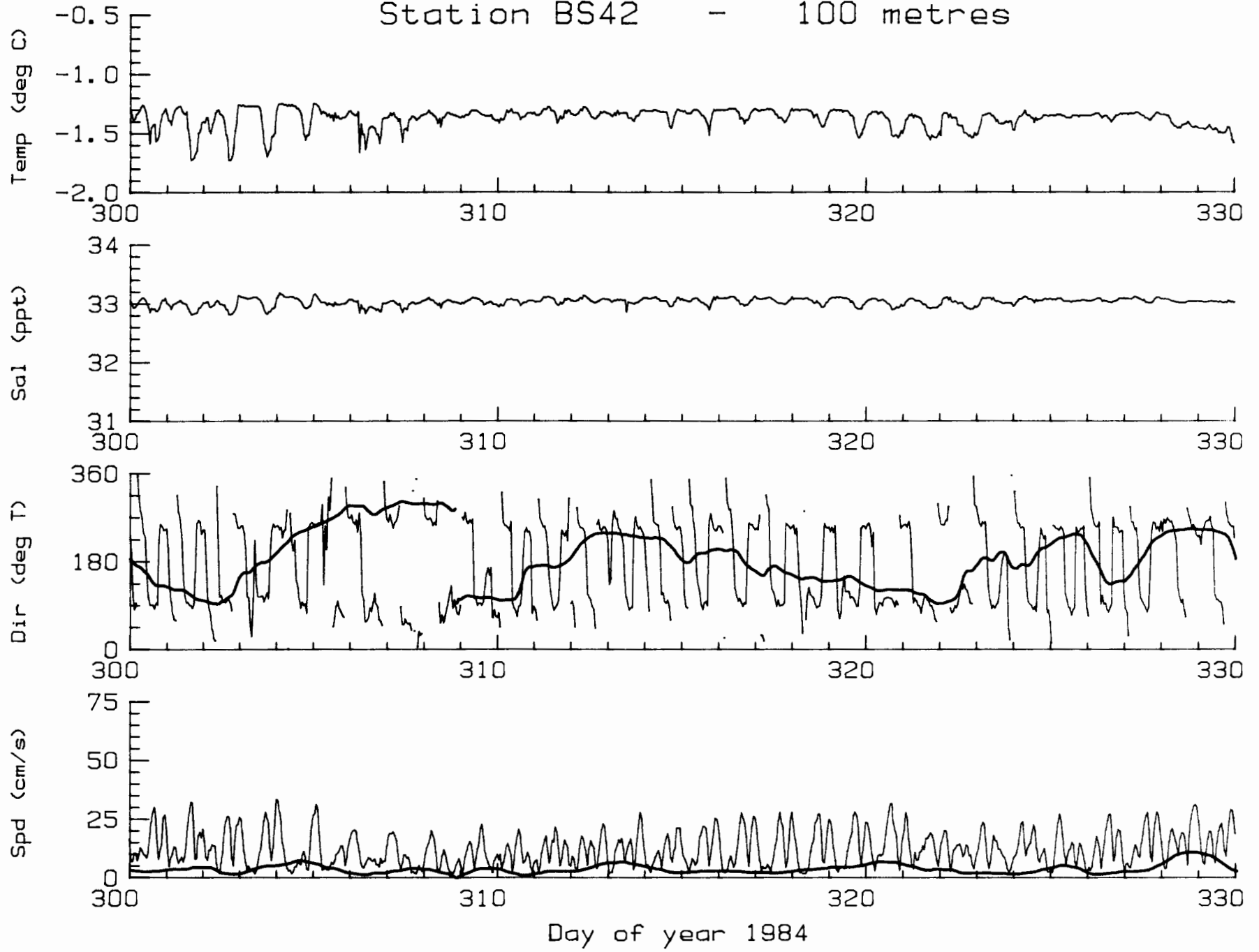
Day of year 1984

Station BS42 - 100 metres

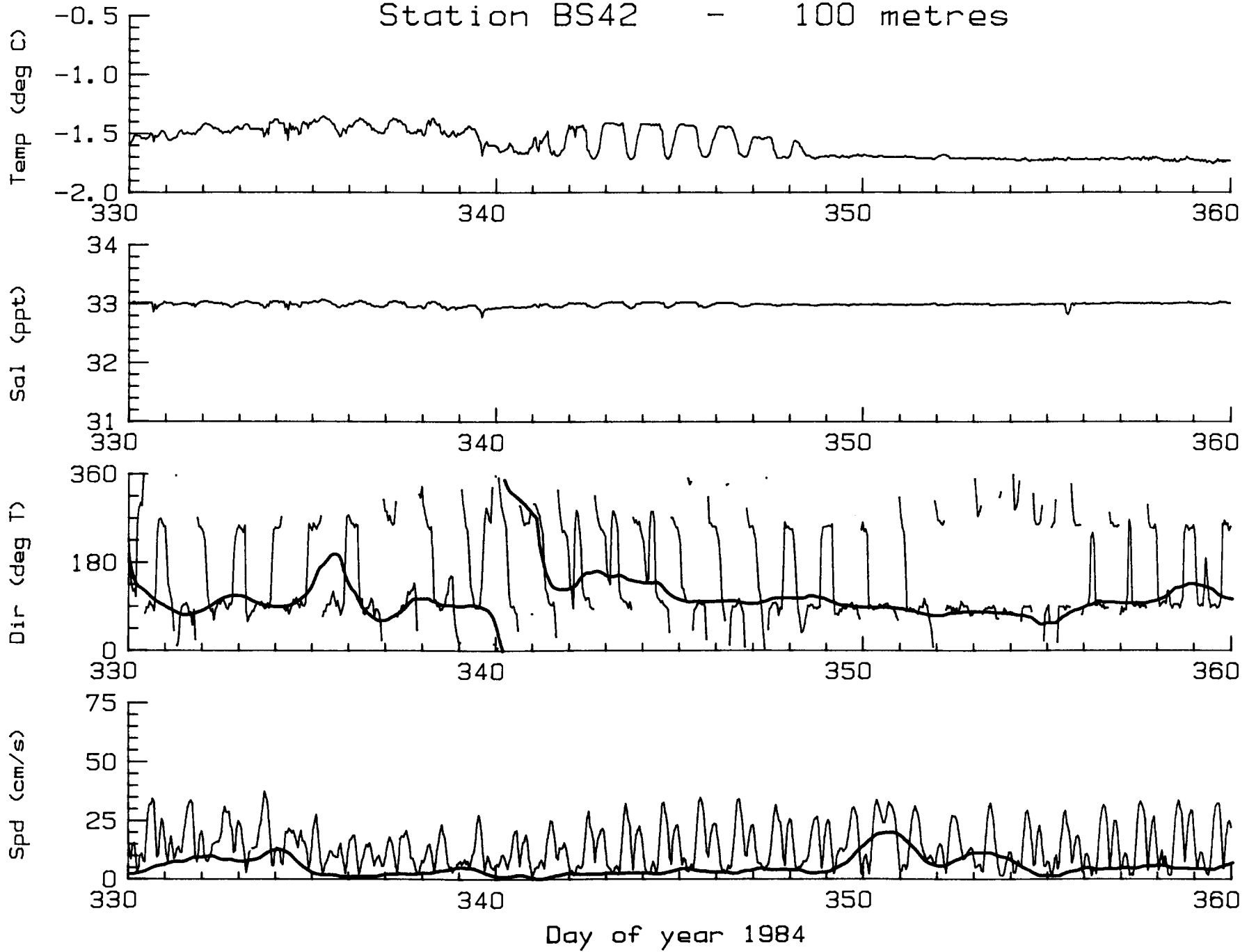


Day of year 1984

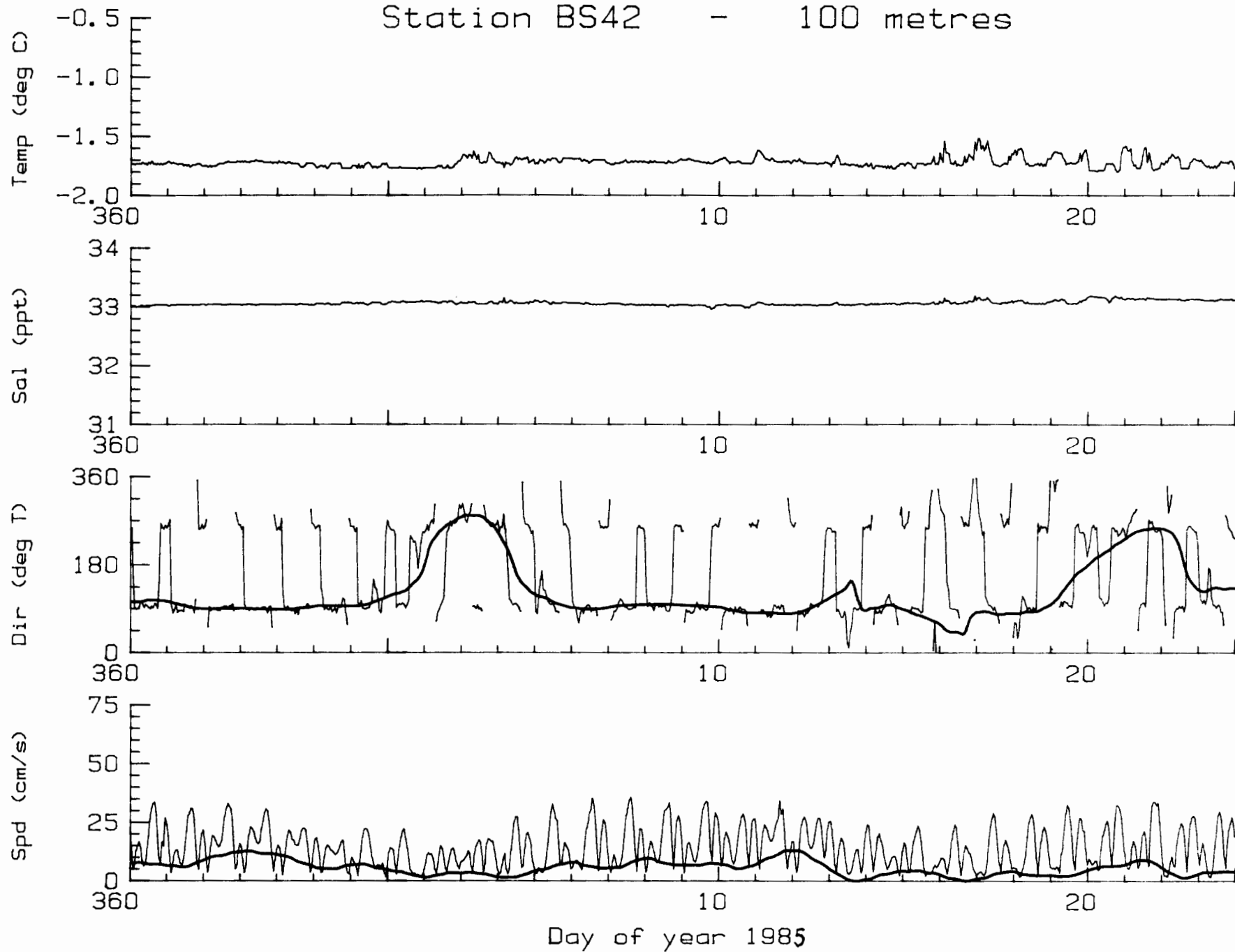
Station BS42 - 100 metres



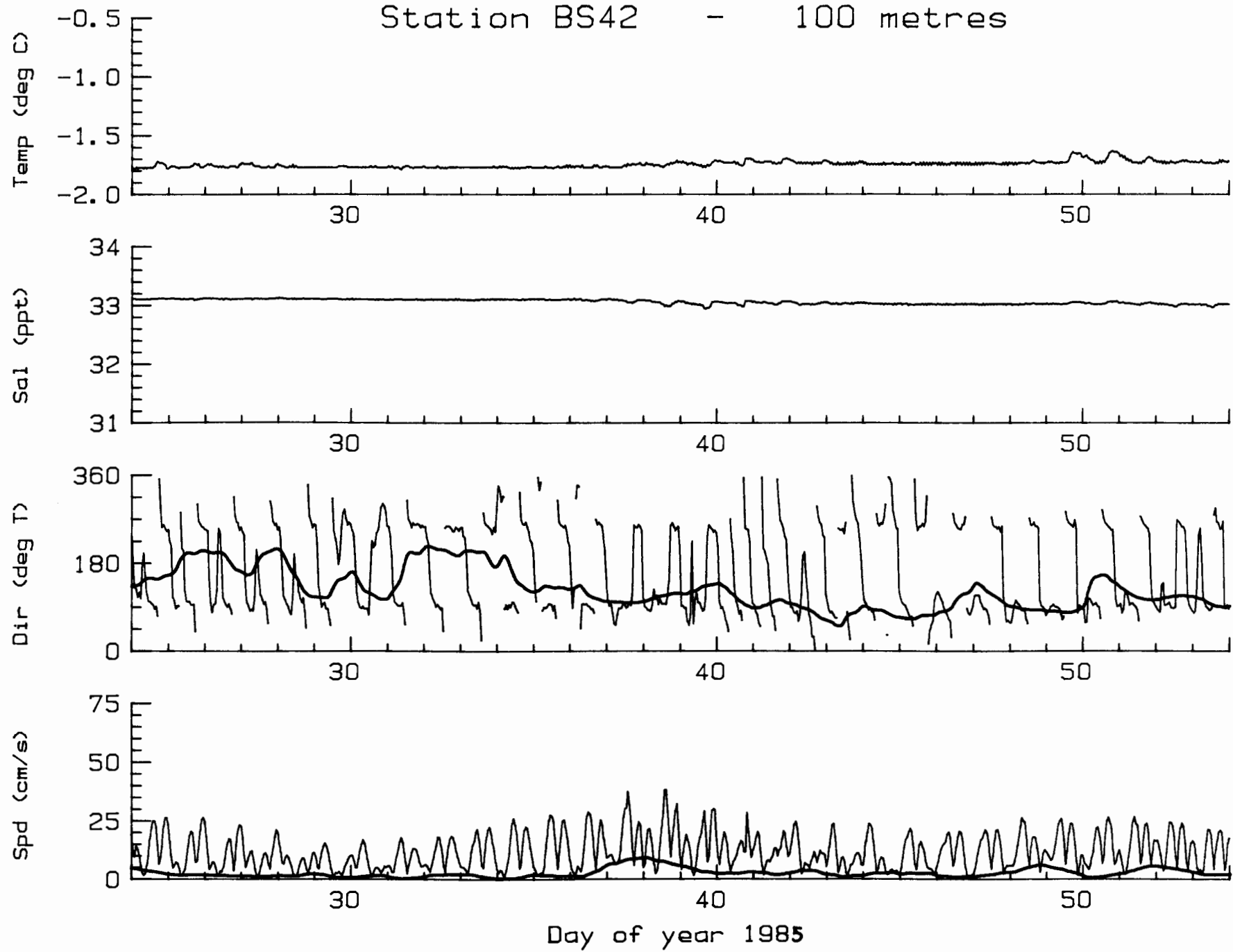
Station BS42 - 100 metres



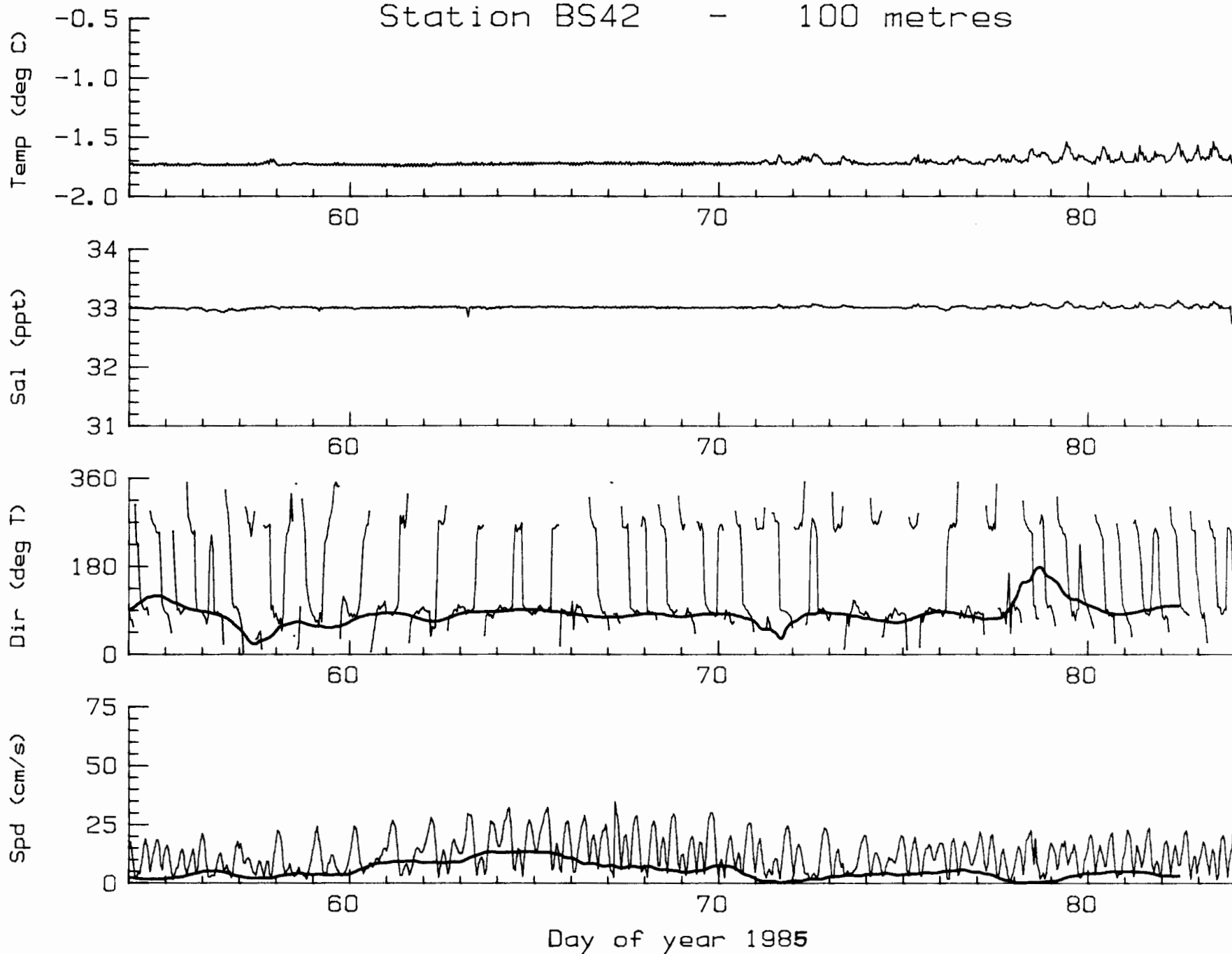
Station BS42 - 100 metres



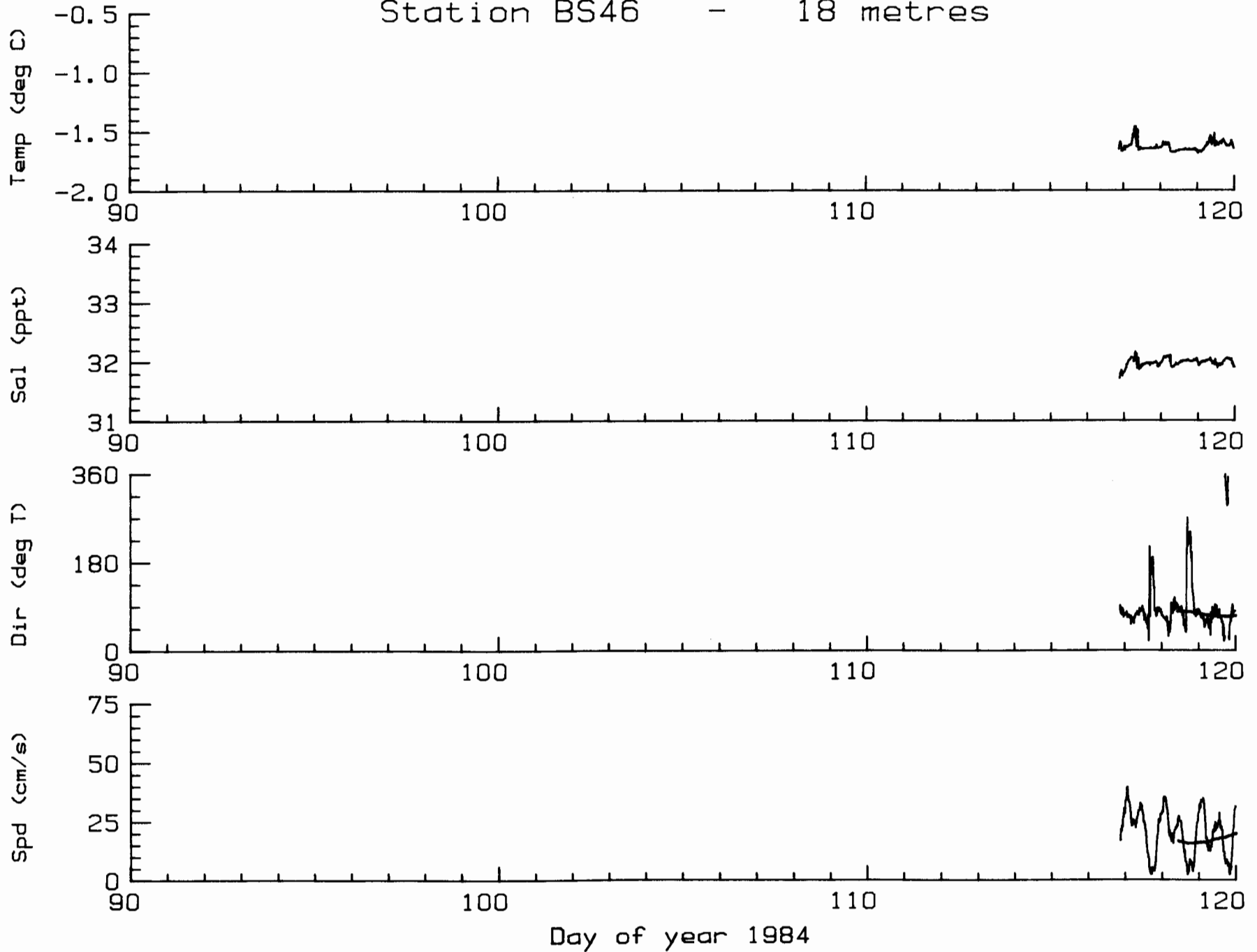
Station BS42 - 100 metres



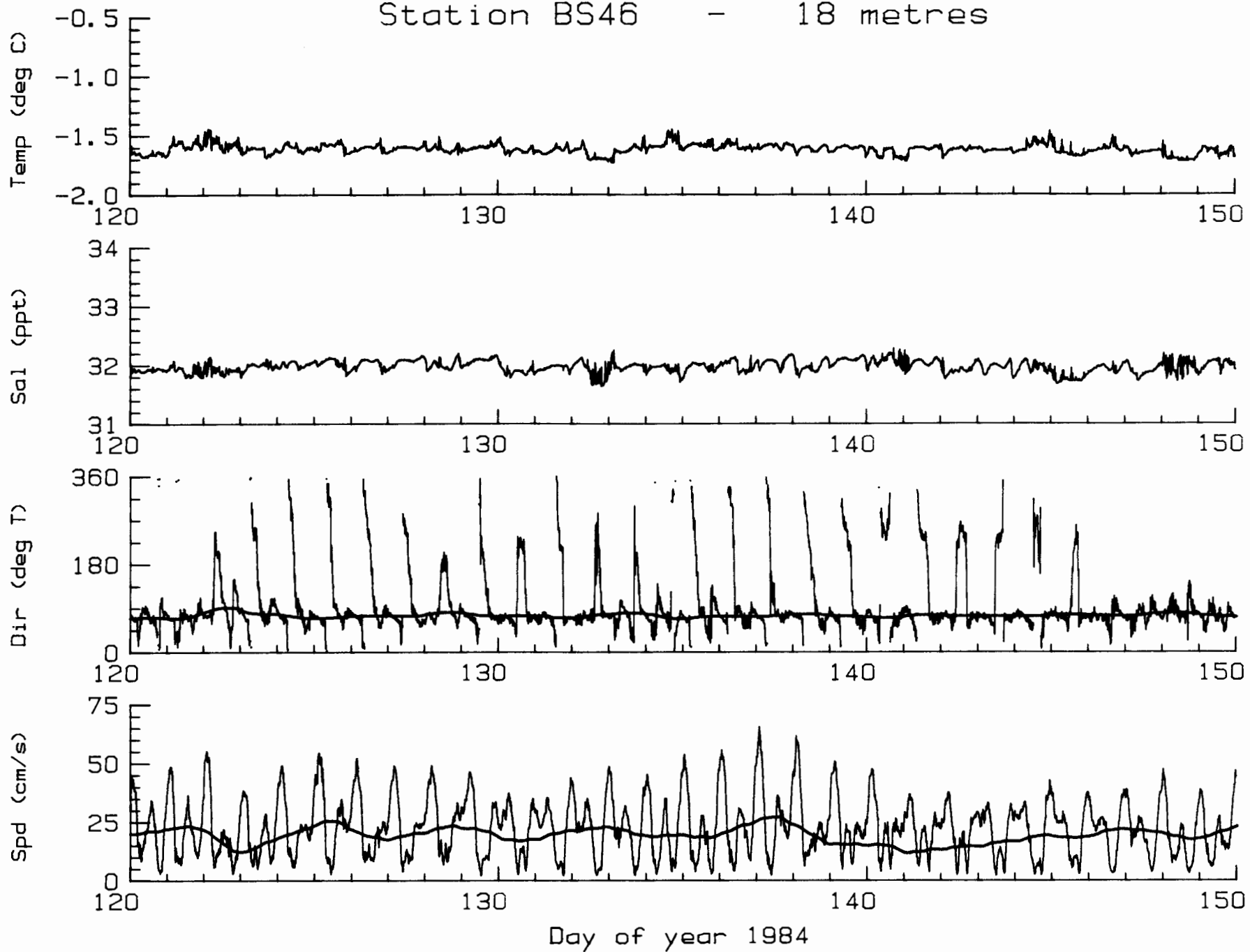
Station BS42 - 100 metres



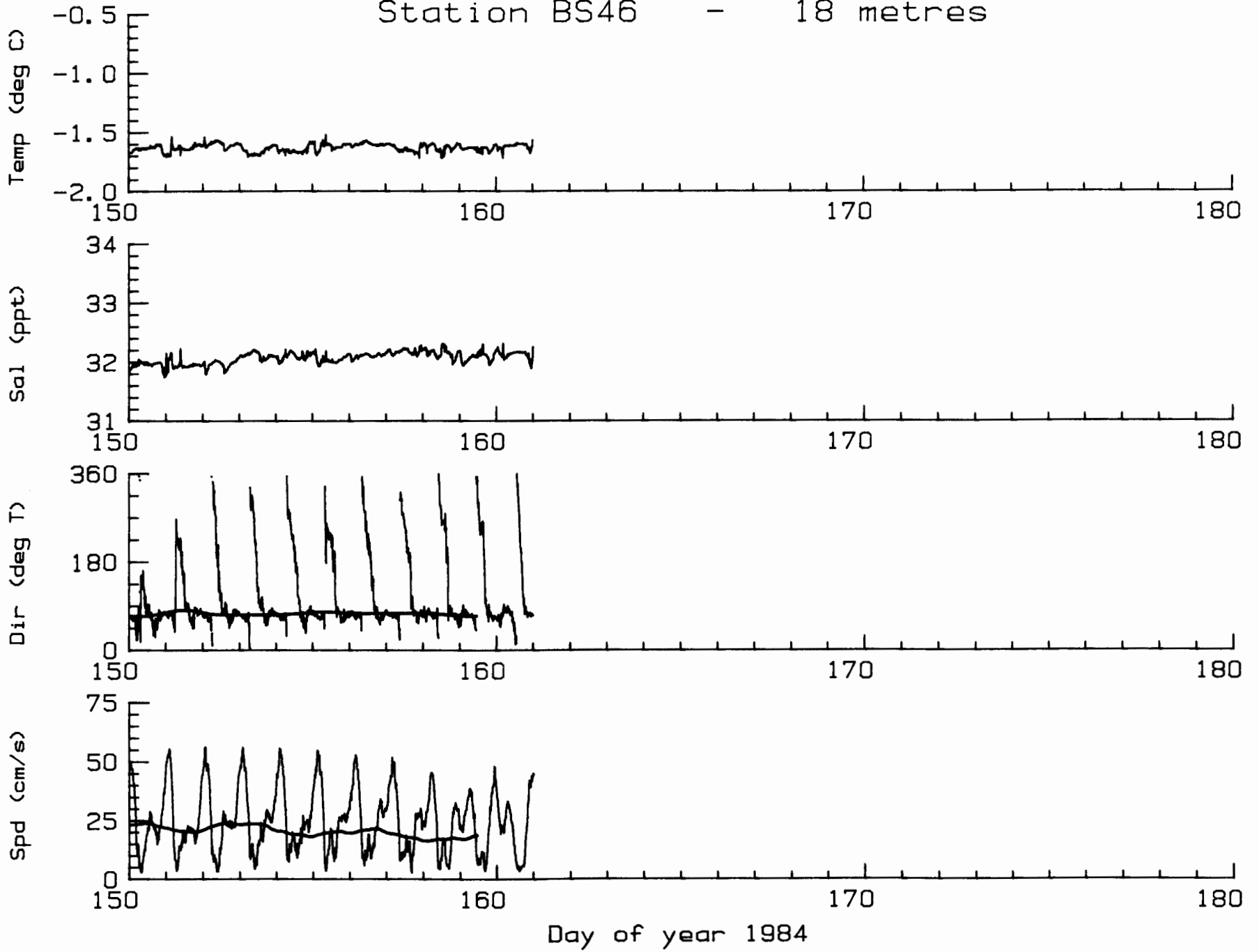
Station BS46 - 18 metres



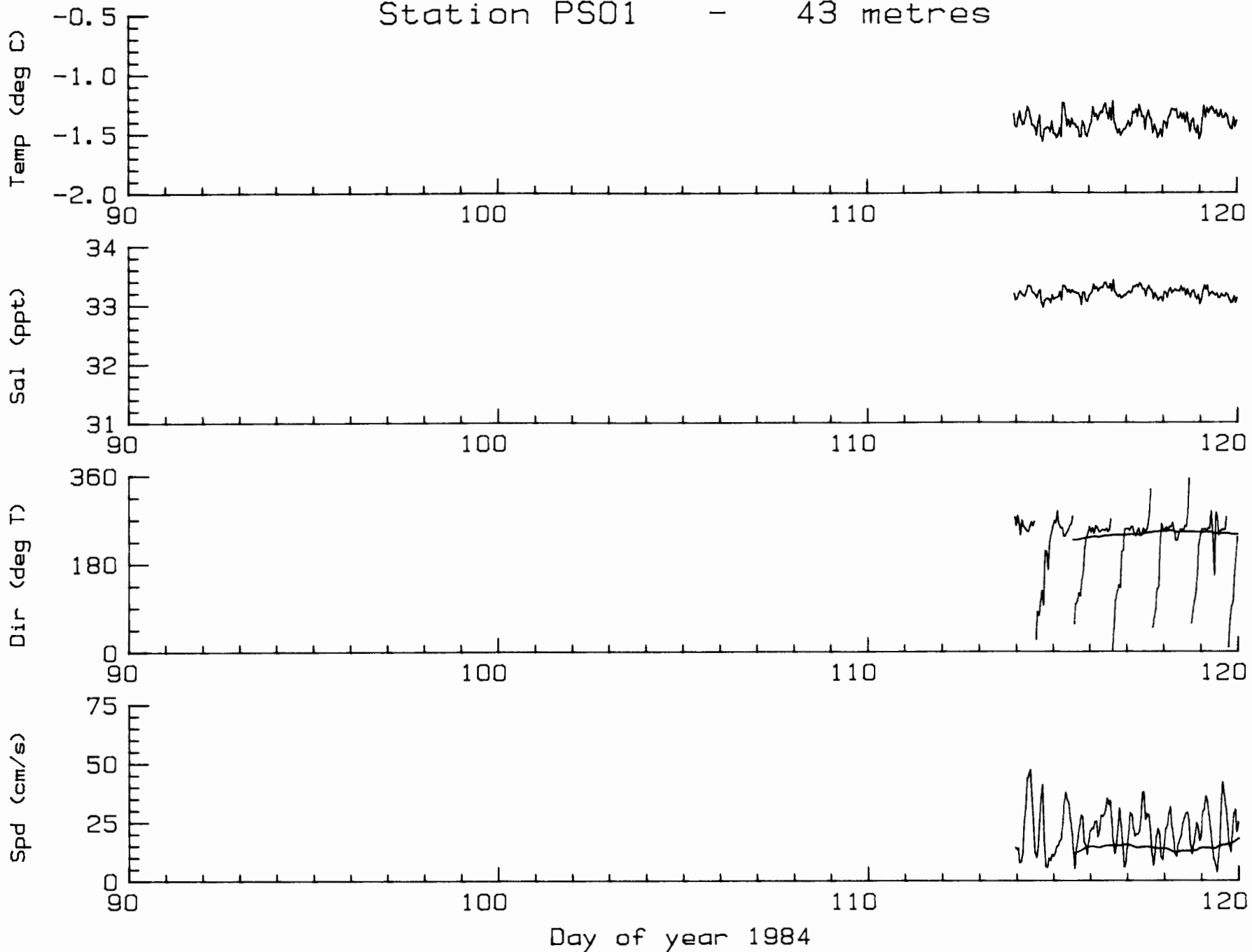
Station BS46 - 18 metres



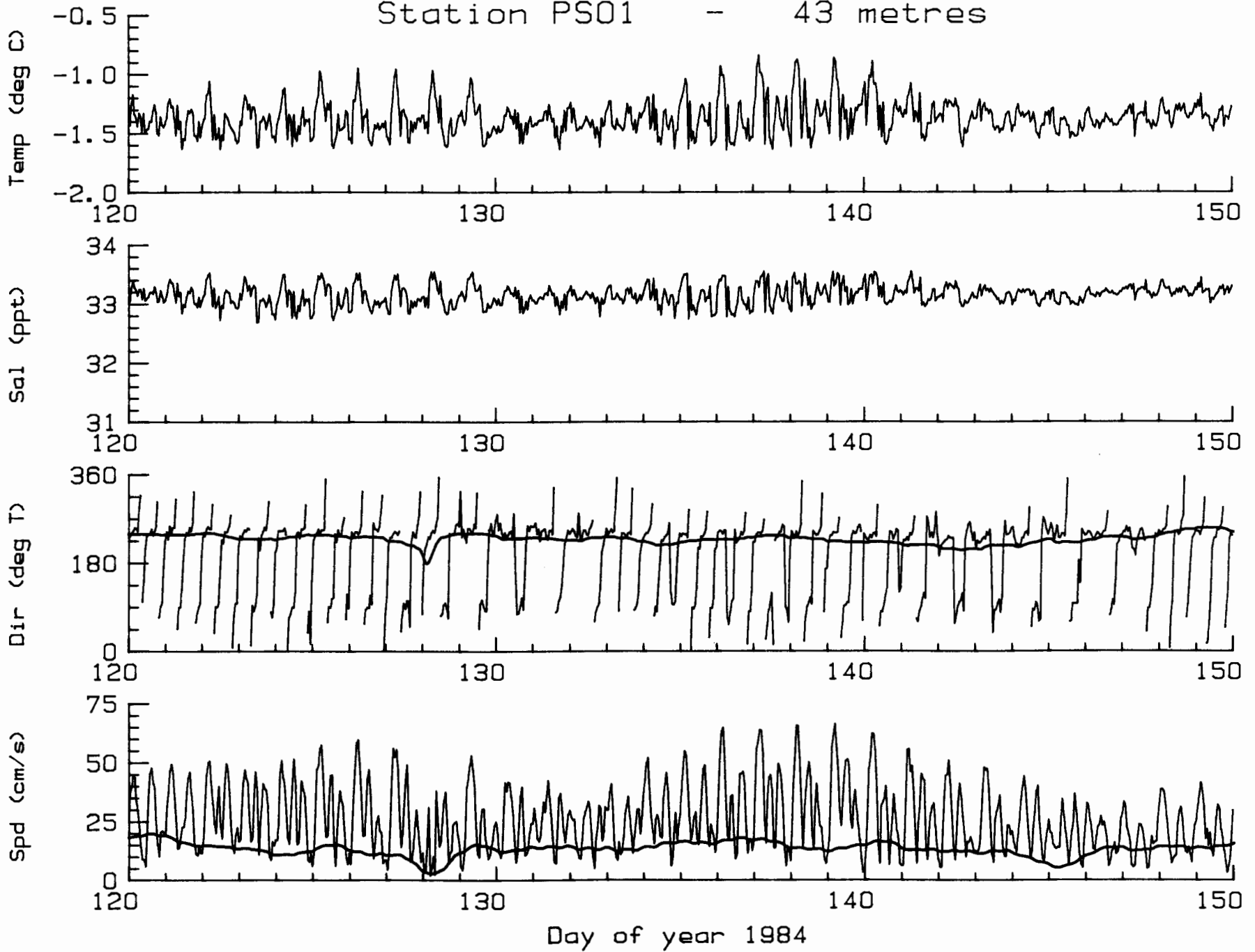
Station BS46 - 18 metres



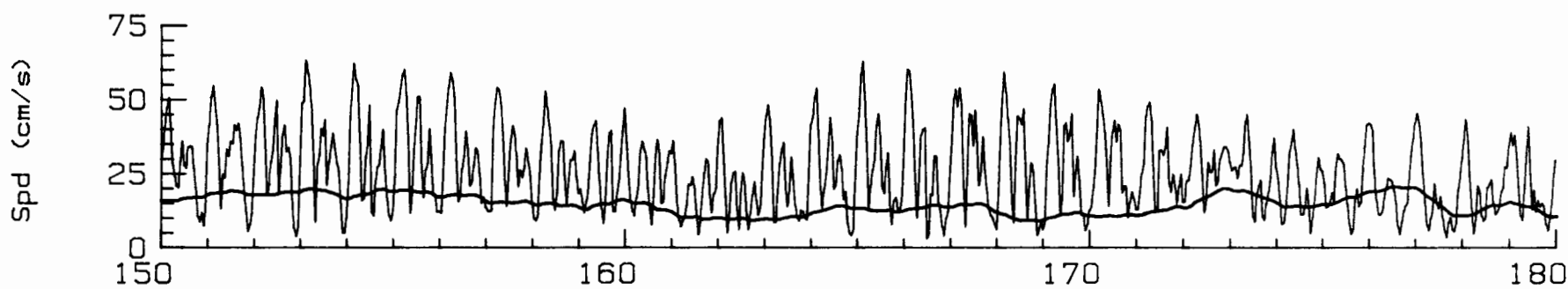
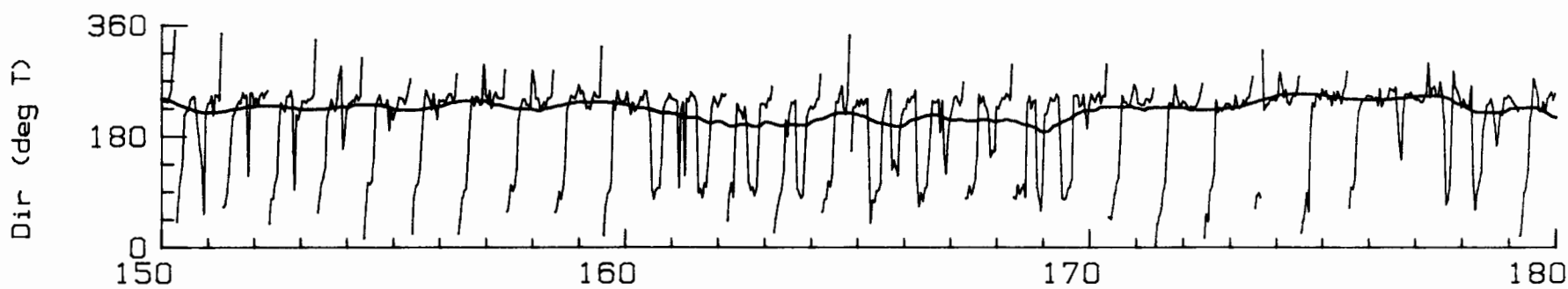
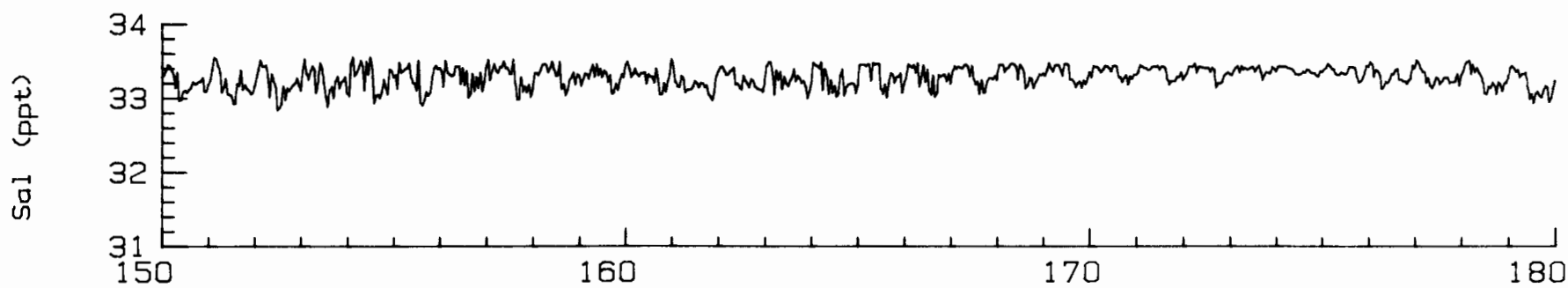
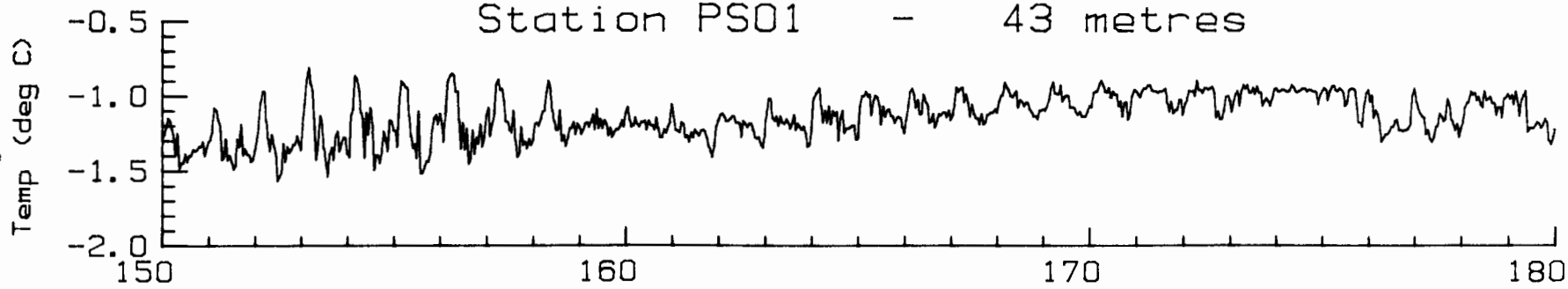
Station PS01 - 43 metres



