

81-2

HMSC  
GC  
856  
.0735  
no. 81-2  
cop. 2

Journal of

# OCEANOGRAPHY



**FRONTS 80: Preliminary Results  
From an Investigation of the  
Wintertime North Pacific  
Subtropical Front**

edited by  
C. A. Paulson  
and  
P. P. Miller

Reference 81-2  
January 1981

Reproduction in whole or in part is  
permitted for any purpose of the  
United States Government

OREGON STATE UNIVERSITY

MARILYN POTTS GUIN LIBRARY  
HATFIELD MARINE SCIENCE CENTER  
OREGON STATE UNIVERSITY  
NEWPORT, OREGON 97365

41msc  
GC  
856  
.0735  
no. 81-2  
Cop. 2

FRONTS 80: PRELIMINARY RESULTS FROM  
AN INVESTIGATION OF THE WINTERTIME  
NORTH PACIFIC SUBTROPICAL FRONT

edited by

C. A. Paulson

and

P. P. Niiler

School of Oceanography  
Oregon State University  
Corvallis, Oregon 97331

Reference 81-2  
January 1981

MARILYN POTTS GUIN LIBRARY  
HATFIELD MARINE SCIENCE CENTER  
OREGON STATE UNIVERSITY  
NEWPORT, OREGON 97365

## PREFACE

The FRONTS-80 experiment is a joint investigation supported by the Office of Naval Research (ONR) as the lead agency with additional contributions from the National Oceanic and Atmospheric Administration (NOAA), the National Space Administration (NASA), the U.S. Navy and the Canadian Forces. Support from these agencies is gratefully acknowledged. We also gratefully acknowledge the assistance and cooperation provided by the officers and crews of the NOAA Ship OCEANOGRAPHER, the R/V THOMAS WASHINGTON, the HMCS PROVIDER, the HMCS GATINEAU, the HMCS KOOTENAY, the HMCS RESTIGOUCHE and the aircraft of the Commander Patrol Wing Two, U.S. Navy.

It should be emphasized that this report is preliminary. It is a report of the observational phase of FRONTS-80 and preliminary results from individual investigators. The report is intended to aid and encourage an integrated analysis of the observations. Individual contributions should not be referenced without consent of the authors. Investigators are expected to provide more comprehensive reports and publications which will be suitable for referencing. Specific acknowledgment of support by agency and grant or contract number will be given in these reports and publications.

## TABLE OF CONTENTS

	<u>Page</u>
PREFACE-----	i
OVERVIEW-----	1
Introduction-----	2
Objectives-----	4
Observations-----	4
COMPONENTS-----	10
Aircraft Expendable Bathythermograph (AXBT) Survey----- by M. Miyake	11
Satellite Observations of Surface Temperature----- by R. Berstein, M. VanWoert and R. Whritner	20
GOES Satellite Data----- by T. Green and K. Sowinski	25
Three-Dimensional Thermohaline Structure----- by G. I. Roden	27
Multiship Expendable Bathythermograph (XBT) Survey----- by W. J. Emery	35
Satellite-Tracked Drifters----- by P. P. Niiler	41
Surface Atmospheric and Oceanic Variables----- by C. N. K. Mooers	45
Shipboard Meteorological Observations----- by S. P. Hayes, G. Roden and C. A. Paulson	51
Doppler-Acoustic Velocity Profiles----- by L. Regier and R. Davis	64
Expendable Temperature-Velocity-Pressure (XTVP) Measurements--- by T. B. Sanford and E. Kunz	66
CTD/Velocity Finestructure Measurements----- by S. P. Hayes	76
Towed Temperature Cross-Sections----- by C. A. Paulson	83
Velocity and Temperature Microstructure----- by R. G. Lueck and T. R. Osborn	89

	<u>Page</u>
Temperature Microstructure----- by T. M. Dillon and D. R. Caldwell	97
Mesopelagic Fishes----- by M. D. Willis and W. G. Pearcy	105
REFERENCES-----	108

OVERVIEW

## Introduction

The North Pacific subtropical front is a region near 30°N in which the meridional gradients of temperature and salinity in the upper ocean are large. The region extends unbroken across most of the Pacific. The detailed dynamics of the front are not well understood. However, in general terms, it seems clear that the front is maintained by a combination of wind-driven, convergent currents in the upper ocean and large-scale, meridional variations in air-sea exchanges of heat and water. The westerly winds north of the front cause southward Ekman transports of cool, low-salinity water, while the tradewinds south of the front cause northward transport of warm, high-salinity water. The front is maintained as a consequence of these convergent transports.

The wintertime structure of the North Pacific subtropical frontal zone north of Hawaii has recently been described by Roden (1980). His description is based on a CTD survey with stations spaced 27 km apart. Meridional cross-sections of temperature and salinity from that survey are shown in Fig. 1. This figure shows fronts at 23, 28, 31 and 34°N, each characterized by large, surface gradients of temperature and salinity ranging up to 2°C/27 km and 0.3 ‰/27 km. The density difference across the northernmost front is small because of the compensating effects of temperature and salinity. The density differences across the other fronts are about 0.2  $\sigma_t$  (kg m<sup>-3</sup>). Because of the multiplicity of fronts observed in a synoptic section, Roden prefers to characterize the subtropical front as a zone rather than a single front. Climatologically, the subtropical front has been defined as the boundary south of which lies North Pacific Central Water characterized by wintertime temperatures > 18°C and salinities > 34.8 ‰. Applying this definition to Fig. 1 would place the subtropical front at 31°N.

Roden (1980) also analyzed the wintertime dynamic height topography between 26 and 35°N and 152 and 158°W. He found no similarity between the 0/1500 db topography and the surface temperature and salinity fields indicating that the surface fronts were not governed by the baroclinic flow field. On the other hand, Roden concluded that there was a close association between the 150/1500 db dynamic height topography and the temperature and salinity fields at 150 m depth indicating that subsurface fronts are related to the baroclinic flow. Roden also found that the mean baroclinic surface flow was 2-4 cm s<sup>-1</sup> toward the east and independent of season. However, perturbations of the surface baroclinic flow were as large as 0.5 m s<sup>-1</sup> and dependent on season.

Despite the investigations by Roden (1980) and others, there are many unanswered questions concerning the structure and dynamics of the North Pacific subtropical frontal zone:

- What is the structure of fronts on scales smaller than observed by CTD surveys?
- What is the velocity field associated with the fronts?
- What is the temporal behavior of the fronts and how is this behavior related to atmospheric forcing?
- What dynamical models describe the frontal zone?

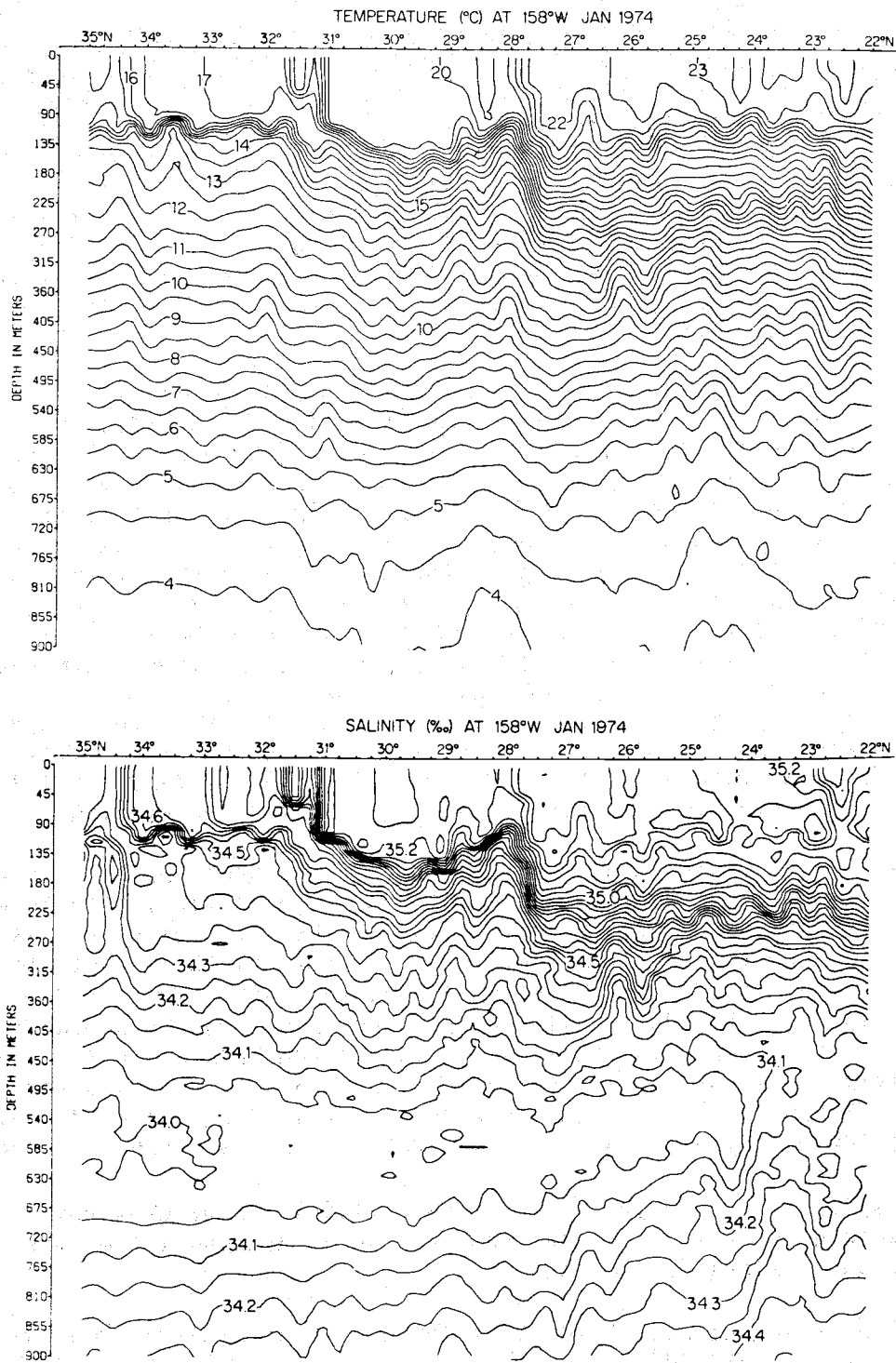


Figure 1. Meridional sections of temperature (top) and salinity (bottom) along longitude 158°W during the winter of 1974 (after Roden, 1980).



In an attempt to answer some of the above questions, a cooperative investigation of the North Pacific subtropical front entitled FRONTS-80 was organized. Observations began in December 1979 north of Hawaii in the same area surveyed by Roden (1980). The purpose of this report is to present an account of the observations including preliminary results of analyses. After a general description of the experiment, there follows a description of components of the experiment by individual investigators.

### Objectives

The objectives of FRONTS-80 were:

- To refine our picture of the scales of variation of scalar properties in the frontal zone.
- To investigate currents and their relation to frontal structure.
- To investigate the temporal behavior of frontal structure.
- To investigate mixing and the dissipation of kinetic energy and their relation to frontal structure.
- To investigate the variability of selected biological populations in the frontal zone.
- To test and compare instrumentation for the investigation of fronts.

### Observations

A schematic diagram of the instruments used and the variables measured in FRONTS-80 is shown in Fig. 2. The aircraft and satellite observations included: aircraft surveys of upper ocean thermal structure using expendable bathythermographs (AXBT); satellite measurements of sea surface temperature; and measurements of horizontal velocity and temperature by use of satellite-tracked drifters drogued at a depth of 30 m. Two research ships participated in the experiment, the NOAA Ship OCEANOGRAPHER and the R/V THOMAS WASHINGTON. Observations made aboard the OCEANOGRAPHER included: vertical profiles of conductivity and temperature with a conventional CTD; towed cross-sections of temperature in the upper 90 m with a towed thermistor chain; vertical profiles of velocity and temperature with an expendable profiler; vertical profiles of velocity, temperature and conductivity with a free-falling retrievable profiler; and vertical profiles of temperature, conductivity and transmissivity microstructure with freely-falling instruments. Observations made aboard the THOMAS WASHINGTON included: vertical profiles of conductivity and temperature with a conventional CTD; vertical profiles of velocity and temperature microstructure with a freely-falling instrument; vertical profiles of velocity with an acoustic-doppler log, and concentrations of micronekton and neuston sampled by means of net tows. In addition to the foregoing, surface meteorological and oceanographic observations from ships of opportunity were made available through the cooperation of

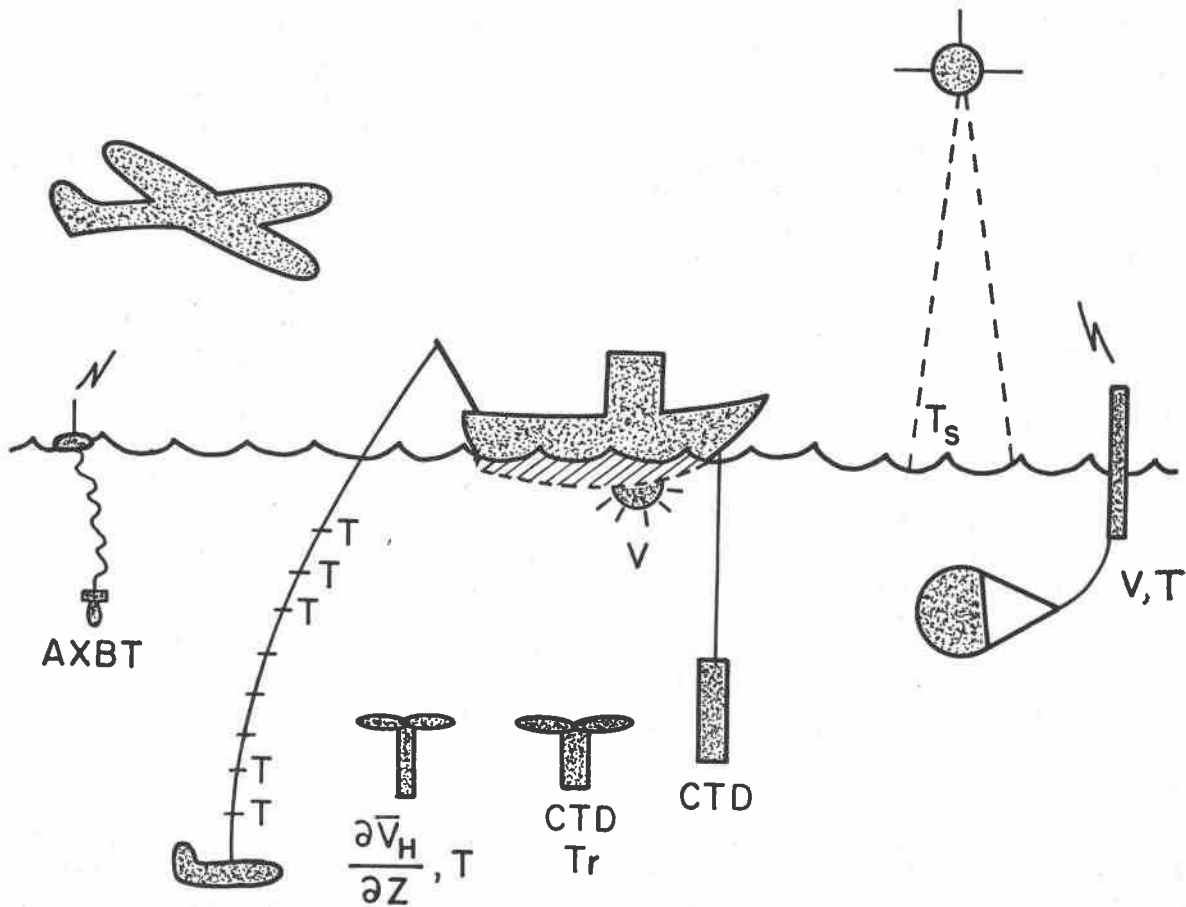


Figure 2. Schematic illustration of observations taken during FRONTS-80. Symbols are:  $T_s$  - surface temperature; AXBT - aircraft expendable bathythermograph; T - temperature; C - conductivity; V - velocity; D - depth; Tr - transmittance; and  $\frac{\partial \bar{V}_H}{\partial z}$  - vertical shear.

Fleet Numerical Oceanography Center. Subsequent to measurements from the OCEANOGRAPHER and WASHINGTON, a survey of the thermal structure of the upper ocean was carried out by four vessels of the Canadian Forces using expendable bathythermographs (XBT).

The locations of the observations are shown in Fig. 3. Times of the observations are shown in Figs. 4 and 5. Surveys of upper ocean thermal structure by use of aircraft dropping AXBTs were initiated on 11 December. A total of eight flights were made between 11 December and 19 February. The cruise track of the OCEANOGRAPHER was chosen to cross a front visible in the initial AXBT surveys at about 30N, 154W.

The first observations from the OCEANOGRAPHER were taken on 15 January at a microstructure station located at 34N, 150W (see Fig. 3). Following this station the thermistor chain was towed toward the southwest, turning north at 29N, 155W. Velocity profiles were then measured by means of the expendable profiler (XTVP) and a recoverable profiler (TOPS). Additional microstructure stations were occupied and the thermistor chain tows were continued as shown in Fig. 3, ending finally at a microstructure station near 26N, 155.7W on 29 January. The times of observations taken aboard the OCEANOGRAPHER are shown in Fig. 5.

The THOMAS WASHINGTON began on 24 January a CTD survey on a  $1/3 \times 1/3^{\circ}$  grid within the small box shown in Fig. 3. The grid was occupied twice, from 24-30 January and from 31 January to 11 February, the end of observations. Velocity microstructure was measured at many of the stations by use of a freely-falling profiler (CAMEL). Biological samples were also occasionally taken by means of trawl and net tows between stations. Throughout the cruise, vertical profiles of horizontal velocity were measured by use of an acoustic doppler log. These measurements also yielded absolute velocity based on satellite navigation of the ship. The times of observations taken aboard the THOMAS WASHINGTON are summarized in Fig. 5.

Four Canadian ships conducted an XBT survey on parallel tracks between 27 and 33N from 10-12 February and between 25 and 31N from 26-30 March.

During the FRONTS observational phase, satellite imagery and surface observations from ships of opportunity were compiled at Scripps Institution and at the Naval Postgraduate School (see Fig. 4).

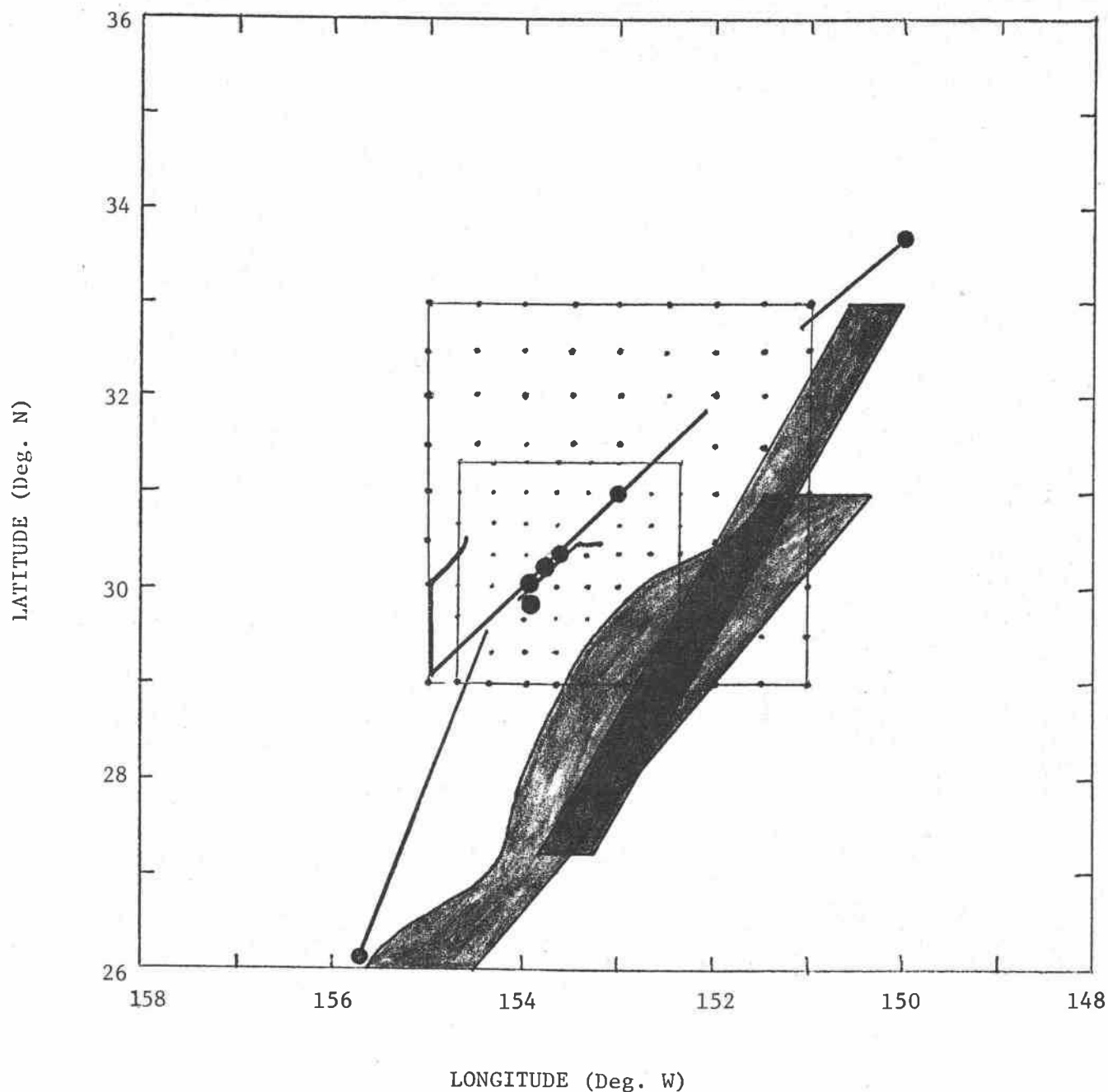


Figure 3. Sampled locations in FRONTS-80. The small box contains the CTD stations spaced 1/3 deg. apart. The large box contains the AXBT stations spaced 1/2 deg. apart. The heavy line is the track along which the thermistor chain was towed. The large solid circles are temperature microstructure stations. Velocity microstructure was measured at selected stations within the small box. Velocity profiles were measured along an east-west section 60 km long centered on 30°20'N, 153°30'W. Biological samples were taken at locations within the small box. Multiship XBT surveys were conducted within the shaded areas, within the narrow strip from 16-12 Feb. and within the irregular area from 26-30 March.