Station PS01 - 43 metres

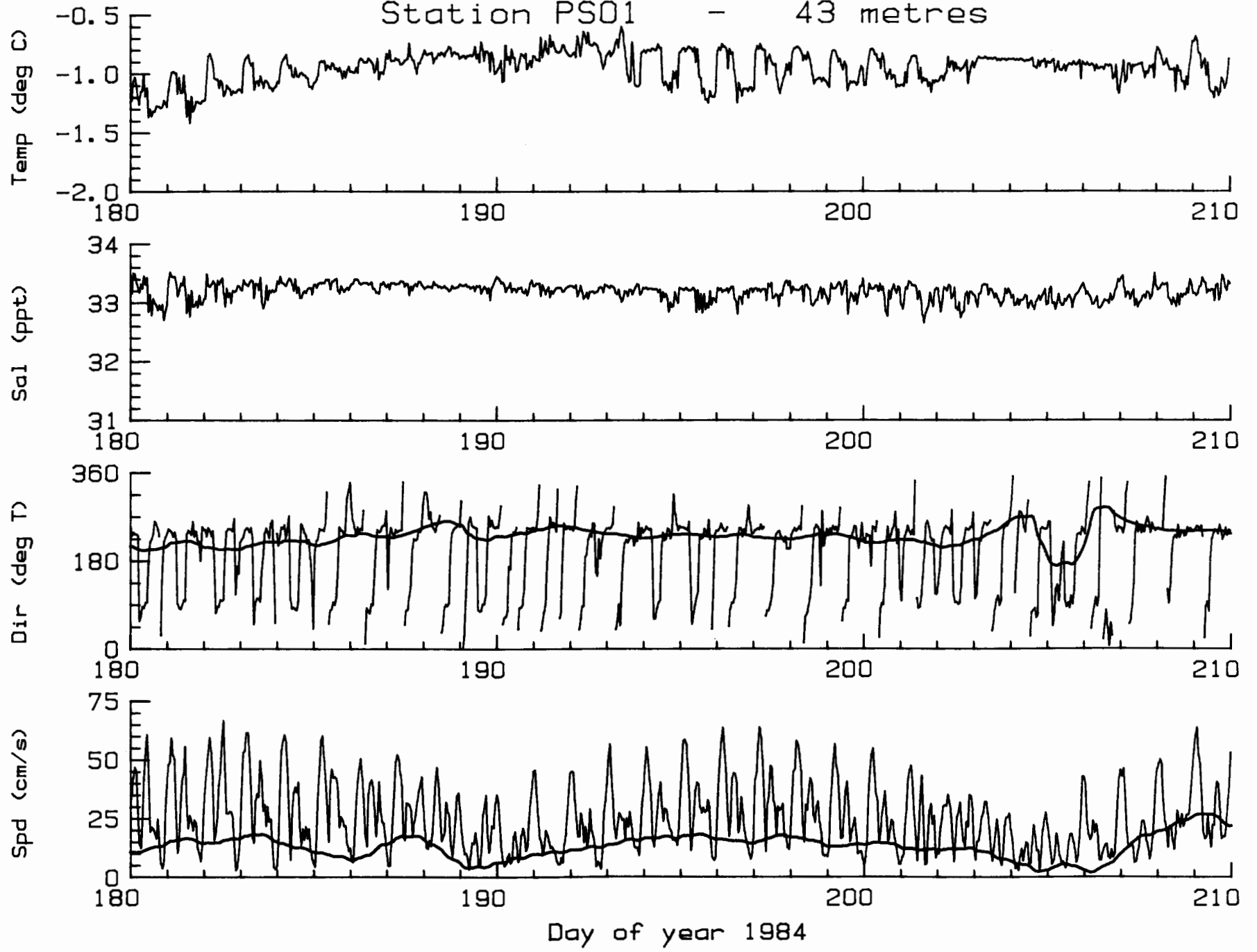


Station PS01 - 43 metres

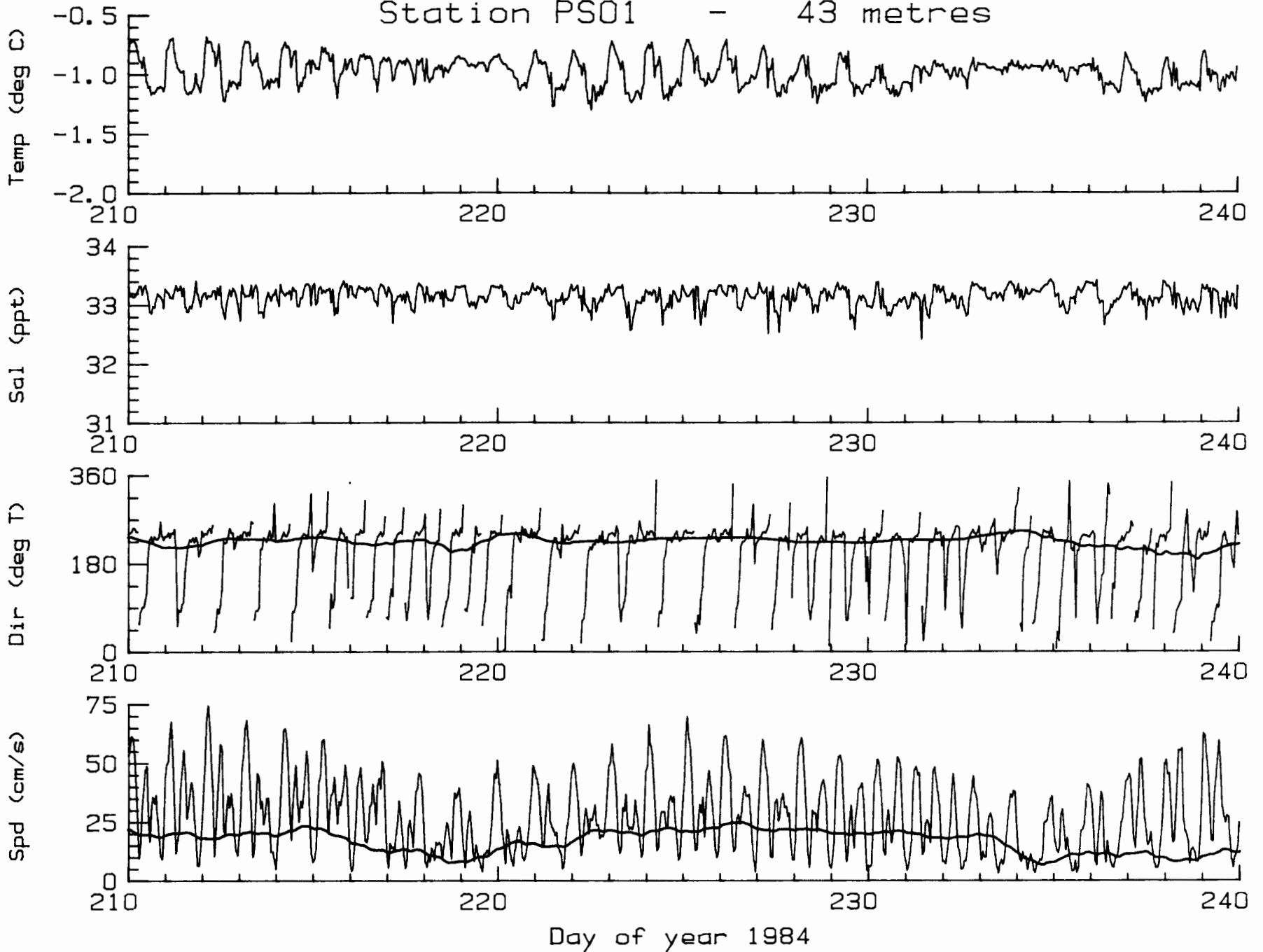


Day of year 1984

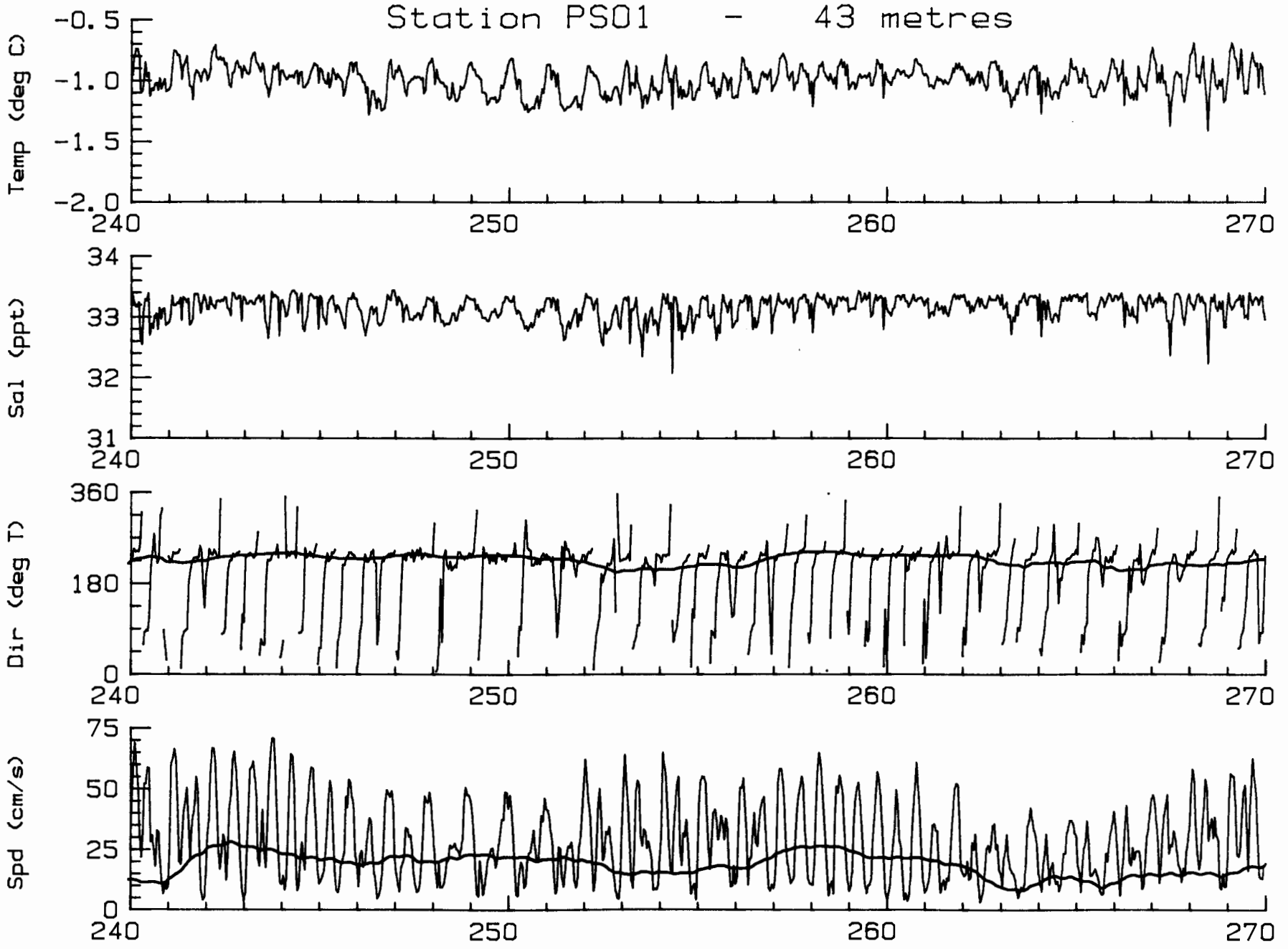
Station PS01 - 43 metres



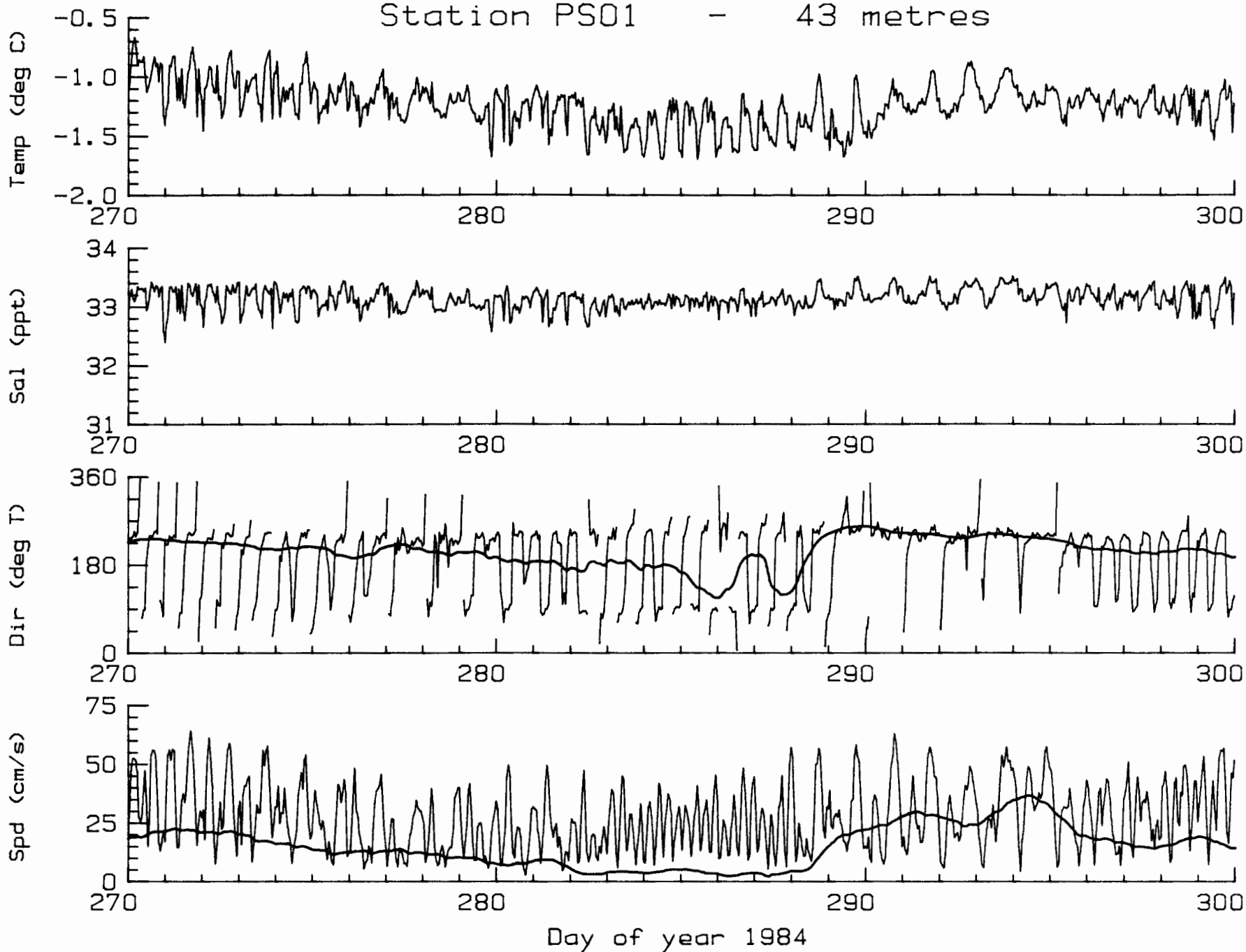
Station PS01 - 43 metres



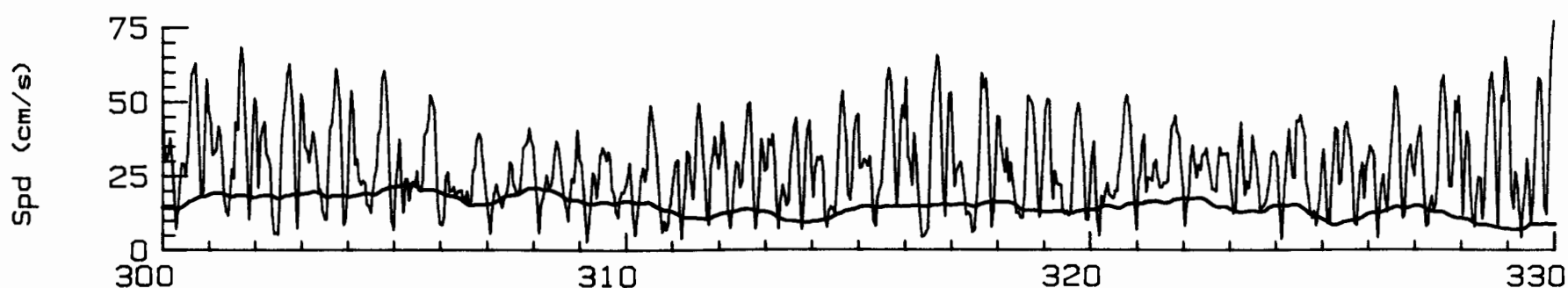
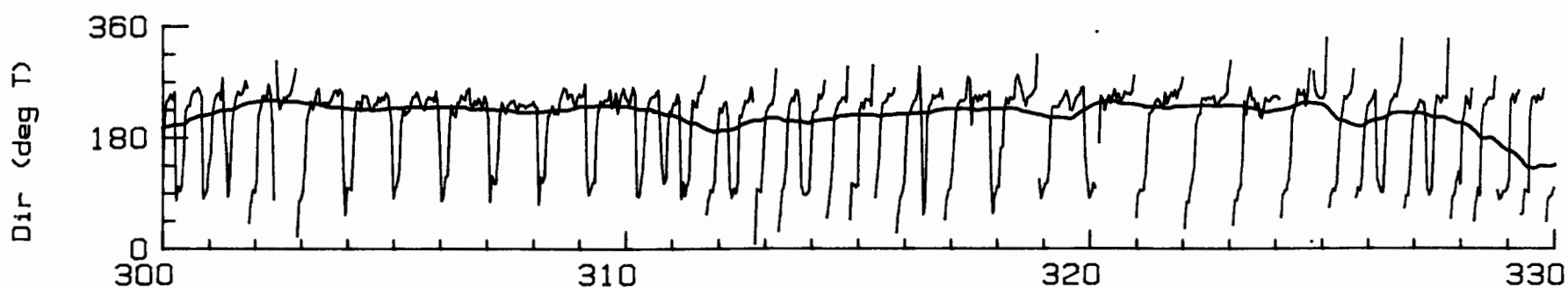
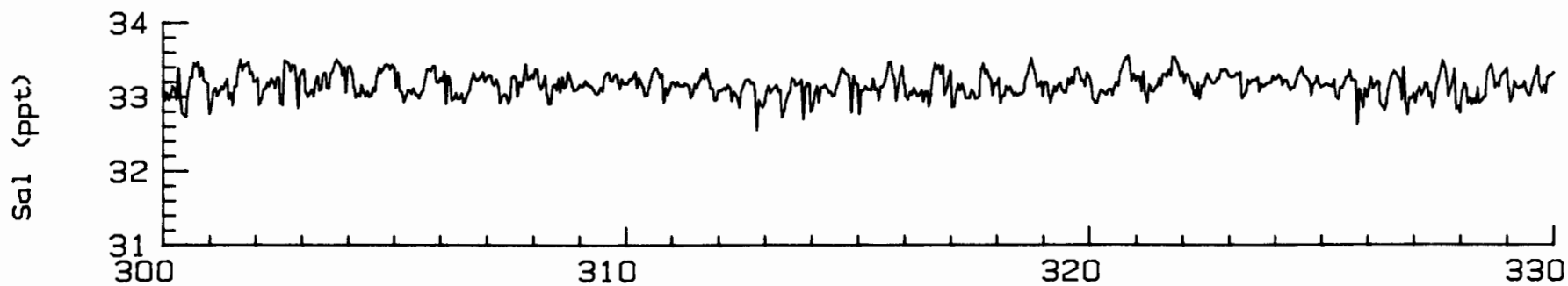
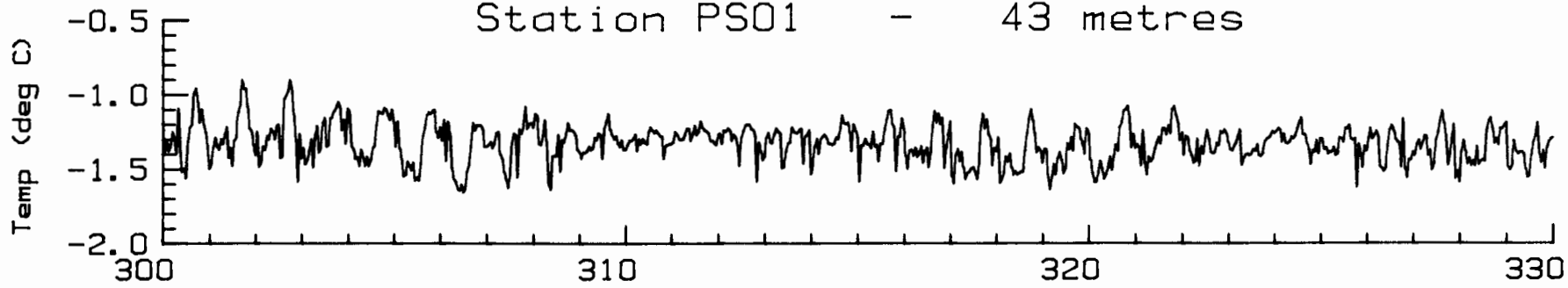
Station PS01 - 43 metres