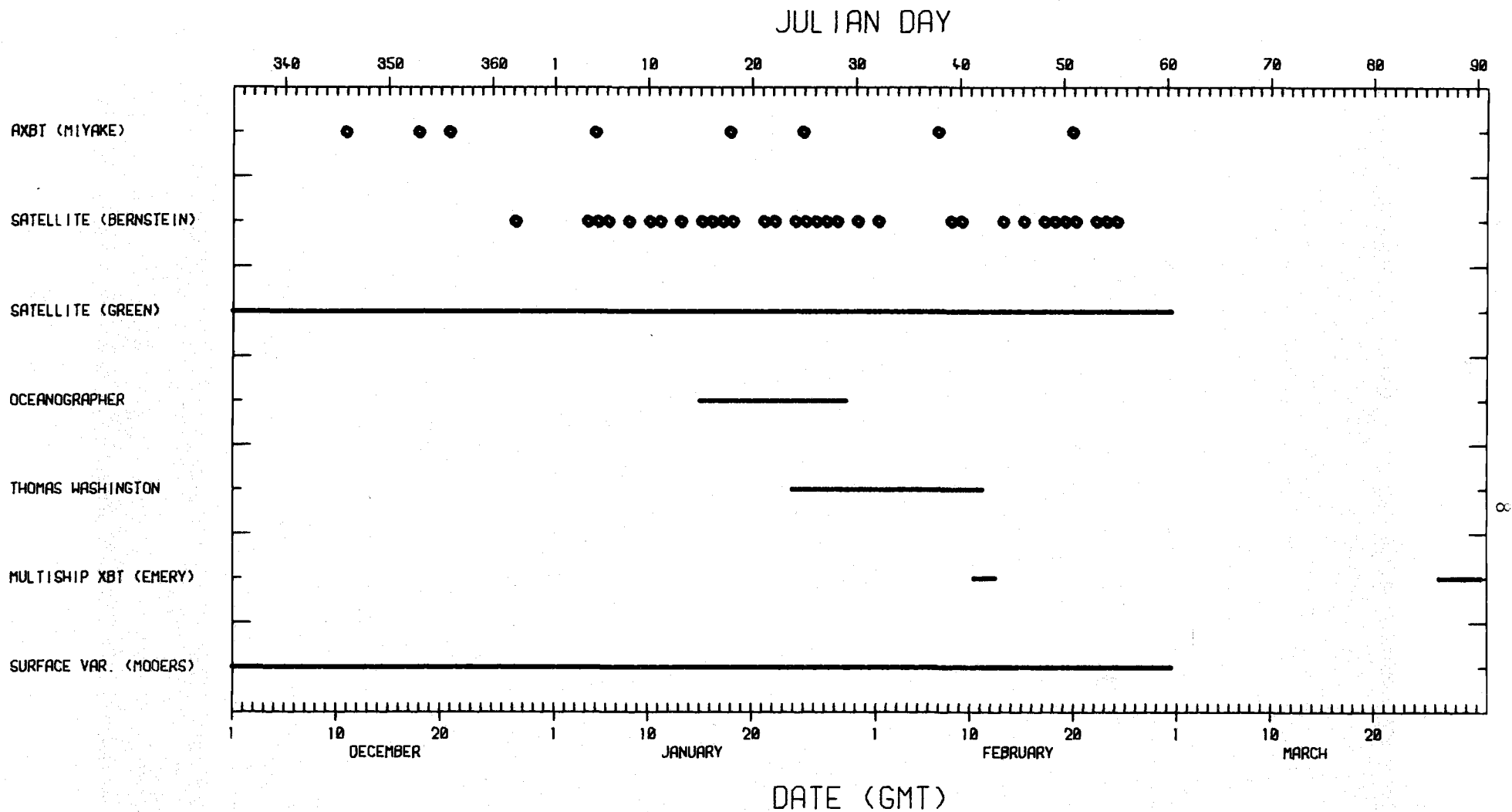


Figure 4. Times of observations during FRONTS-80. The names in parentheses refer to the first author in the section entitled Components.

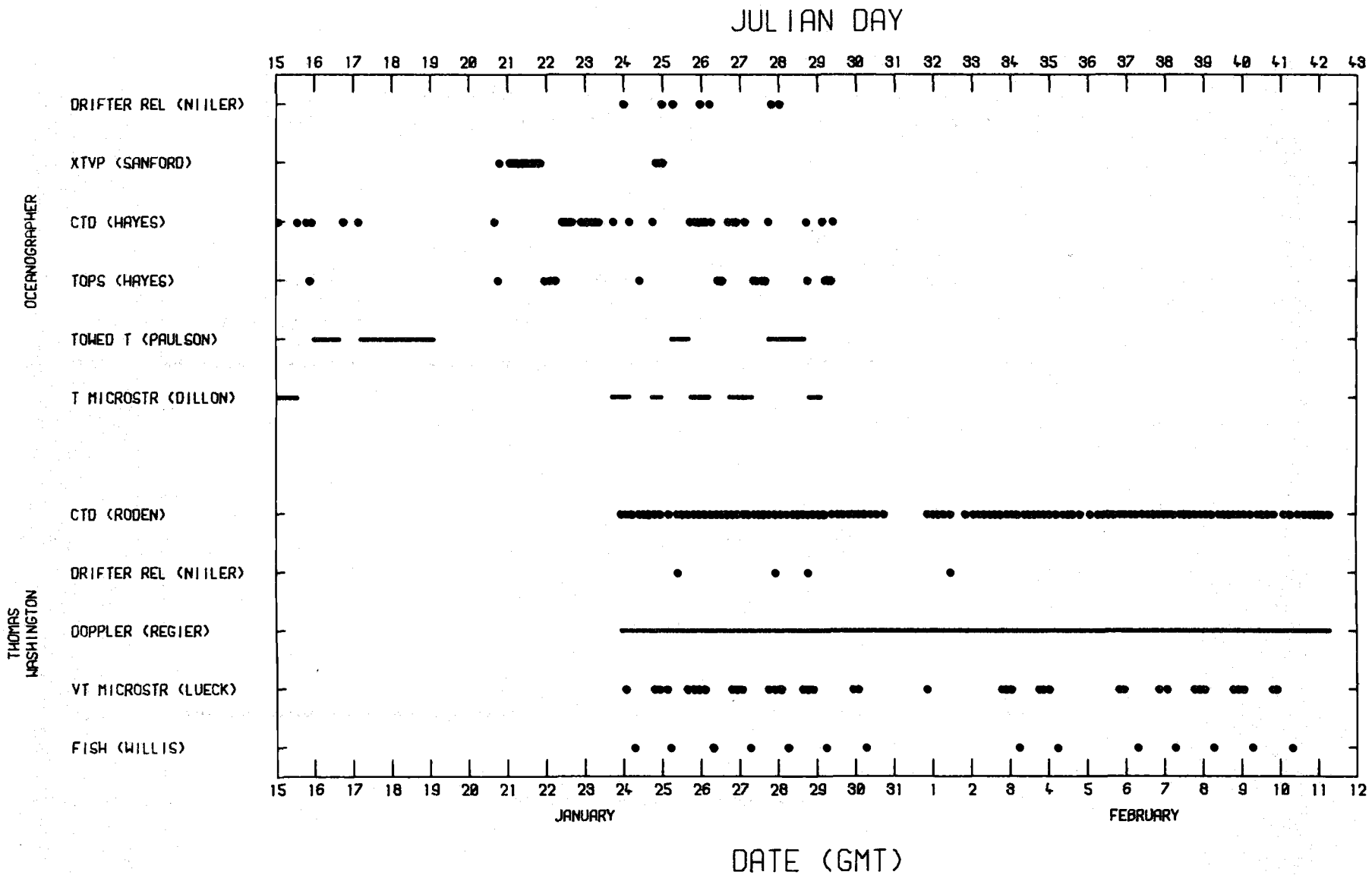


Figure 5. Times of observations from the NOAA Ship OCEANOGRAPHER and the R/V THOMAS WASHINGTON during FRONTS-80. The names in parenthesis refer to the first author in the section entitled Components.

COMPONENTS

## AXBT Observations

by

M. Miyake

Institute of Ocean Sciences

In the period from 11 December 1979 to 19 February 1980, eight AXBT surveys were made of the FRONTS area. Most of the probes used were manufactured by MAGNAVOX, acquired from Navy stores through usual ONR procedures. A number of instrument lots had faulty activation switches and the first (11 December) and last (19 February) flights have only 30% data return. The data sets just before and during the time the NOAA Ship OCEANOGRAPHER and the R/V THOMAS WASHINGTON were in the FRONTS area are of good quality and are sampled on a  $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$  latitude-longitude grid to a nominal depth of 400 m. A complete set of eight AXBT sections is available in the band  $153^{\circ}$ - $154^{\circ}$ W,  $28^{\circ}$ - $33^{\circ}$ N. A number of simultaneous deployments were made with HERMES probes and CTD lowerings from the research vessels.

Figs. 1 to 8 display the mixed layer temperature contours for each flight. In the period 19-21 December, two intensified surface temperature gradient regions are evident at  $31.5^{\circ}$ N,  $153^{\circ}$ W and  $30.5^{\circ}$ N,  $152^{\circ}$ W. By 17 January, the latter frontal pattern further intensified, while the former dissipated. Apparently, measurements from the NOAA Ship OCEANOGRAPHER were made in a dissipating frontal area. During the AXBT survey the north-south temperature gradient appears to be deformed into equally strong east-west gradients by the local meso-scale circulation patterns. However, no large scale (50 km scale) "breaking" of the meso-scale wave pattern into separate surface pools of hot or cold water was observed (as is observed in the Antarctic Polar front). Temporal changes of 50 km spatial scale appear to be adequately resolved: a "wave crest" centered between  $154.5^{\circ}$ W and  $153.0^{\circ}$ W on 18 December was replaced by a "trough" by 19 February and this development can be followed by eye in the sequence of surface temperature patterns. The extraordinarily strong gradient shown in Fig. 7 (6 February) results from a single anomalously warm temperature profile which is probably erroneous.

Analysis of the AXBT observations, together with the ship CTD and drifting buoy temperature data will produce a temporal and spatial record of the evolution of the surface and subsurface temperature field in FRONTS.



DEC. 11, 1979

FRONT 001

30.0 TO 80.0 METERS

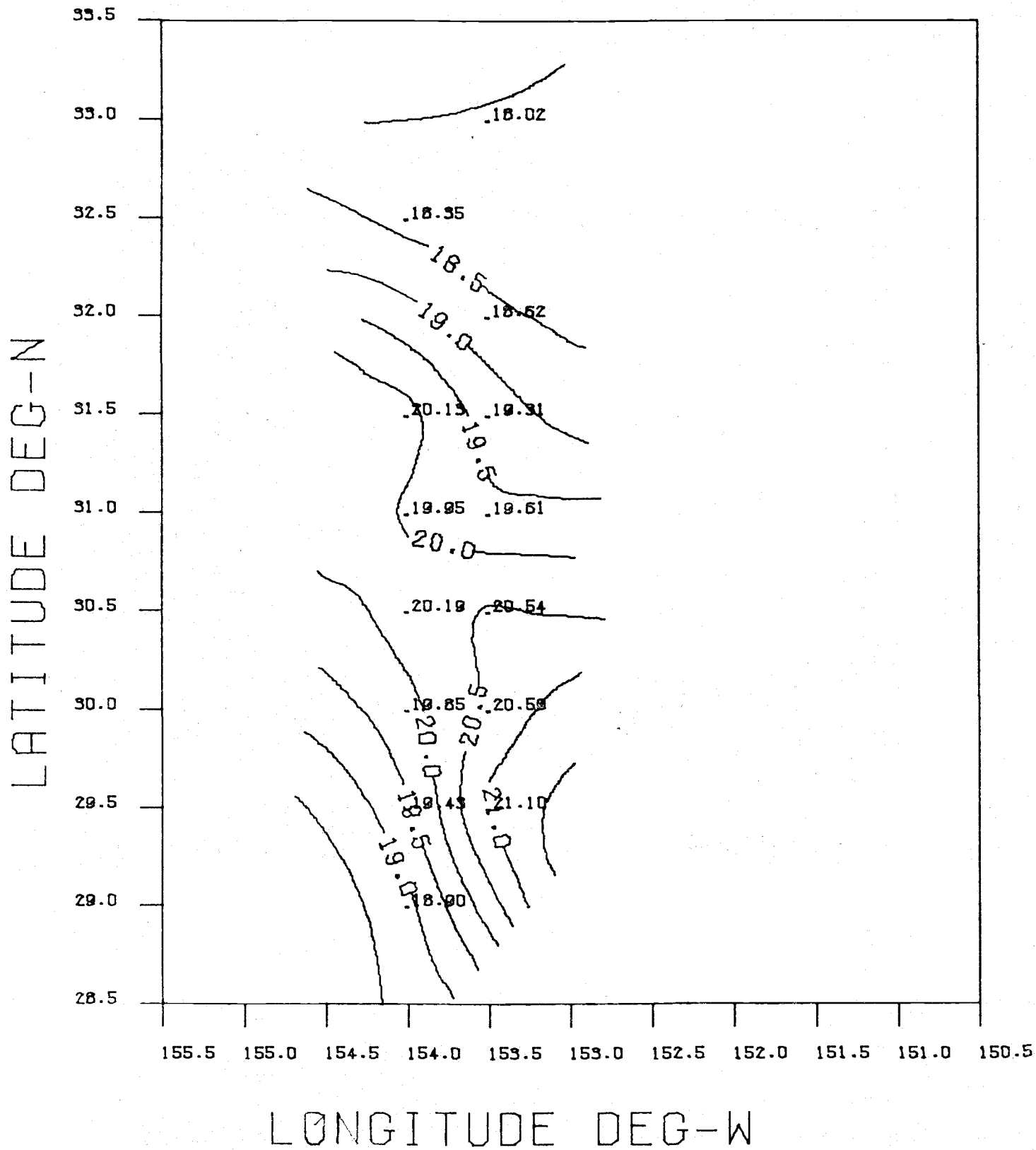


Figure 1. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

DEC. 18, 1979

FRONT 002

30.0 TO 80.0 METERS

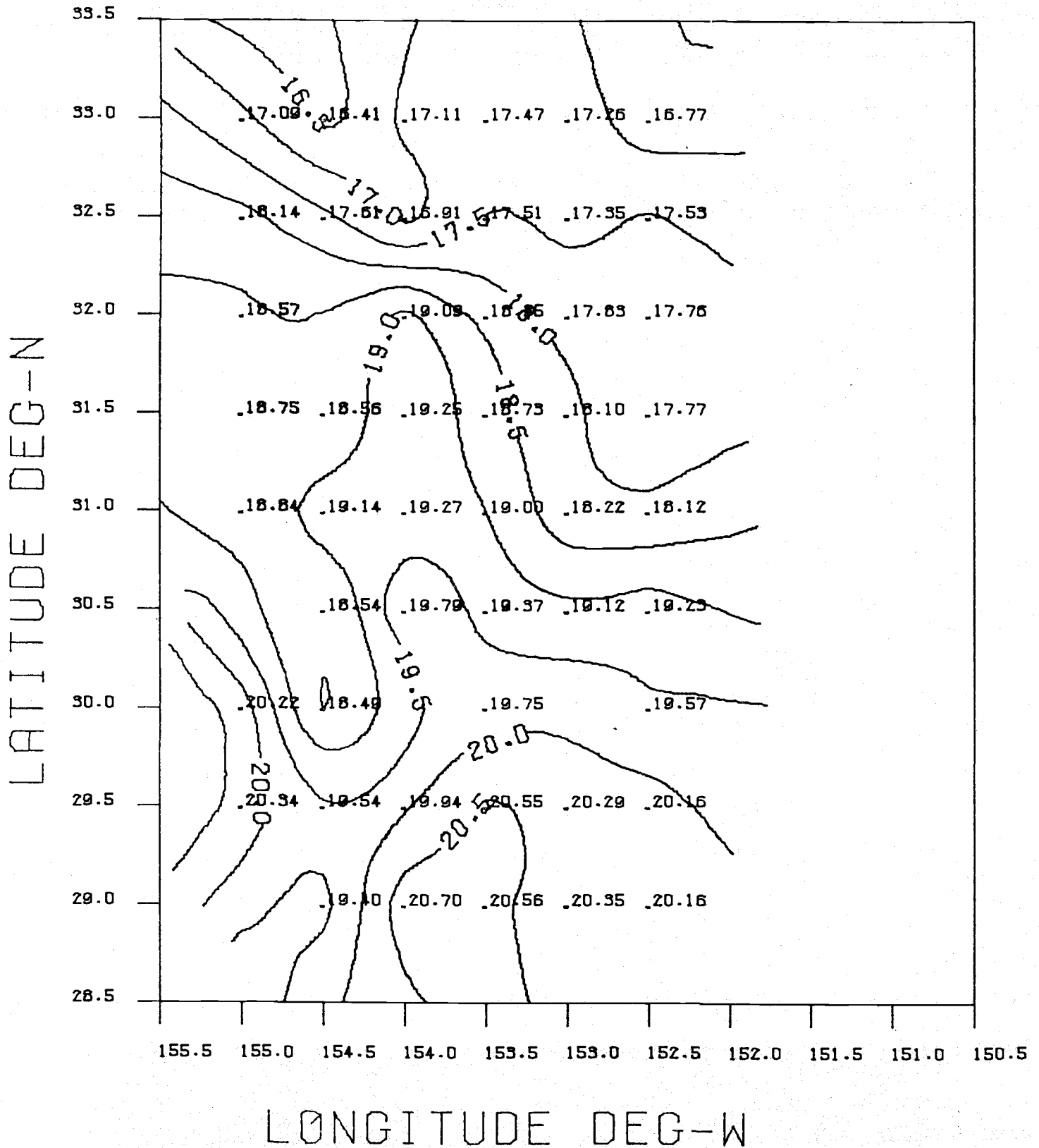


Figure 2. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

DEC. 21, 1979

FRONT 003  
30.0 TO 80.0 METERS

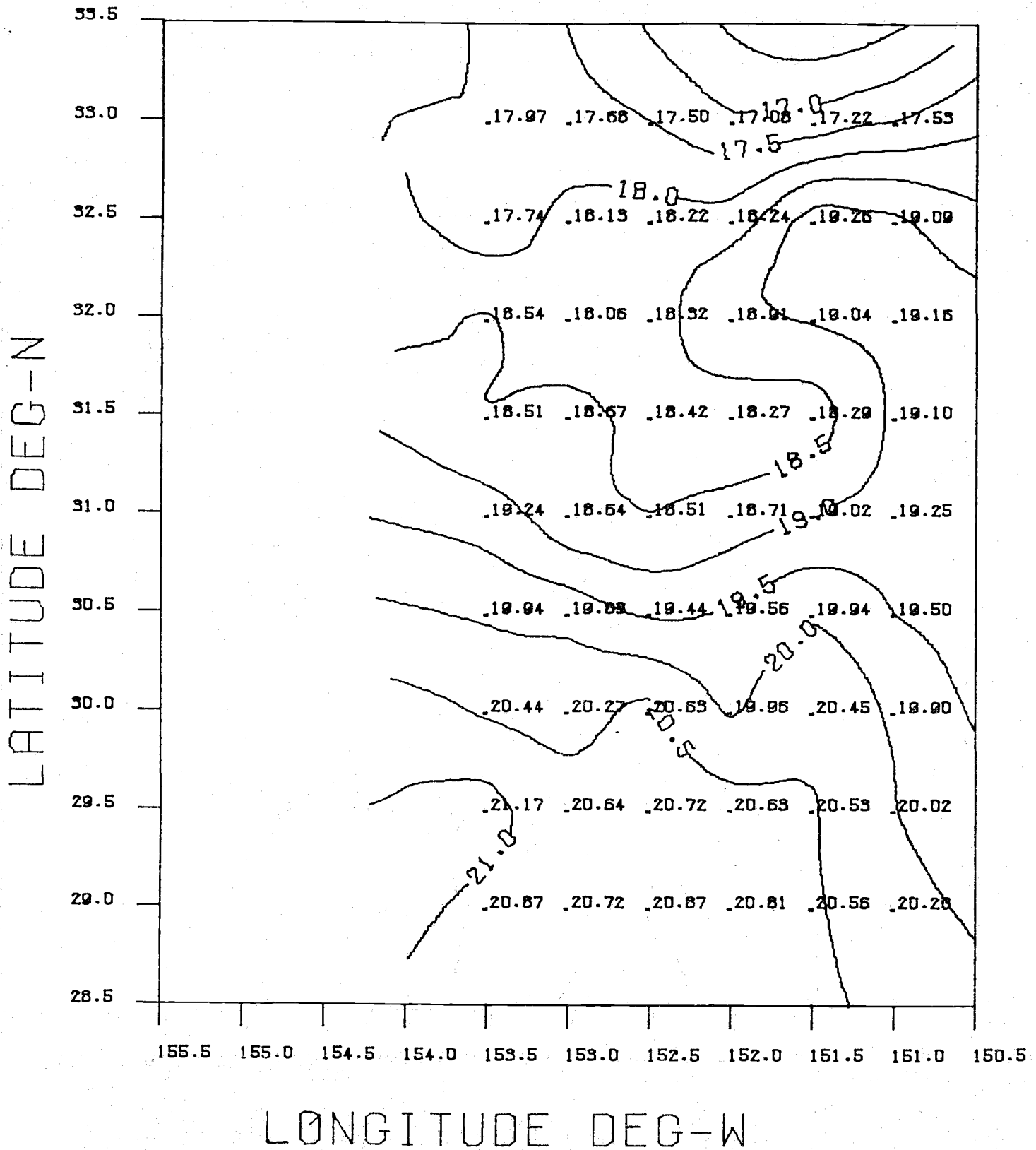


Figure 3. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

JAN. 4, 1980

FRONT 004

30.0 TO 80.0 METERS

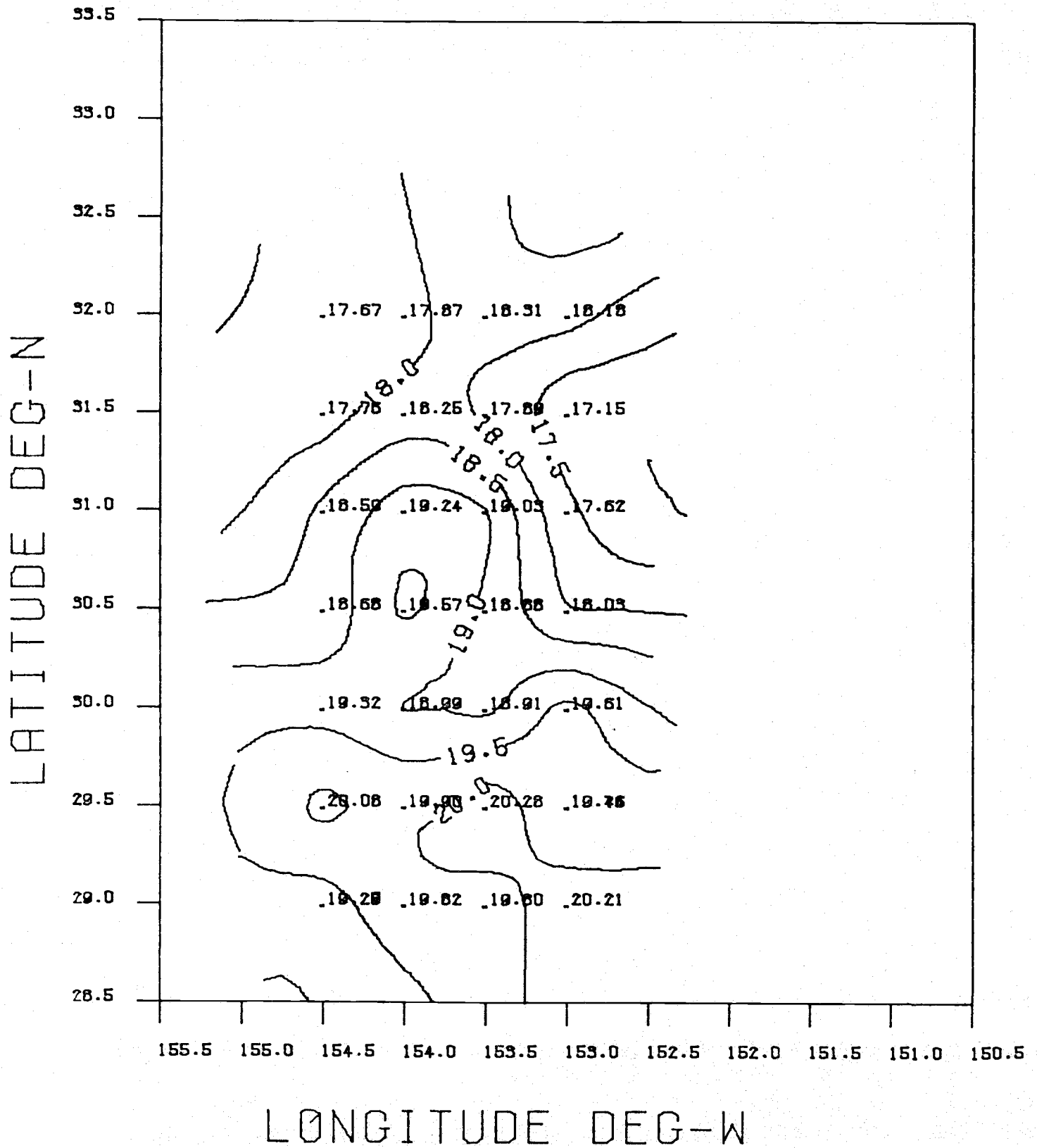


Figure 4. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

JAN. 17, 1980

FRONT 005

30.0 TO 80.0 METERS

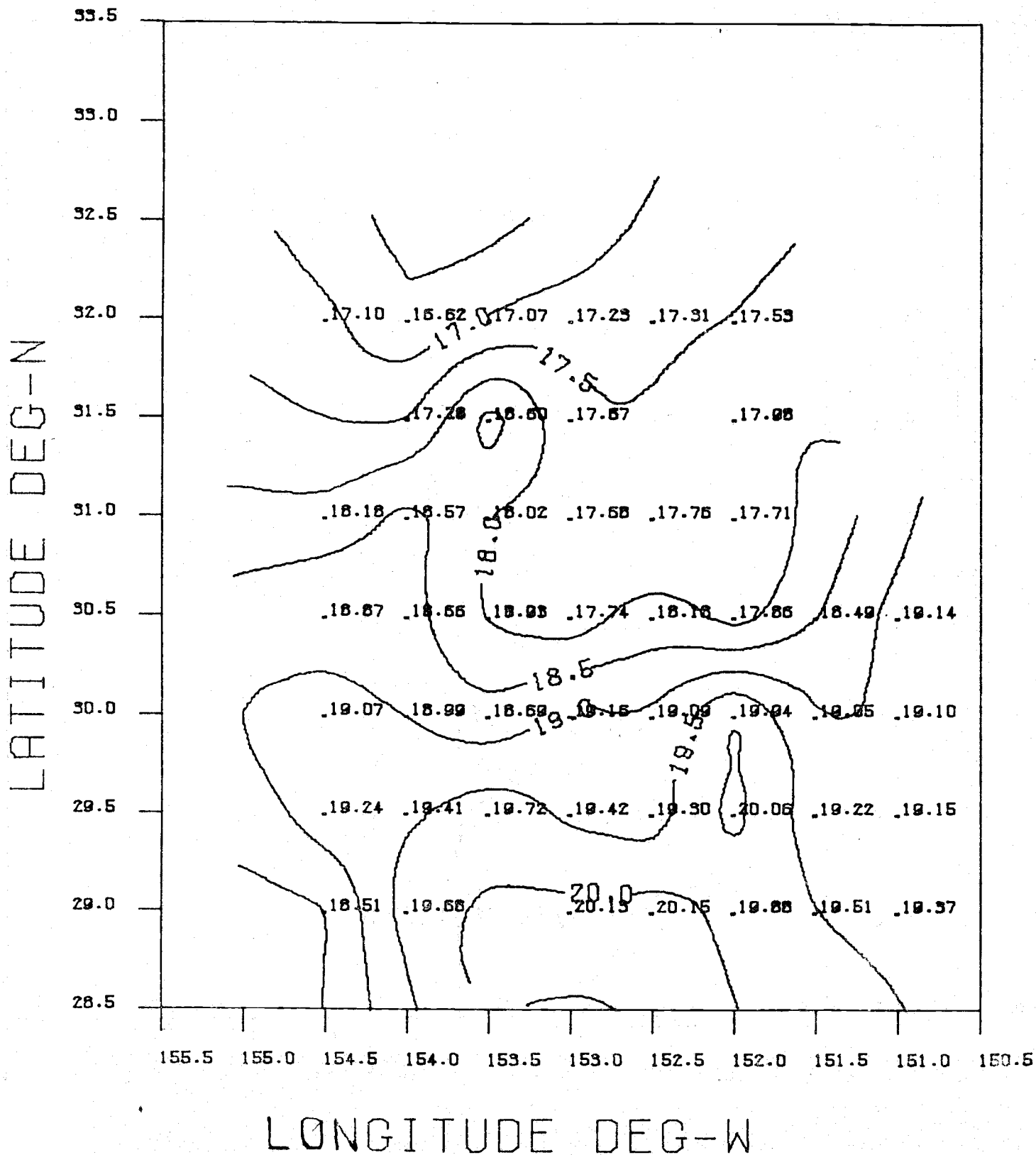


Figure 5. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

JAN. 24, 1980

FRONT 006

30.0 TO 80.0 METERS

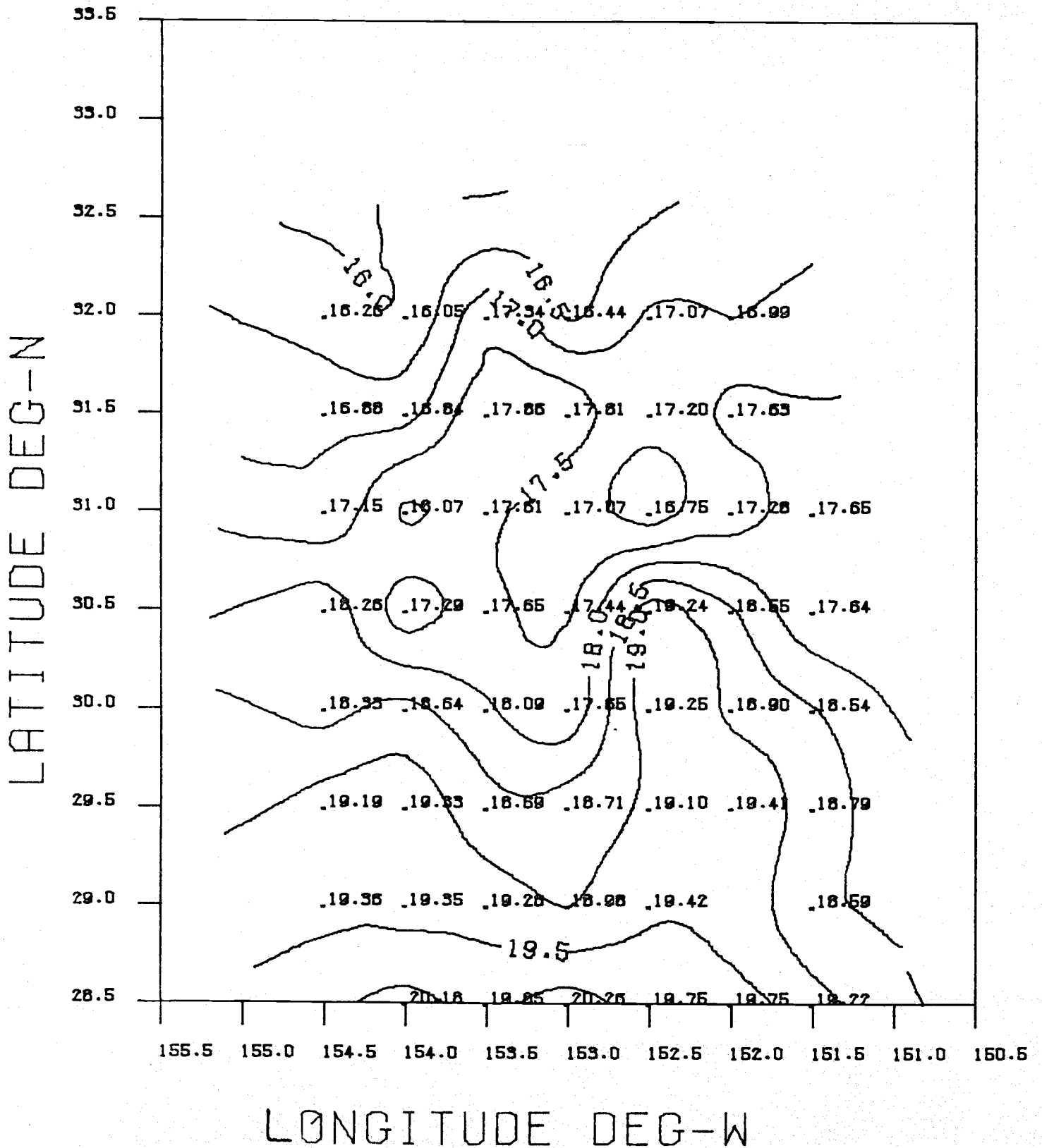


Figure 6. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

FEB. 6, 1980

FRONT 007

30.0 TO 80.0 METERS

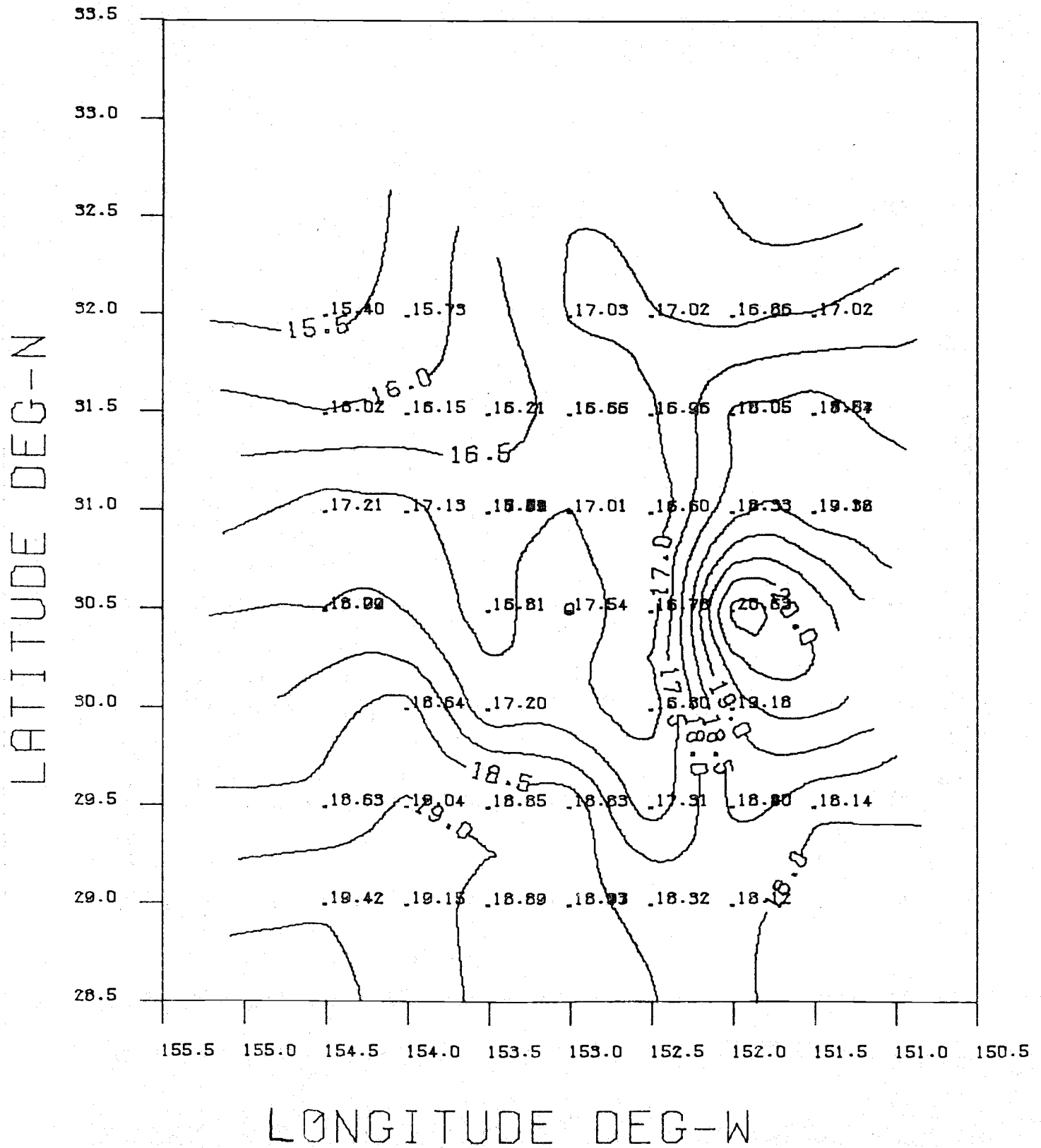


Figure 7. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.

FEB. 19, 1980

FRONT 008  
30.0 TO 80.0 METERS

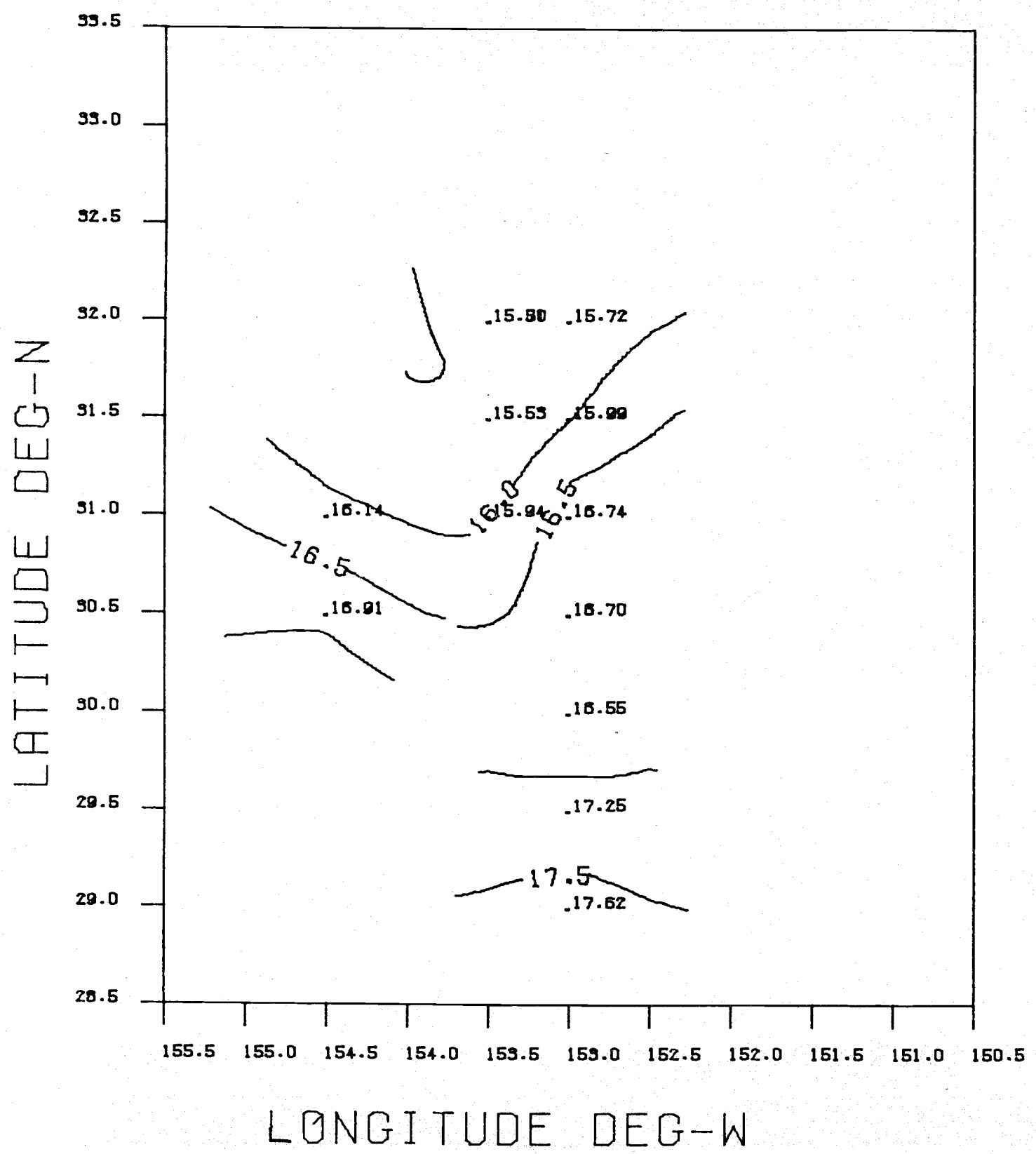


Figure 8. Mixed layer isotherms drawn to AXBT temperatures averaged between 30 and 80 m depth.



## Satellite Observations of Surface Temperature

by

Robert Bernstein, Michael Van Woert, and Robert Whritner

Scripps Institution of Oceanography

The Scripps Remote Sensing Facility can routinely track satellites offshore to about  $145^{\circ}\text{W}$  longitude. Beyond this longitude the satellite rarely appears high enough above the horizon for the Scripps facility to receive it, and when the satellite is high enough the swath is very limited in extent. In order to provide more complete coverage for the FRONTS Experiment it was decided that a receiver close to the experiment area would be necessary. With the kind of cooperation of Capt. A. Adams and Msgt. C. Henderson, Jr., NOAA-6 Advanced Very High Resolution Radiometer (AVHRR) data was collected at Hickman AFB, Hawaii and shipped airmail to Scripps for processing. Daily ascending passes were collected, the decision to collect the pass being made on the basis of ephemeris data generated at Scripps (Fig. 1). In all, thirty-four satellite passes were collected between the dates 28 December 79 and 24 February 80. A complete list of the passes collected is given in Table 1.

Each pass consists of four data channels, two visible channels and two infrared channels. The visible channels were not processed because the passes were collected after dark. Both infrared channels were processed. It appears that the  $3.55\text{--}3.93\ \mu$  channel will be the most useful for oceanographic studies because it is affected less by atmospheric moisture than is the  $10.5\text{--}12.5\ \mu$  channel. An example of the  $3.55\text{--}3.93\ \mu$  radiometer data is provided (Fig. 2).

A number of qualitative features are visible in the data. For purposes of discussion the data for 17 January 1980 is presented, (Fig. 2). Evident in the data are a number of warm and cold tongues of water. An obvious cool tongue of water extends in a southeasterly direction from  $30.5^{\circ}\text{N}\ 152^{\circ}\text{W}$ . Just west of this is a warm tongue of water which extends northwest. In addition to these obvious tongues, tongues of cool water are evident near  $32^{\circ}\text{N}\ 154^{\circ}\text{W}$  and  $29.5^{\circ}\text{N}\ 153^{\circ}\text{W}$ . This compares favorably with the 50 m analysis from the 24 January 1980 AXBT flight (Fig. 3). The boundaries of the warm and cold tongues form regions of strong horizontal temperature gradients. The gradient near  $30.5^{\circ}\text{N}\ 152.5^{\circ}\text{W}$  is particularly strong. One might call this the subtropical front. Also evident are regions of weaker gradients which are not obviously related to the tongues of water. Such a feature can be seen near  $31^{\circ}\text{N}\ 152^{\circ}\text{W}$ .

Future plans for analysis include a more detailed description of the satellite data combined with AXBT data, CTD, and drifter data in the hopes of substantiating the features observed in the satellite data. In addition, attempts will be made to compute accurate horizontal gradients of temperature. In this way we hope to learn something about the large-scale horizontal structure of the front.

TABLE 1. FRONTS Satellite Pass Summary\*

<u>Julian Day</u>	<u>Date</u>	<u>Julian Day</u>	<u>Date</u>
362	28 Dec 79	026	26 Jan 80
004	4 Jan 80	027	27 Jan 80
005	5 Jan 80	028	28 Jan 80
006	6 Jan 80	030	30 Jan 80
008	8 Jan 80	032	1 Feb 80
010	10 Jan 80	039	8 Feb 80
011	11 Jan 80	040	9 Feb 80
013	13 Jan 80	044	13 Feb 80
015	15 Jan 80	046	14 Feb 80
016	16 Jan 80	048	17 Feb 80
017	17 Jan 80	049	18 Feb 80
018	18 Jan 80	050	19 Feb 80
021	21 Jan 80	051	20 Feb 80
022	22 Jan 80	053	22 Feb 80
024	24 Jan 80	054	23 Feb 80
025	25 Jan 80	055	24 Feb 80

\* All data is NOAA-6 AVHRR data collected at approximately 0500Z on the given days.

SATELLITE: NOAA6    SENSOR: AVHRR  
START TIME: 1/17/80 5:31: 0  
STOP TIME: 1/17/80 5:47: 0  
PROJECTION: EQUIRECTANGULAR

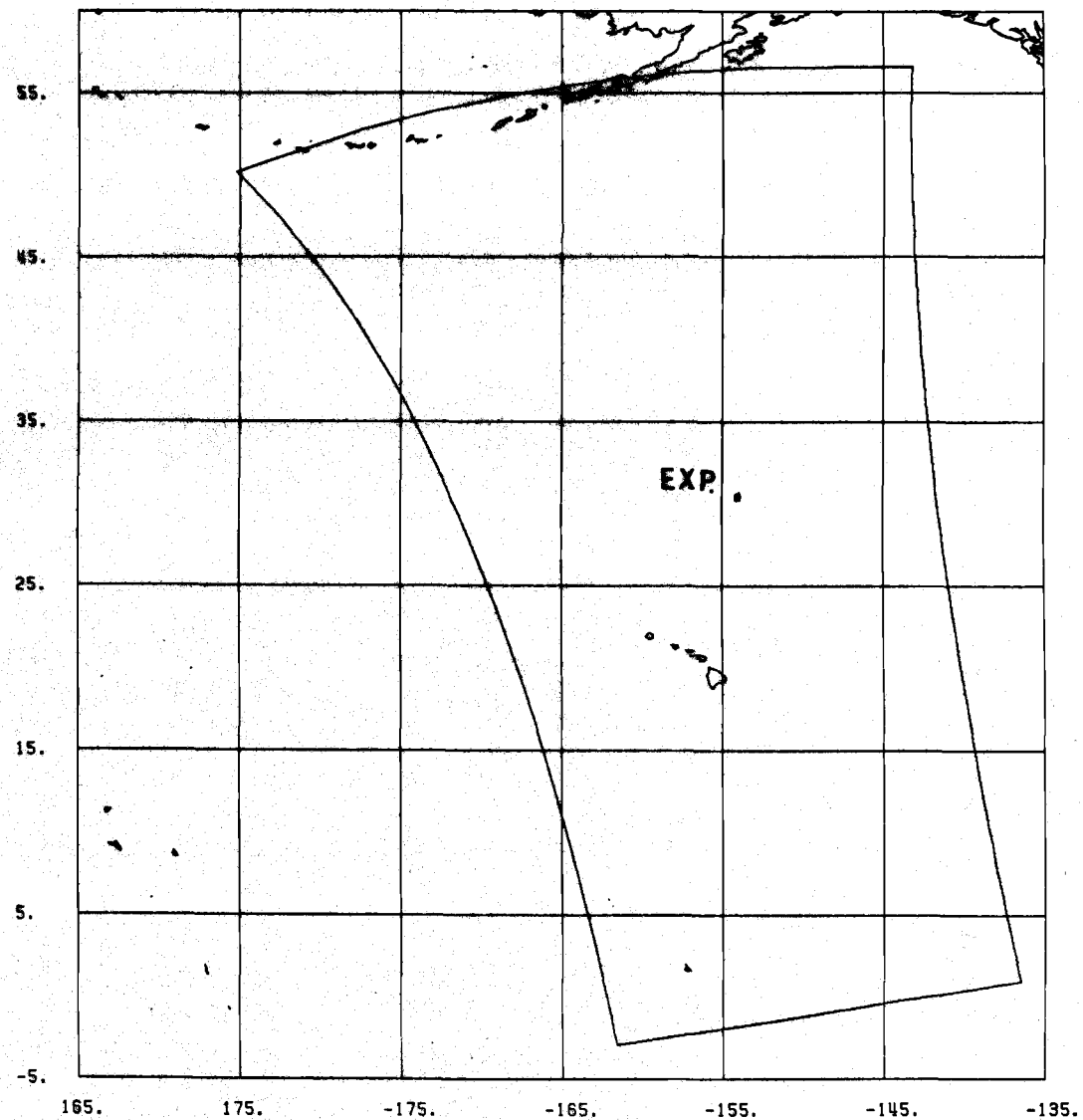


Figure 1. Ephemeris data generated at Scripps for the pass on 17 January 1980. The center point for the experiment is denoted on the map.