Station PS01 - 43 metres

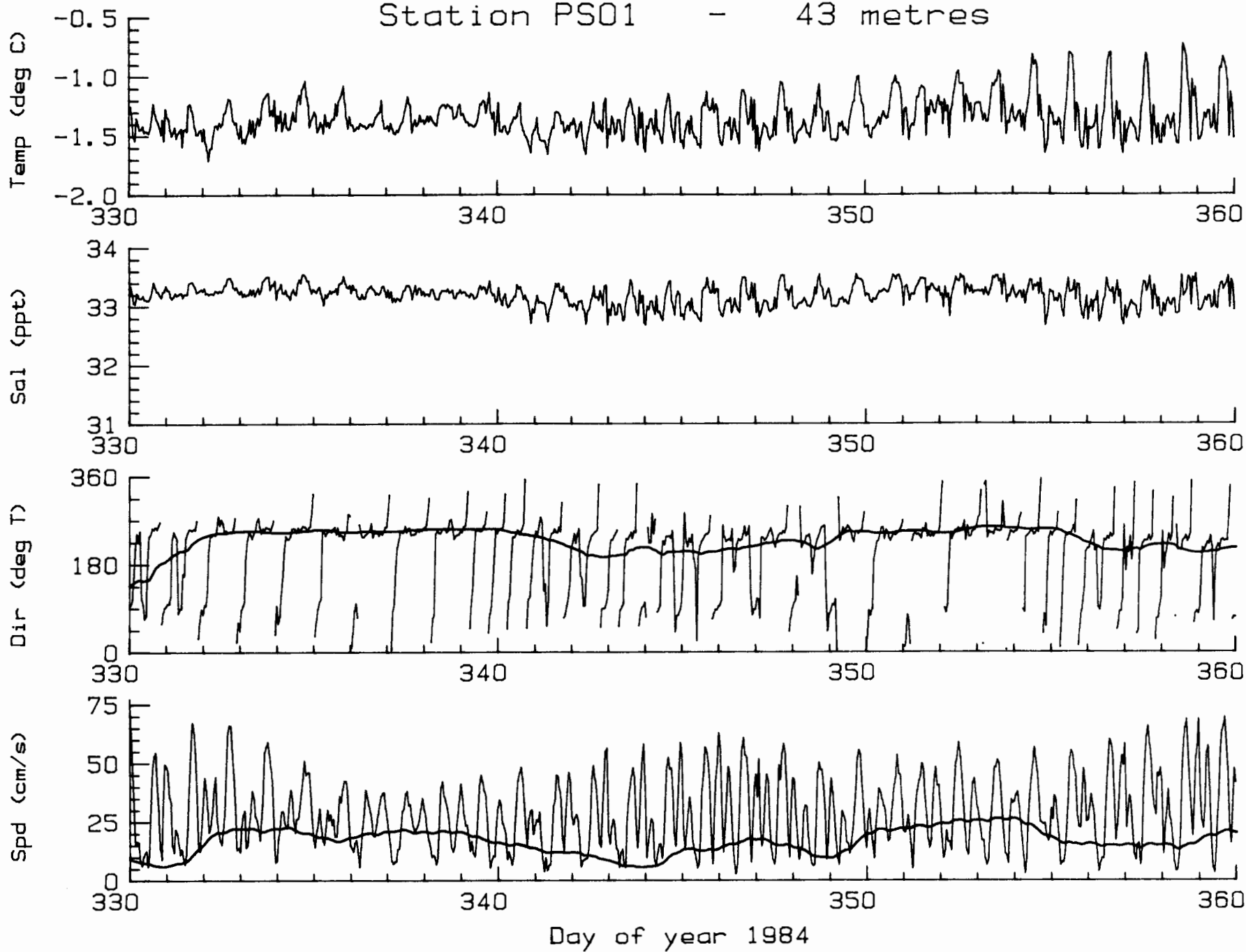


Station PS01 - 43 metres

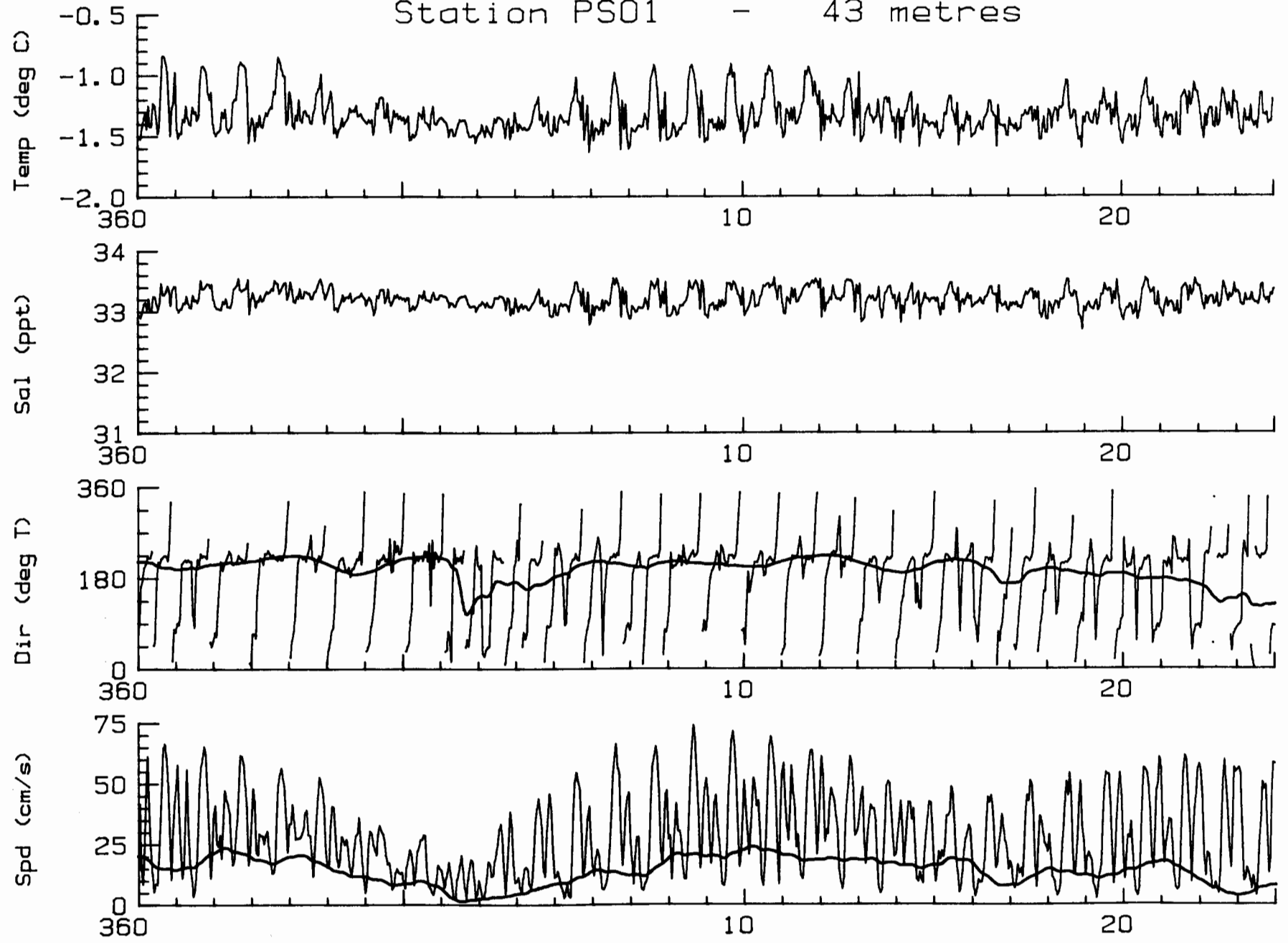


Day of year 1984

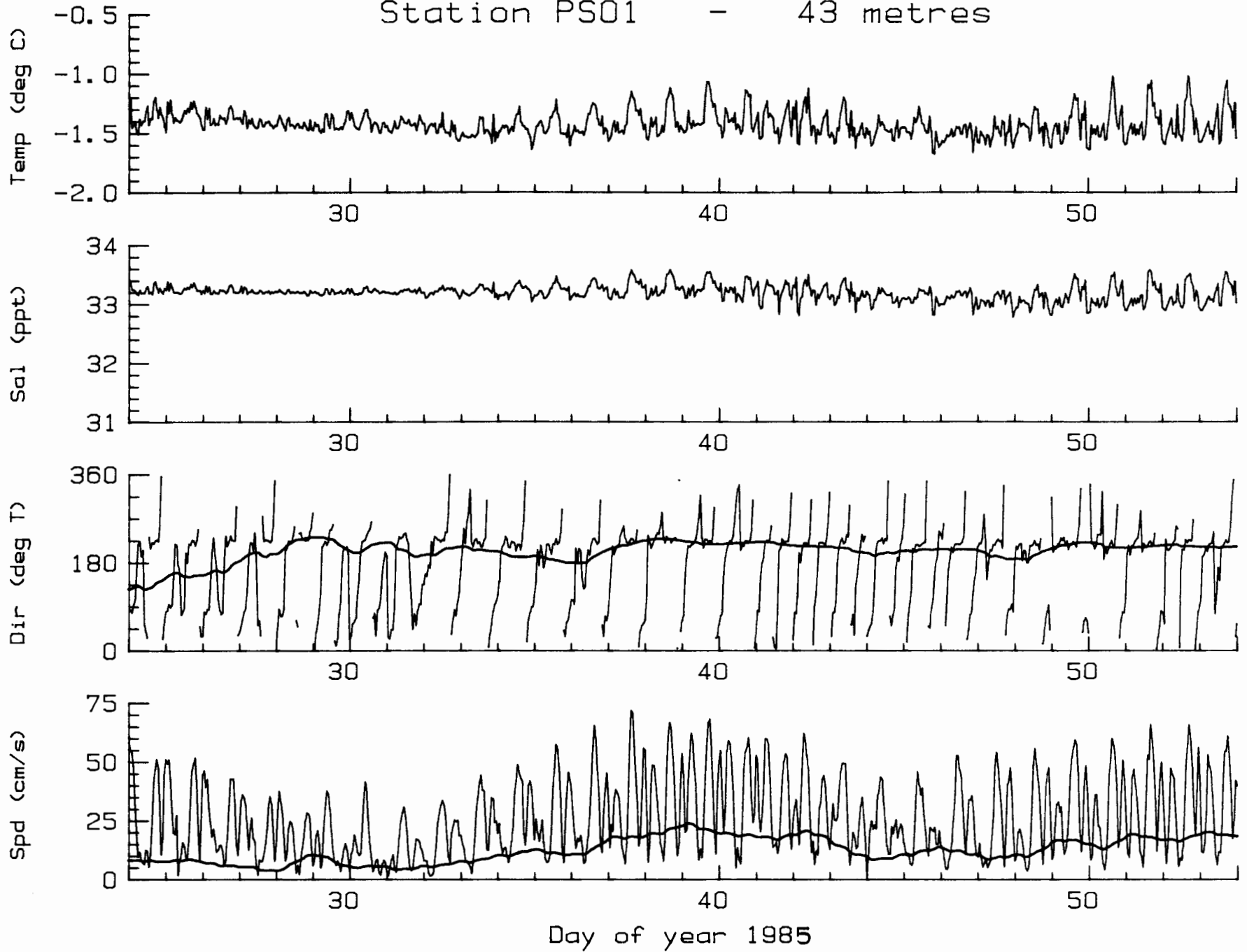
Station PS01 - 43 metres



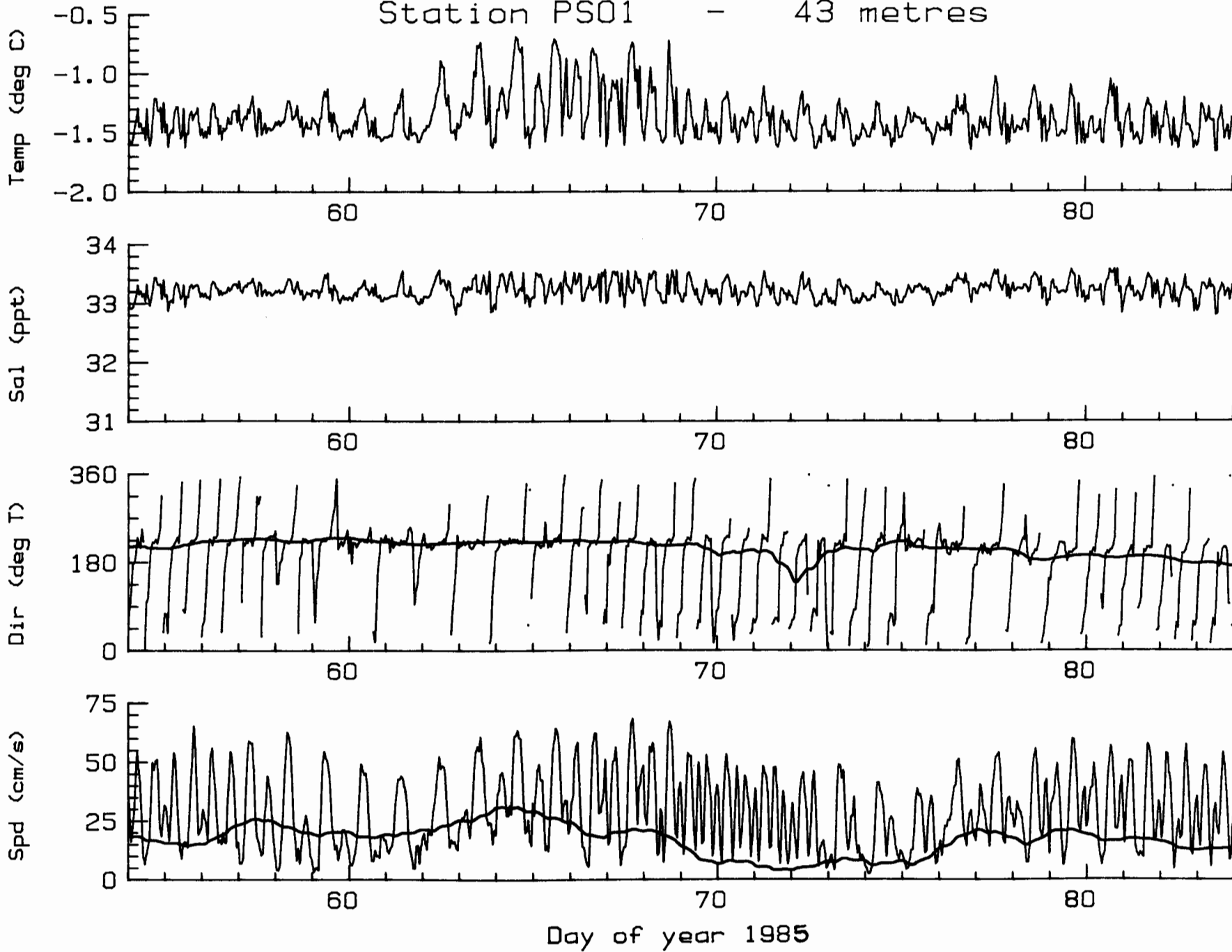
Station PS01 - 43 metres



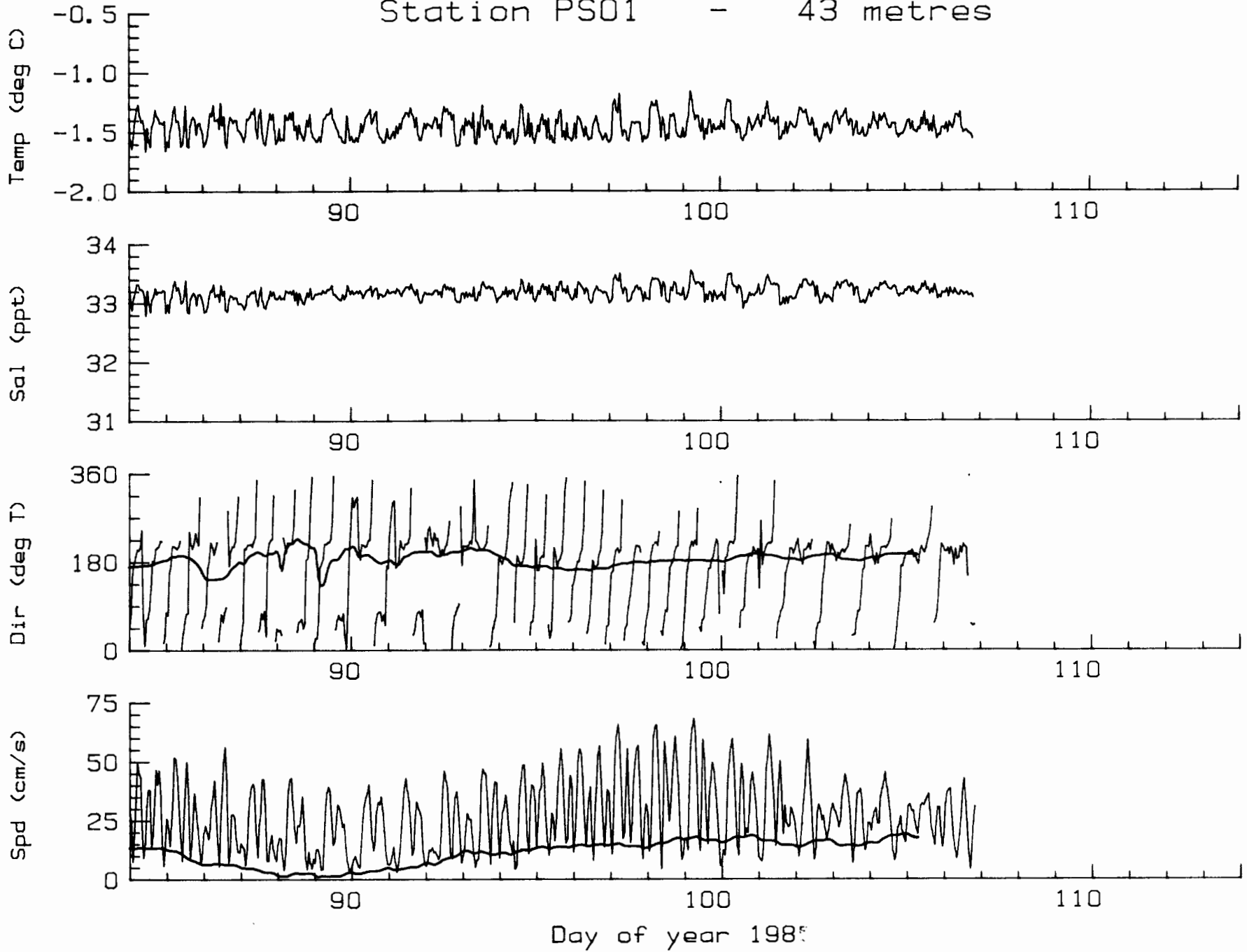
Station PS01 - 43 metres



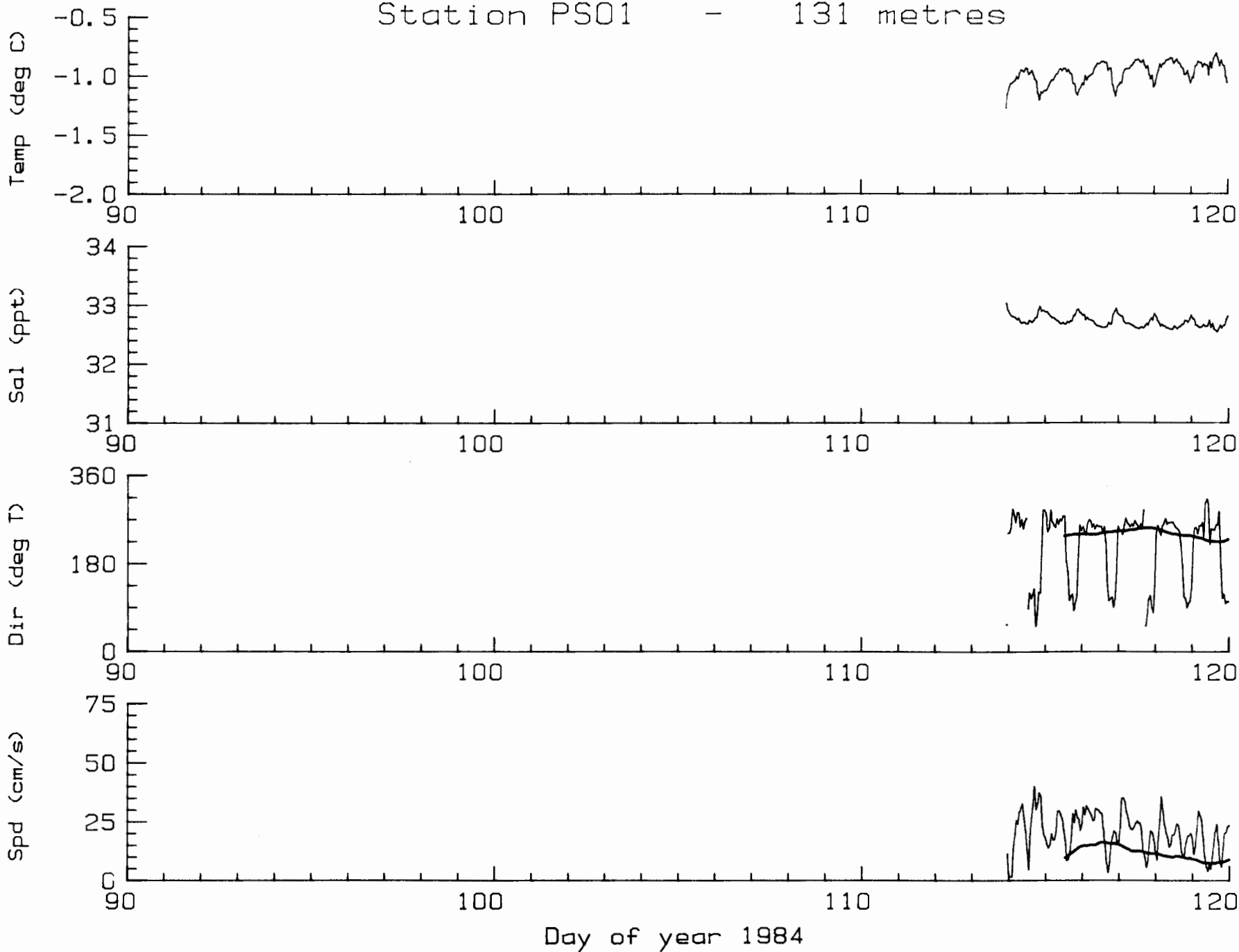
Station PS01 - 43 metres

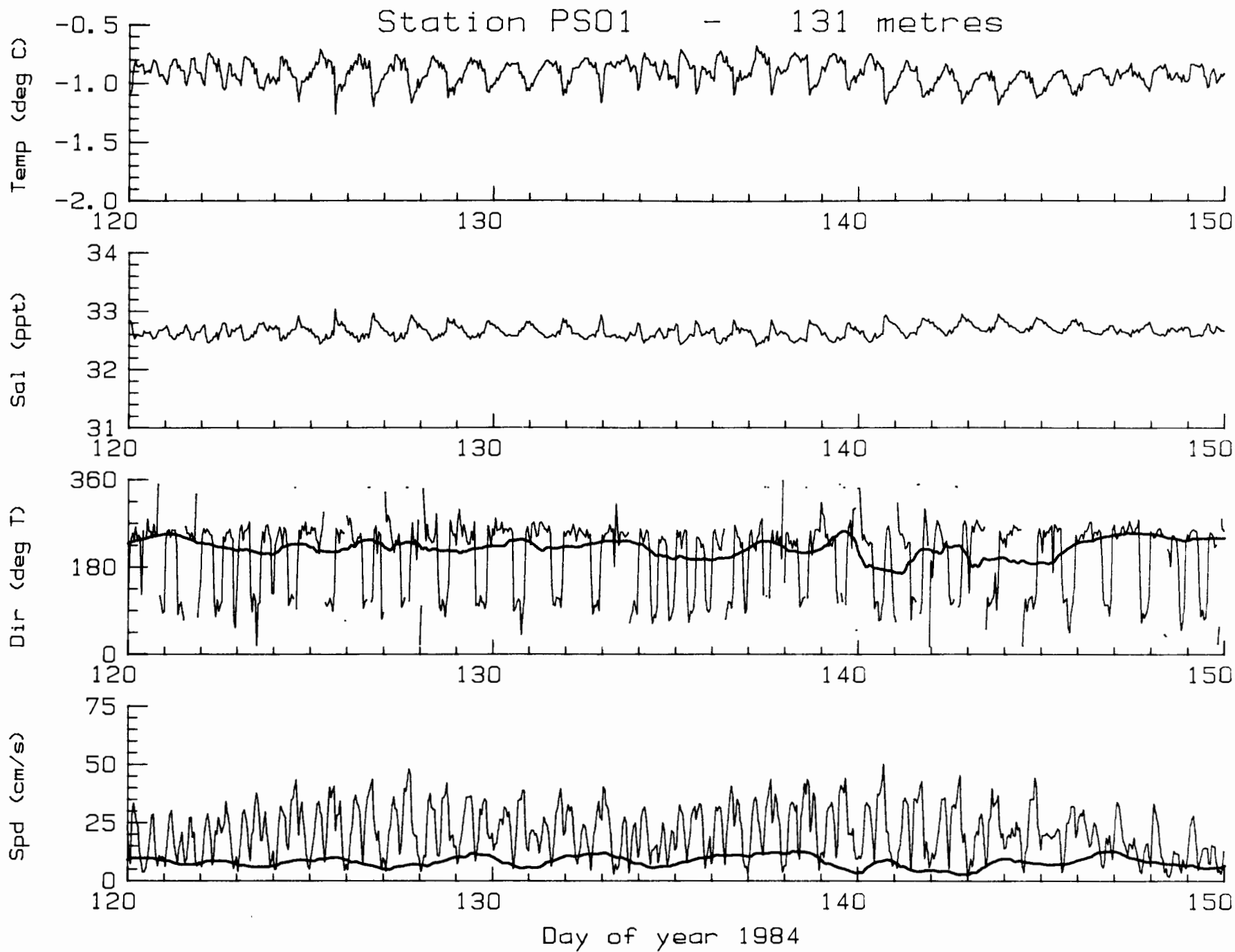


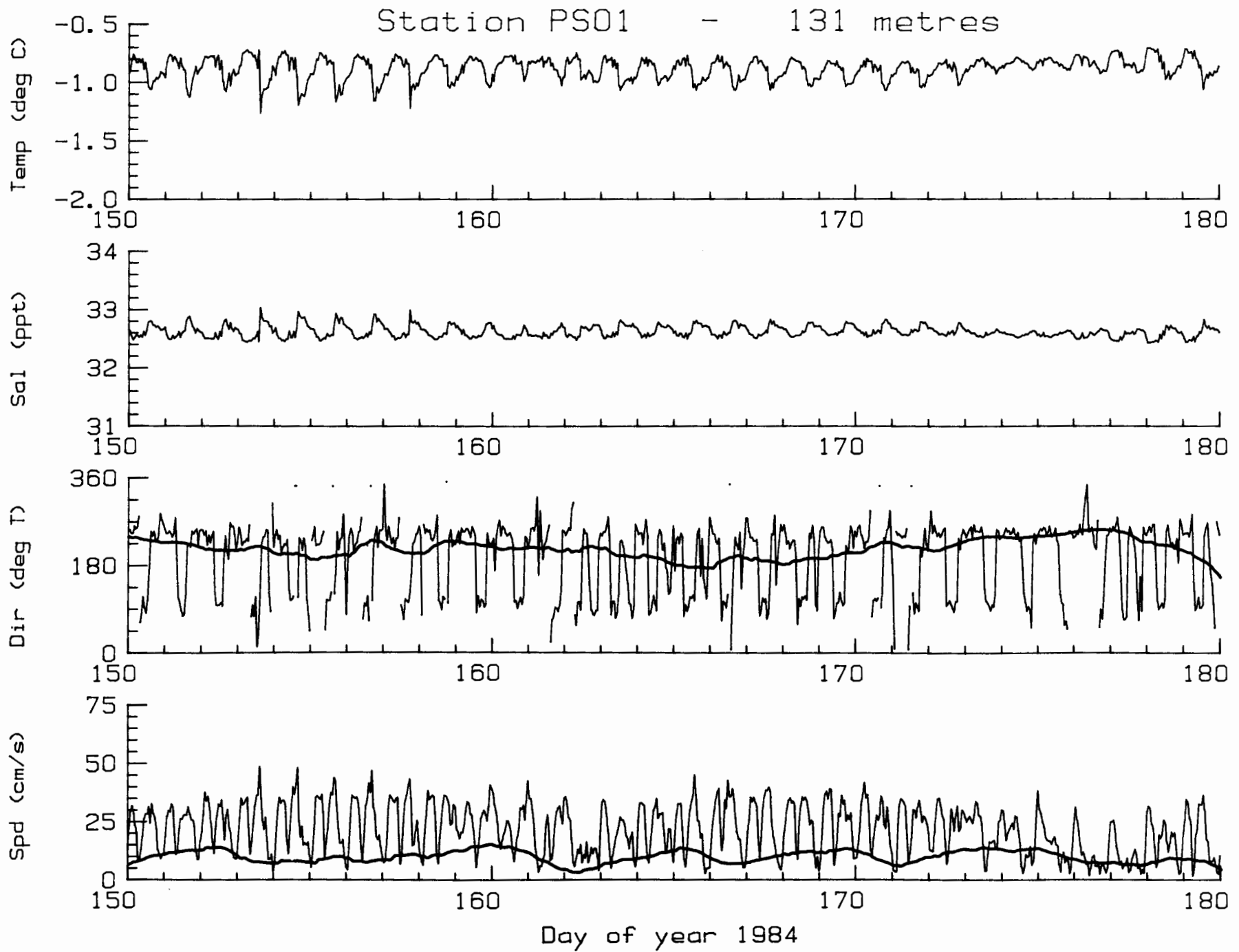
Station PS01 - 43 metres



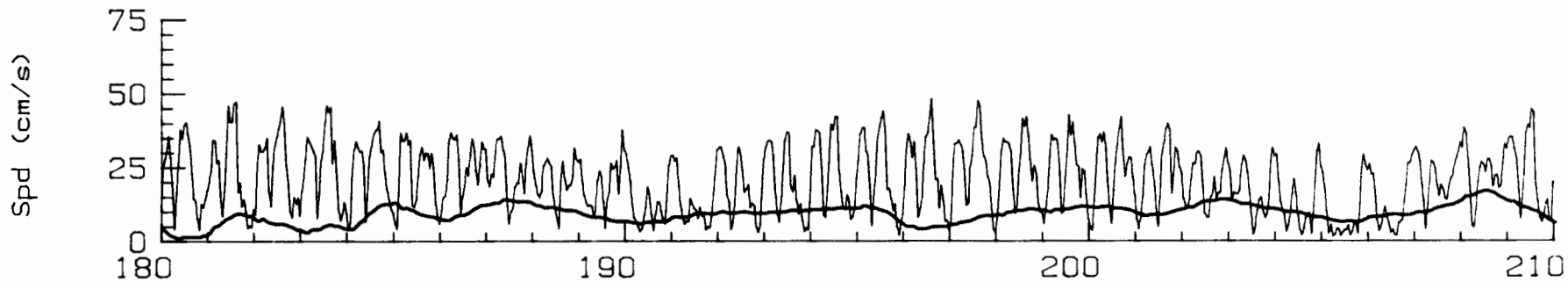
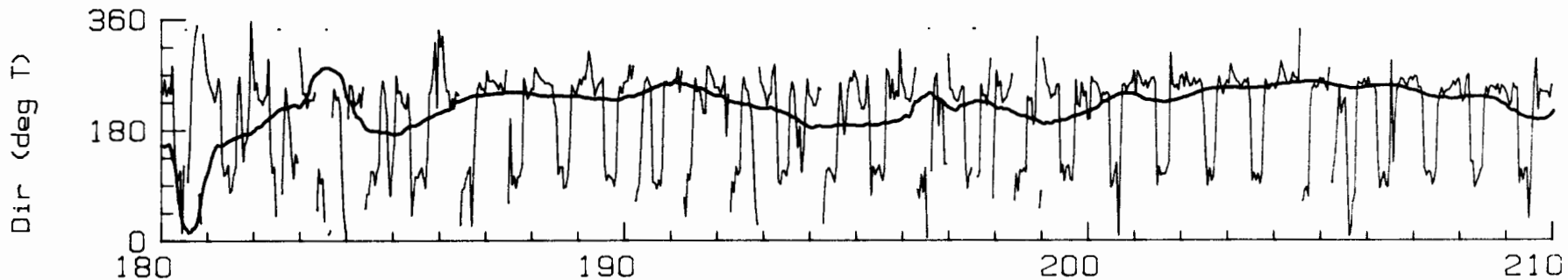
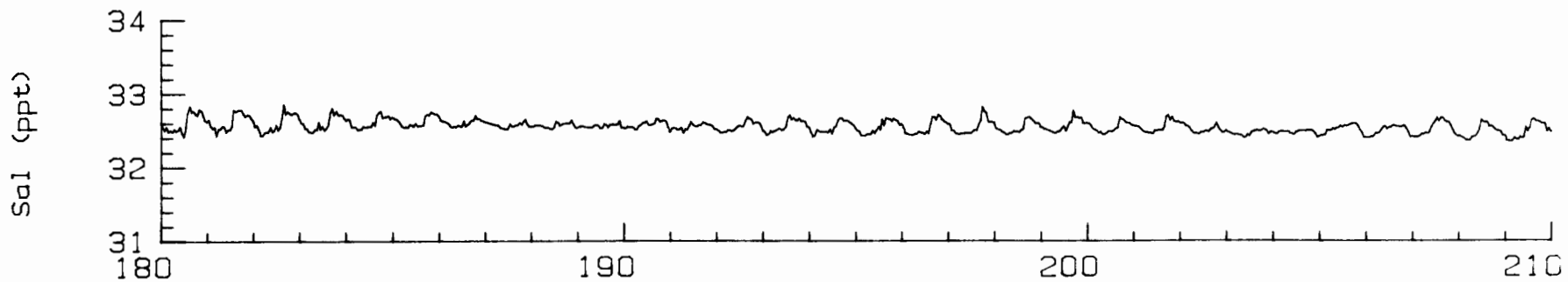
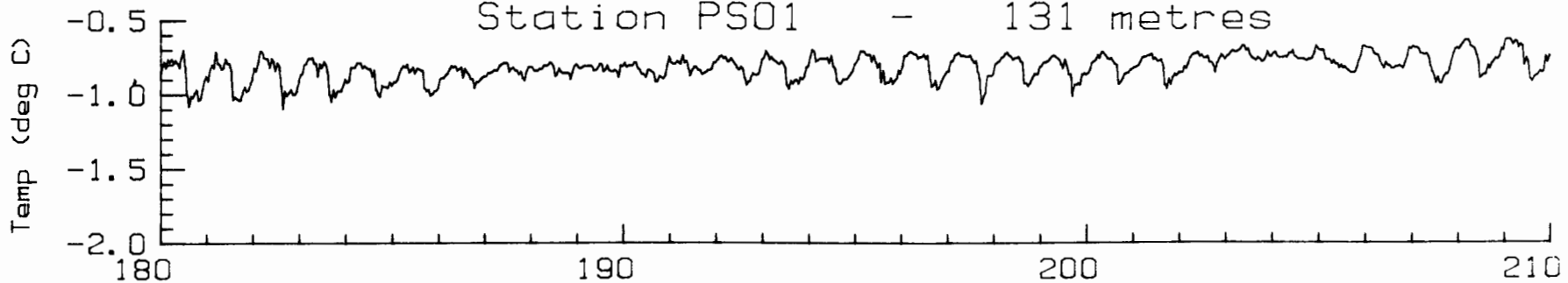
Station PS01 - 131 metres