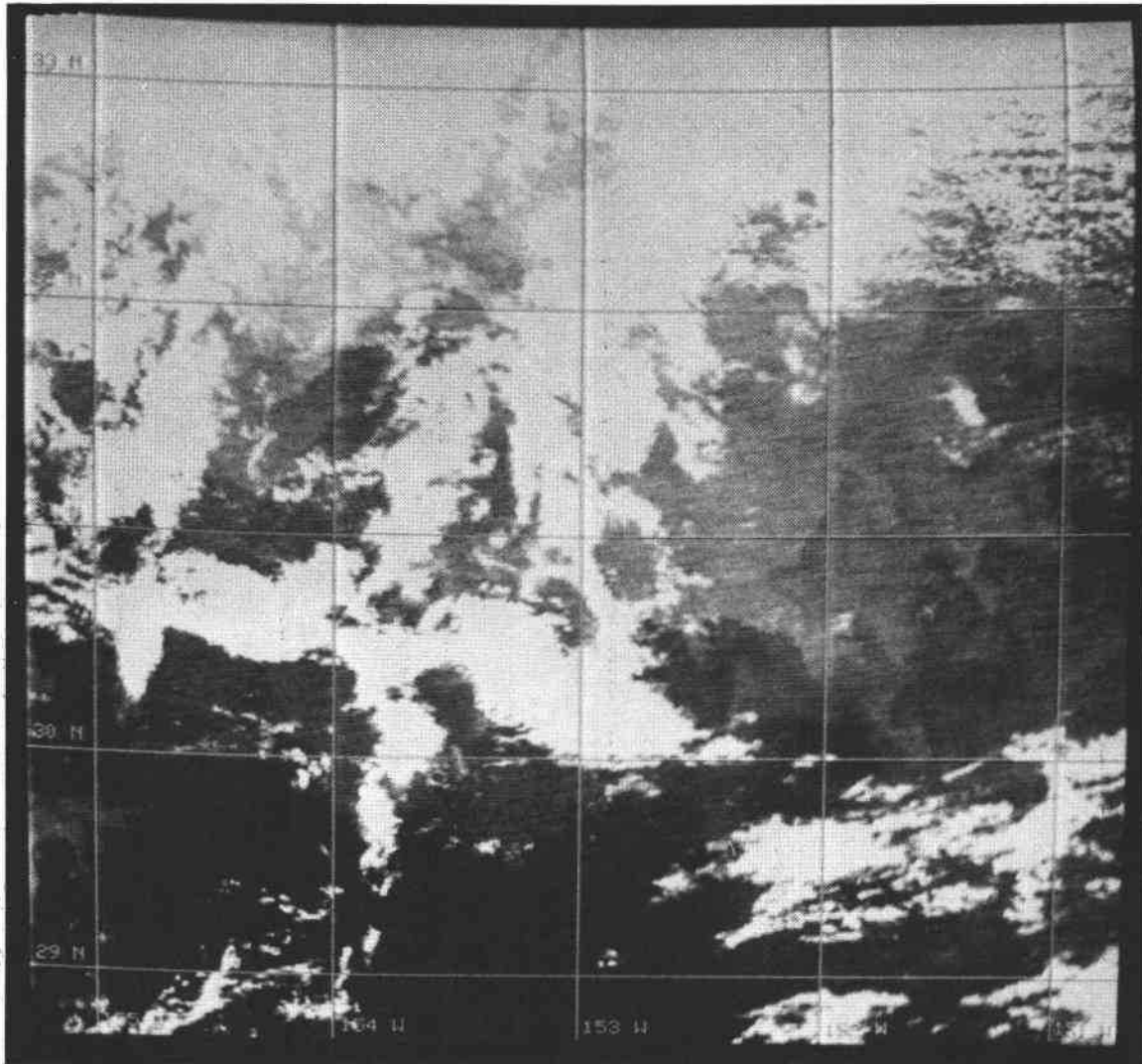


Figure 2. AVHRR data, 3.53-3.93  $\mu$  band for the data 17 January 1980. Warm water is dark, cool water is grey and clouds are white.

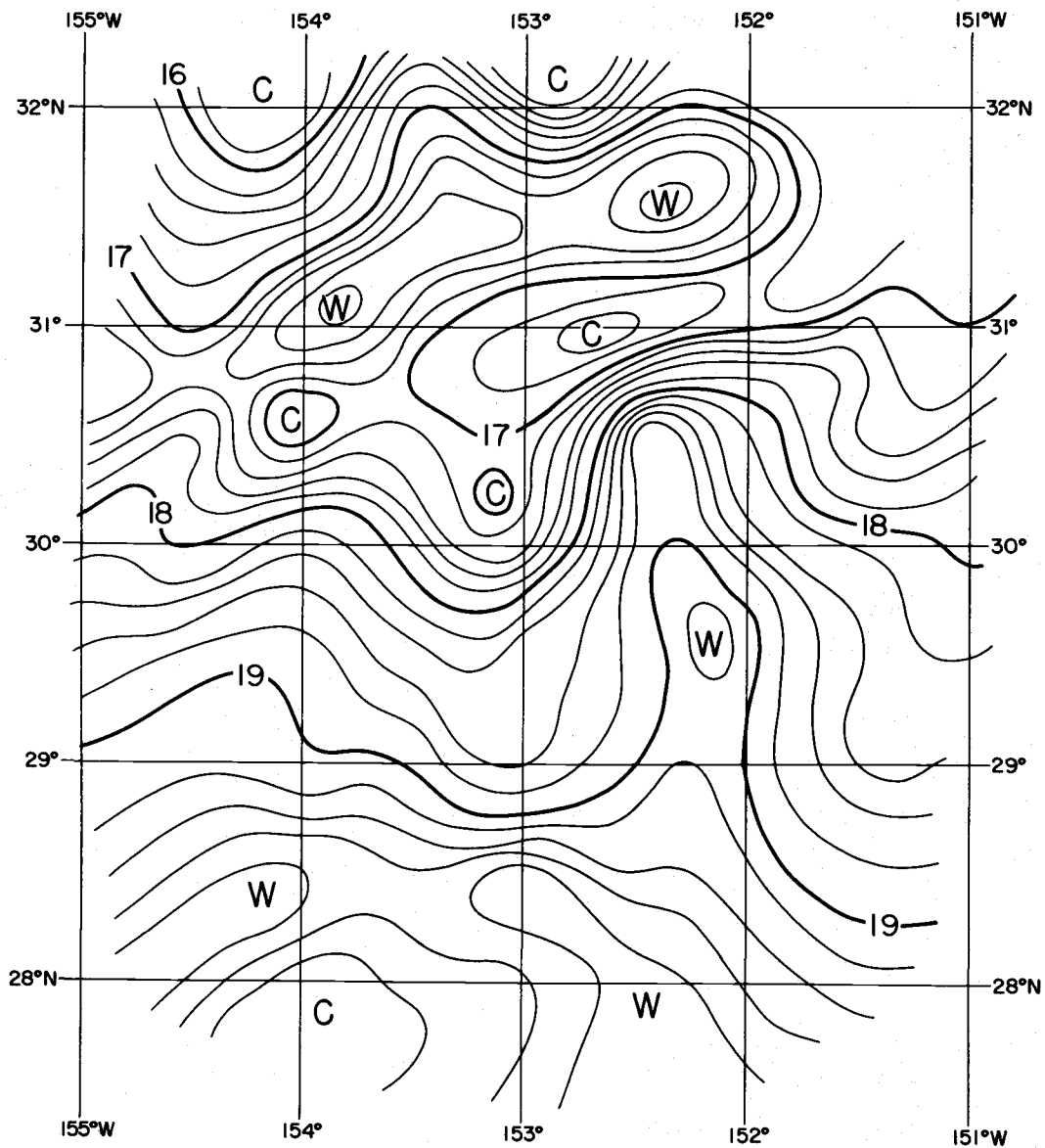


Figure 3. 50 m analysis of the AXBT data for the day 24 January 1980. The contour interval is  $0.2^{\circ}\text{C}$ . A transparent overlay of this analysis should be made and superimposed on Fig. 2.

## GOES Satellite Data

by

T. Green and K. Sowinski

Marine Studies Center  
University of Wisconsin

In an effort to provide an overview of the sea-surface temperature field during FRONTS, GOES infrared and visual imagery are being examined for the period December, 1979 to February, 1980. The data are less reliable than data from polar-orbiting satellites (e.g., NOAA-6) due to atmospheric contamination and relatively poor spatial resolution. However, the time resolution is much better.

Brightness-minimization techniques are used on the half-hourly data to remove the cloud cover where possible. The stationarity of the resulting SST patterns (over about a day) would suggest that atmospheric contamination (presumably moving with atmospheric time scales) was not present. Conversely, motion of the patterns suggests that they are unreliable, and should not be interpreted as SST fields. We have found both situations, as shown in the table below.

Low-level clouds were also tracked to estimate the surface winds in the study area.

So far, we have examined imagery about every five days with the partial success shown in the table. We are more enthusiastic at this point about the usefulness of the wind data than that of the SST data. However, further SST data will be analyzed in an effort to find stationary SST data that are also corroborated by AXBT or other information.

TABLE: GOES DATA

<u>DATE</u>	<u>SST IN STUDY AREA*</u>	<u>WINDS</u>	<u>NO. WIND VECTORS IN STUDY AREA</u>
6 JAN	Hints of two ~ 1.5°C fronts: (33°,153° to 33°,151°) and (30.5°,150° to 30.5°,147°)	Cyclonic in area, ~ 15 kts	17 (~30 possible)
11 JAN	Two strong fronts: ~ 2°C (32°,153°) to (33.5°,149°), (30°,156°) to (31.5°,150°). These stationary; meanders on them are not.	Fairly uniform WSW, 50 kts (?)	7 (~30 possible)
16 JAN	Two fronts ~ 2°C. One from (29.5°,158°) to (32.5°,152.5°) with "sock" hanging down (~ 1° wide, 2° long, pointing SE from 30.5°,156°). Another from (33°,156°) to (33°,151°) perhaps spurious	Fairly uniform SW, 25 kts	10 (~30 possible)
19 JAN	Too cloudy to resolve SST.	NW, 35 kts	8 (~20 possible)
24 JAN	Too cloudy	N, 30 kts	18 (~30 possible)
27 JAN	Many patchy clouds. Some evidence of 1.5°C "sock": (30°,154°) to 28.5°, 153.5°) to (30°,153°)	Anticyclonic, stationary at (32.5°,153°). 10-15 kts near edge of area.	36 (~50 possible)

---

\* Taken as 28°-35°N, 148°-158°W.

## Three-Dimensional Thermohaline Structure

by

Gunnar I. Roden

University of Washington

The three-dimensional thermohaline structure was determined with a Neil Brown CTD lowered from the surface to 1500 m. The station pattern in the frontal area was occupied twice in order to determine the change of the thermohaline structure with time. Analysis of the CTD data will concentrate on the description and explanation of the thermohaline structure in the frontal area as a function of depth and time. Analysis of the baroclinic flow field and of the sound velocity field will be included in this study. Preliminary findings indicate the following:

## Location and shape of front (Figs. 1-3)

The surface front was encountered between  $29^{\circ}20'N$  and  $31^{\circ}00'N$ , about 80 km south of its mean position. The shape of the front was convoluted, somewhat resembling a wave, with a "wavelength" of about 200 km (warm high salinity peak to warm high salinity peak) and a "wave amplitude" of about 55 km (one half the distance between the warm high salinity peak and the cold low salinity trough). The shape of the surface temperature, salinity and density fronts was similar.

## Intensity of front (Figs. 1-3)

Because of the convoluted shape of the front, both strong zonal and meridional gradients were encountered. Maximum horizontal salinity gradients were 0.3% per sampling interval (37 km), maximum horizontal temperature gradients were 1.5 C/37 km and maximum horizontal density gradients were about 0.15 sigma-t units/37 km. The front intensified over a ten-day period, which was accomplished by a southward motion of cold and low salinity water, between  $153^{\circ}00'$  and  $153^{\circ}40'W$ .

## Baroclinic flow relative to 1500 db (Fig. 4)

The baroclinic flow field was characterized by three main features: anticyclonic flow around warm-core high salinity ridges, cyclonic flow around cold-core low salinity troughs and regions of confluence flow in between, where thermohaline gradients were concentrated. Maximum flow speeds were near 20 cm/s. Note that the cold-core low salinity trough progressed southeastward during the ten-day period between the surveys. Fronts were strongest where baroclinic confluence occurred. Satellite-tracked buoys closely followed paths suggested by the dynamic height topography.

## Vertical thermohaline structure perpendicular to front (Figs. 5 and 6)

The basic vertical structure showed a warm and high salinity top layer (dotted), about 125-150 m depth, a well-developed thermocline and halocline between 150-200 m, followed by a more gradual decrease of temperature and salinity with depth and by a deep salinity minimum between about 500 and 600 m (shaded).



The thermohaline fronts were most pronounced in the upper 150 m. In the NNE-SSW section shown, the fronts occurred between  $29^{\circ}40'W$  and  $30^{\circ}00'N$  during both the first and second surveys. While the position of the fronts remained approximately the same, the intensity of the fronts increased from 1 C/37 km to 1.5 C/37 km and from 0.15%/37 to 0.25%/37 km over a ten-day period. This can be ascribed to advancing cool and low salinity water from the north; the 17 C isotherm and the 34.85‰ isohaline were displaced southward about 180 km during this time interval, indicating a flow speed of close to 20 cm/s, which is in agreement with the 0/1500 db baroclinic flow. The thermocline and halocline were sharper north than south of the subtropical front as known from previous investigations.

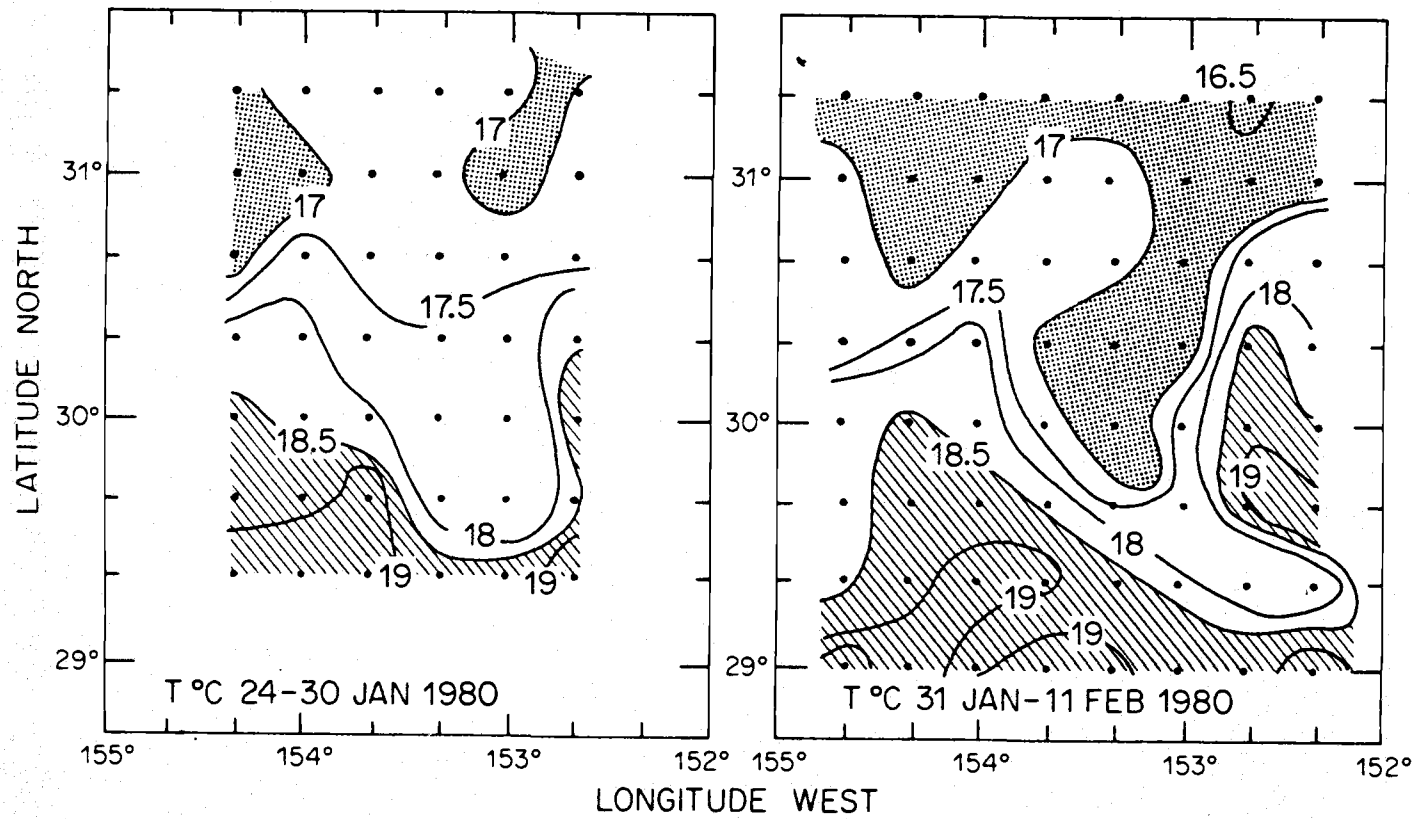


Figure 1. Maps of surface temperature.

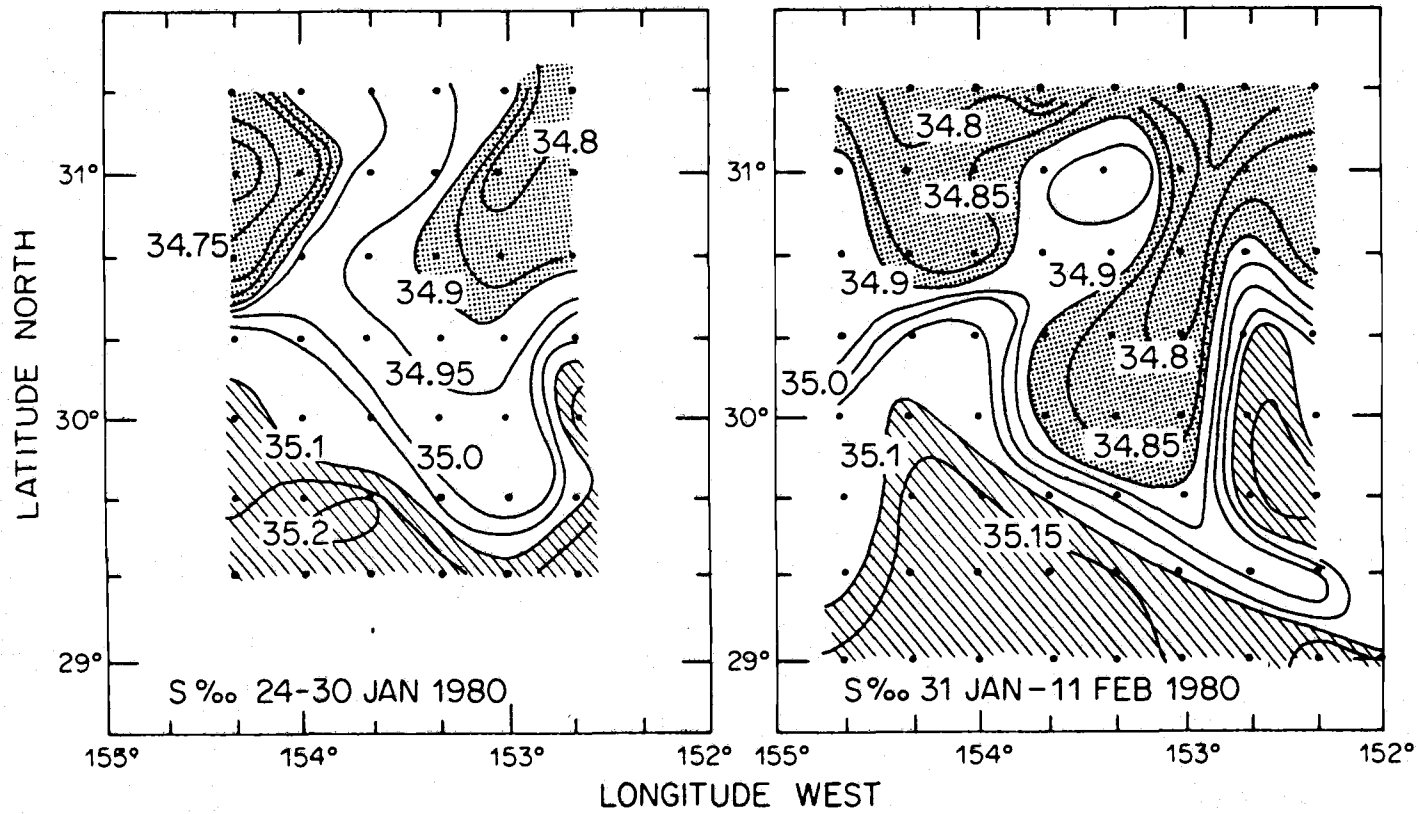


Figure 2. Maps of surface salinity.

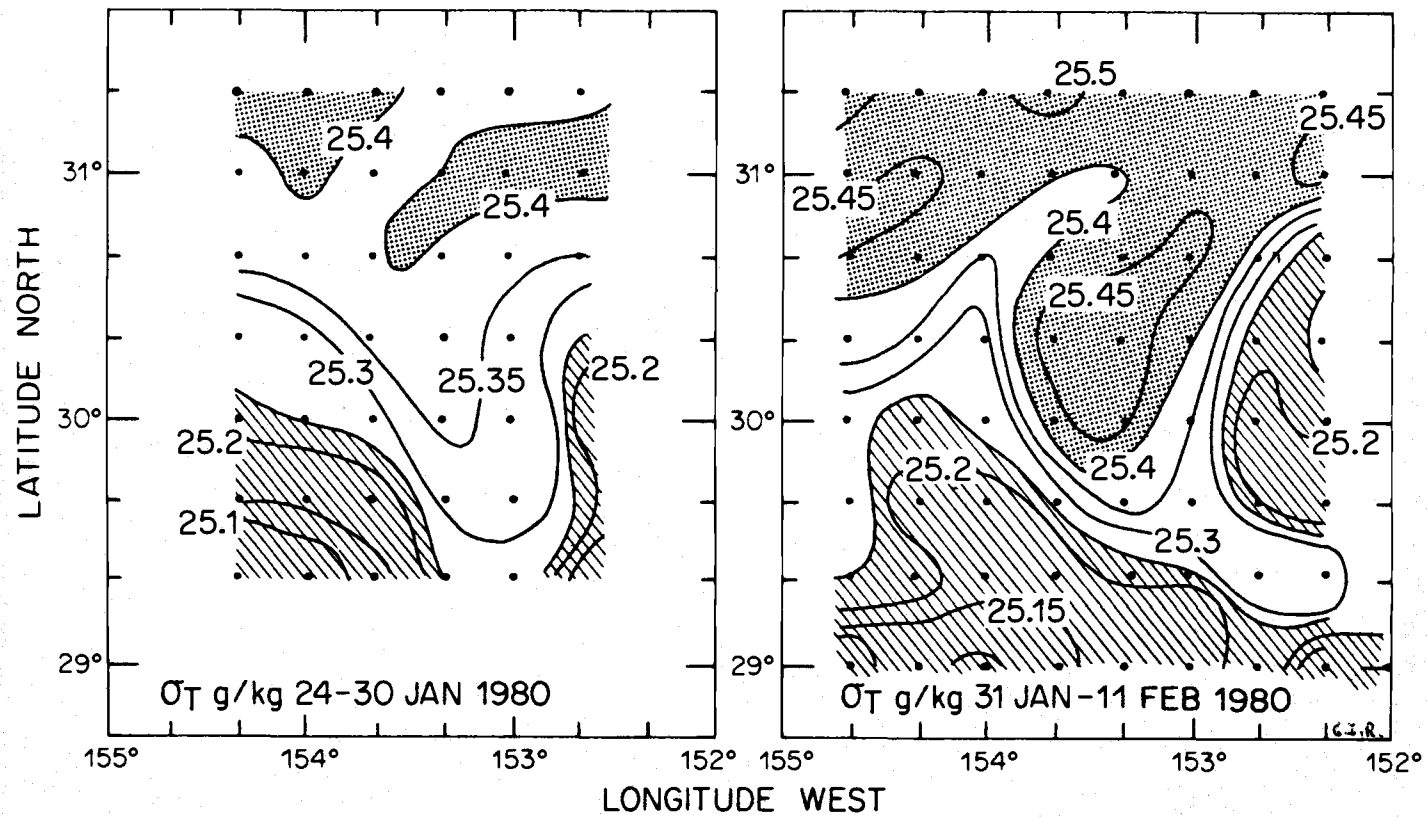


Figure 3. Maps of surface density anomaly.

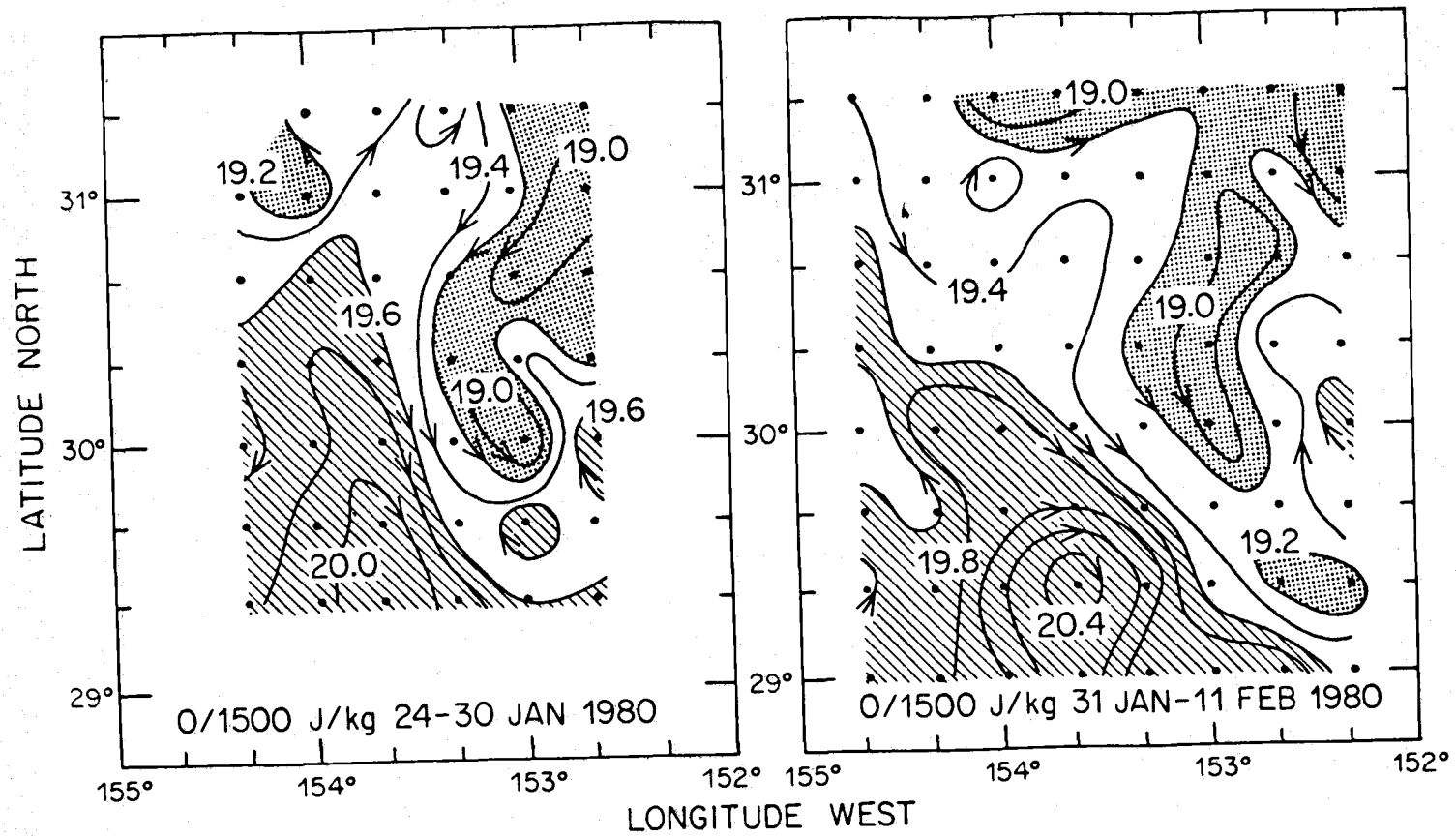


Figure 4. Maps of surface to 1500 decibar dynamic height.

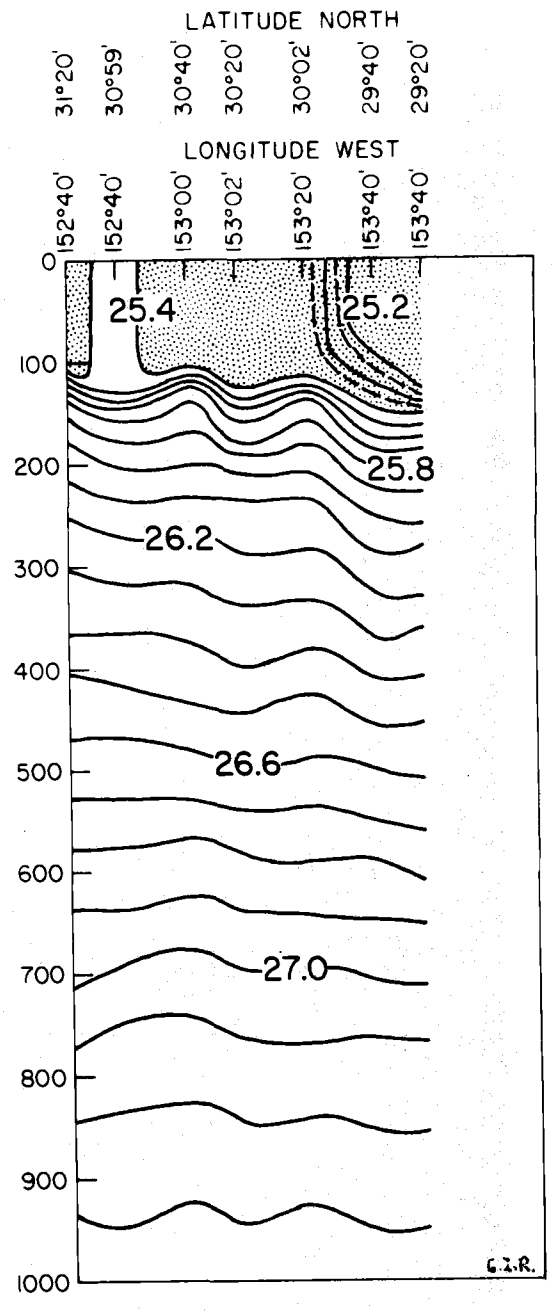
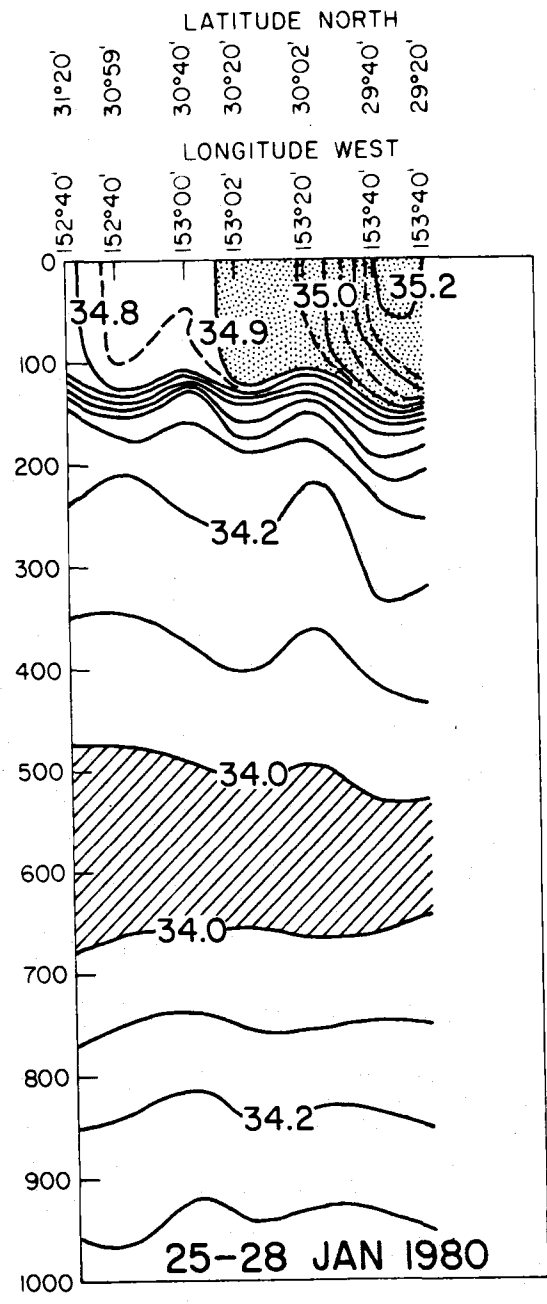
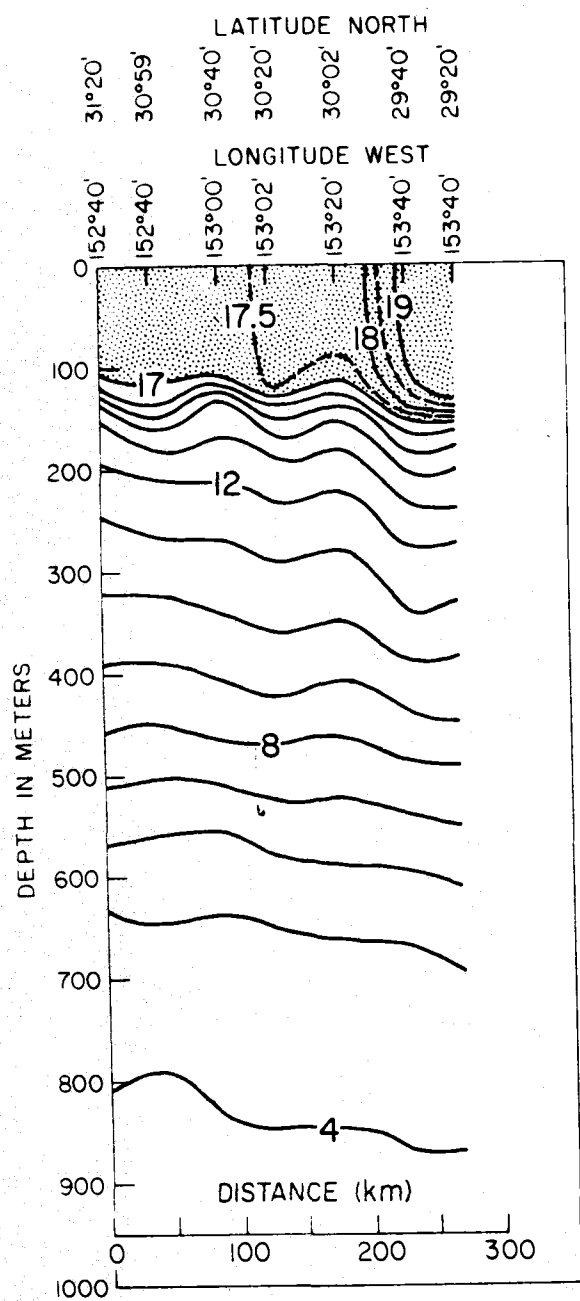


Figure 5. Cross-sections of temperature, salinity and  $\sigma_t$  observed 25-28 January 1980.

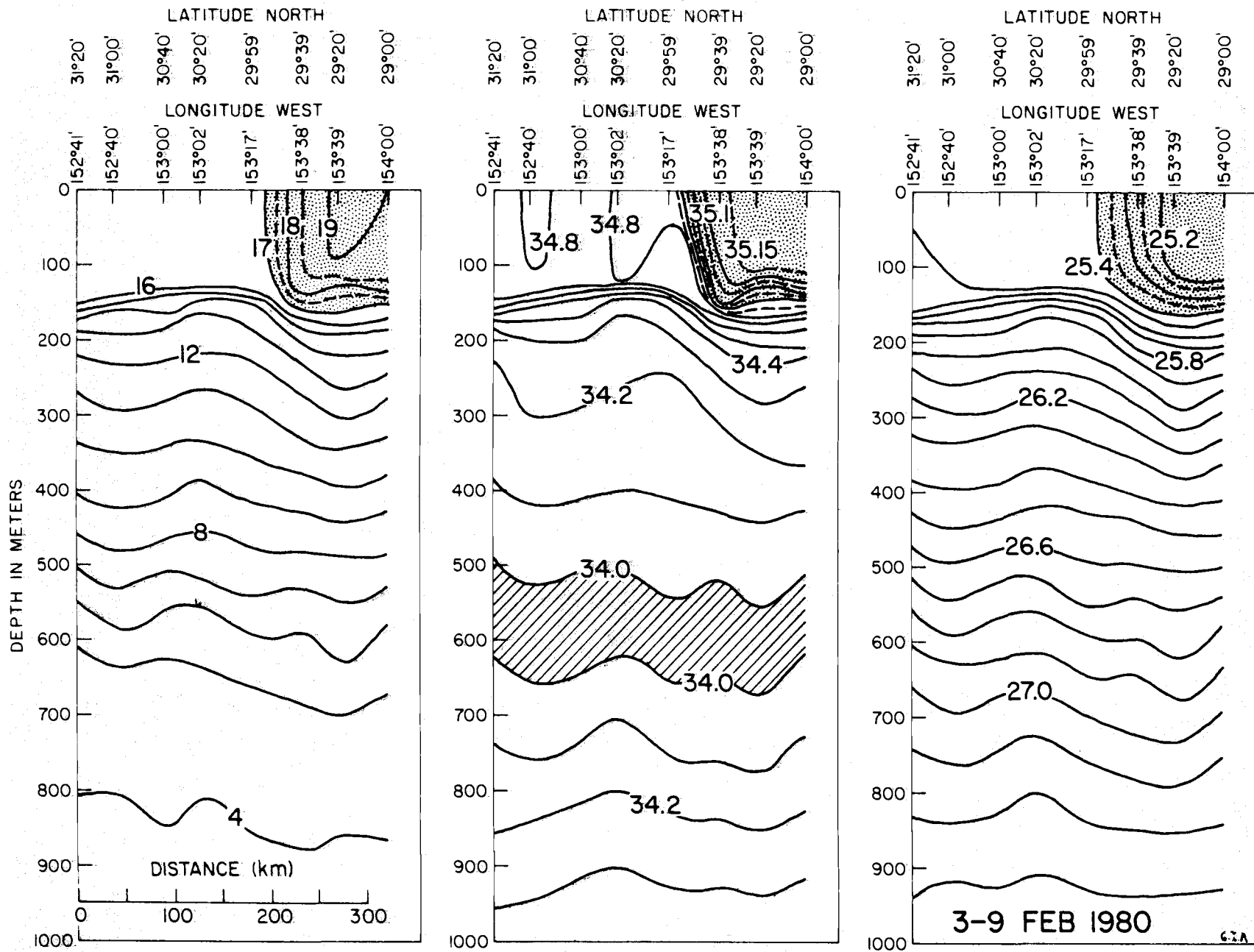


Figure 6. Cross-sections of temperature, salinity and  $\sigma_t$  observed 3-9 February 1980.

## Multiship Expendable Bathythermography (XBT)

by

W. J. Emery

University of British Columbia

On the transit to Hawaii in February, XBT casts were taken every hour (~ 15 NM spacing) from HMCS PROVIDER between Esquimalt, British Columbia and Honolulu. In the area from 33 to 28°N the three destroyers spread out and steamed in parallel lines, separated by 10 NM, taking XBT's every half hour (~ 7.5 NM spacing). In Fig. 1 the surface temperature and the temperature at 200 m from all four ships shows two separate frontal features. The first, and strongest is at 32°N ranging between 16 and 18°C at the surface and 13 to 15°C at 200 m. As is confirmed by the plot of surface salinity (Fig. 1), this is the subtropical front. In this survey it exhibits a northward turn with a suggestion at 200 m that it might be part of a meander or eddy.

The second weaker front is between 28 and 29°N with temperatures from 19 to 20°C at the surface and 14 to 15°C at 200 m. The reappearance of these temperatures farther south at 200 m demonstrates the convoluted structure displayed by this survey. The vertical section (Fig. 2) from PROVIDER (second ship from the east) confirms the locations of both of these fronts. At 32°N the upper isotherms turn sharply upward, giving rise to the surface frontal expression. Similar isotherm uplifts at depth lead to the frontal feature at 200 m. The subsurface isotherm uplifts are strongest somewhat farther to the south. The cold feature at 25°30'N is suggestive of a cyclonic eddy but since the survey did not extend this far south this cannot be confirmed.

On the return trip approximately six weeks later (March) PROVIDER again took XBTs between Honolulu and Esquimalt. Based on the earlier survey it was decided to start the four-ship survey at about 27°30'N and to spread the ships 20 NM apart rather than 10 NM giving a much better survey pattern. Unfortunately, the four ship survey was prematurely terminated at 15 hours rather than the arranged 24 hours due to a medical emergency. Repeated crossings of the area by PROVIDER however added new samples to the area already sampled.

As shown in Fig. 3 this second survey contained an interesting anti-cyclonic eddy about 30 NM in diameter. The feature is very intense having a scale only slightly larger than the local Rossby radius (~ 40 km) and estimated circulation speeds of 20-50 cm/sec. A similar feature was seen in a survey by Roden about a month earlier. Assuming this to be the same eddy, it has moved slowly eastward during this time.

As with the previous multiship survey, this swath contains two frontal expressions. The strongest is now at 30°N with temperatures of 19 to 20°C at the surface and 13 to 14°C at 200 m. The front is not well expressed at 200 m which may be due to the presence of the eddy. Surface salinity confirms not only the location but also the shape of the surface front with its sharp east-west meander. It is interesting that the surface temperature shows no sign of the eddy below. In contrast, surface salinity shows a maximum at this point.



The second front is at about 26°N with surface temperatures of 19.5 to 21.5°C and 200 m temperatures of 15 to 16.5°C. The vertical temperature section (Fig. 4) from PROVIDER (central ship track) demonstrates again the nature of these two fronts. The general upward trend leading to shoaling is apparent at both 26 and 30°N with the latter intensified by the presence of the warm eddy. It is interesting that a general warming has occurred between the surveys with the northern surface expression shifting from 16-18°C to 18-20°C and the southern surface gradient increasing from 19-20°C to 21-22°C.

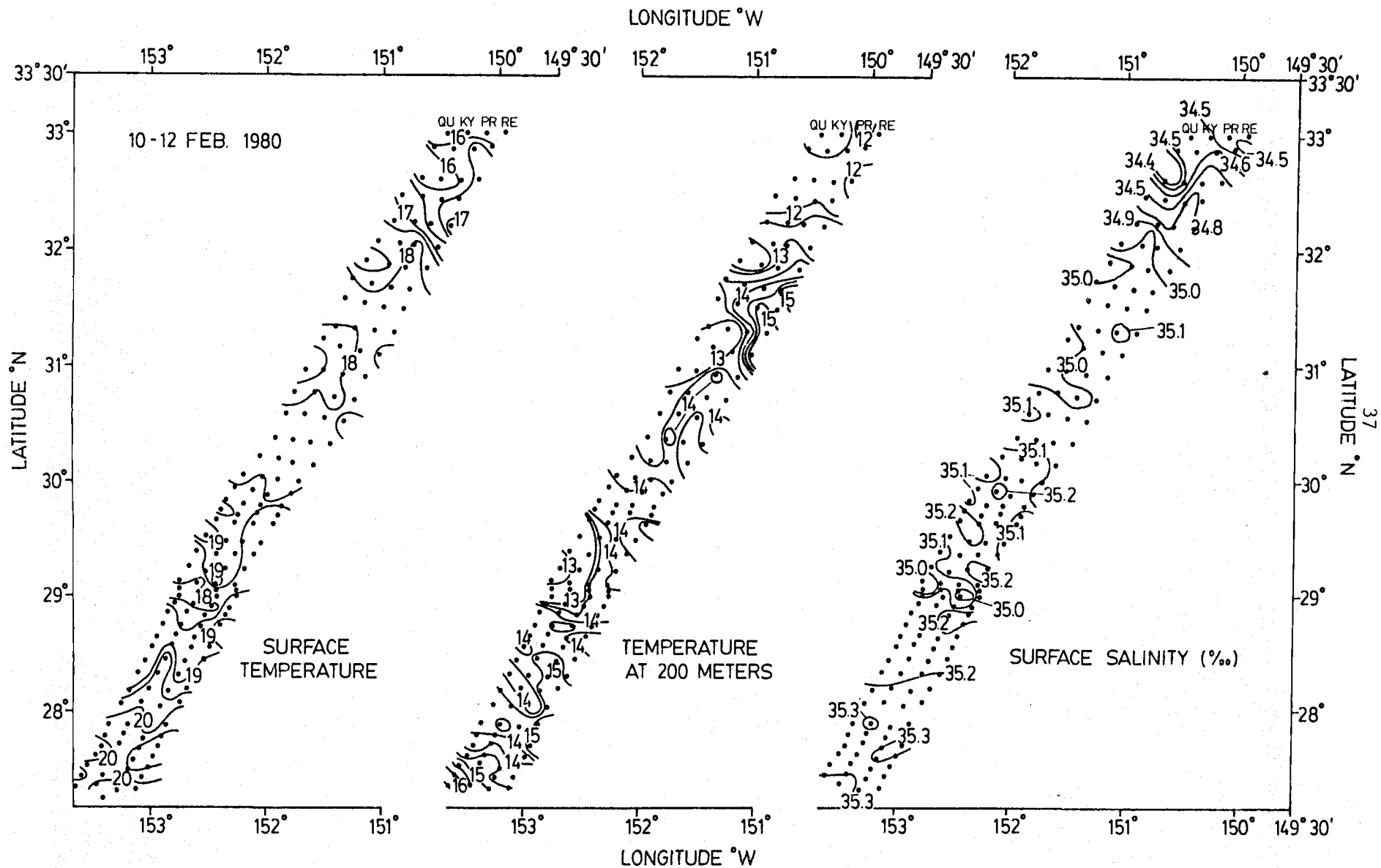


Figure 1. Isopleths drawn to observations of surface temperature, temperature at 200 m depth and surface salinity.

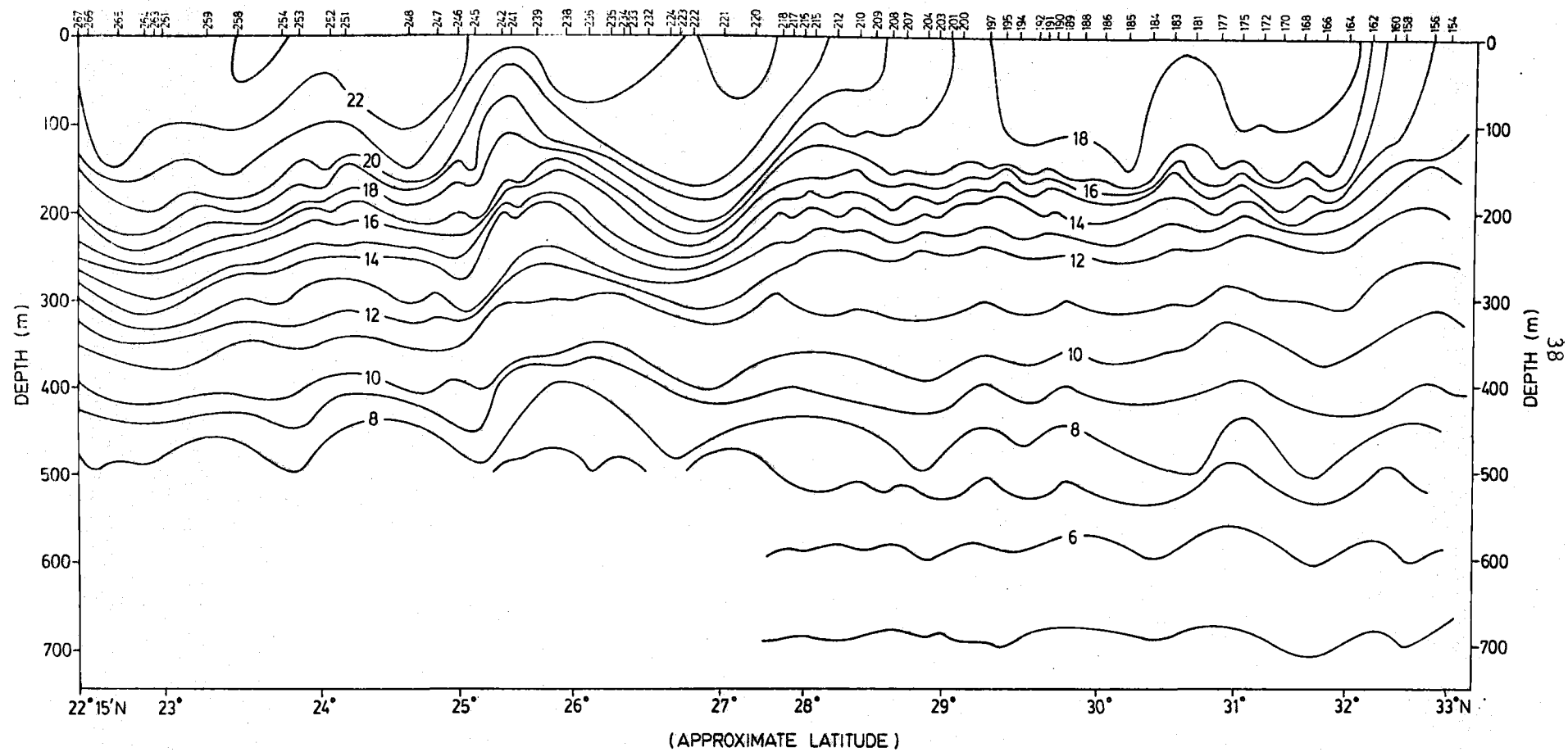


Figure 2. Isotherms drawn to XBT observations from HMCS PROVIDER 10-12 February 1980.