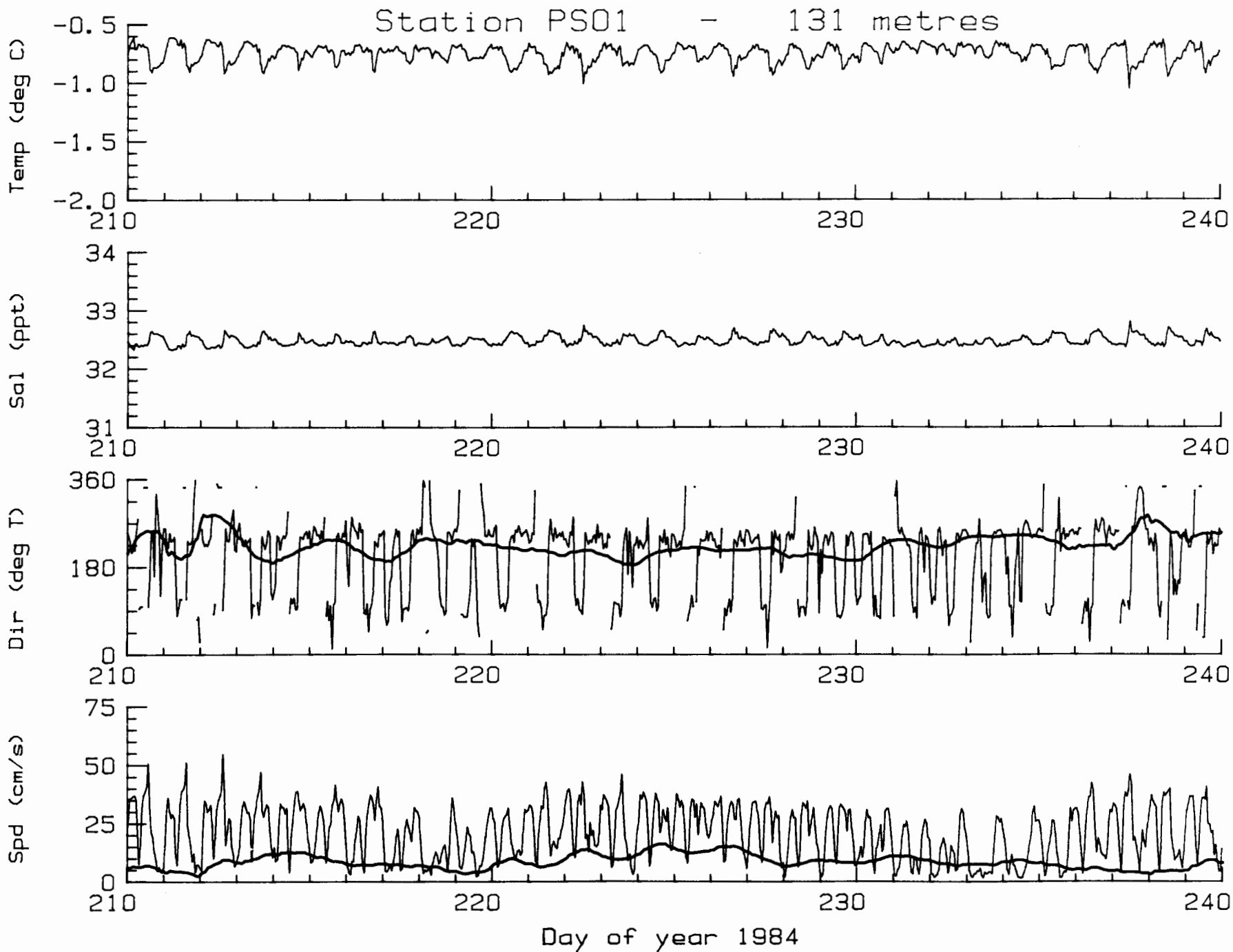




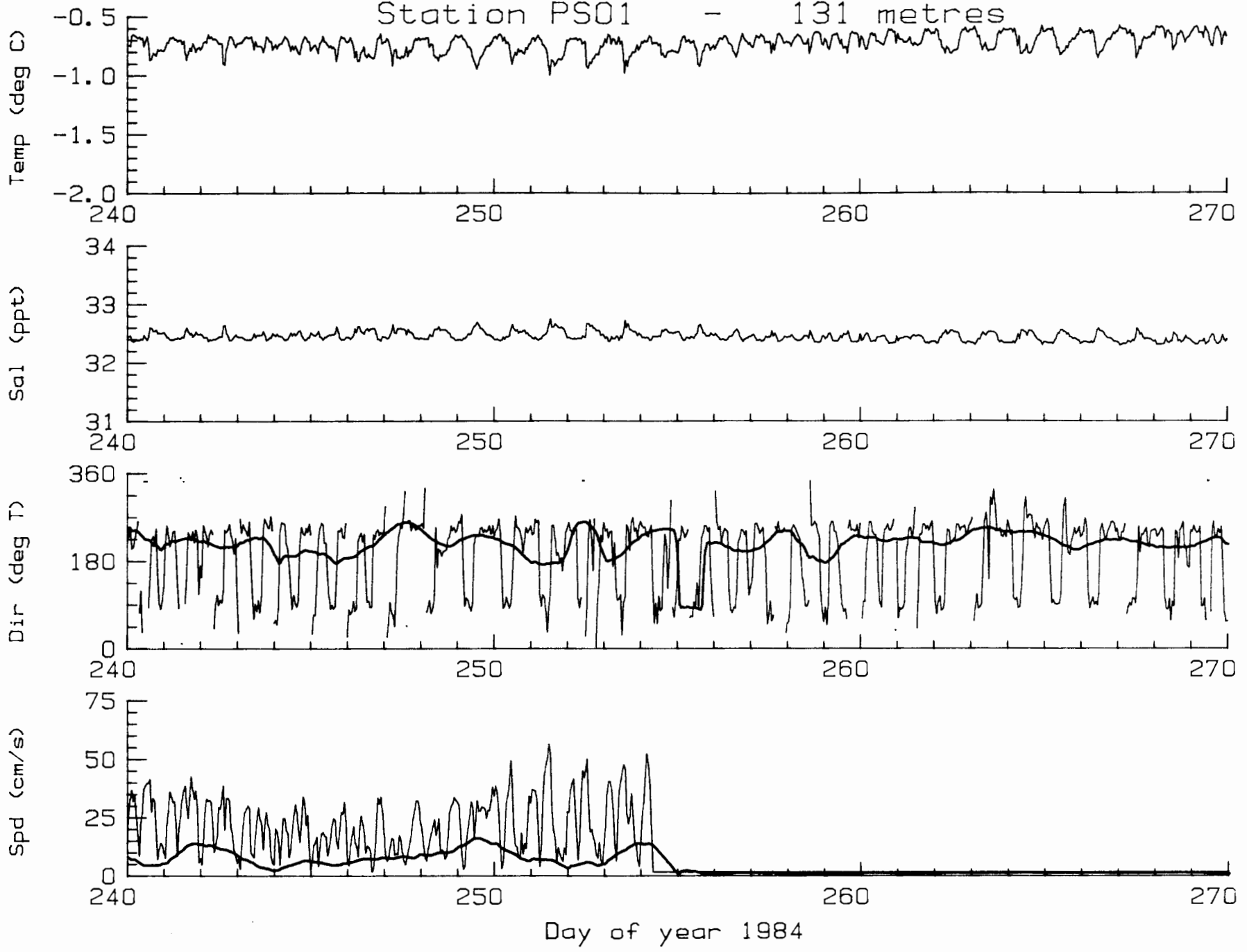
Station PS01 - 131 metres

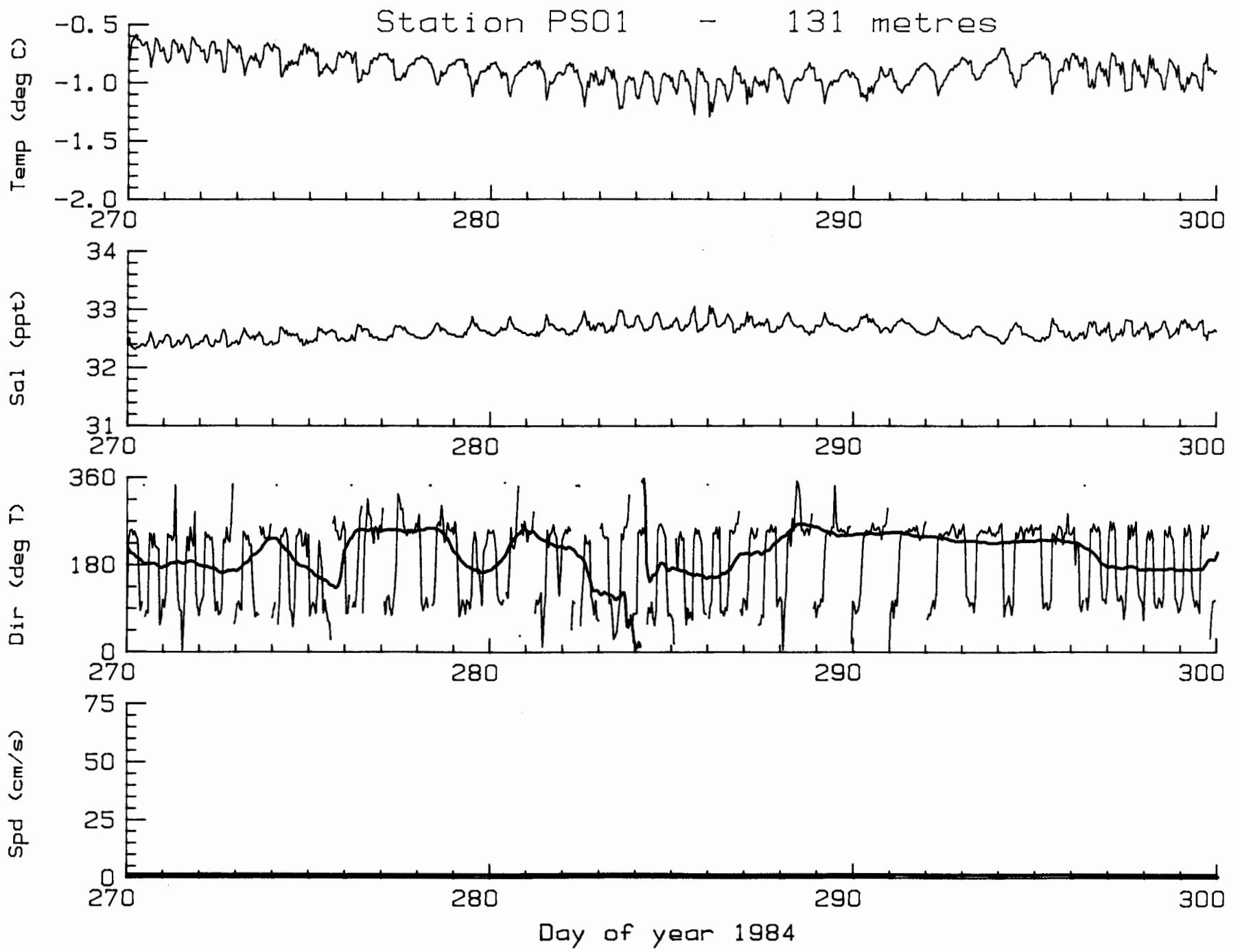


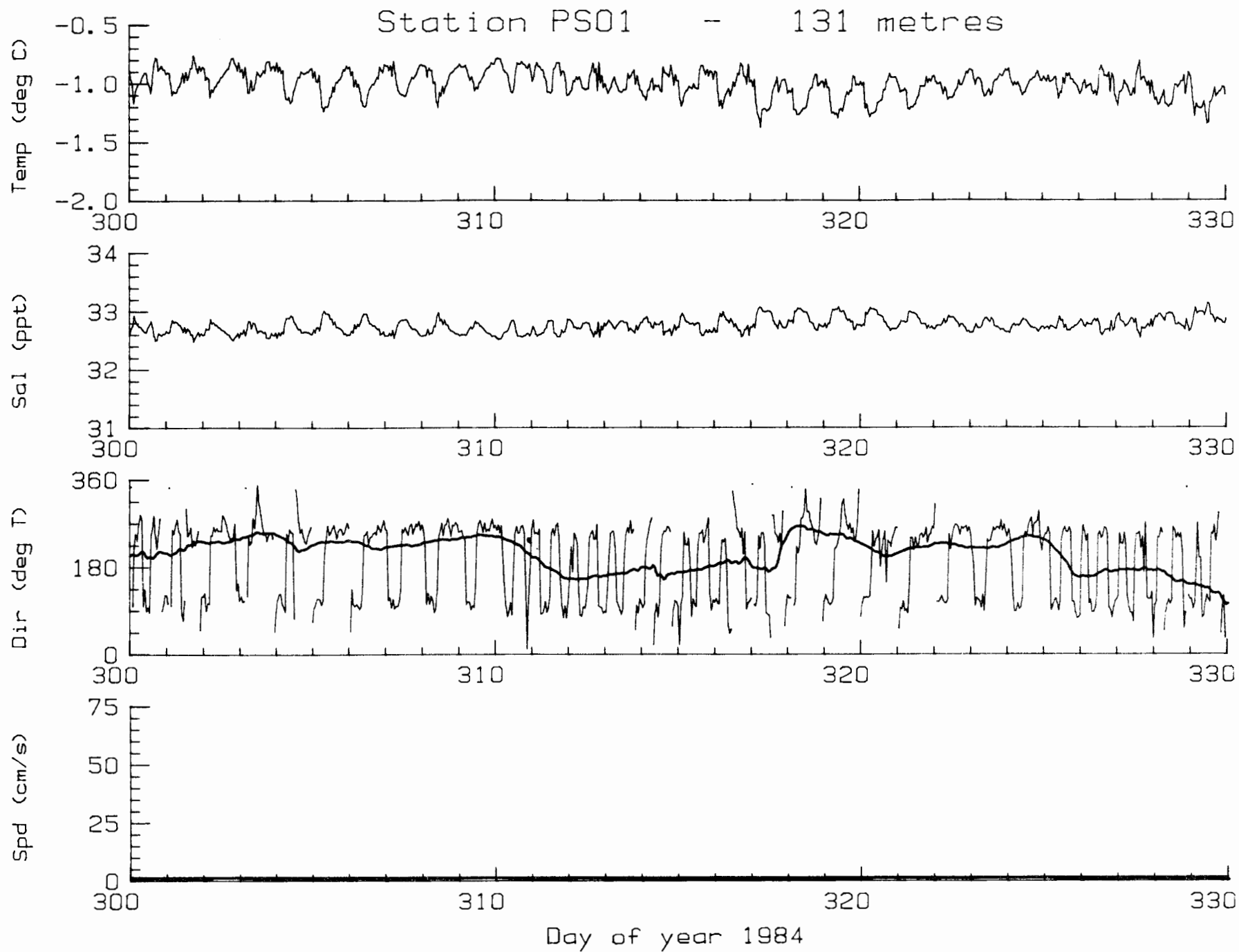
Day of year 1984



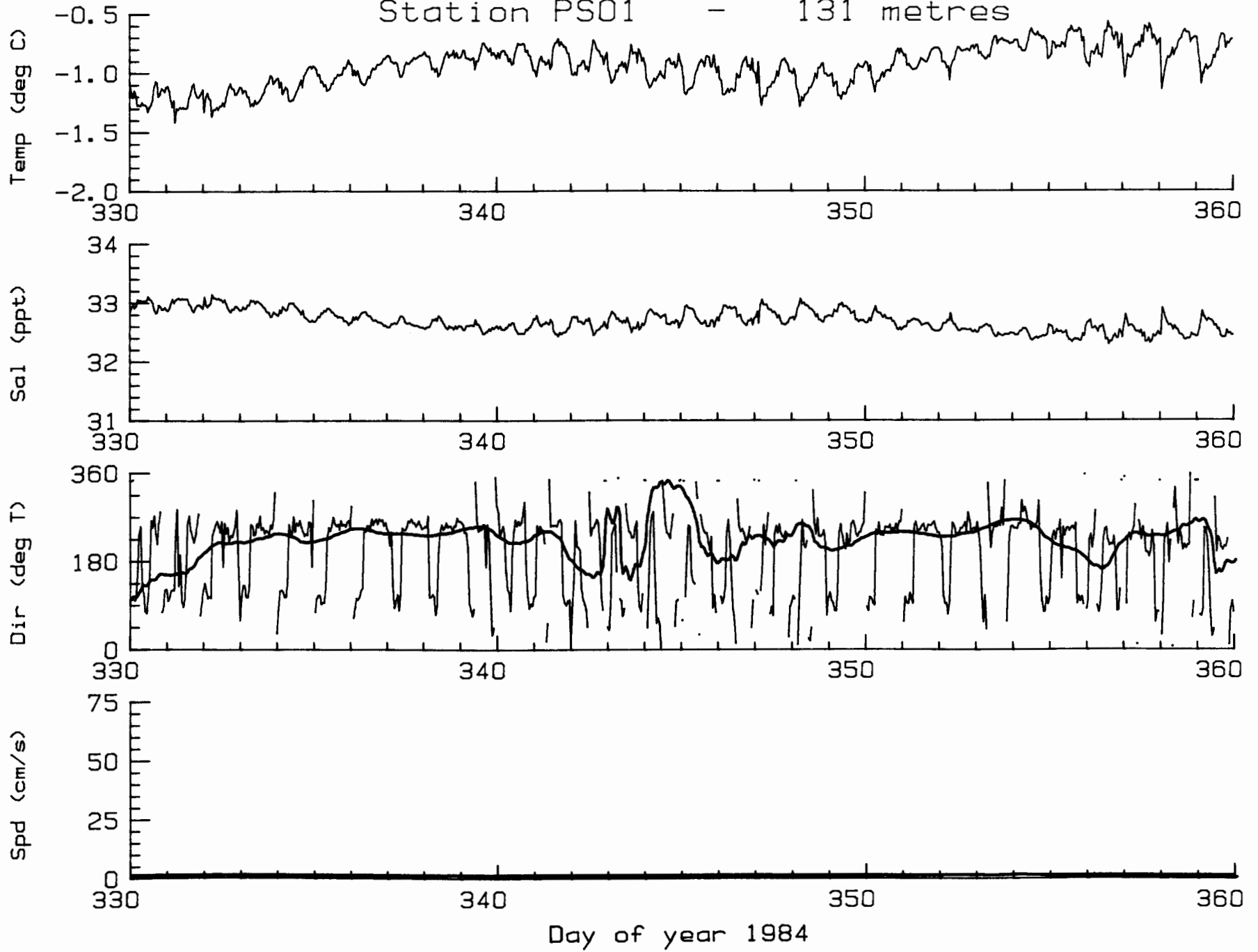
Station PS01 - 131 metres



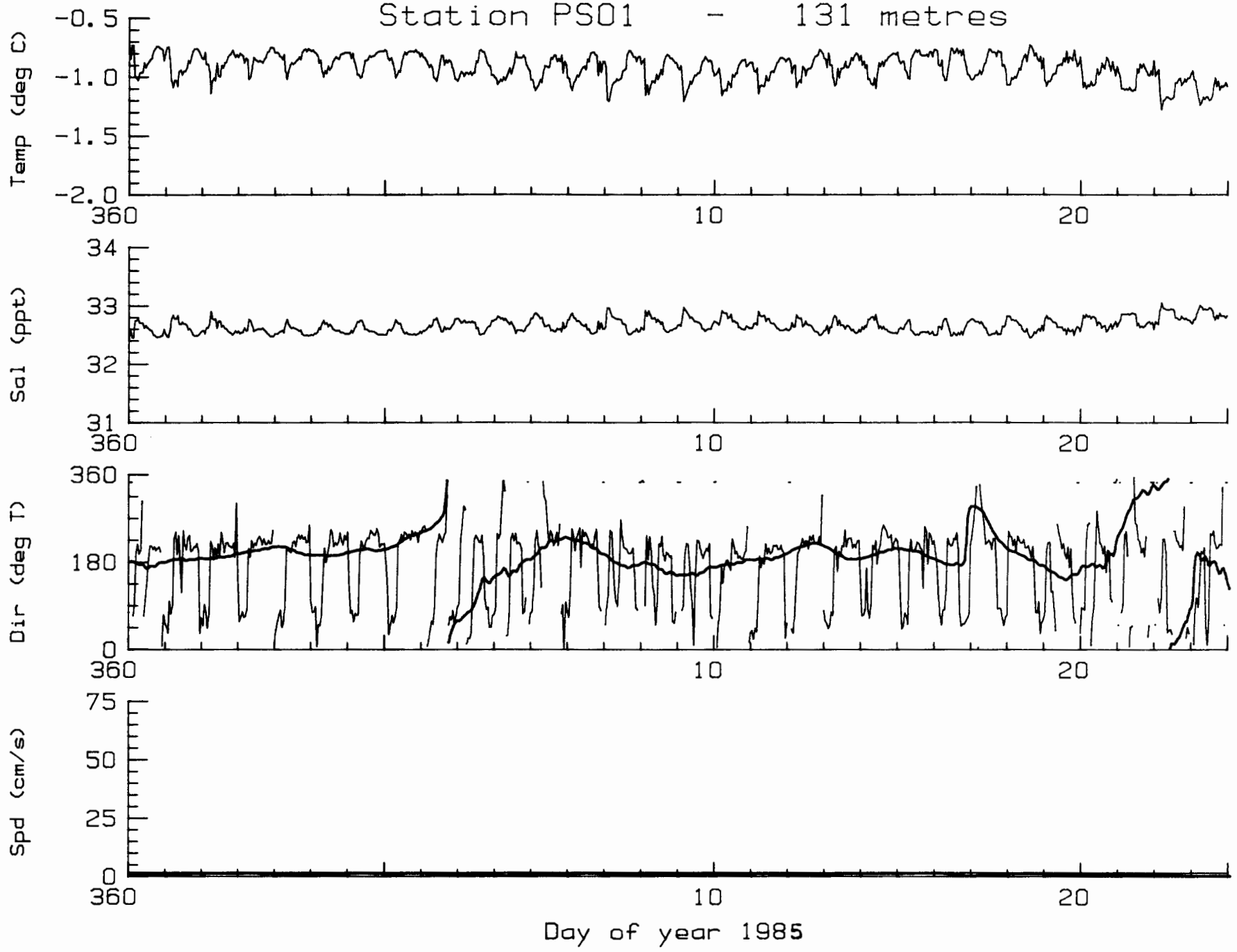




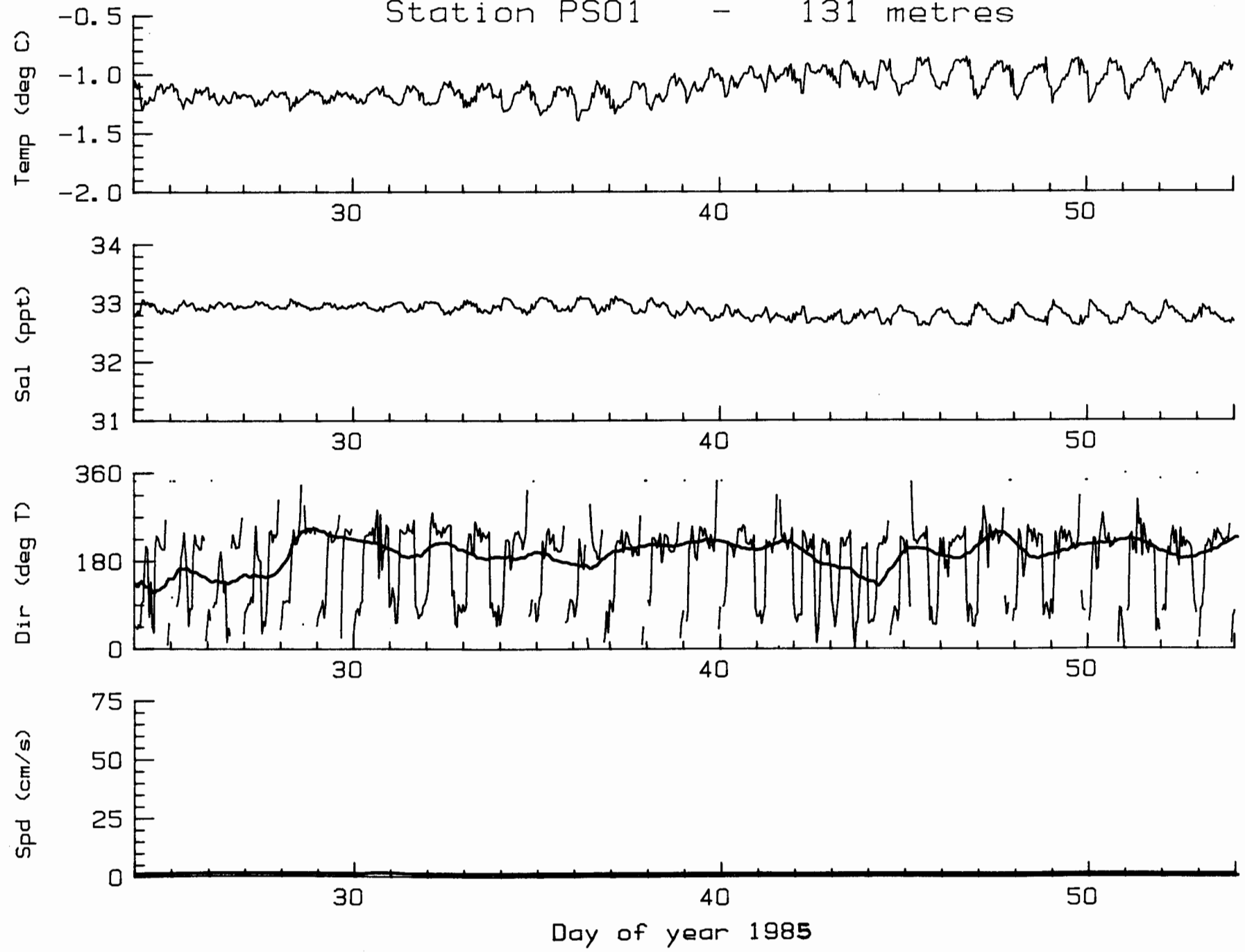
Station PS01 - 131 metres

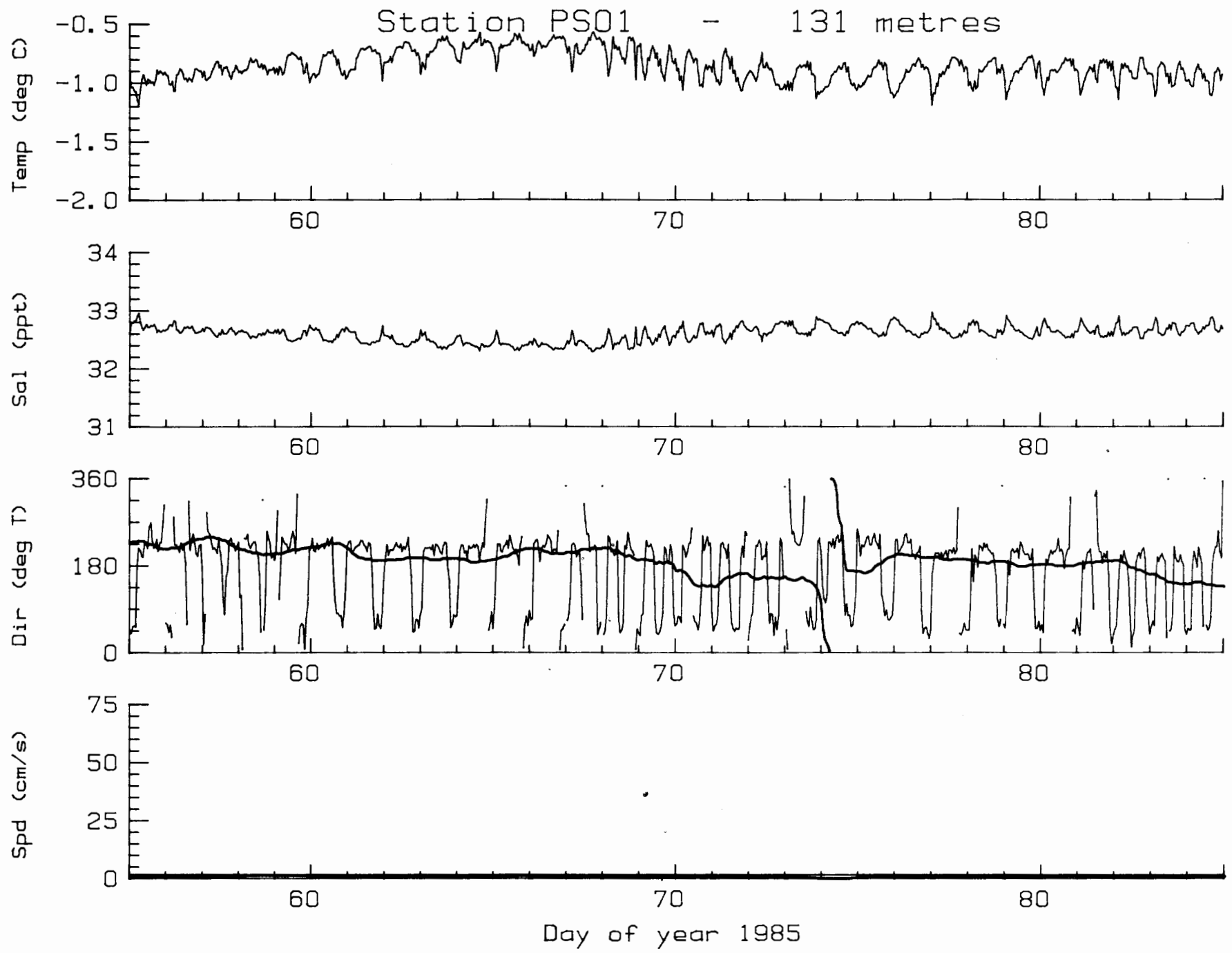


Station PS01 - 131 metres

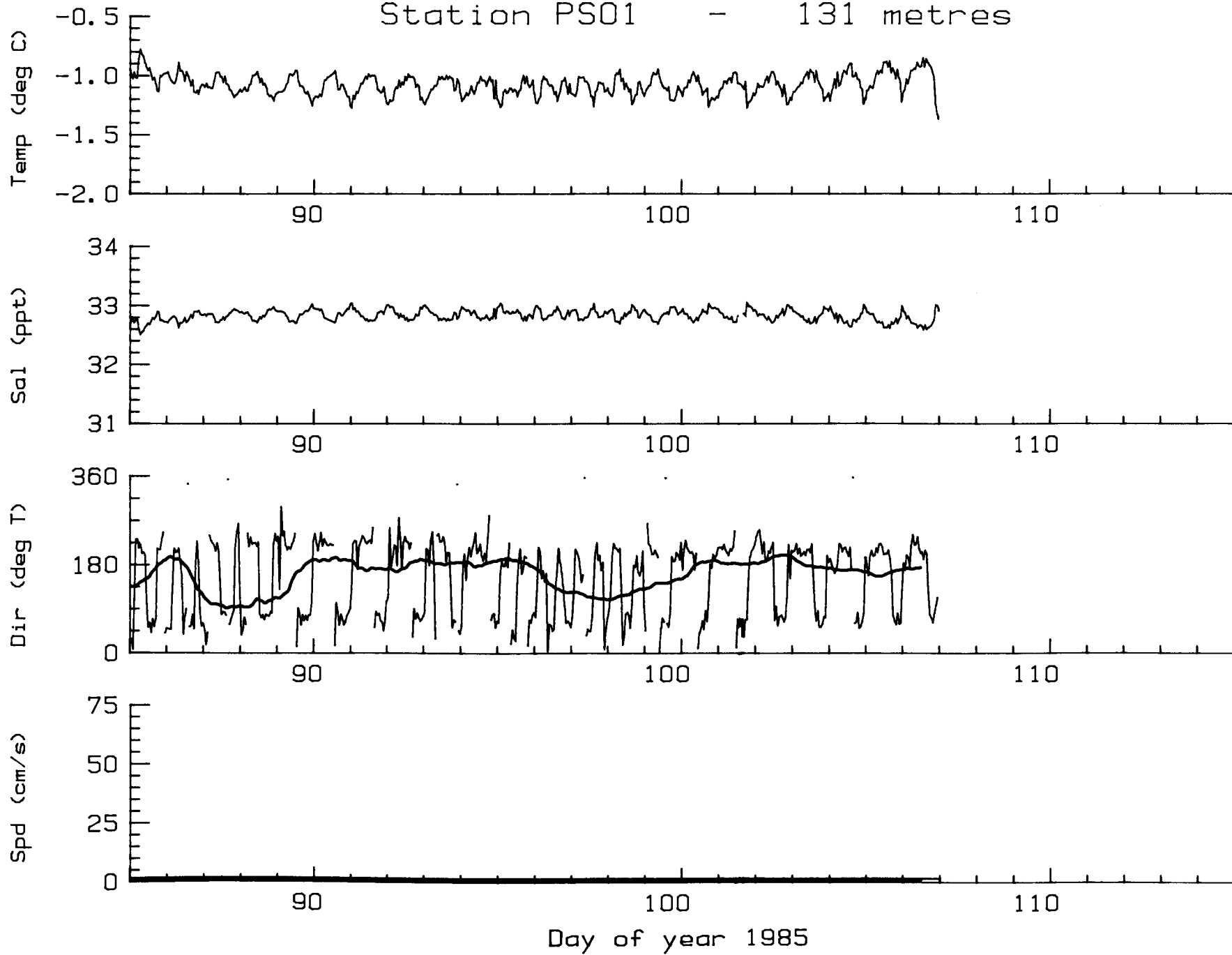


Station PS01 - 131 metres

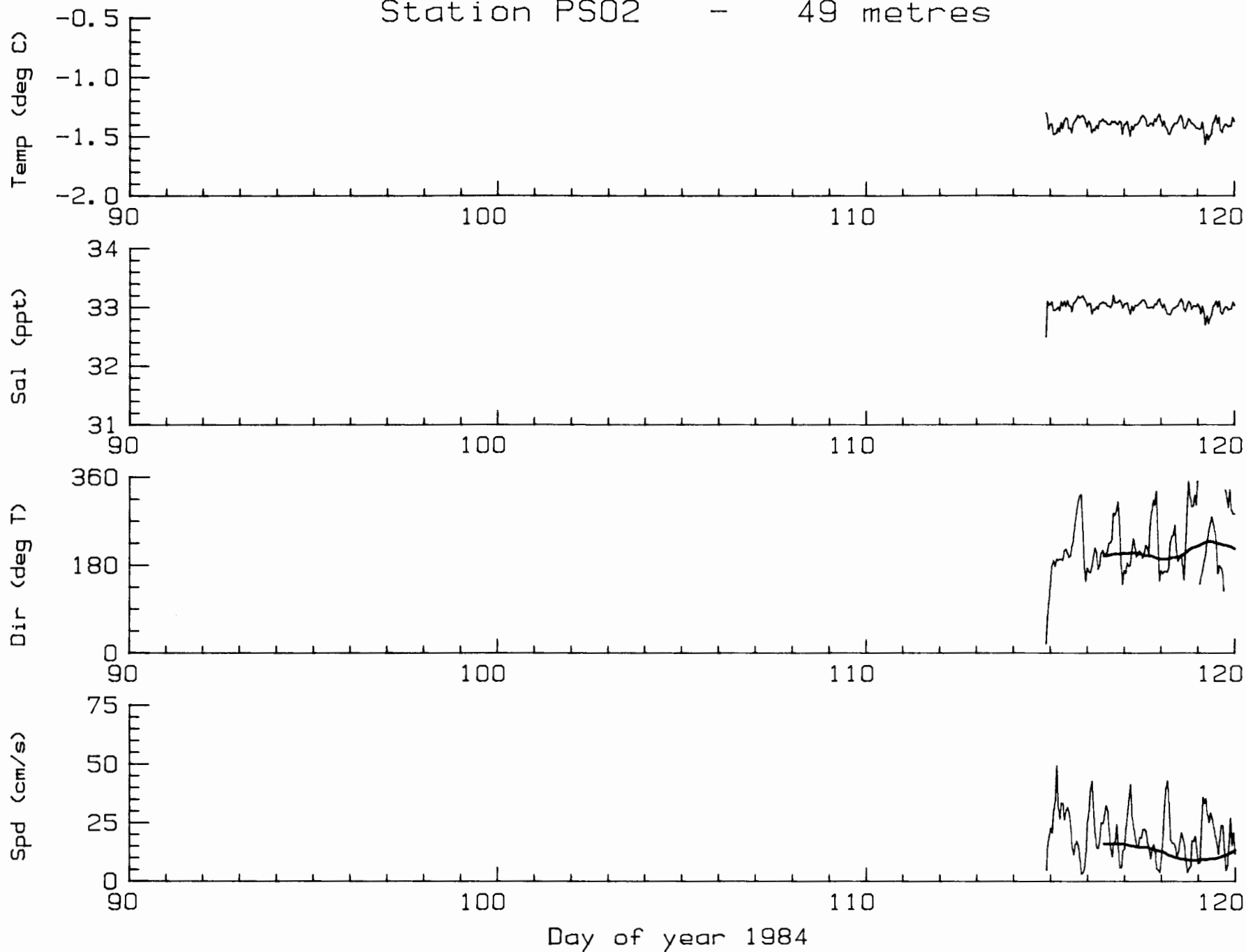




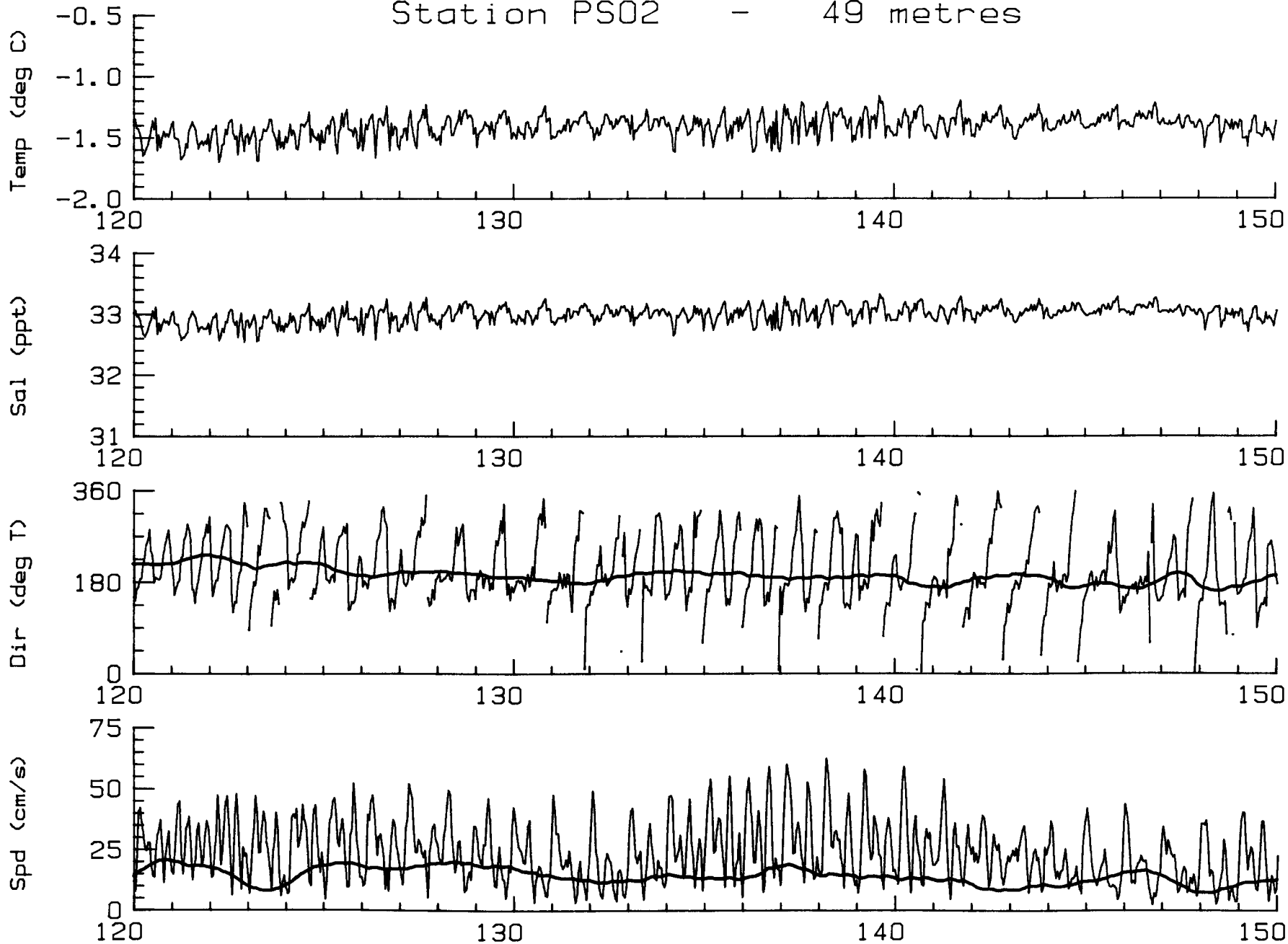
Station PS01 - 131 metres



Station PS02 - 49 metres

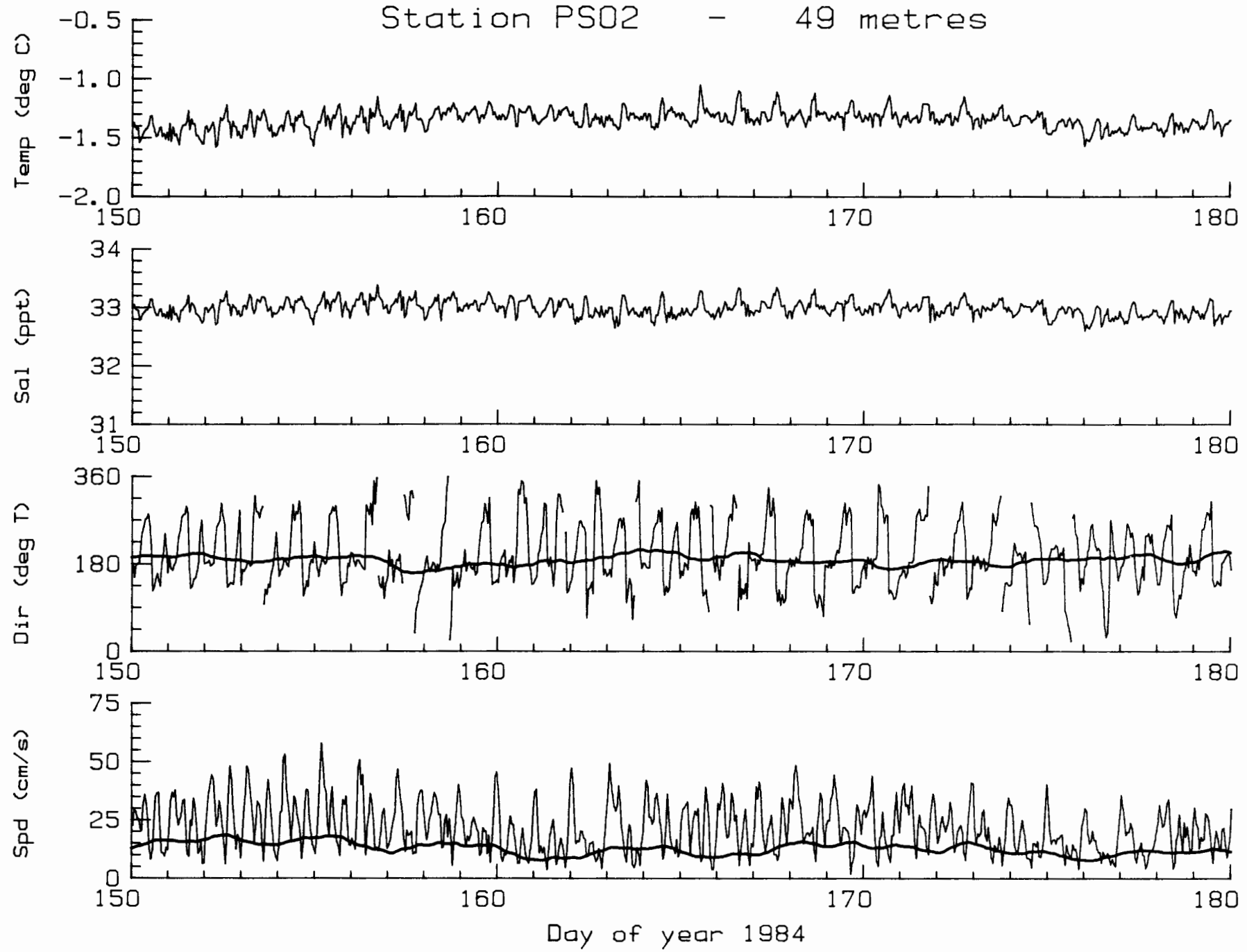


Station PS02 - 49 metres

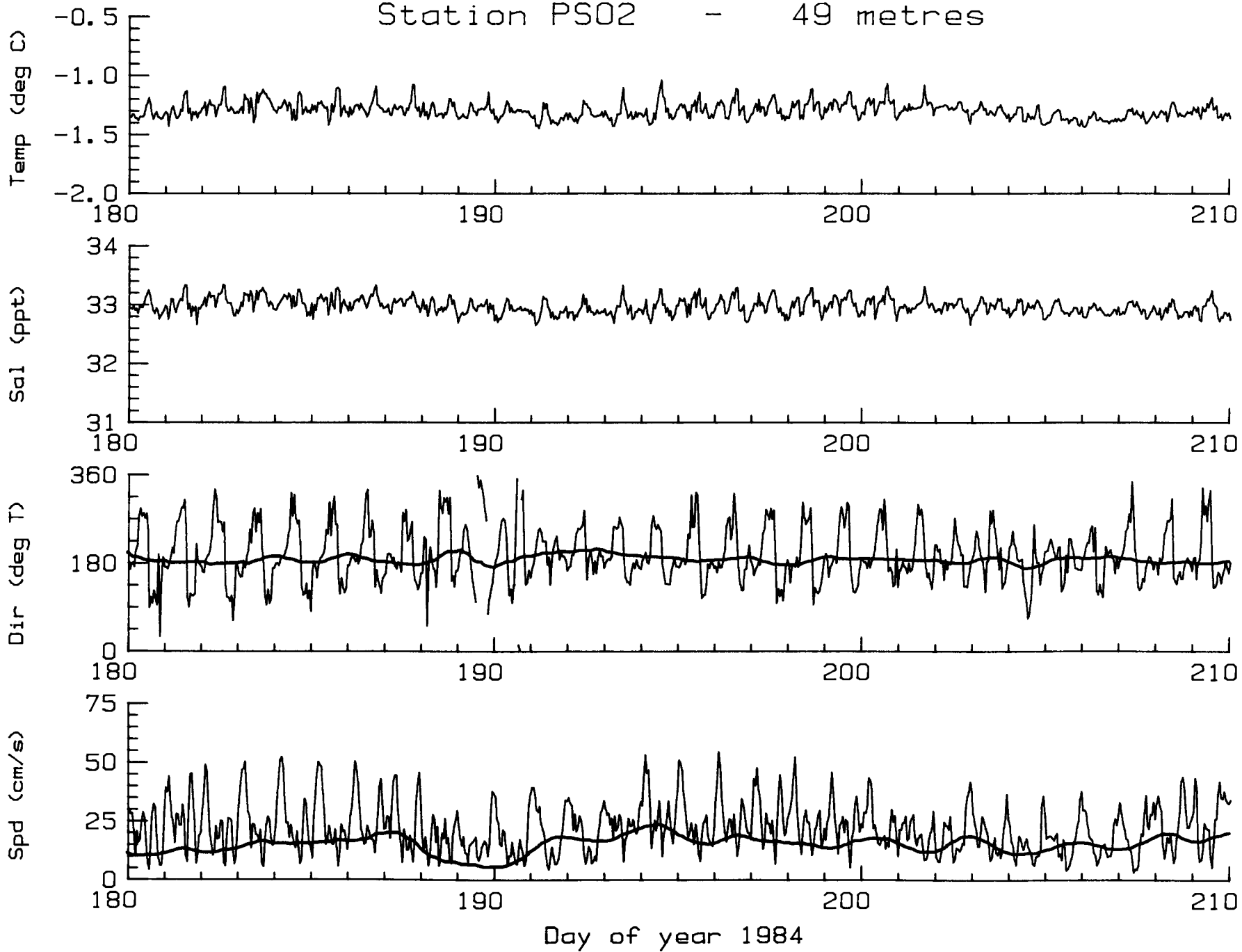


Day of year 1984

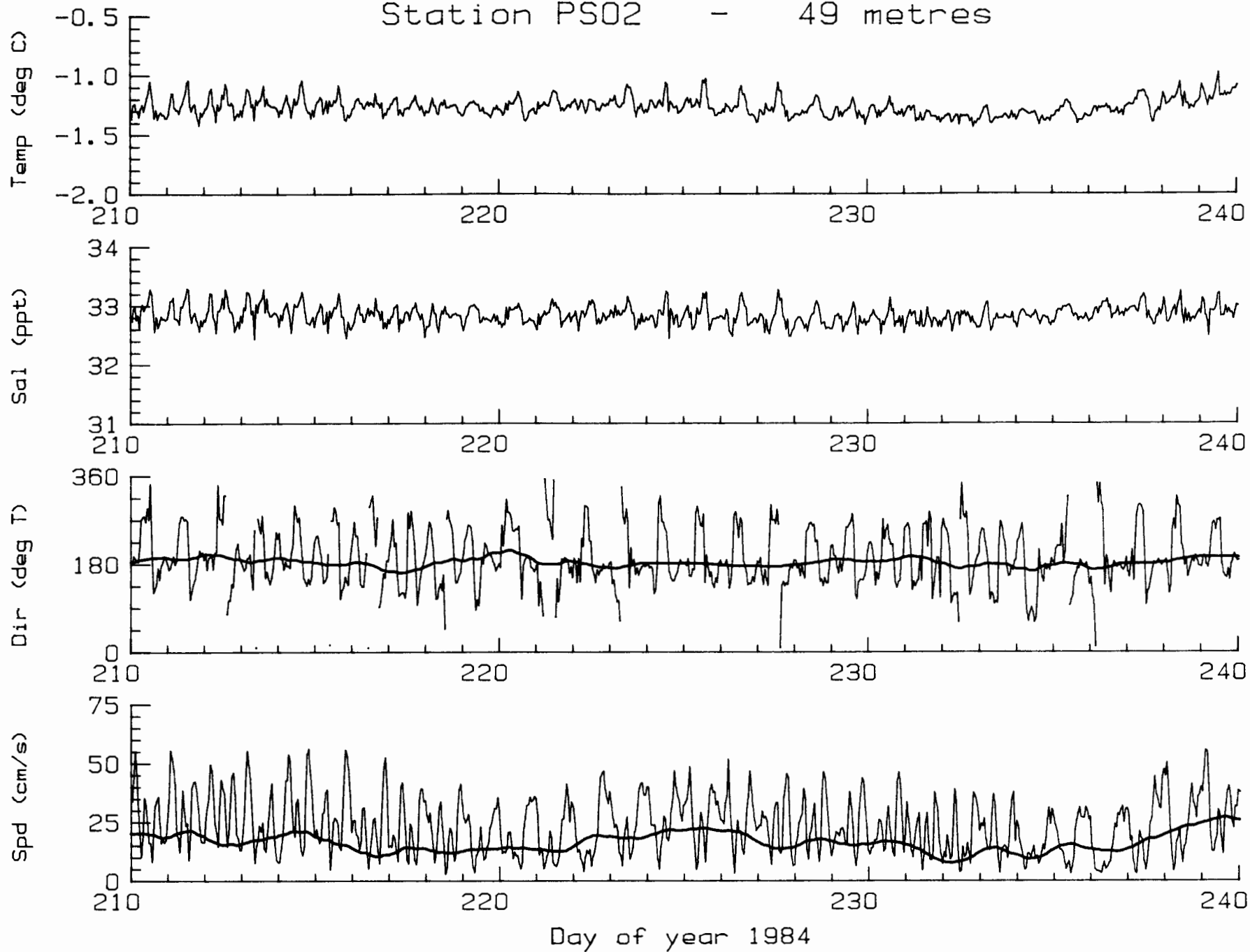
Station PS02 - 49 metres



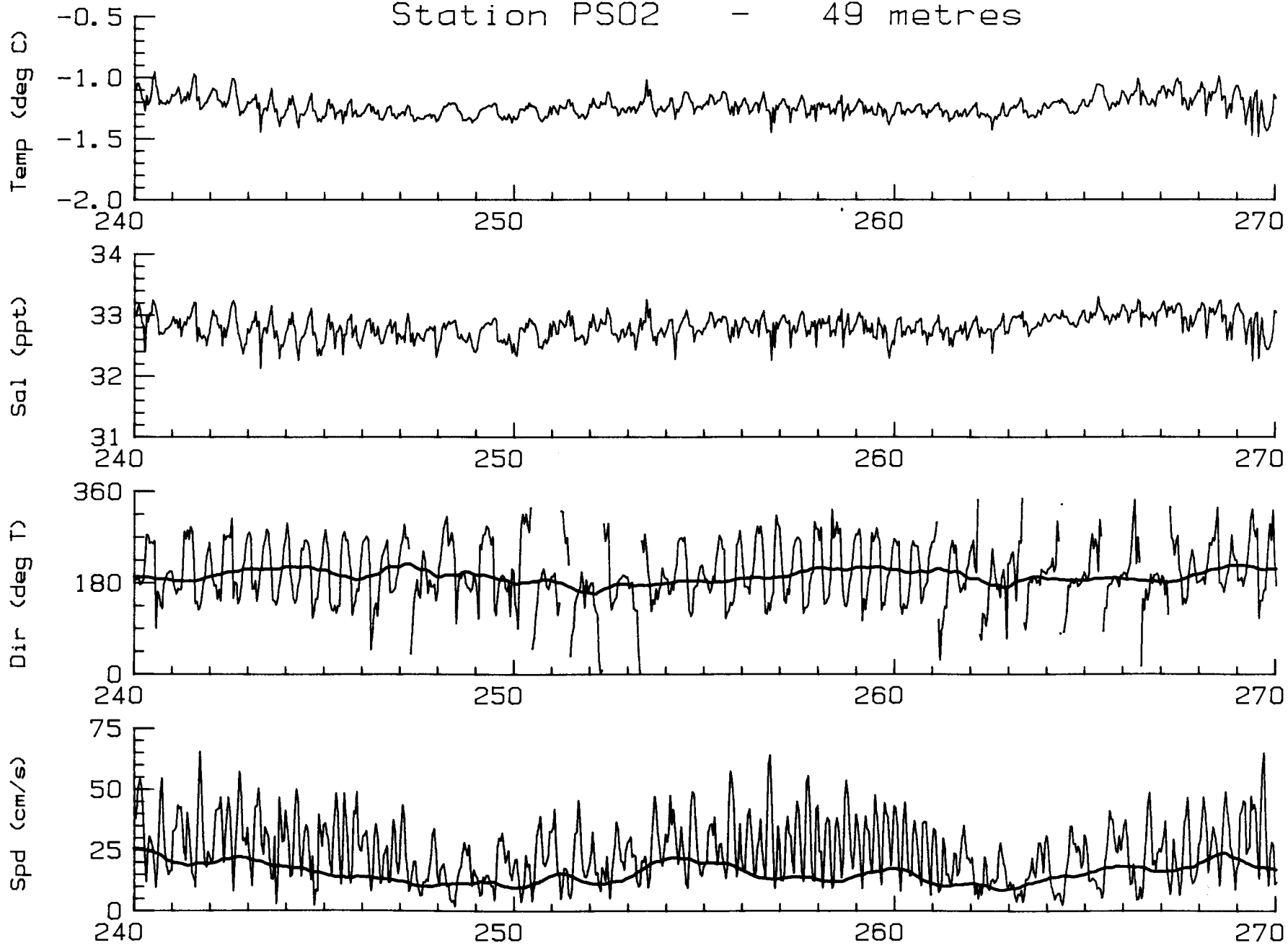
Station PS02 - 49 metres



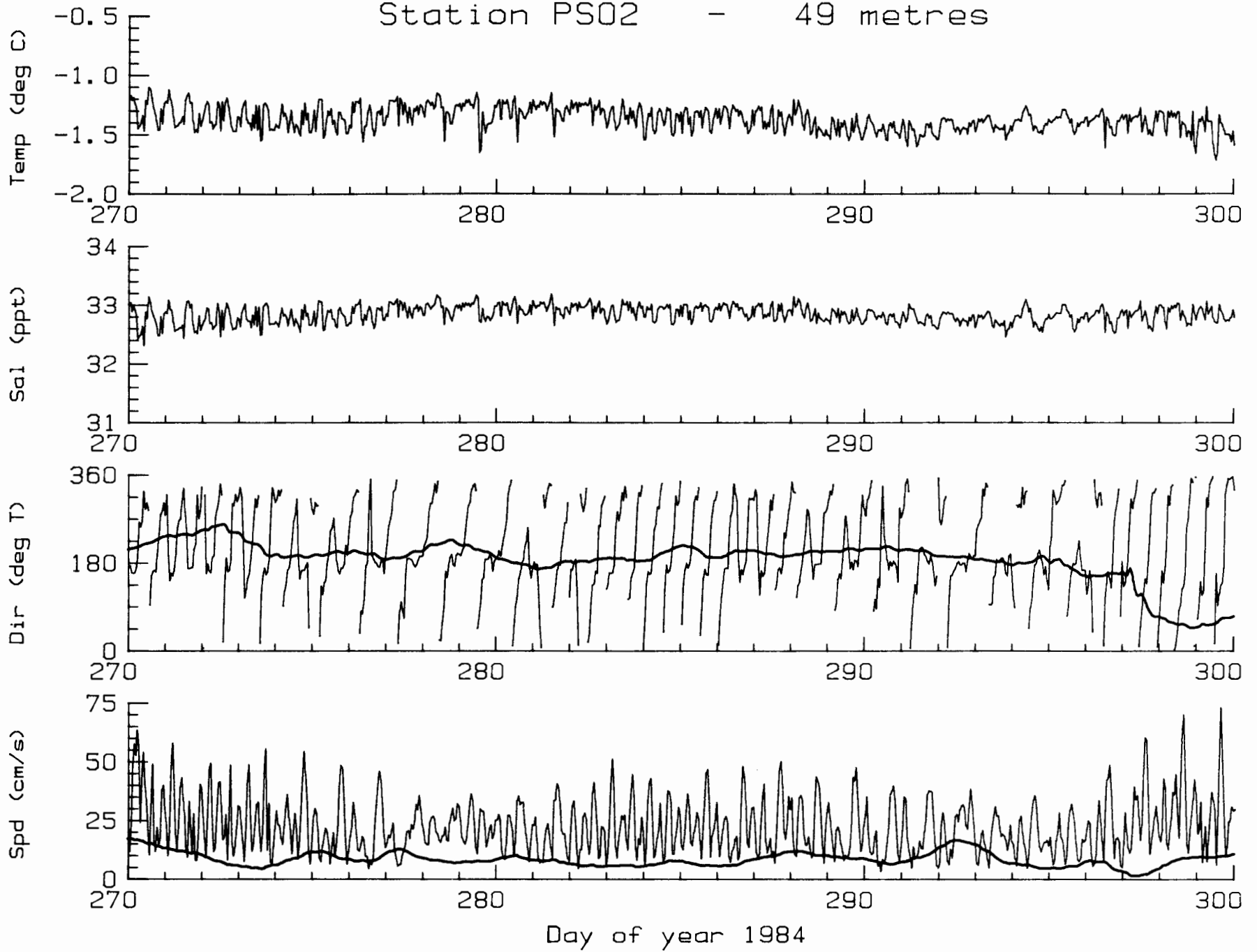
Station PS02 - 49 metres



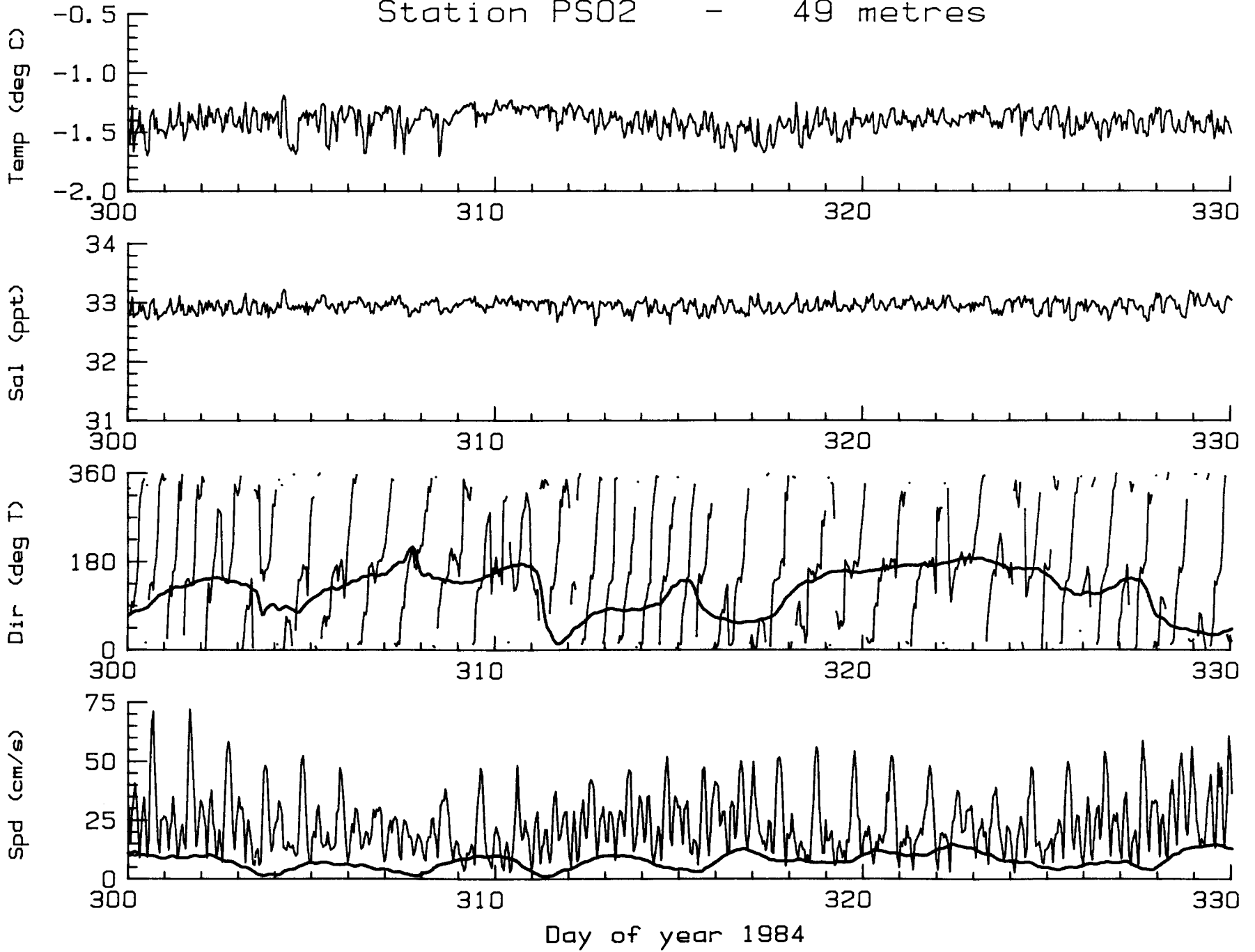