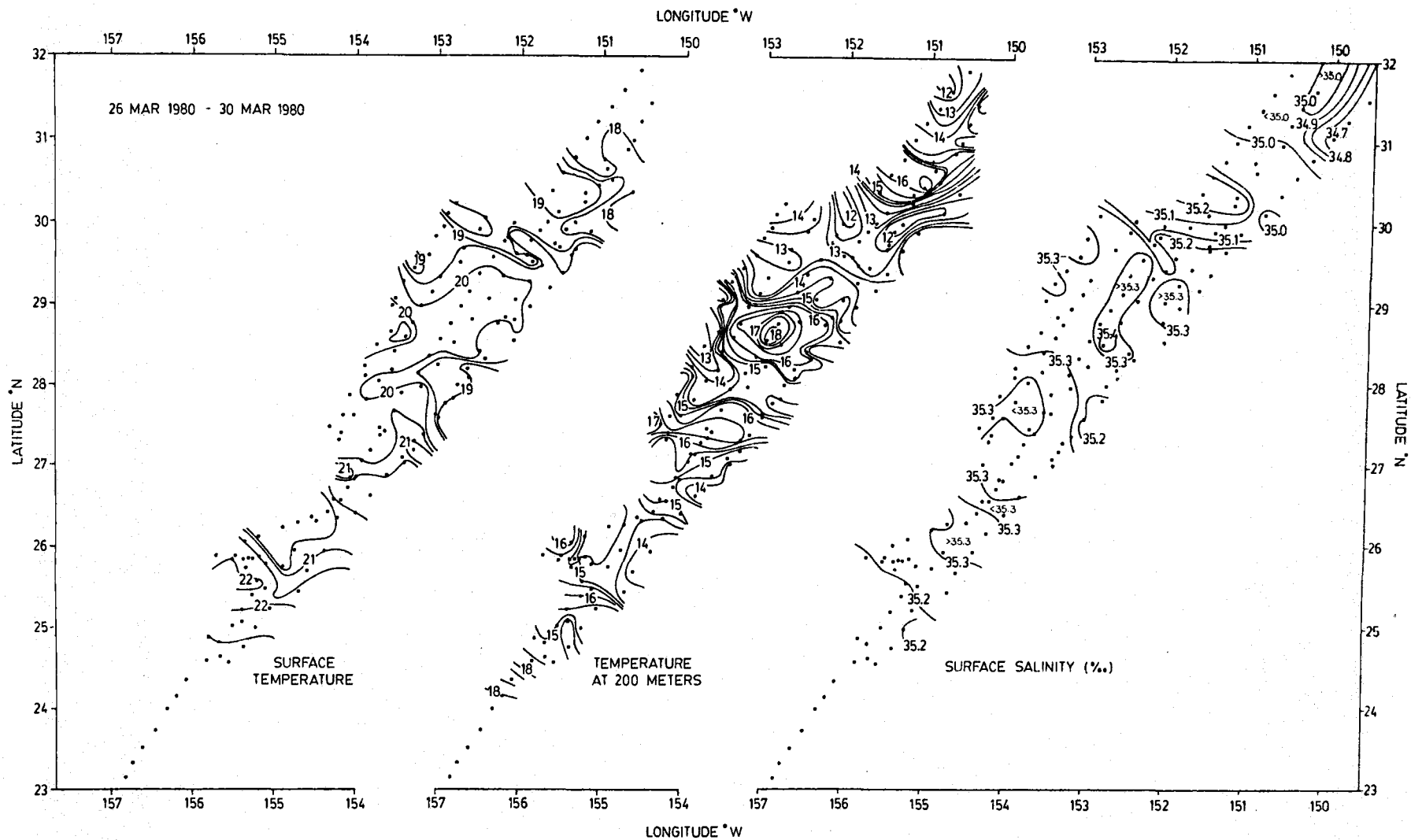


Figure 3. Isopleths drawn to observations of surface temperature, temperature at 200 m depth and surface salinity.

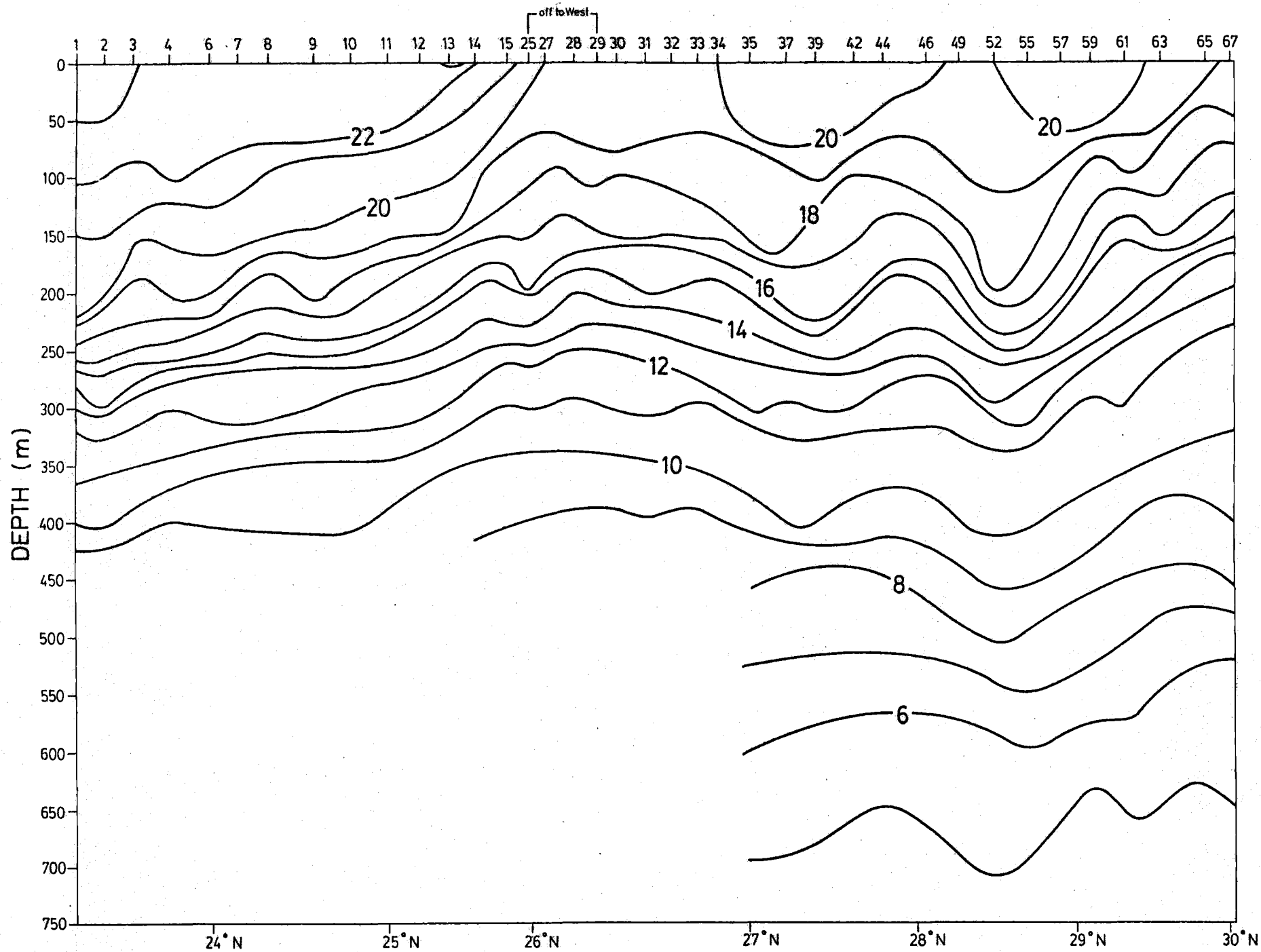


Figure 4. Isotherms drawn to XBT observations from HMCS PROVIDER  
10-12 February 1980.

## Satellite-Tracked Drifters

by

Peter Niiler

Oregon State University

Eleven Polar Research satellite-tracked drifters were released in the FRONTS area between January 23 and February 1. On July 2, nine buoys were reporting excellent position and ten had reported complete surface temperature records. In late April and early May all buoys reported that the window shade drogue, which was on a 20-m-long tether, was missing (or the transducer had failed). Fig. 1 displays the movement pattern from time of deployment to February 12. A persistent convergent pattern is apparent at  $29.5^{\circ}\text{N}$ ,  $153.5^{\circ}\text{W}$ . Eventually, six of the nine buoys passed through this region with an average speed of 26-34 km/day. Accordingly, during the first week in February, frontogenesis occurred along the "heel and arch of a sock" whose "toe" is at  $29.2^{\circ}\text{N}$ ,  $152.6^{\circ}\text{W}$ . Fig. 1 can be overlain on the 1500 m relative dynamic topography and surface salinity maps from the CTD survey (see Roden, this report) where the "sock" is quite apparent as a developing feature. Because the buoys appear to follow the salinity meso-scale isopleths, the particle flow through these features is more rapid than is implied by the motions of the salinity or temperature patterns.

The position data from 23 January to 15 April is displayed in Fig. 2. For the first two months the buoys, on average, moved eastward. Subsequent reports indicate that this trend halted and between 1 May-2 July the buoys moved westward. The buoy hulls, or the current at 20 m, apparently respond to the onset of the north-east trades. The center of buoy mass was clustered at  $153.8^{\circ}\text{W}$  upon release, and 114 days later, (May 19) it is at  $151.6^{\circ}\text{W}$ , with a large variance. By July 2, the center of mass had returned to the original position. It is notable, however, that the buoys which were initially in  $19^{\circ}\text{C}$  water south of the front have drifted to the south from  $29.5^{\circ}\text{N}$  to  $25.6^{\circ}\text{N}$ . Those initially in  $18^{\circ}\text{C}$ , or colder water, were deployed at mean latitude of  $30.7^{\circ}\text{N}$ . It appears that along the southern side of the subtropical front there is an upwelling or divergent pattern of flow and a presumably downwelling or convergent pattern on the northern side. In such a flow buoys would not easily cross the convergent area.

We computed the daily average position of each buoy and, from the difference in daily average movements, a velocity. Table I gives the preliminary statistics of this computation, grouped accordingly to the initial distribution of the buoys. The 20 m level eddy energy, or the daily average velocity variance is about two orders of magnitude larger than the eddy energy reported in this area from near-bottom current measurements (Bruce Taft, personal communication).

Plans are to carry out a statistical description of the upper ocean meso-scale structure and wind response based on the buoy motion in the fronts area. The drifters are meandering above the mountain range of the Murray fracture zone, so particular attention will be given to the behavior of buoy tracks in relationship to bottom topography.

TABLE 1. Drifter Statistics

	<u>Eastward component</u> mean cm/sec	<u>variance</u> cm <sup>2</sup> /sec <sup>2</sup>	<u>Northward component</u> mean cm/sec	<u>variance</u> cm <sup>2</sup> /sec <sup>2</sup>	<u>Bucket temperature</u> mean °C
Warm water buoys	5.7	236	-4.0	180	19.5°
Cold water buoys	4.0	142	0.0	160	17.9°

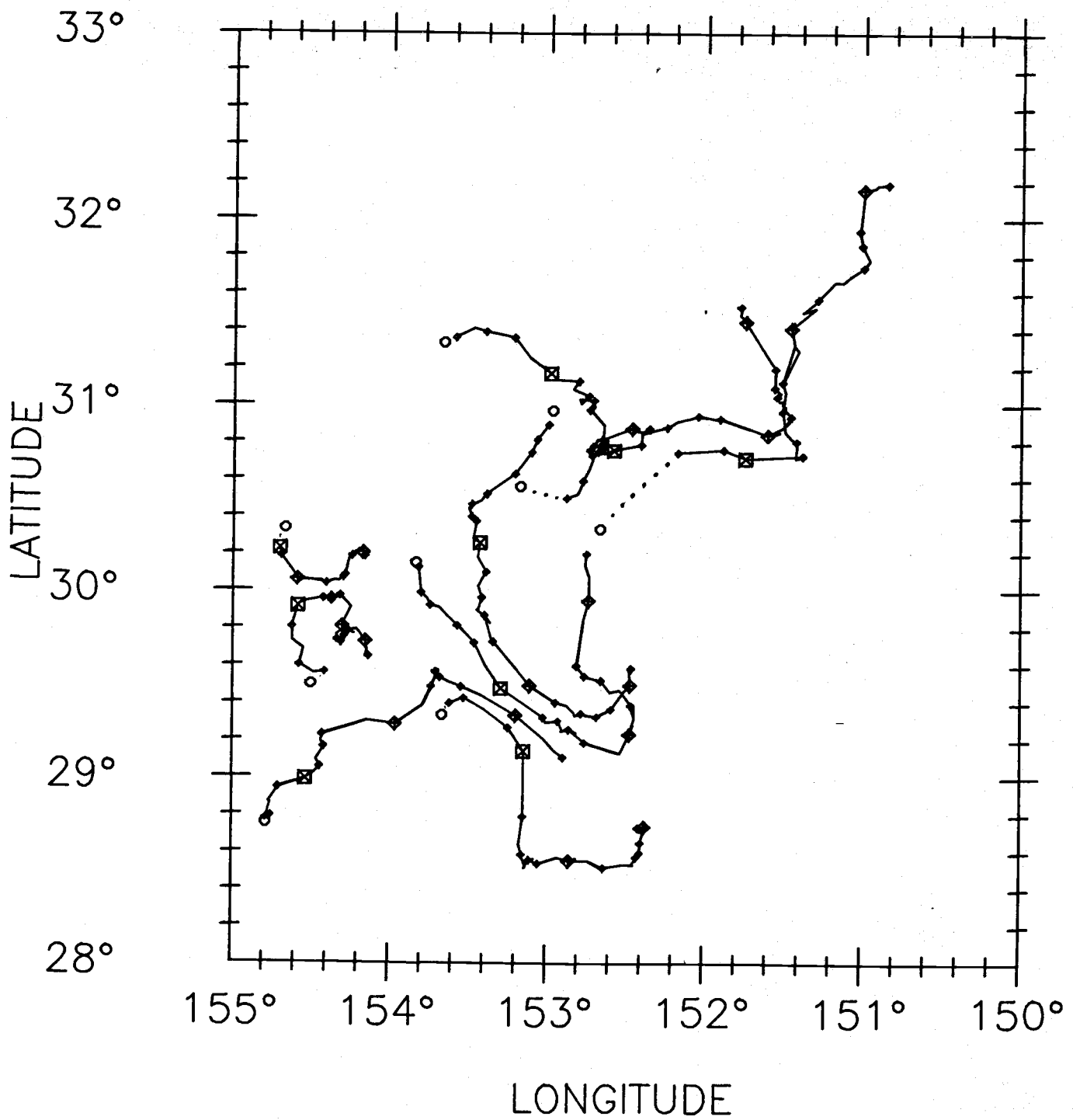


Figure 1. Polar Research Satellite drifter tracks during FRONTS, Jan. 23-Feb. 12, 1980.  
○ - deployment position, ☒ - 1 February 1980,  
◆ - daily average position, .... no reports.



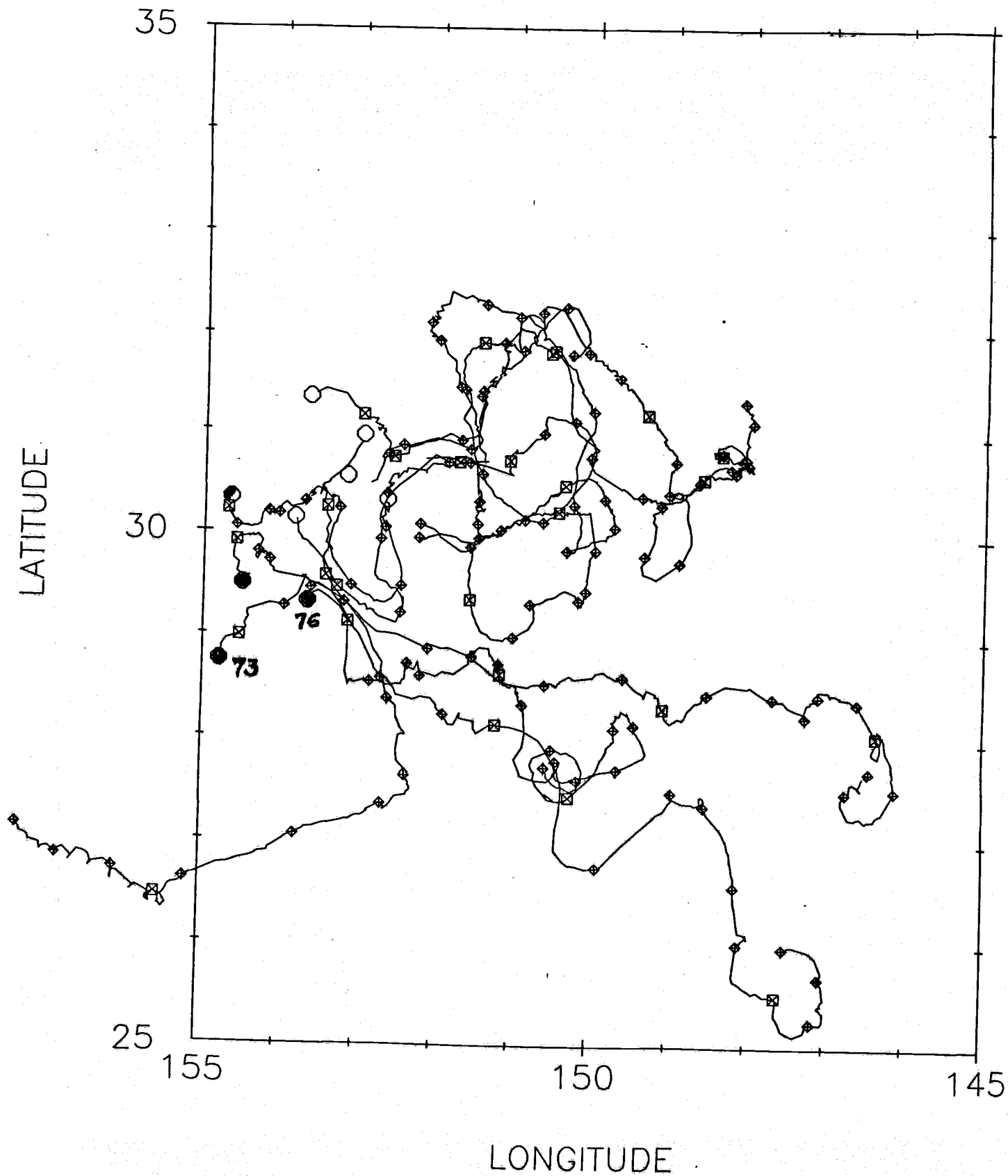


Figure 2. Polar Research Satellite drifters tracks, Jan. 23-Apr. 17, 1980.  
 ●-deployment position of warm water buoys,  
 ○-deployment position of cold water buoys,  
 ◇-every 5th day, ◻ every 30th day, beginning 1 February 1980.

## Surface Atmospheric and Oceanic Variables

by

Christopher N. K. Mooers

Naval Postgraduate School

Time series of semidaily surface atmospheric pressure (Fig. 1), wind speed (Fig. 2) and direction (Fig. 3), air (Fig. 4) and sea (Fig. 5) temperatures at three positions [26°N, 153°W (dash-dot curves); 30°N, 153°W (dashed curves); and 35°N, 153°W (solid curves)] are examined for the period of 1 December 1979 to 29 February 1980. (The first data point is 0000 GMT 1 Dec 79, the last at 1200 GMT 29 Feb 80.) Due to a few missing values, there are breaks in the data curves. These time series have been obtained from standard analyses performed and archived at Fleet Numerical Oceanography Center (FNOC); they are part of a larger data base at NPS especially extracted and archived for FRONTS. The latter data base covers the same time period but a larger spatial domain: 26 to 36°N, 148 to 158°W, and it includes additional variables; such as, subsurface temperature at various levels and cloud cover and other standard meteorological elements. The atmospheric variables will be used to construct a grided atmospheric forcing function data set, and these, together with the oceanic variables, will be used in a diagnostic model for FRONTS.

Some very preliminary and qualitative remarks are made regarding these surface variables. The surface atmospheric pressure (Fig. 1) dropped about 10 mb at each position over the time domain, while generally maintaining a differential of 2-to-5 mb between 26 and 35°N. From 5 to 11 January 1980, there was a ca. 30 mb drop at all stations. The surface wind speed (Fig. 2) varied from nearly calm to greater than 50 kts at the northernmost station on 29 December 1979. The wind direction (Fig. 3) was generally from the southwest to northwest and without much differential except during the passage of synoptic scale disturbances. The surface air temperature (Fig. 4) dropped about 4-to-5°C at each position over the time domain, while essentially maintaining a ca. 6°C differential between 26 and 35°N. A 7°C cooling occurred ca. 10 February 1980. The sea surface temperature (Fig. 5) dropped about 3-to-4°C at each position over the time domain, while essentially maintaining a ca. 6°C differential between 26 and 35°N. Overall, the predominant time scales of variability in all variables seemed to be 10-to-15 days and several days, consistent with expected values for mid-latitude synoptic scale disturbances. (Surface air temperature also had a diurnal component.)

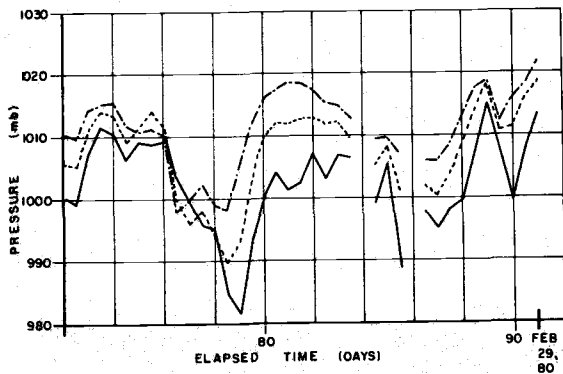
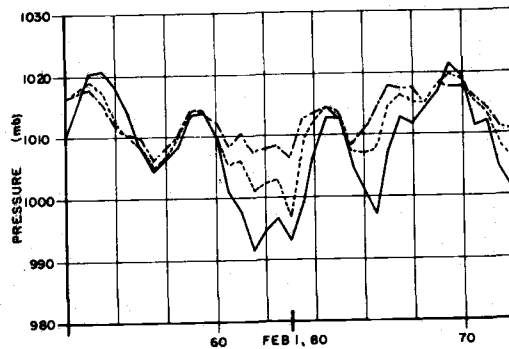
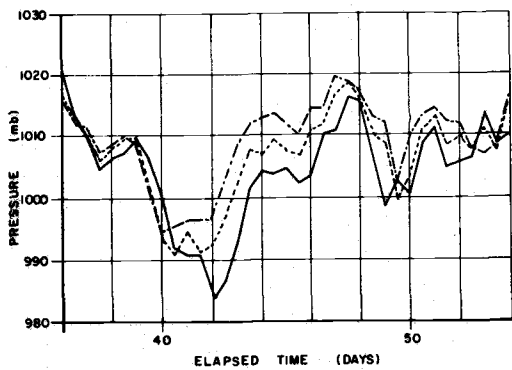
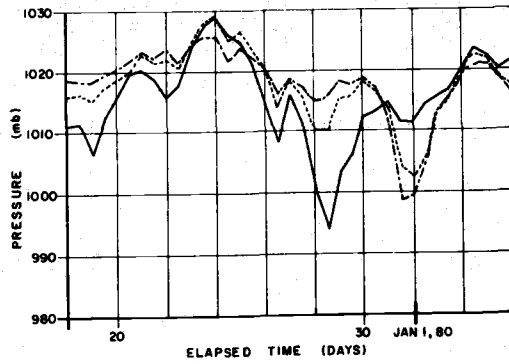
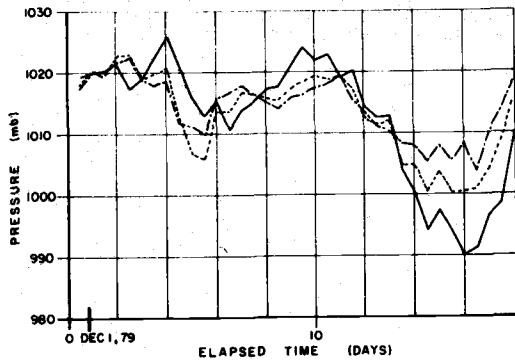


Figure 1. Sea surface pressure (mb).