Station PS02 - 49 metres



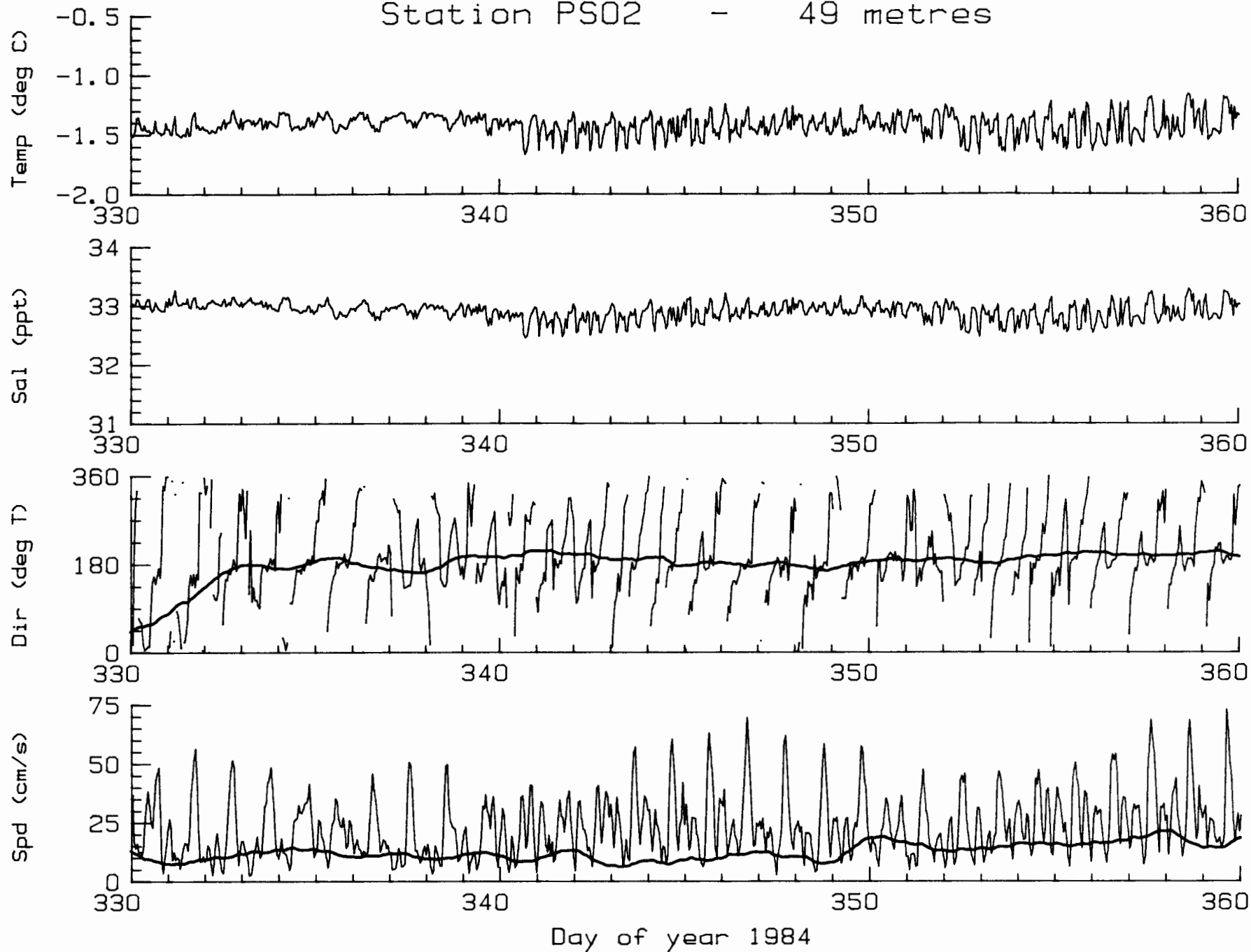
Station PS02 - 49 metres



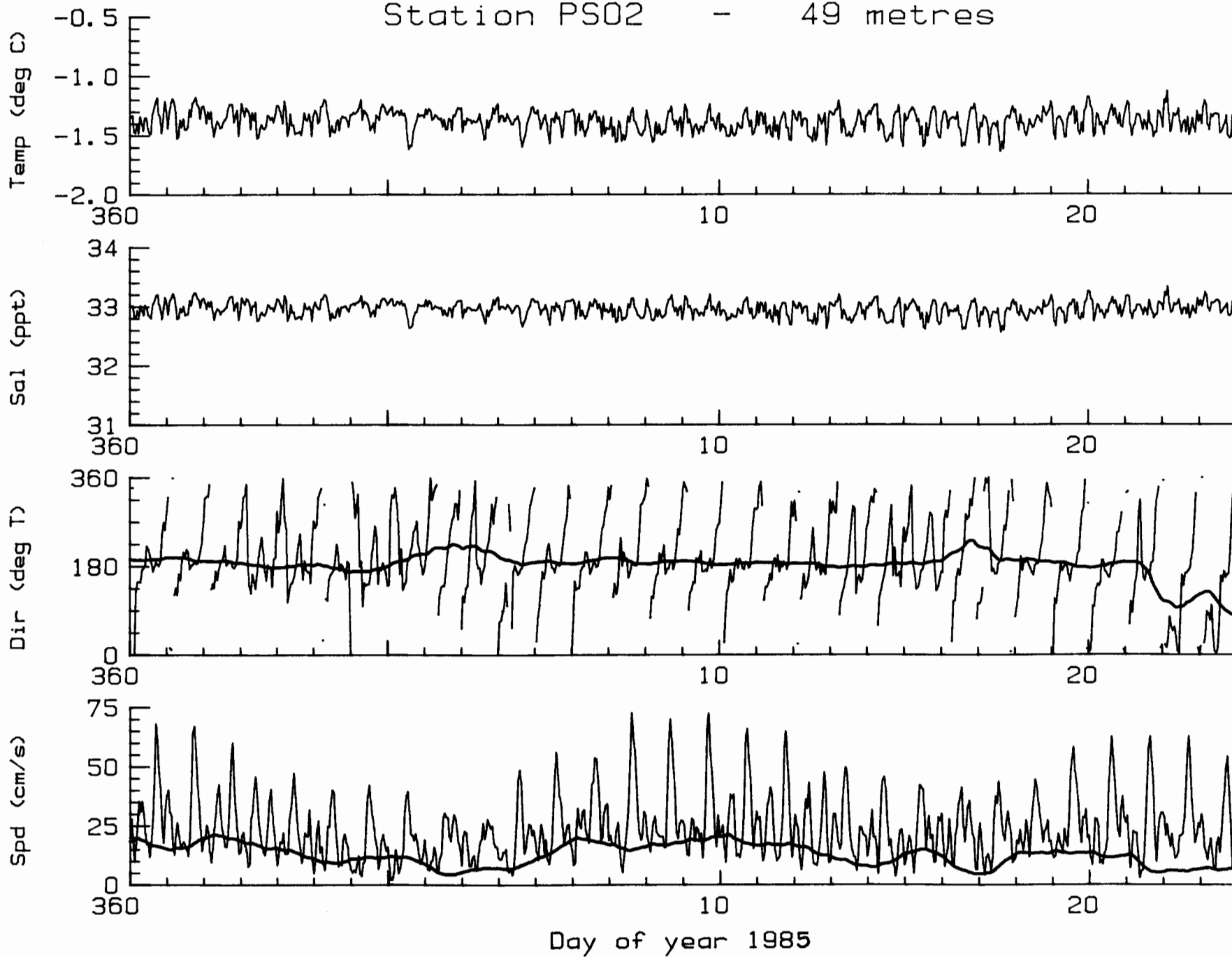
Station PS02 - 49 metres



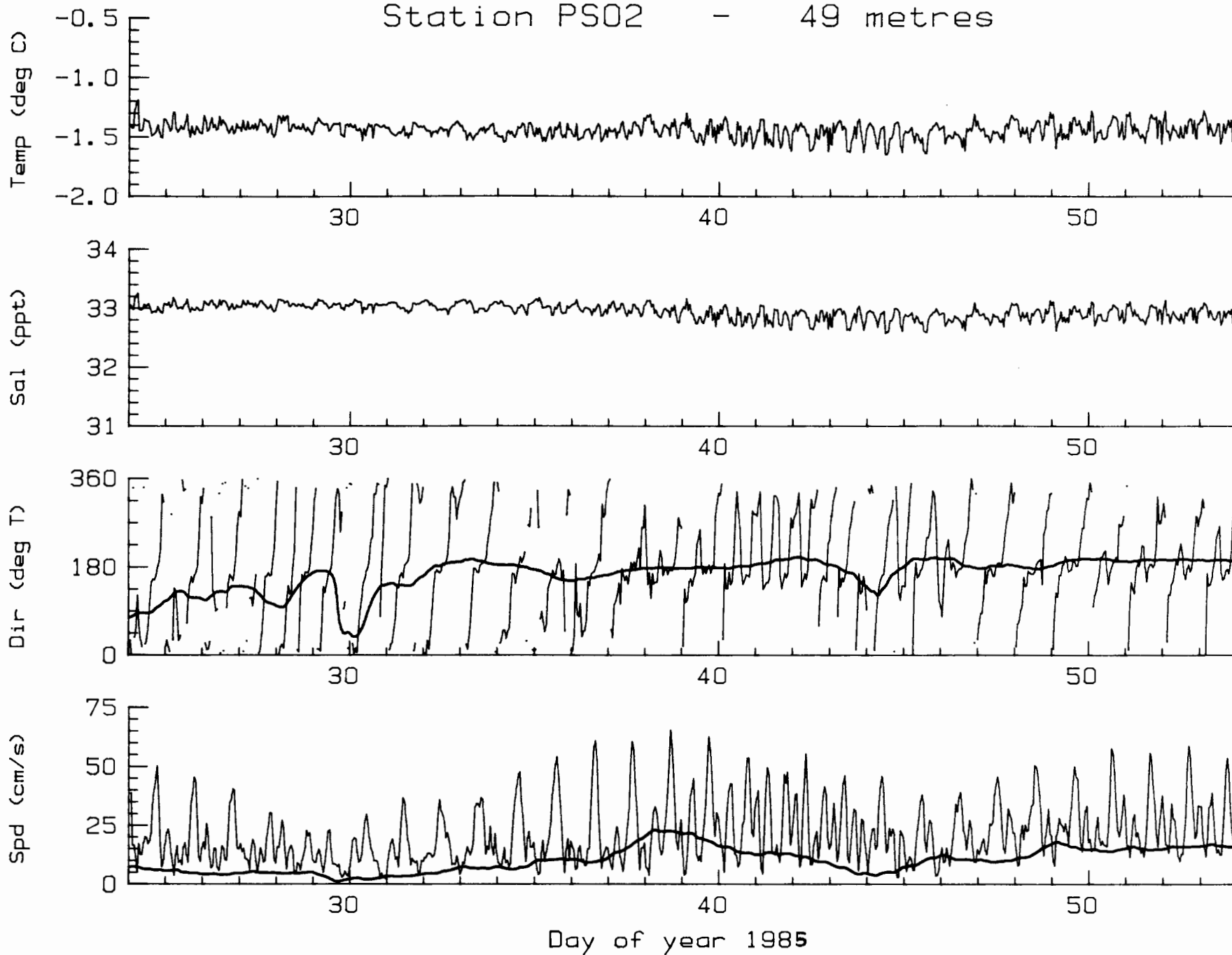
Station PS02 - 49 metres



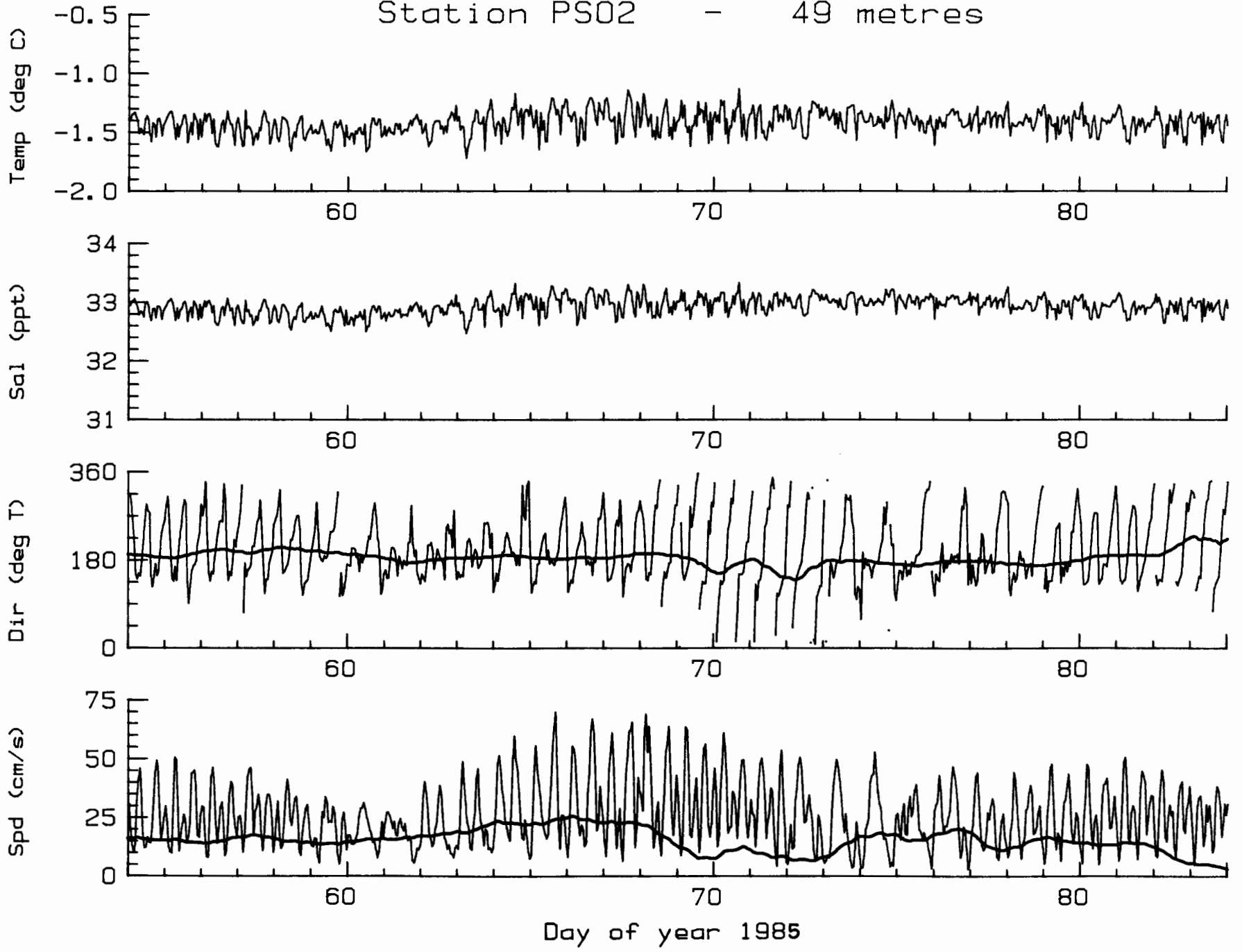
Station PS02 - 49 metres



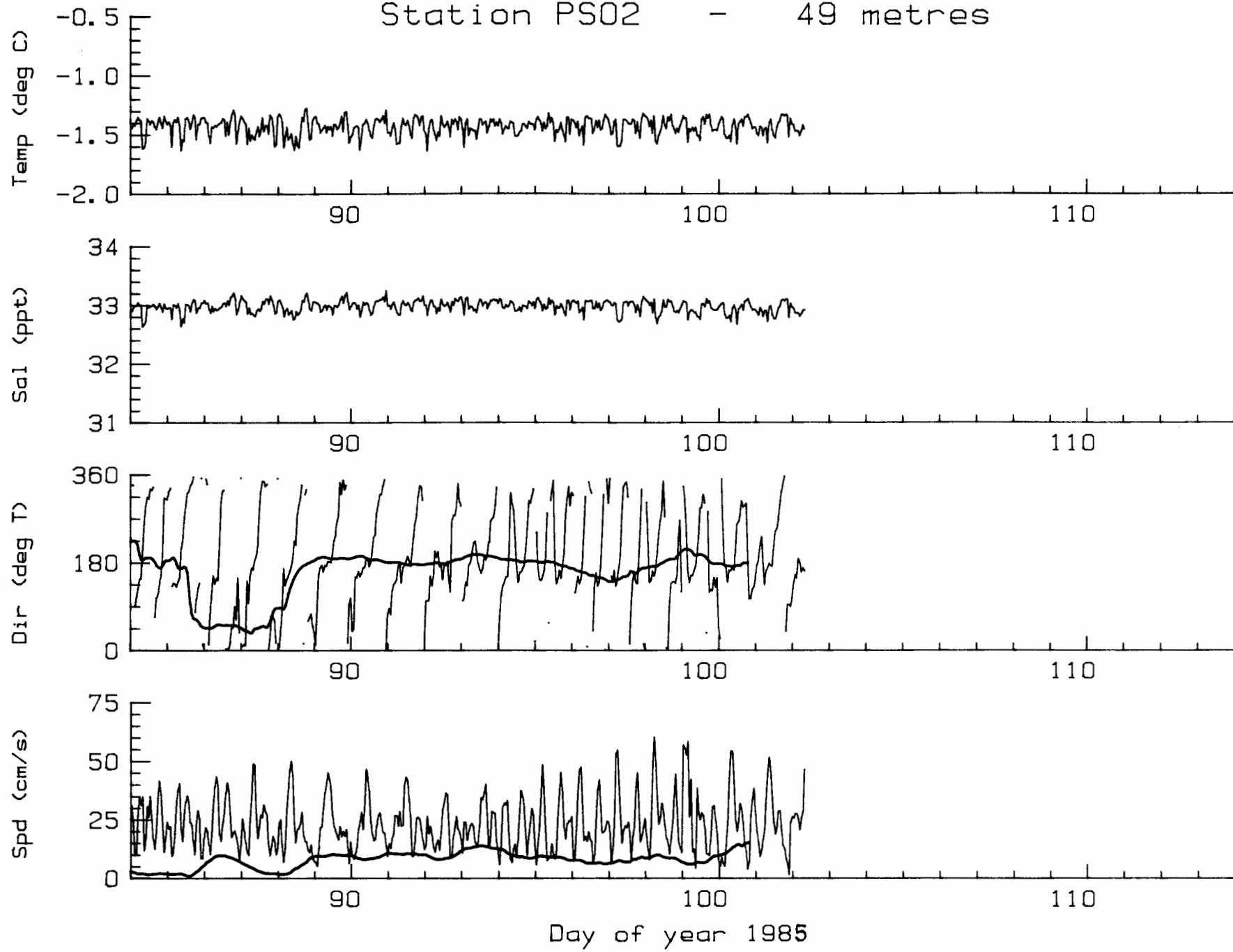
Station PS02 - 49 metres



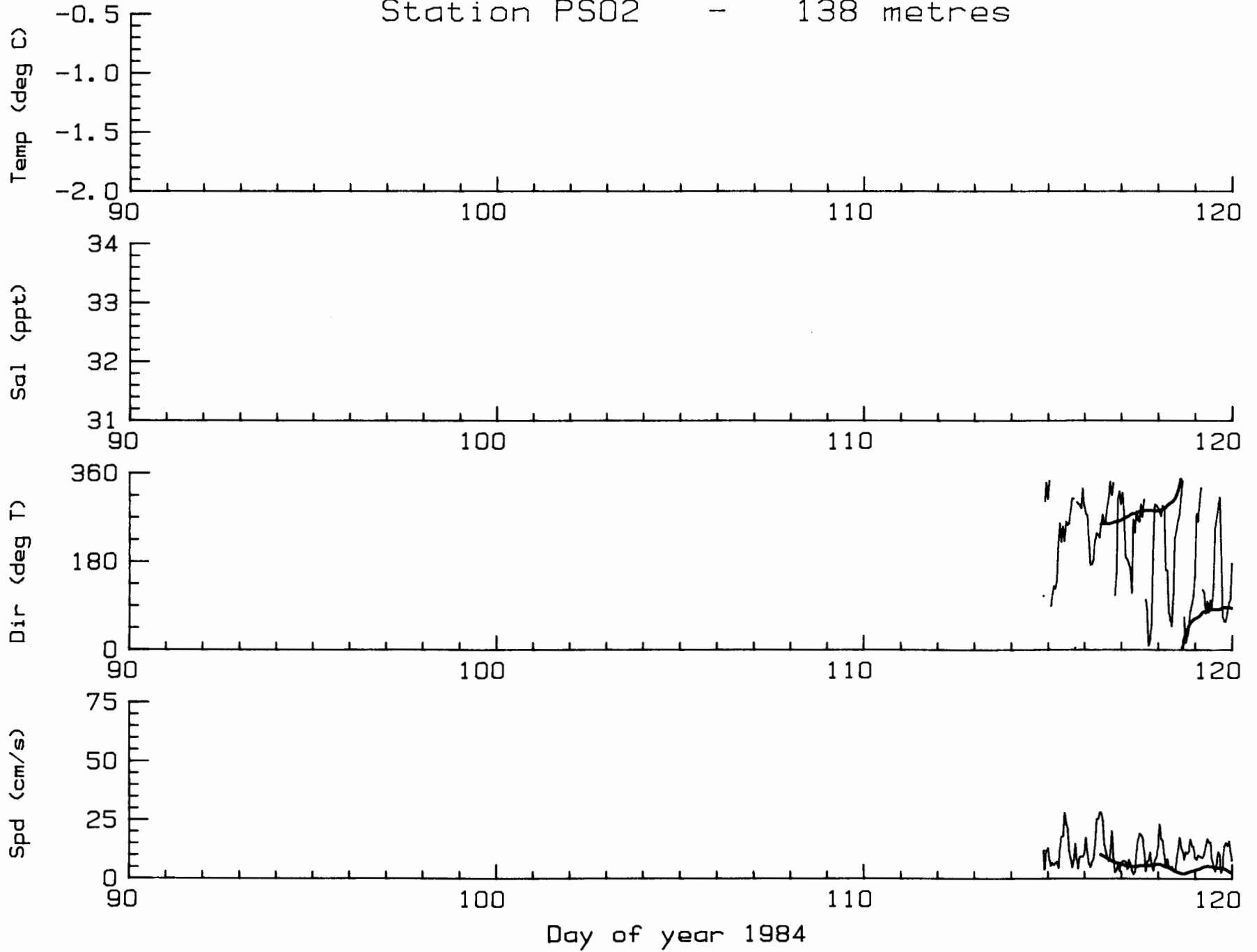
Station PS02 - 49 metres



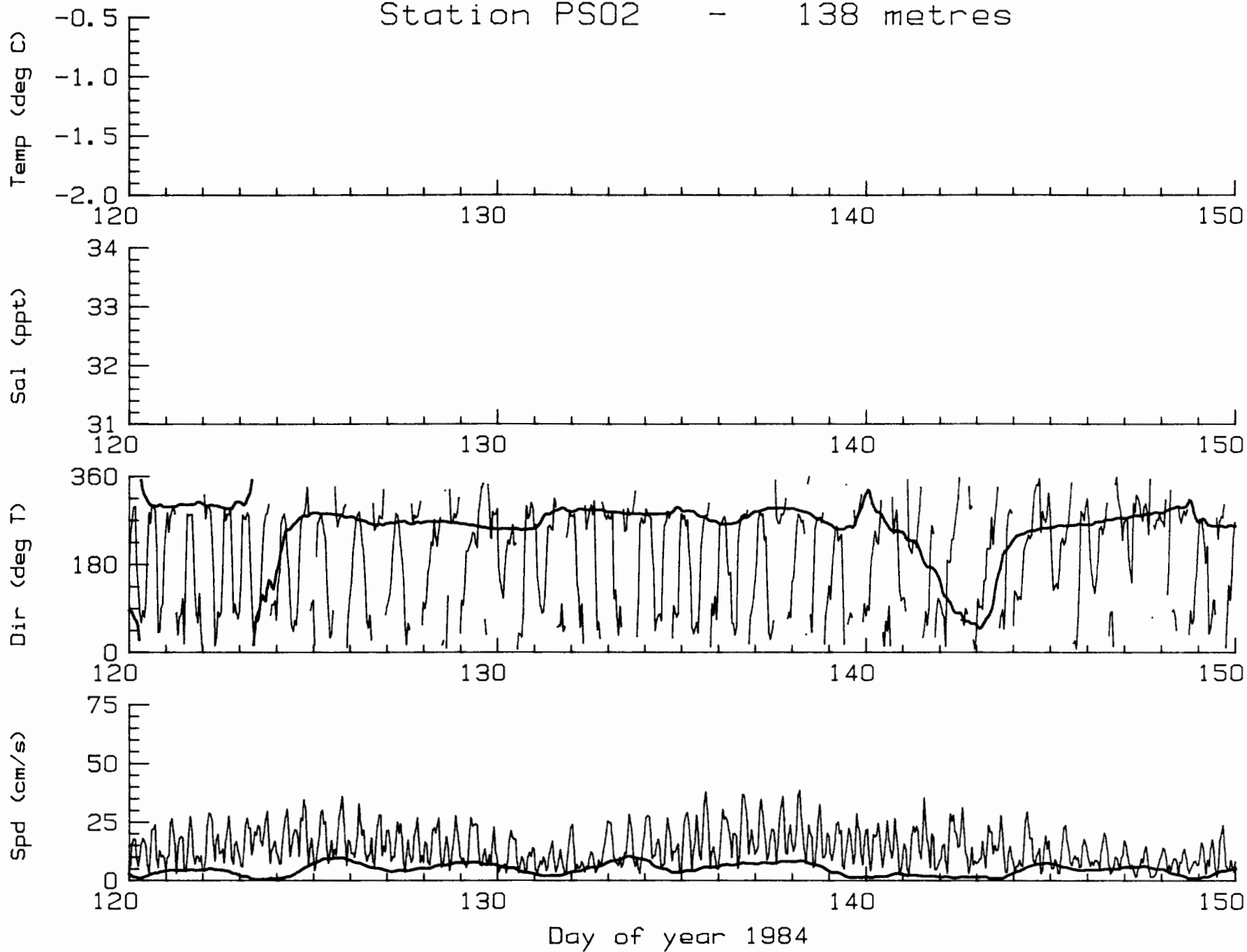
Station PS02 - 49 metres



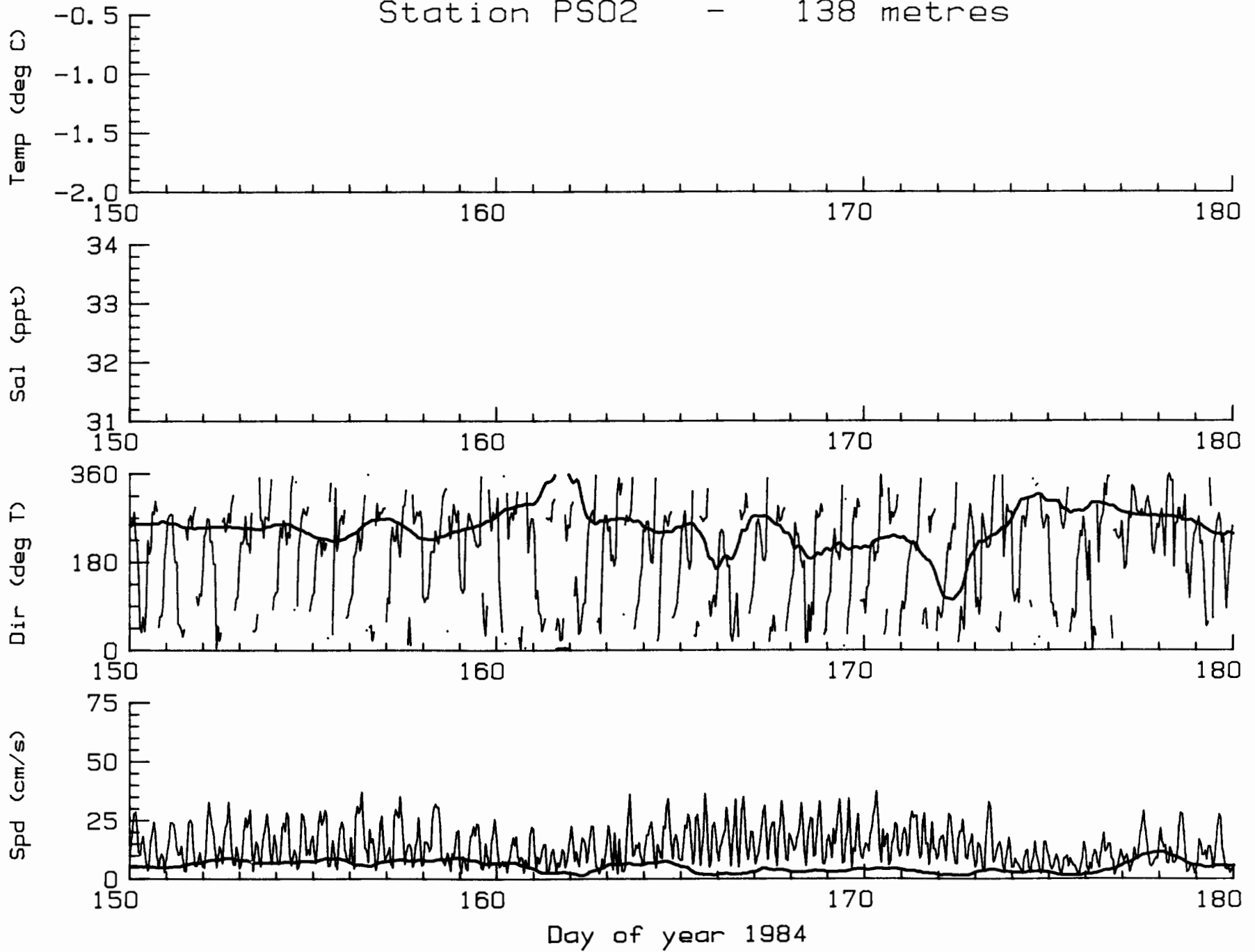
Station PS02 - 138 metres



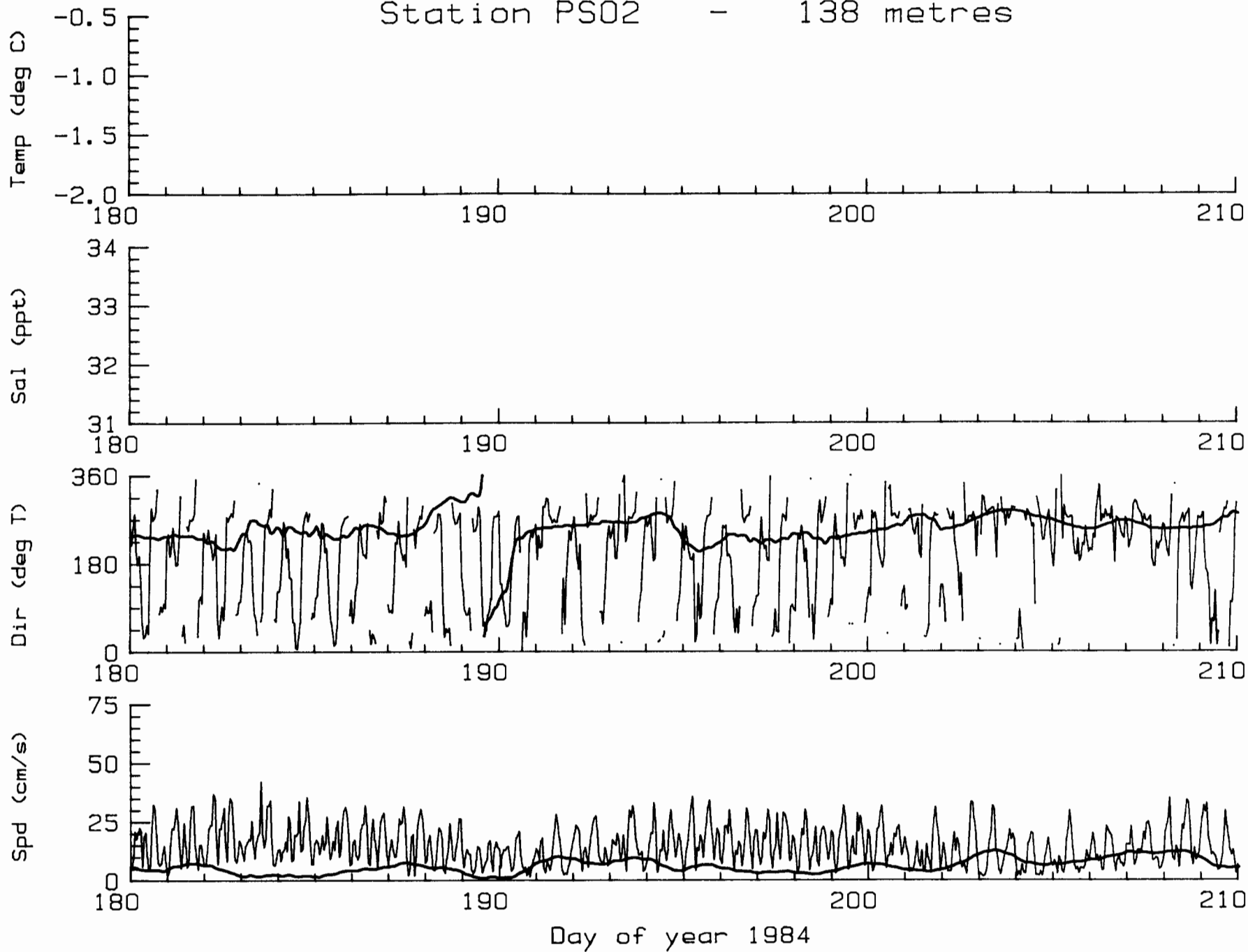
Station PS02 - 138 metres



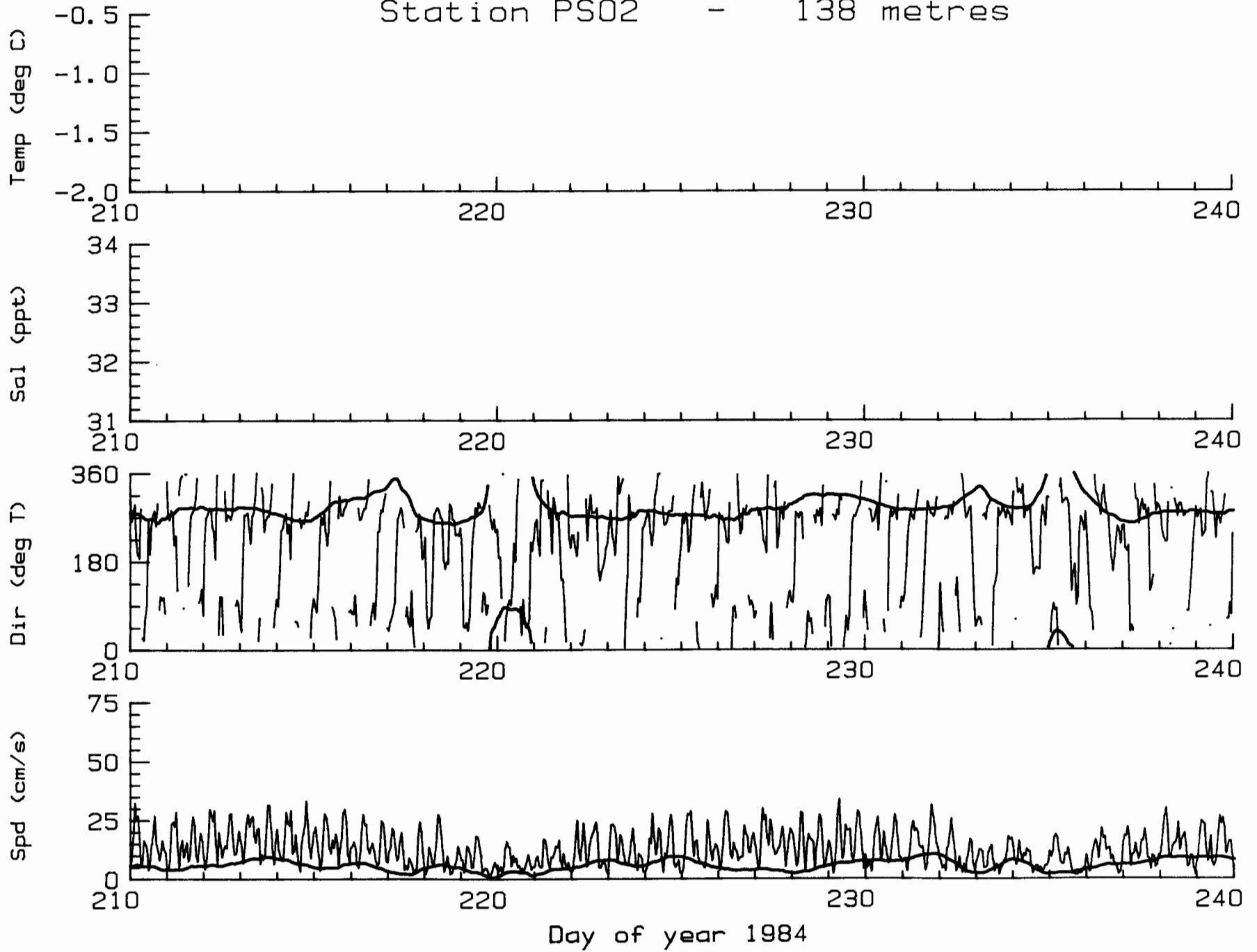
Station PS02 - 138 metres



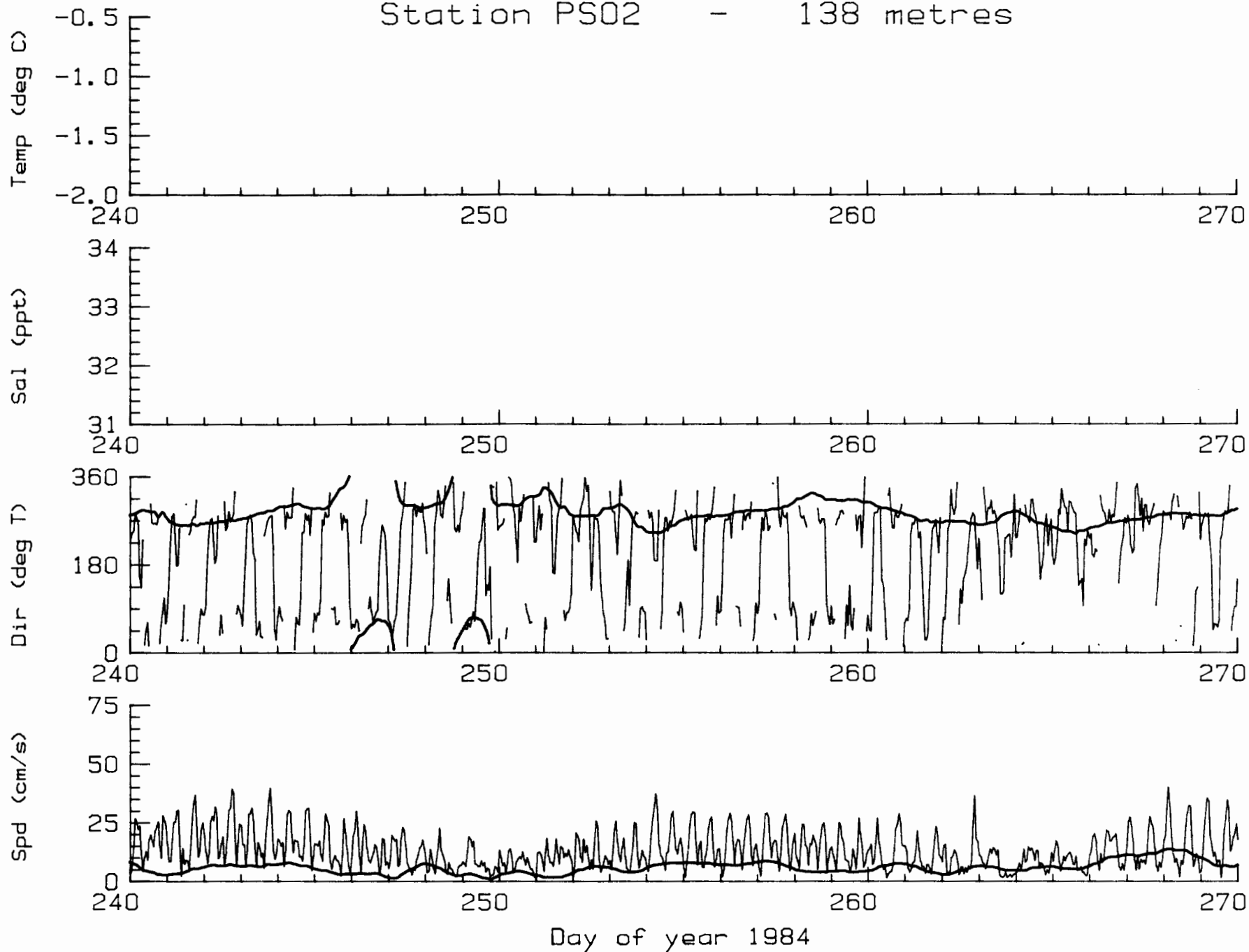
Station PS02 - 138 metres



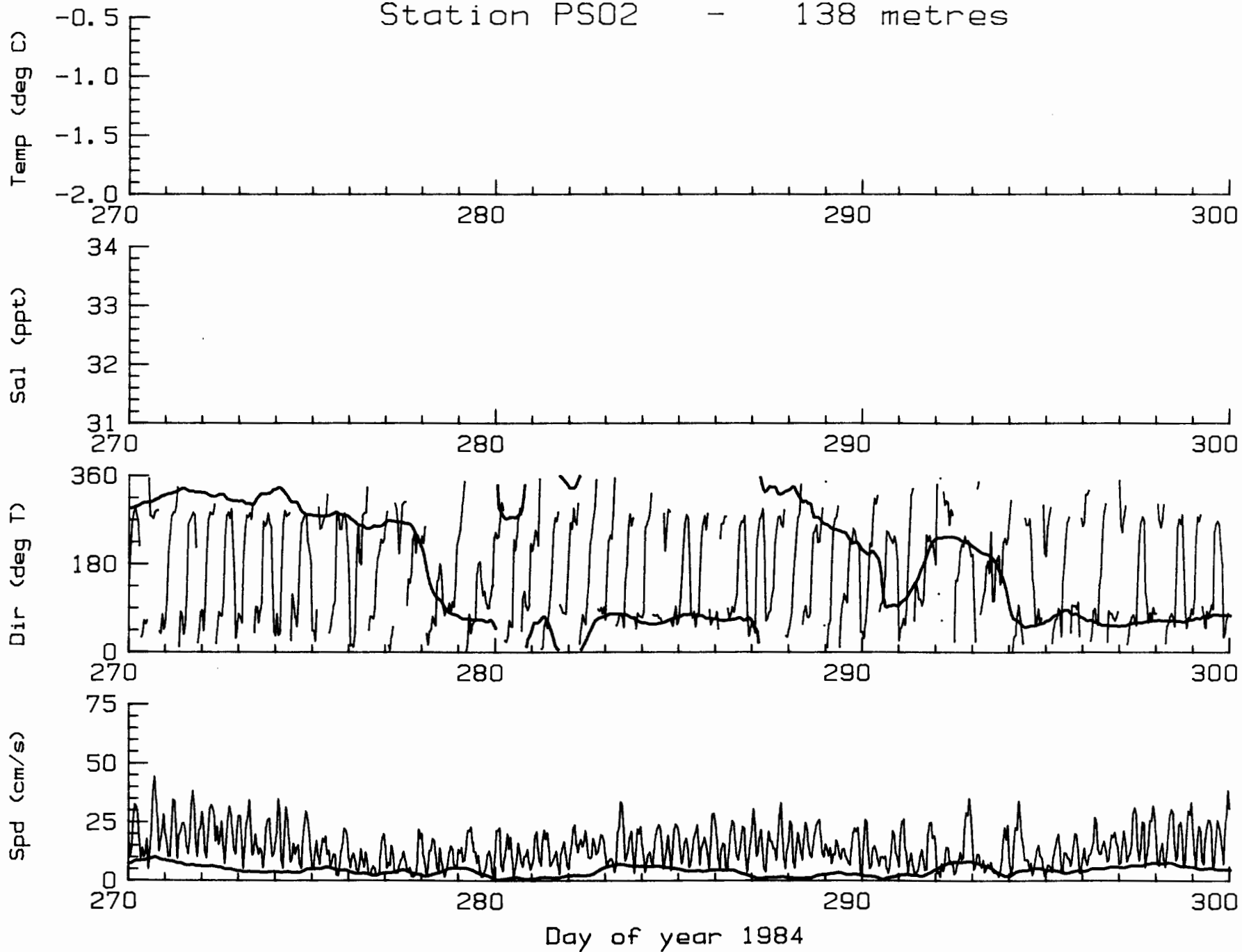
Station PS02 - 138 metres



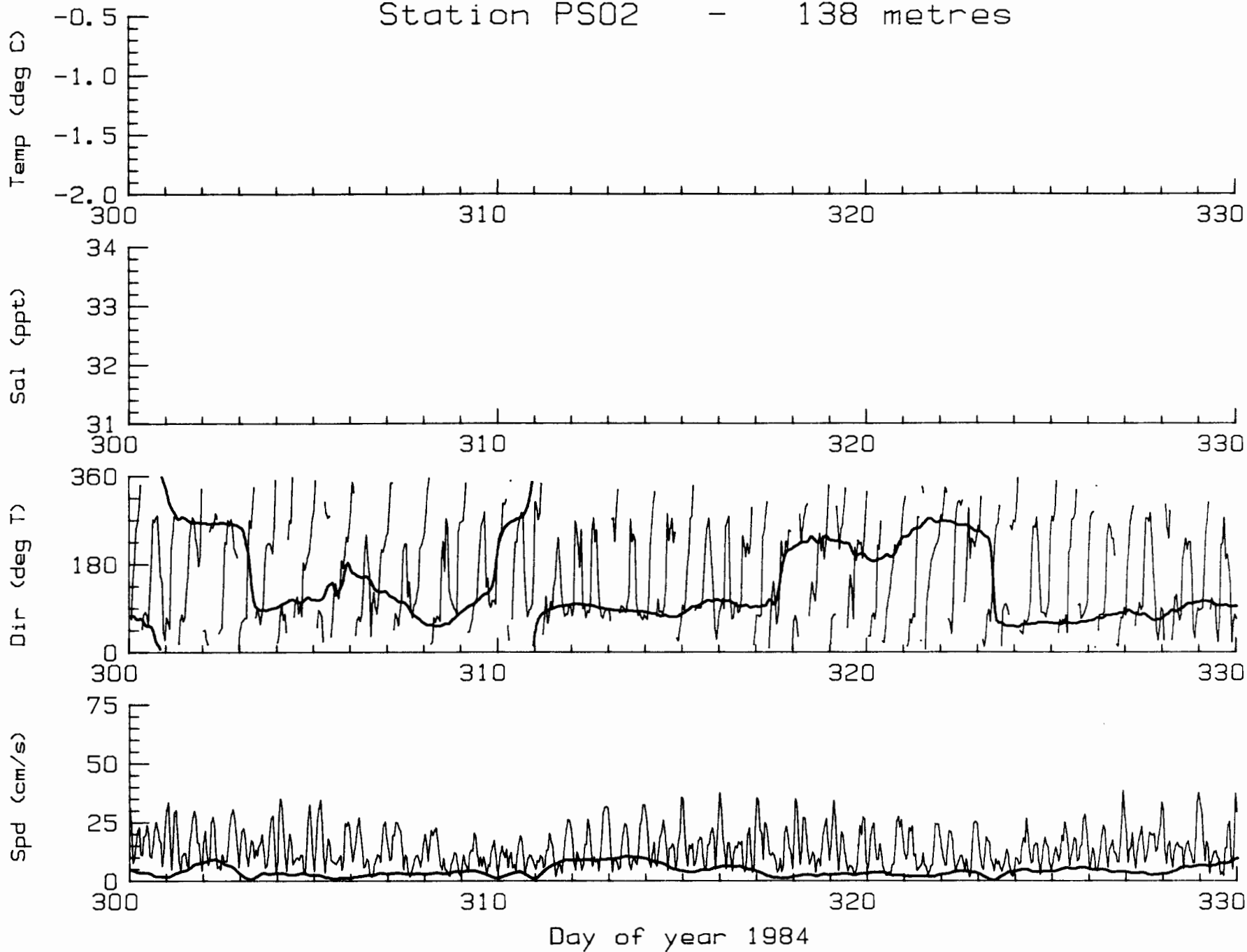
Station PS02 - 138 metres



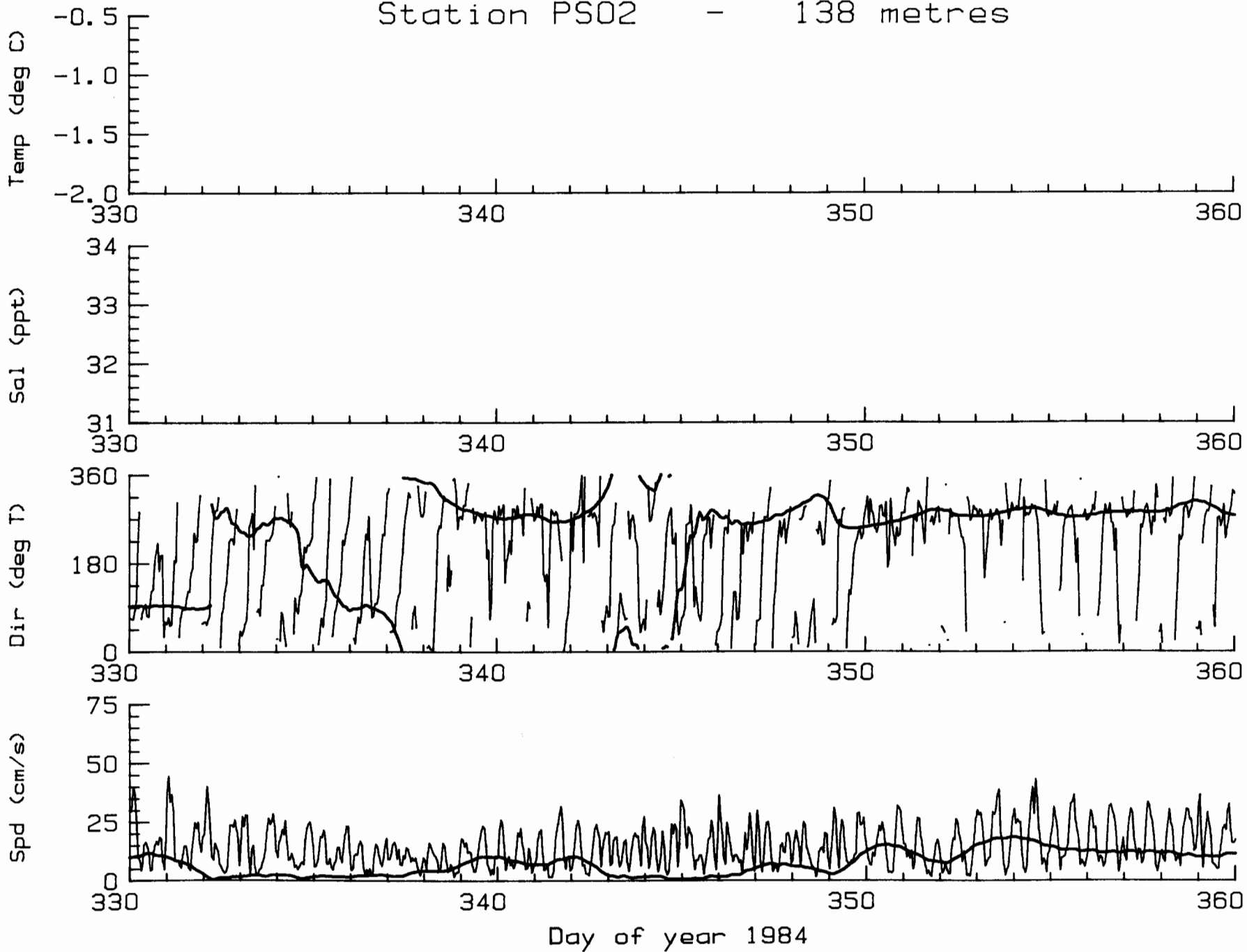
Station PS02 - 138 metres



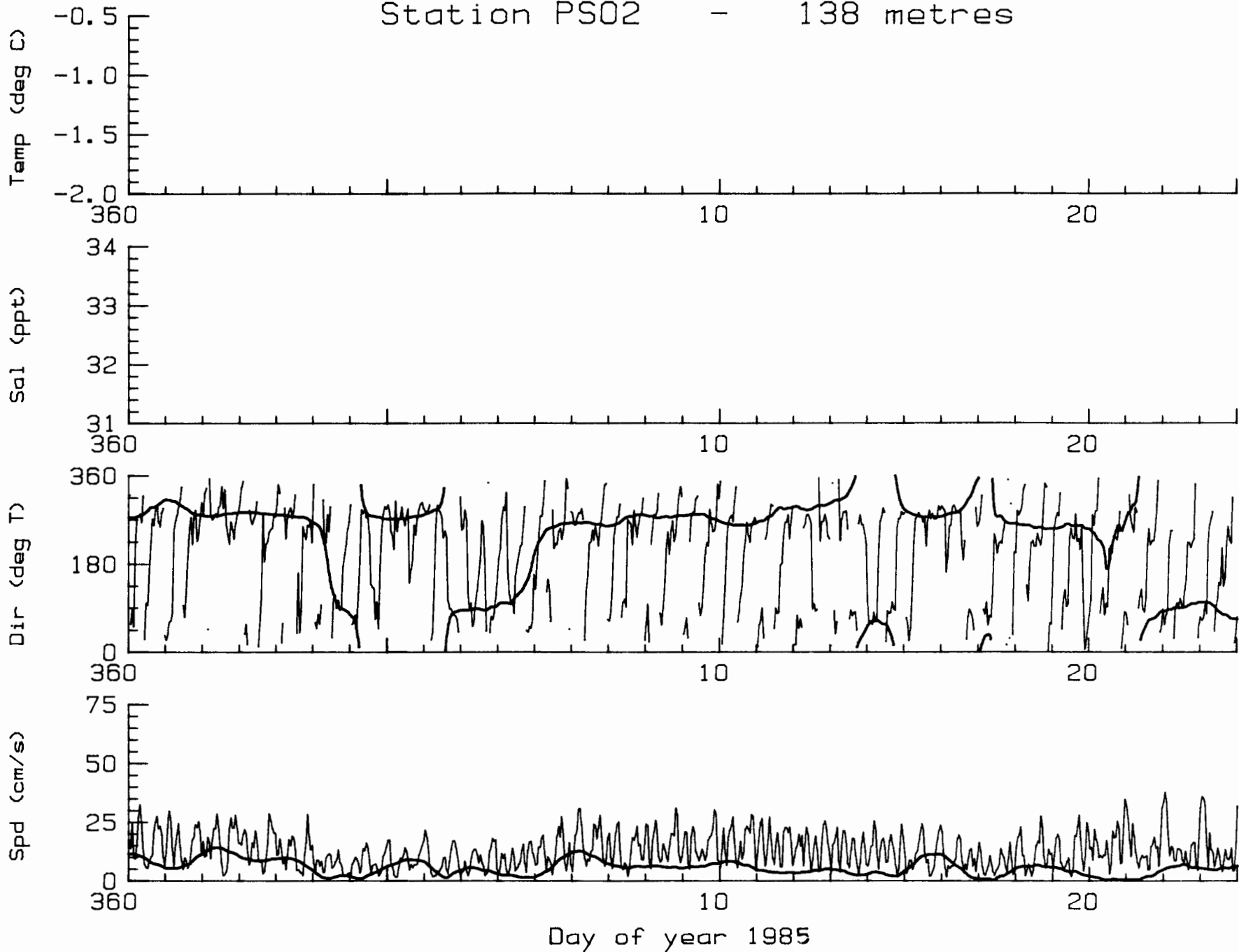