- 35N, 153W
- - - 30N, 153W
- . - . 26N, 153W

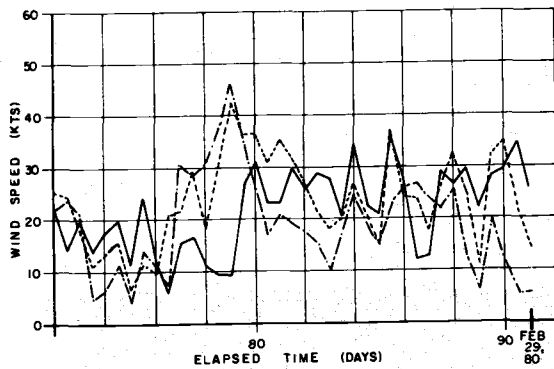
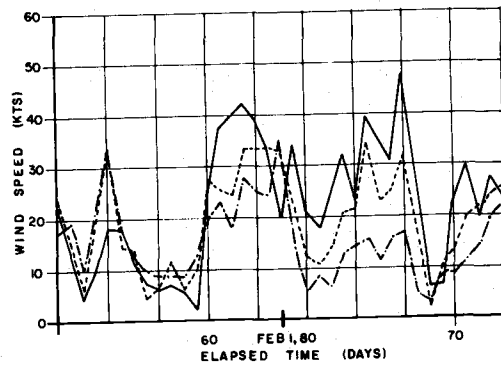
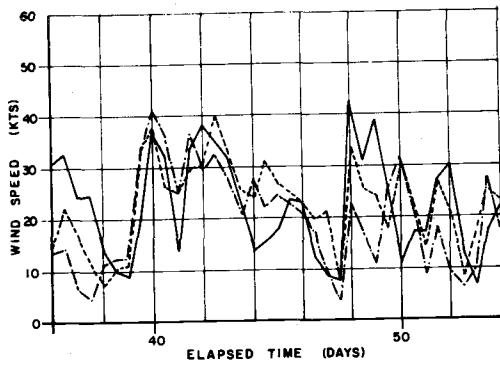
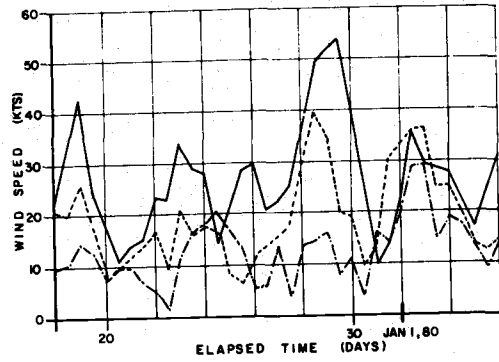
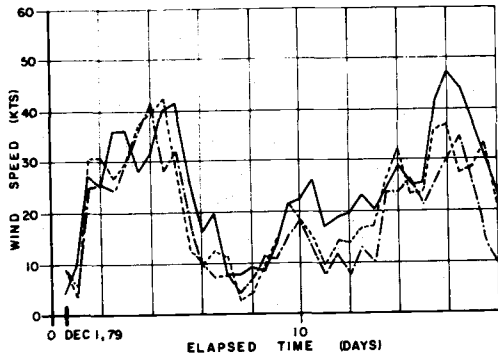


Figure 2. Sea surface wind speed (knots).

- 35N, 153W
- - - 30N, 153W
- . - . 26N, 153W

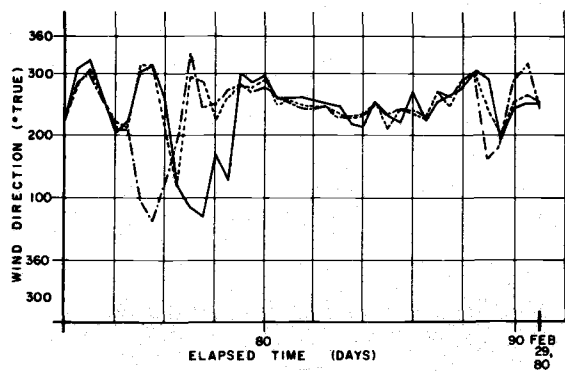
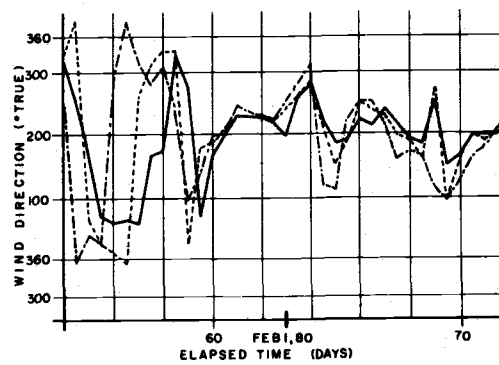
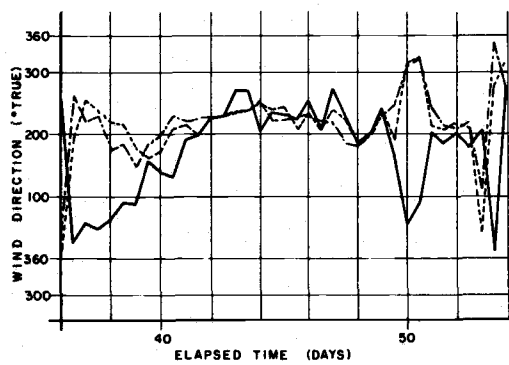
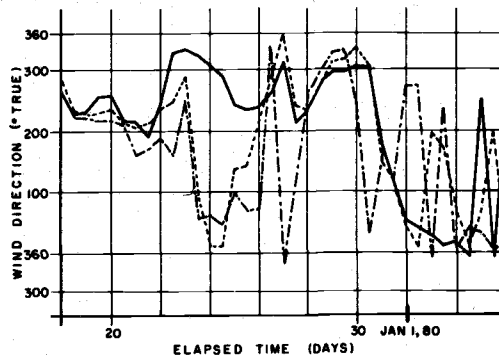
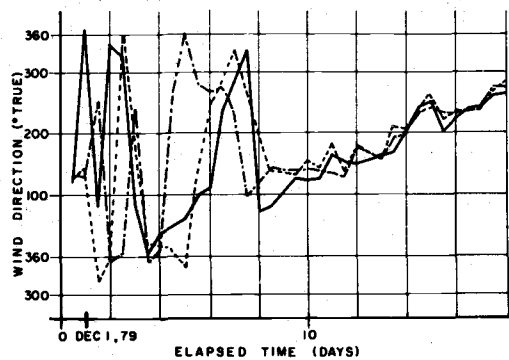


Figure 3. Sea surface wind direction.  
(direction from which the wind blow in degrees from N)

- 35N, 153W
- - - 30N, 153W
- · - 26N, 153W

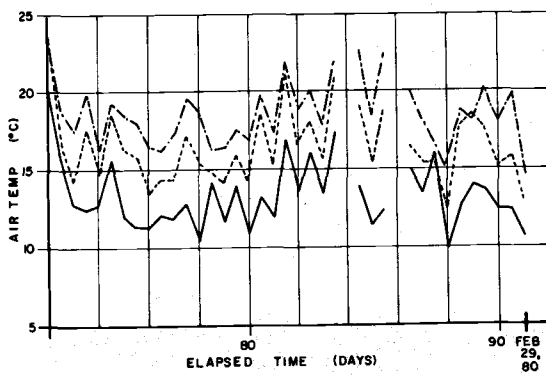
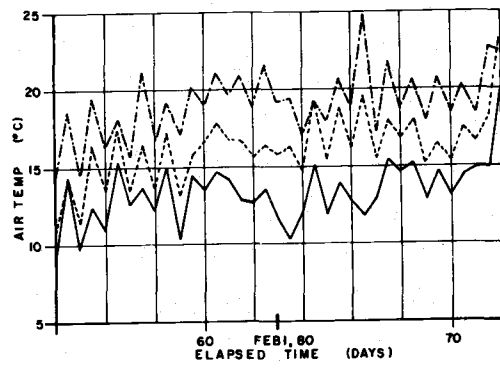
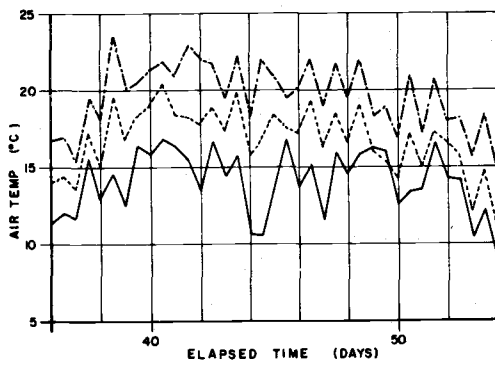
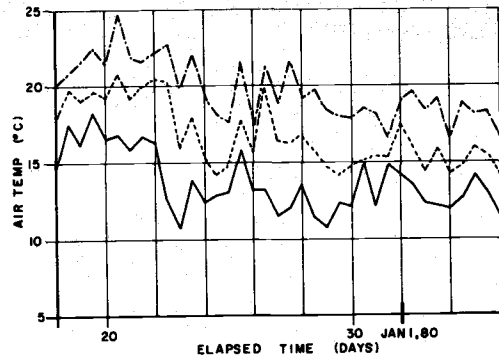
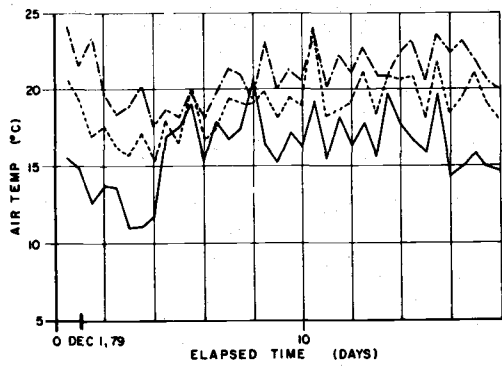


Figure 4. Sea surface air temperature (°C).

- 35N, 153W
- - - 30N, 153W
- · - · 26N, 153W

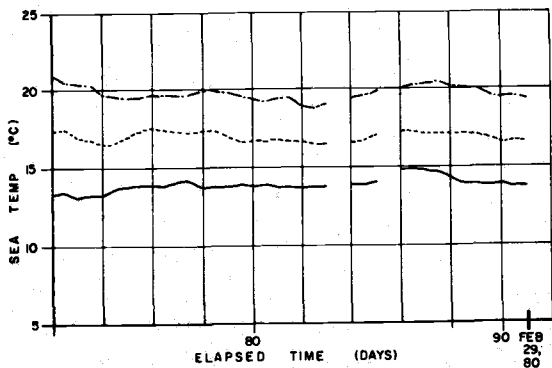
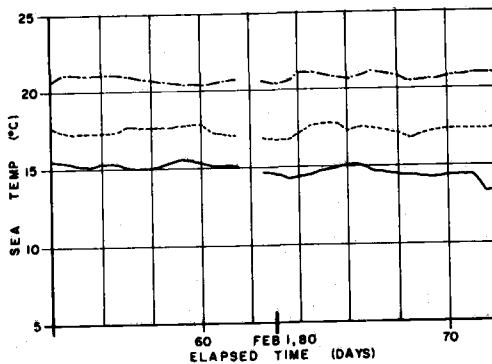
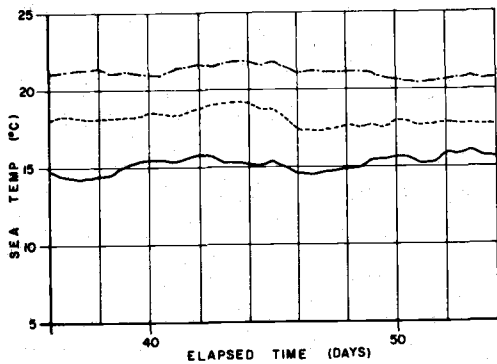
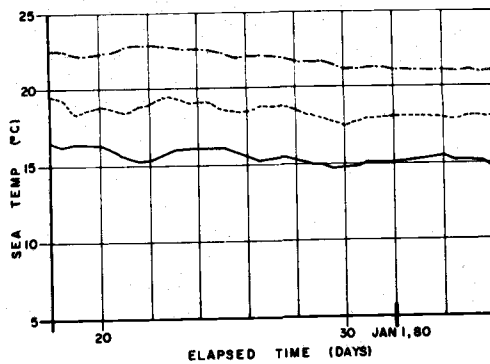
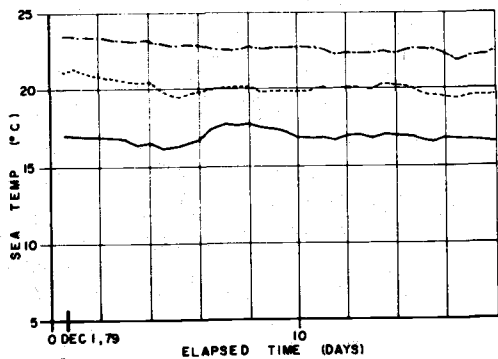


Figure 5. Sea surface temperature (°C).

- 35N, 153W
- - - 30N, 153W
- · - 26N, 153W

## Shipboard Meteorological Observations

by

Stanley P. Hayes, C. A. Paulson and Gunnar Roden

Shipboard meteorological observations during FRONTS were taken aboard the NOAA Ship OCEANOGRAPHER and the R/V THOMAS WASHINGTON. Observations were taken at one-hour intervals aboard the OCEANOGRAPHER and at three-hour intervals aboard the THOMAS WASHINGTON. Time series of positions of the OCEANOGRAPHER (hourly) and THOMAS WASHINGTON (3/day) are shown in Figs. 1 and 6, respectively.

Measurements made aboard the OCEANOGRAPHER included fractional cloud cover, barometric pressure, wind speed and direction, dry and wet bulb temperature and sea surface temperature. Wind speed and direction were from an anemometer and vane located on the ship's mast 34.4 m above mean sea level. Psychrometric observations were taken 12.5 m above mean sea level. Sea surface temperature was from a thermometer in a sea chest above 5 m below mean sea level. Incoming solar radiation was measured by use of a pyranometer mounted on the jack staff. Daily averages of incoming solar radiation are tabulated in Table 1.

Measurements made aboard the THOMAS WASHINGTON included fractional cloud cover, barometric pressure, wind speed and direction, and dry and wet bulb temperature. Wind speed and direction were estimated from the sea state. The psychrometric observations were taken 7 to 10 m above mean sea level.

Fluxes of momentum, sensible heat and latent heat have been estimated from the measurements and are shown in Figs. 10 and following. The drag coefficient used to estimate stress is that recommended by Large and Pond (1980):

$$C_{DN10} = 1.2 \times 10^{-3}, U_{10} < 11 \text{ m/s}$$

$$= (0.49 + 0.065 U_{10}) \times 10^{-3}, U_{10} \geq 11 \text{ m/s}$$

where  $C_{DN10}$  is the drag coefficient for observations at 10 m above mean sea level under conditions of neutral stability. The observations from the THOMAS WASHINGTON were assumed to be at a height of 10 m above mean sea level. The coefficient was corrected for the height of observation aboard the OCEANOGRAPHER following the procedure recommended by Large and Pond (1980). No corrections were made for stability. Conditions were unstable on average. Therefore there will be an average bias of about 10% toward smaller values of stress than if corrections had been made. The value of the bulk exchange coefficient used for estimating sensible and latent heat fluxes was  $C_{TN10} = 1.3 \times 10^{-3}$  following the recommendation of Anderson and Smith (1980). The coefficient was corrected for the heights of observations aboard the OCEANOGRAPHER, but no correction was made for stability. Sensible and latent heat fluxes could not be calculated for the THOMAS WASHINGTON because surface temperature was unavailable.



TABLE 1. Daily totals of incoming solar radiation observed from the OCEANOGRAPHER in FRONTS.

<u>Date</u> (Jan '80)	<u>Lat.</u> (deg.)	<u>Long.</u> (deg.)	<u>Q<sub>s</sub></u> (ly/day)	<u>Cloud</u> <u>Amt.</u> (eighths)	<u>Cloud</u> <u>Type</u>	<u>Remarks</u>
12	41.8-43.6	137.3-139.6	129	7	Cu,Sc	
13	37.8-39.7	143.1-145.6	217	6	Cu,Sc	
14						
15						
16	32.0-32.7	151.2-151.0	254	6.5	Cu,Ci	
17			153			
18	29.0-30.6	154.7-155.1	171	7	Cu,Ac	
19	30.3-30.8	153.6-155.1	321	6	Cu	
20	30.3-30.4	153.2-153.6	94	8	Sc	rain, 1/2 day
21	30.3-30.4	153.5-153.9	311	6	Cu	
22						
23	30.9-31.0	152.9-153.0	329	5.5	Cu,Ac	
24	30.3-30.6	153.2-153.6	271	5.5	Cu,Sc	
25	30.0-30.3	153.6-154.0	276	6.5	Cu,Sc	
26	29.0-30.0	154.0-154.1	131	8	Sc	rain, 1/2 day
27	28.3-29.7	154.4-155.0	347	6	Cu,Sc	
28			345			
29			421			

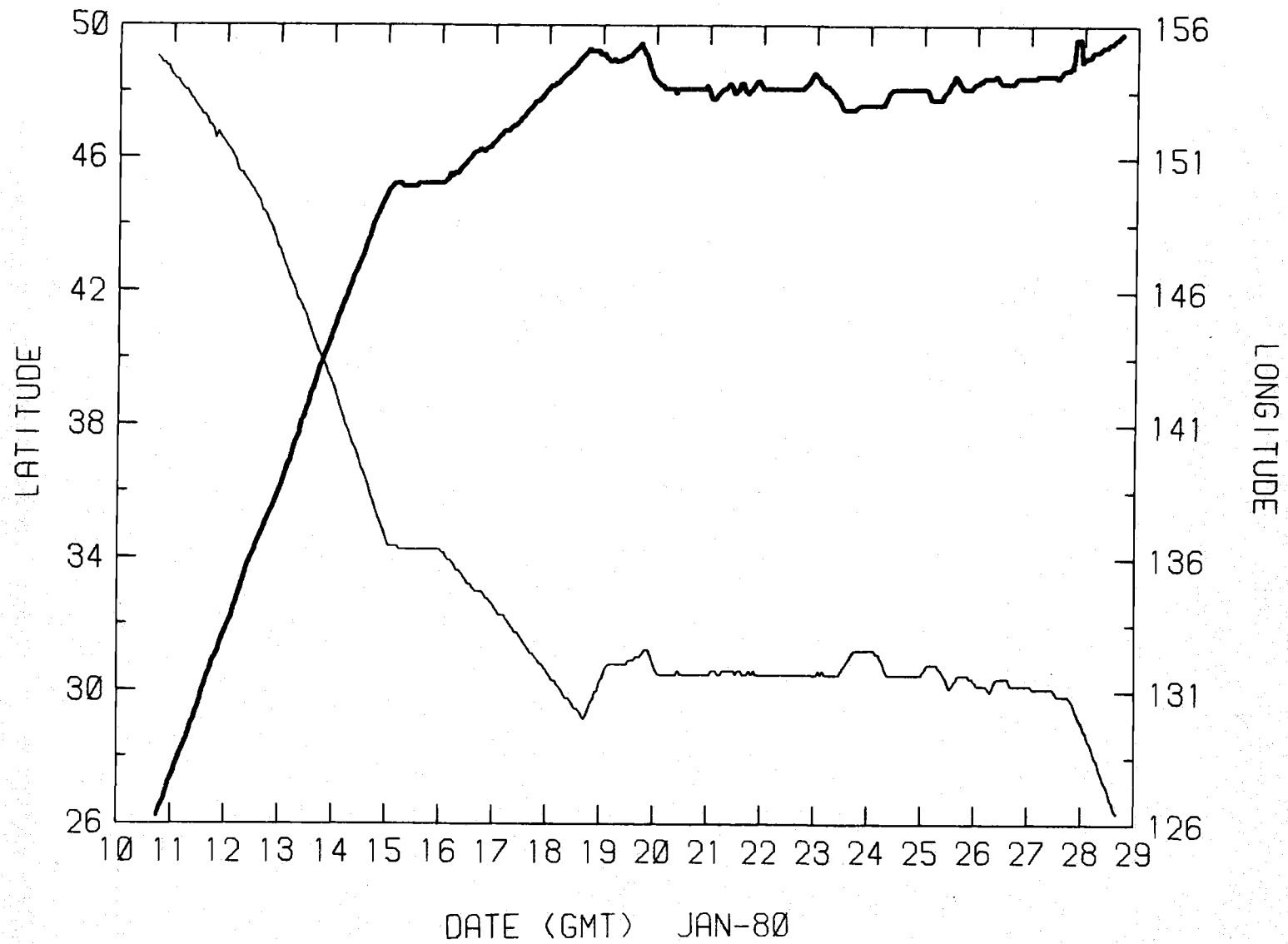


Figure 1. Hourly positions of the NOAA Ship OCEANOGRAPHER during FRONTS-80. The thin line is latitude and the thick line is longitude.

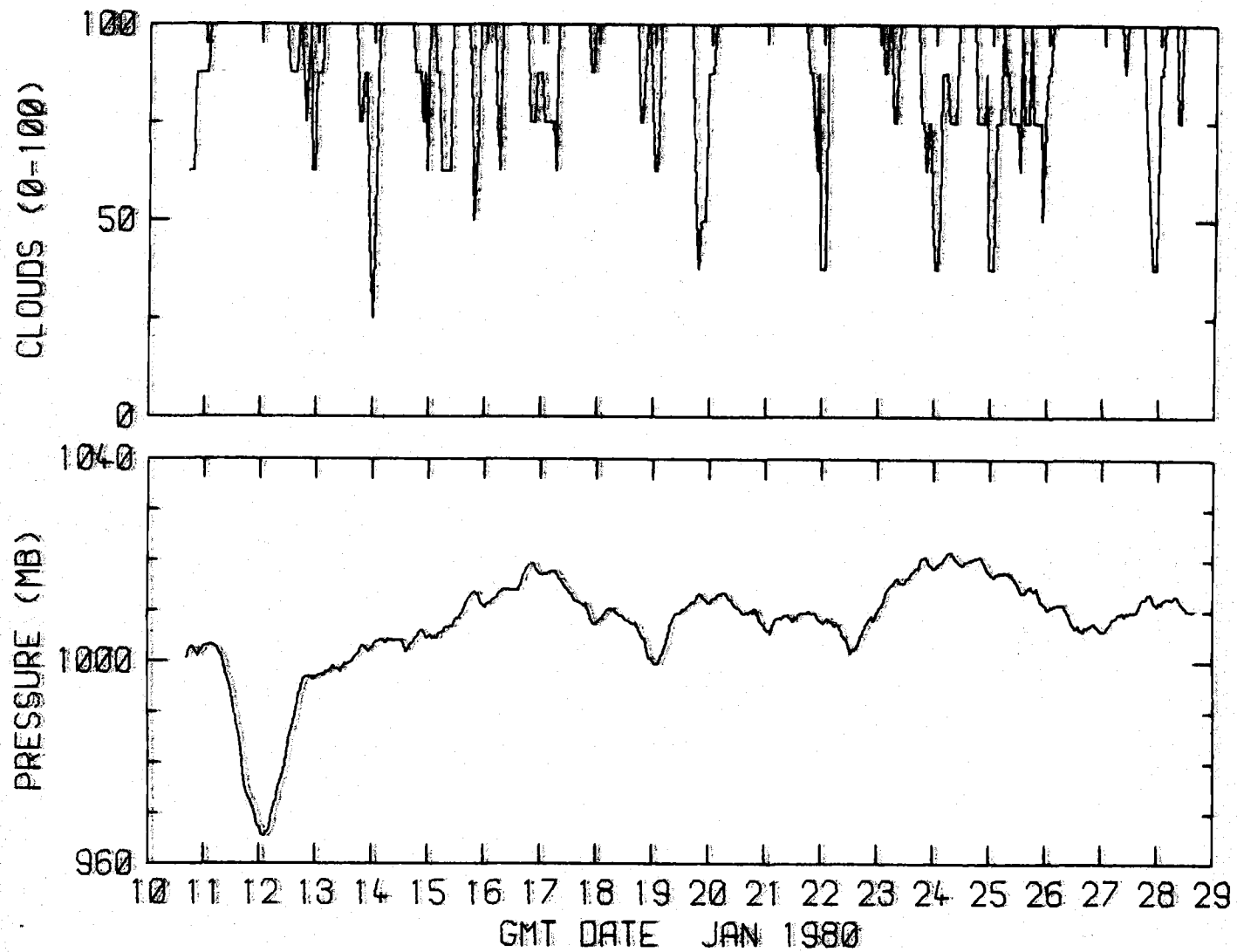


Figure 2. Observations from the NOAA Ship OCEANOGRAPHER of the amount of cloud and sea level pressure.