Station PS02 - 138 metres



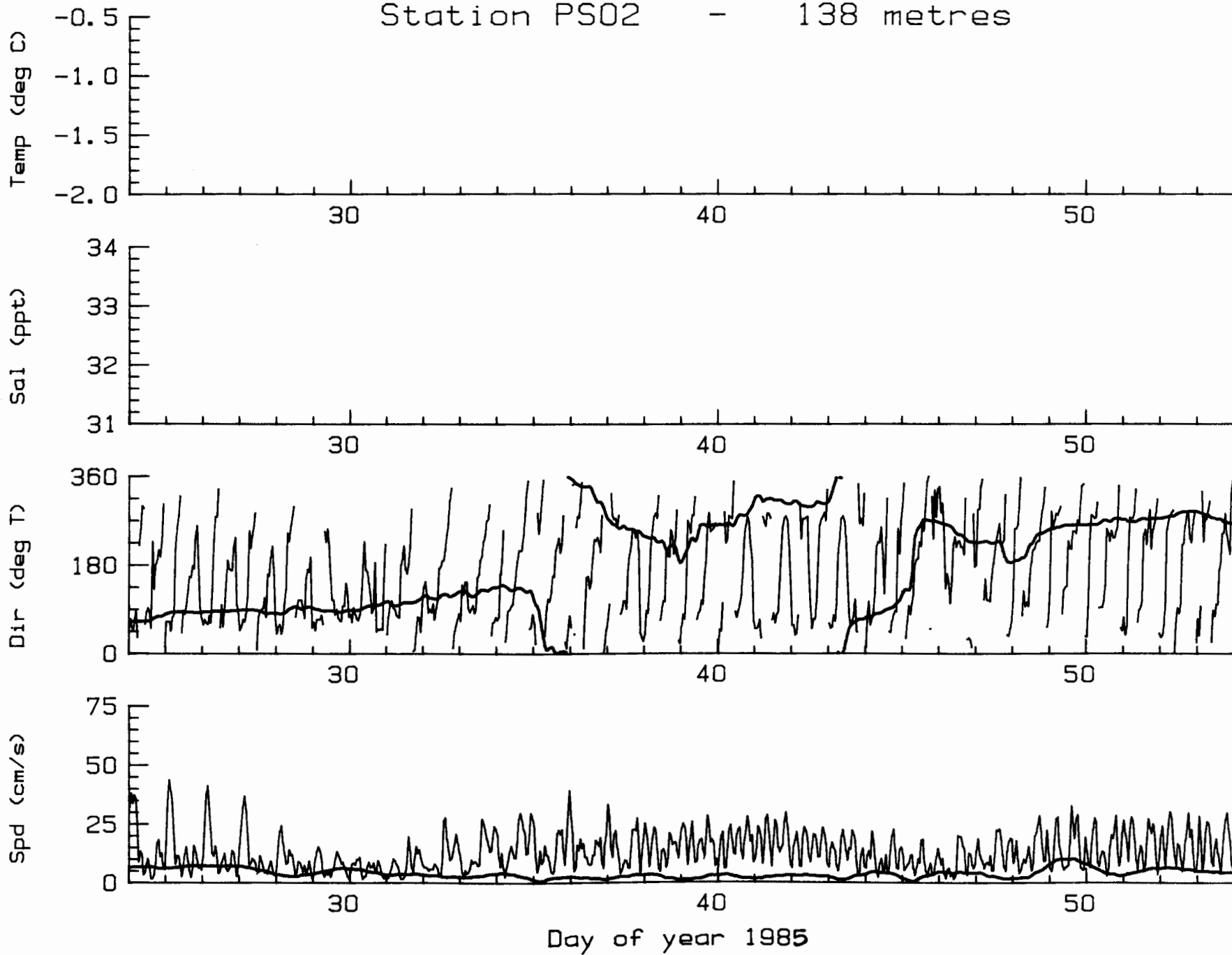
Station PS02 - 138 metres



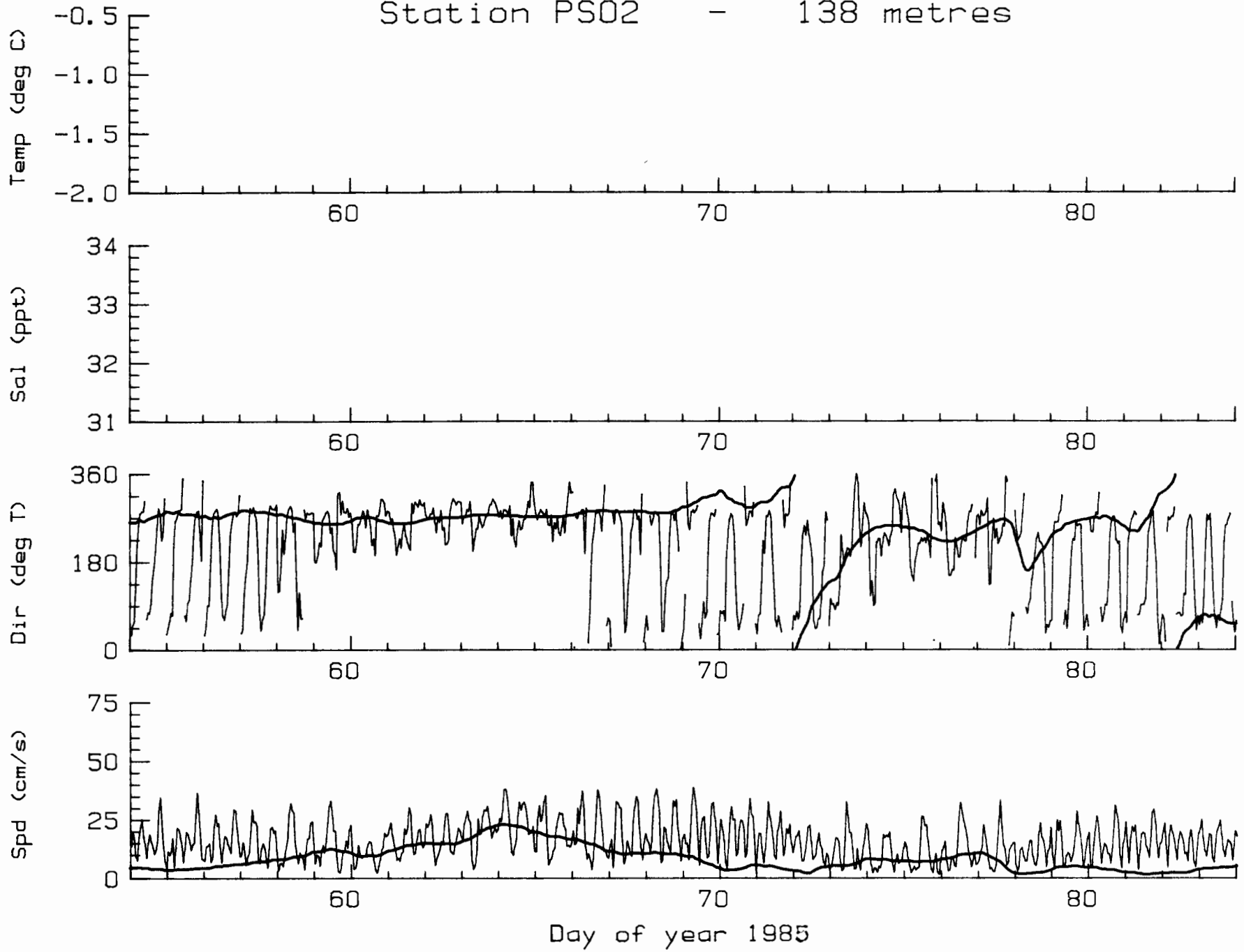
Station PS02 - 138 metres



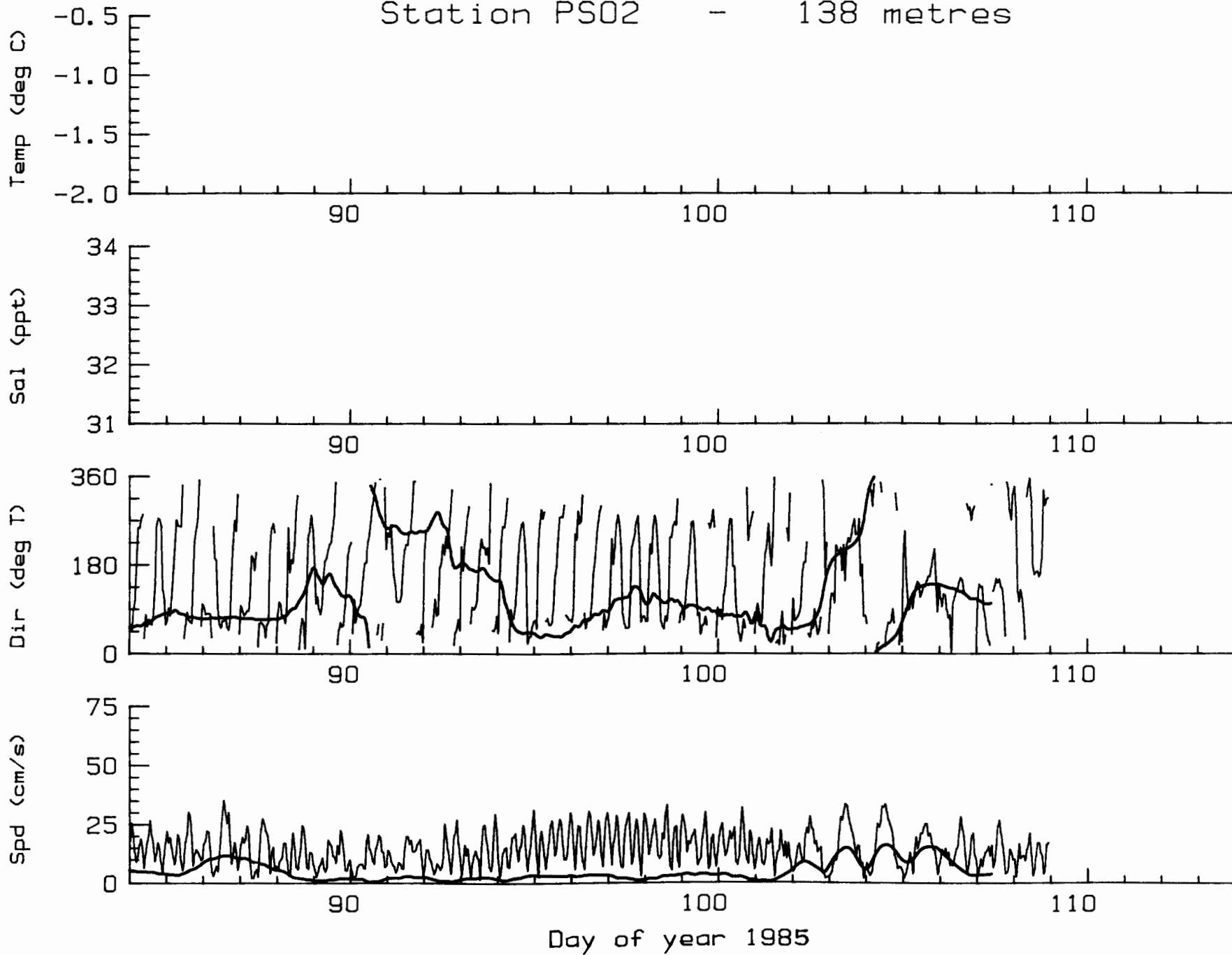
Station PS02 - 138 metres



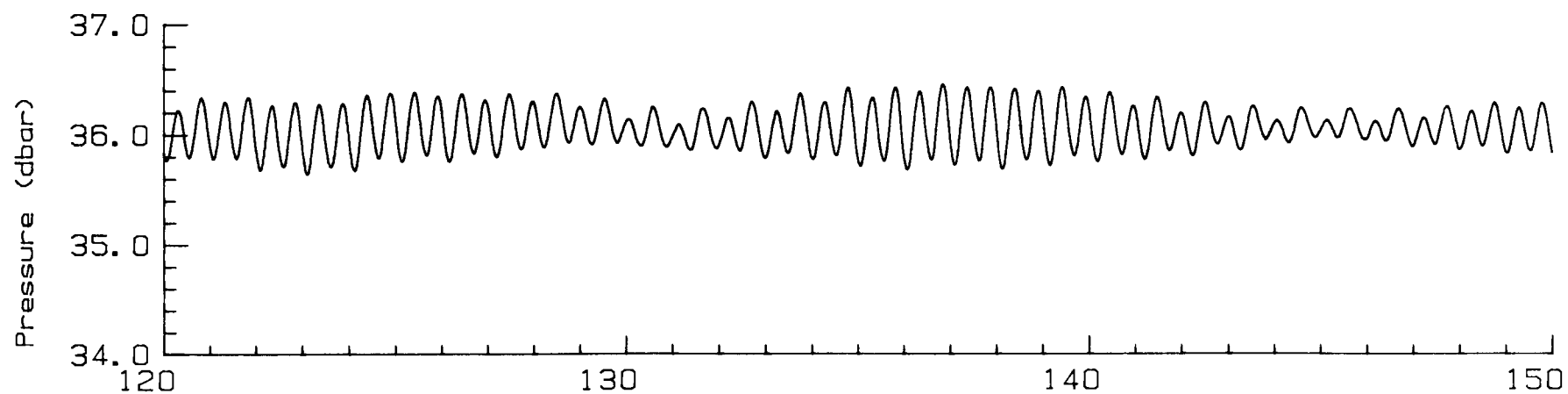
Station PS02 - 138 metres



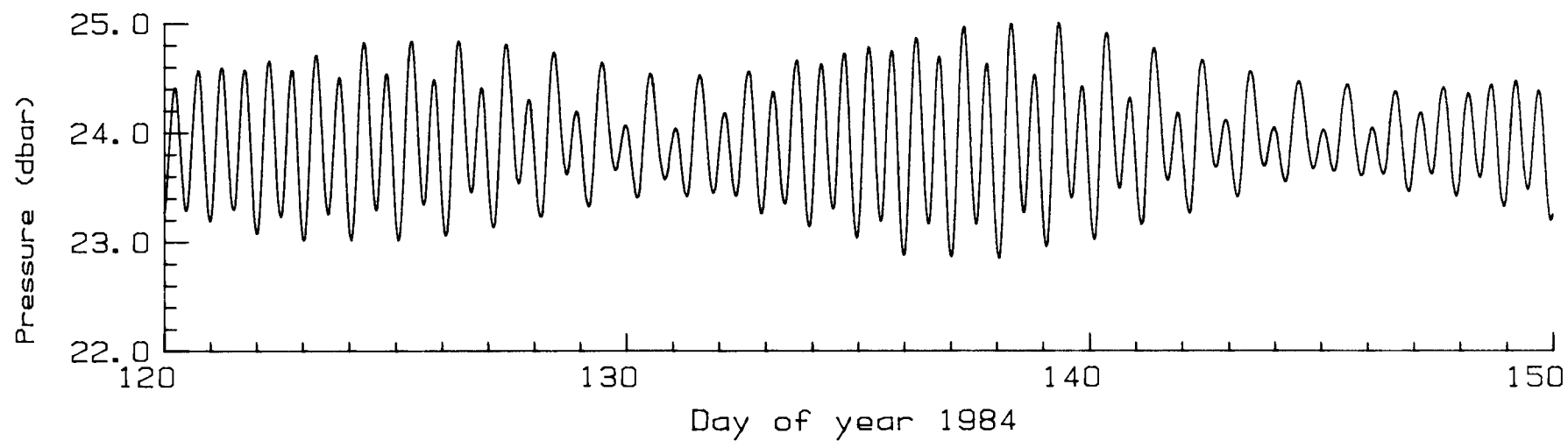
Station PS02 - 138 metres



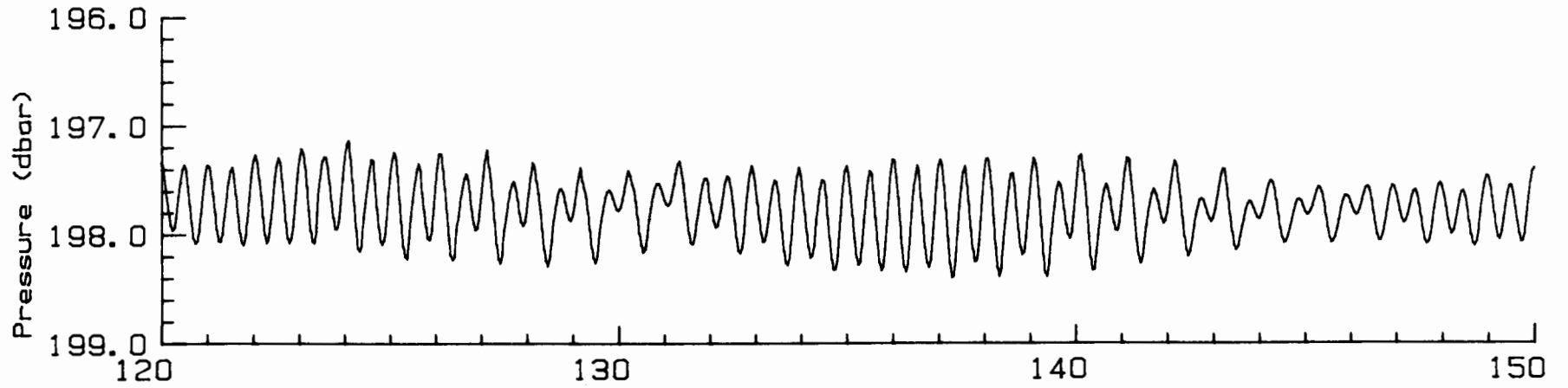
Station BYAM MARTIN CHANNEL WEST



Station SNOWBLIND BAY



Station PS01



Station BS42