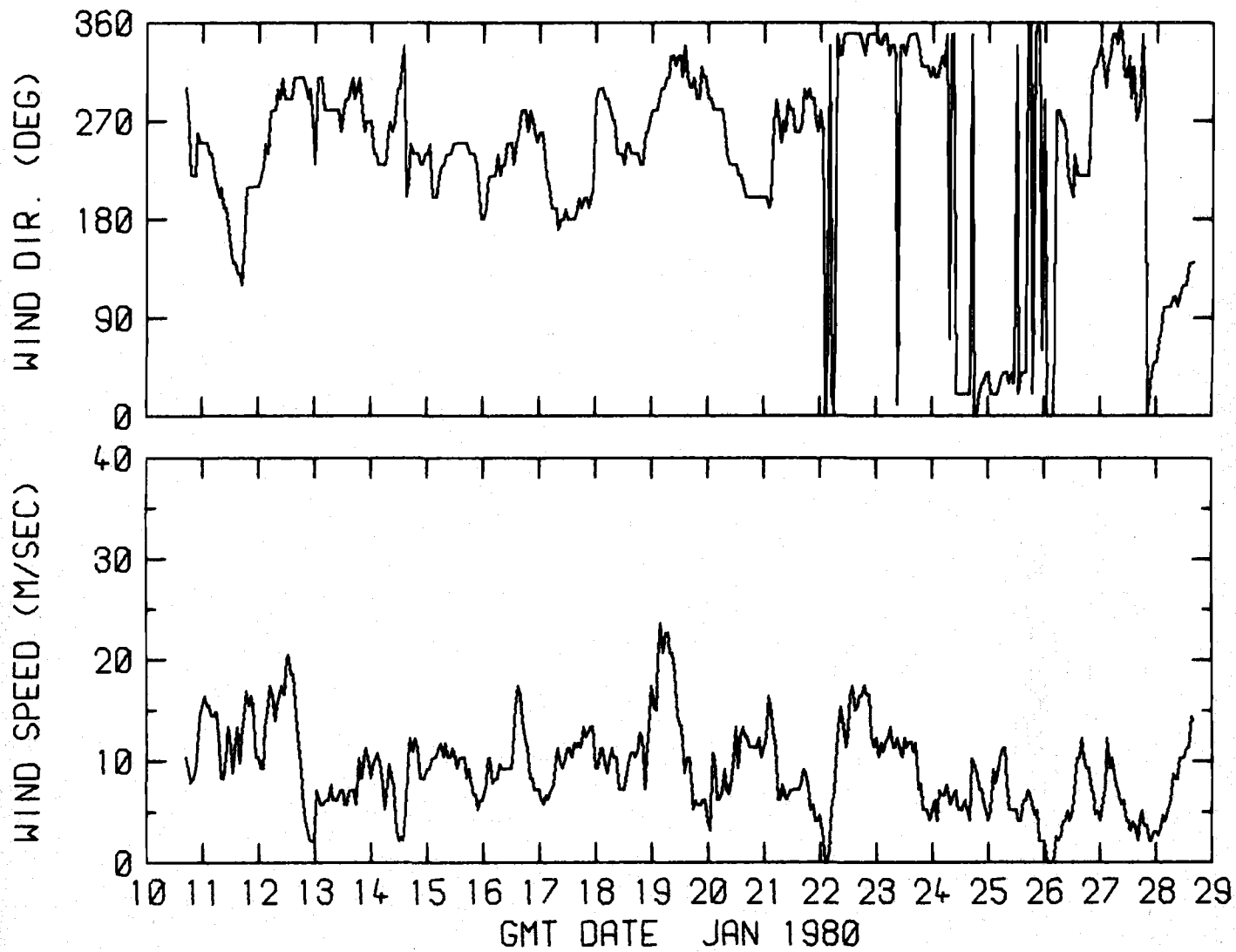


Figure 3. Observations from the NOAA Ship OCEANOGRAPHER of wind direction and speed.

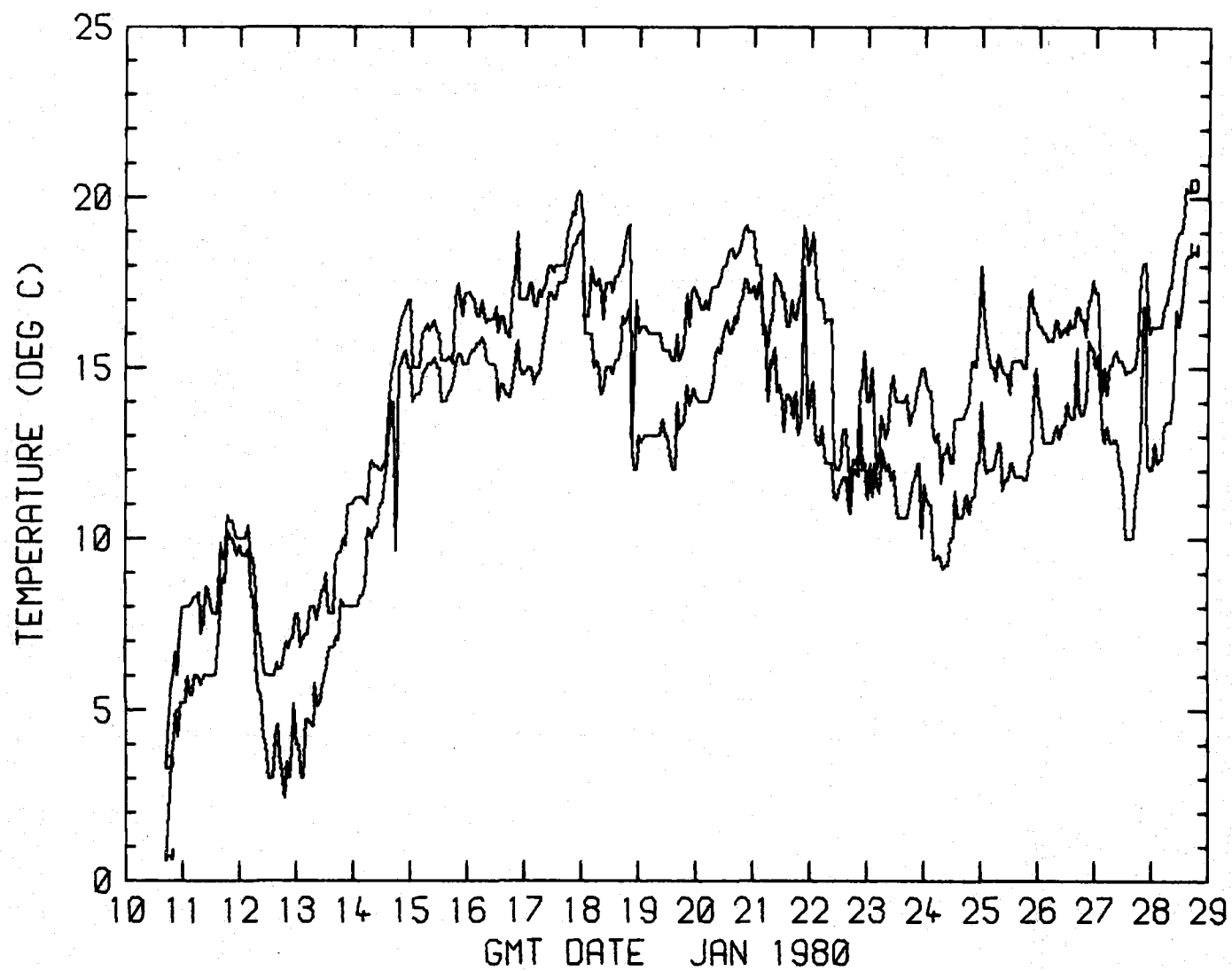


Figure 4. Observations from the NOAA Ship OCEANOGRAPHER of dry bulb and wet bulb temperature.

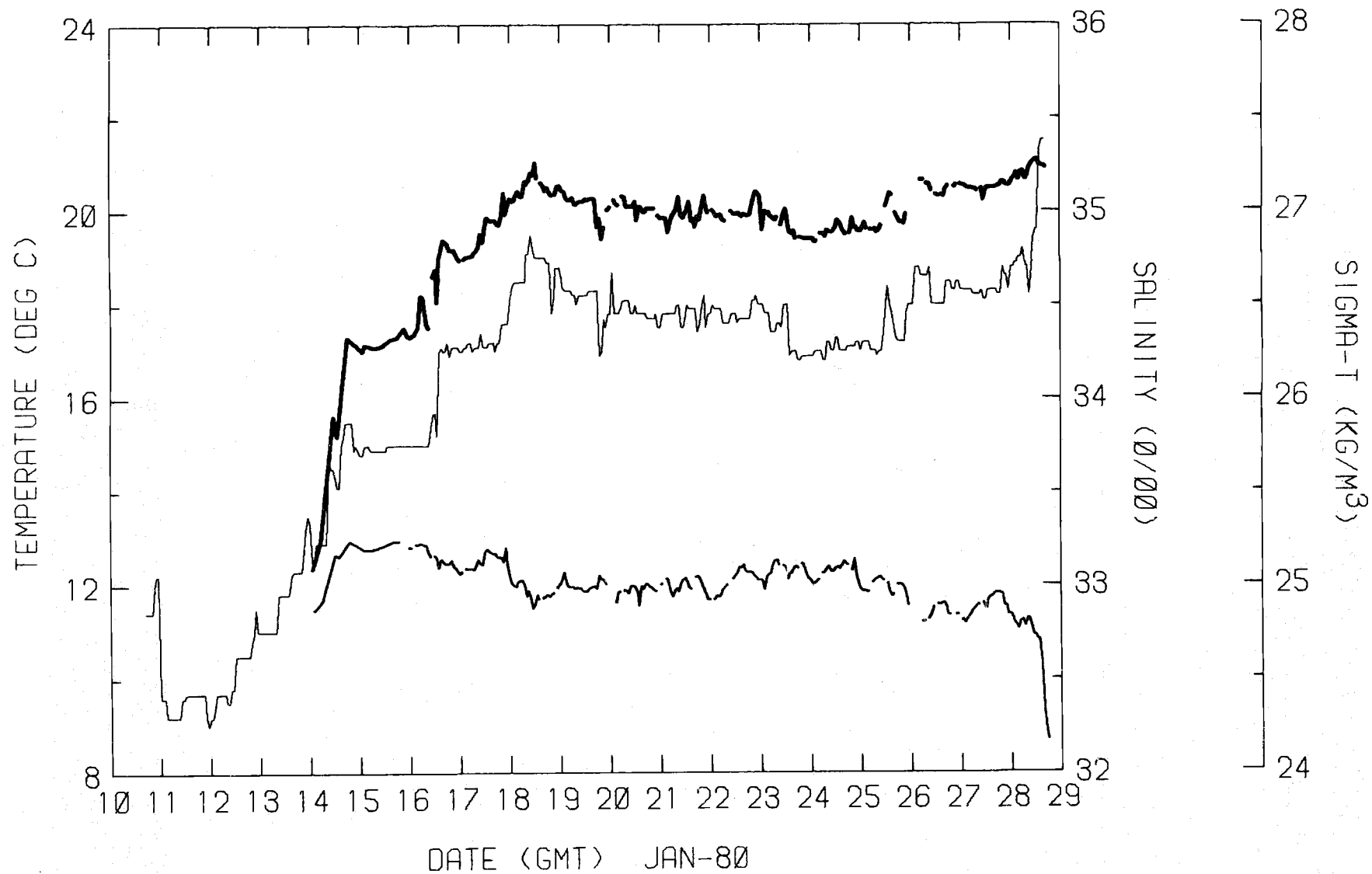


Figure 5. Observations from the NOAA Ship OCEANOGRAPHER of sea surface (intake) temperature (thin line), salinity (thick line) and density anomaly (medium line).

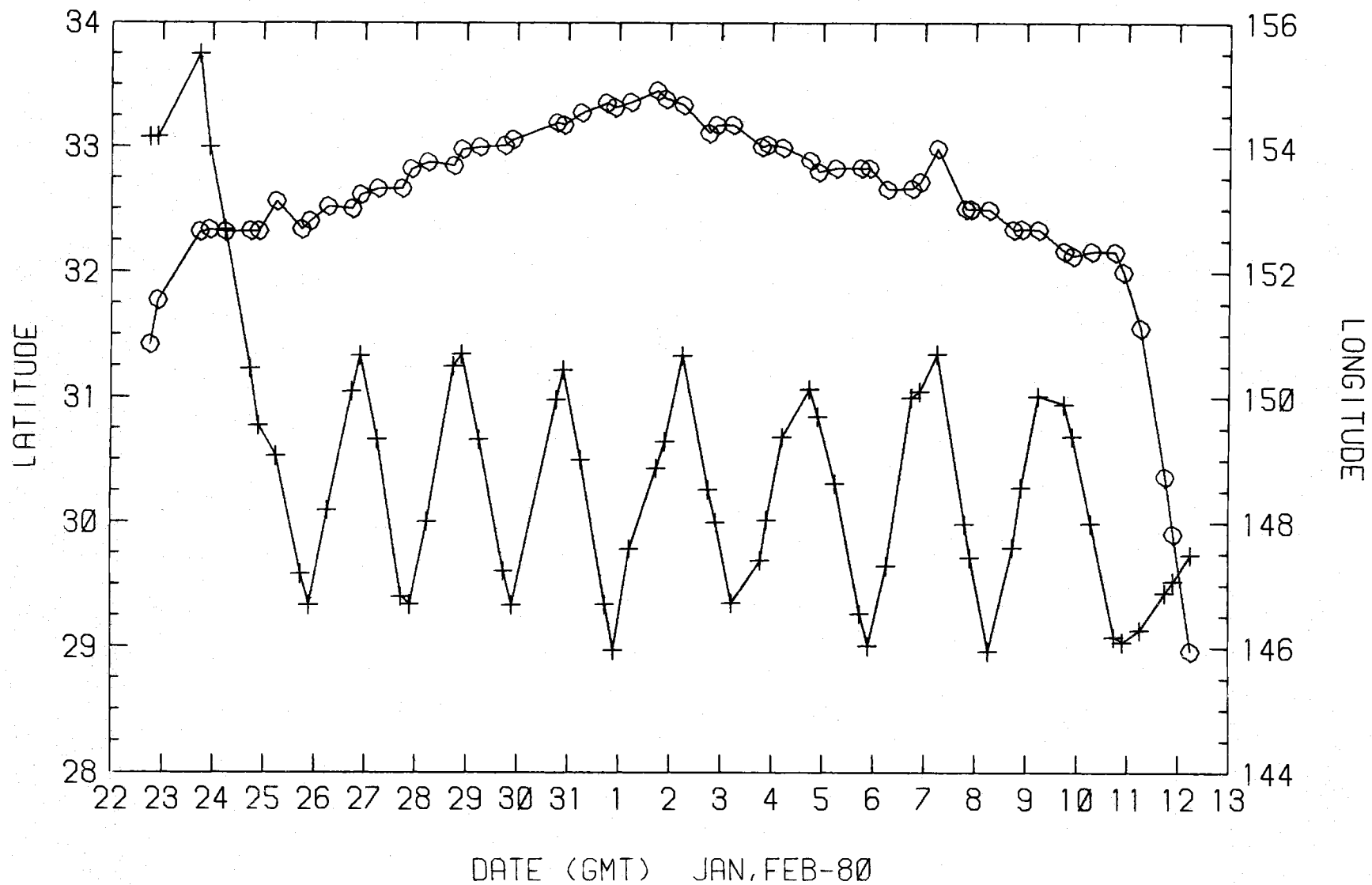


Figure 6. Positions of the R/V THOMAS WASHINGTON during FRONTS-80. The + and 0 represent latitude and longitude respectively.

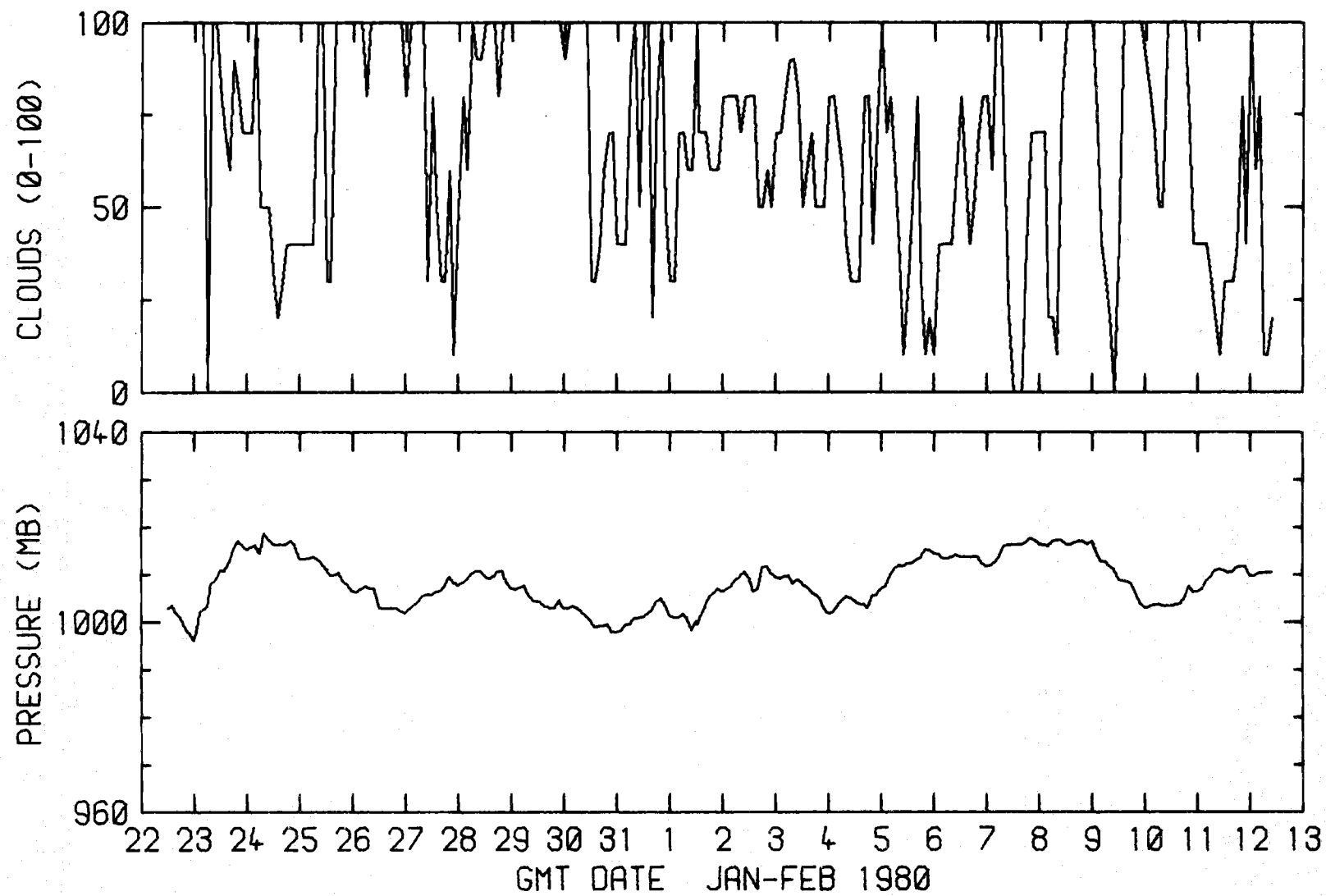


Figure 7. Observations from the R/V THOMAS WASHINGTON of the amount of cloud and sea level pressure.



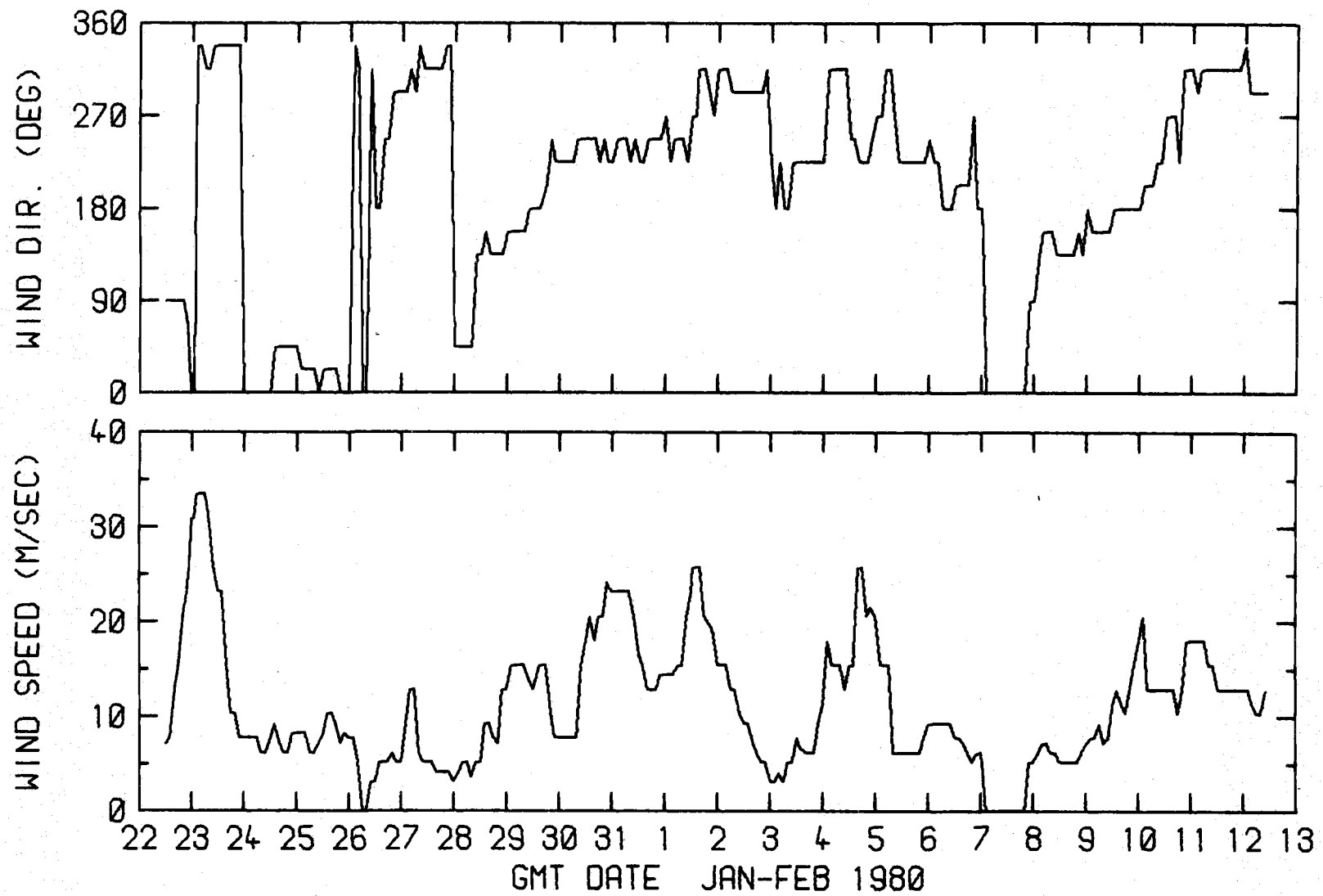


Figure 8. Observations from the R/V THOMAS WASHINGTON of wind direction and speed.

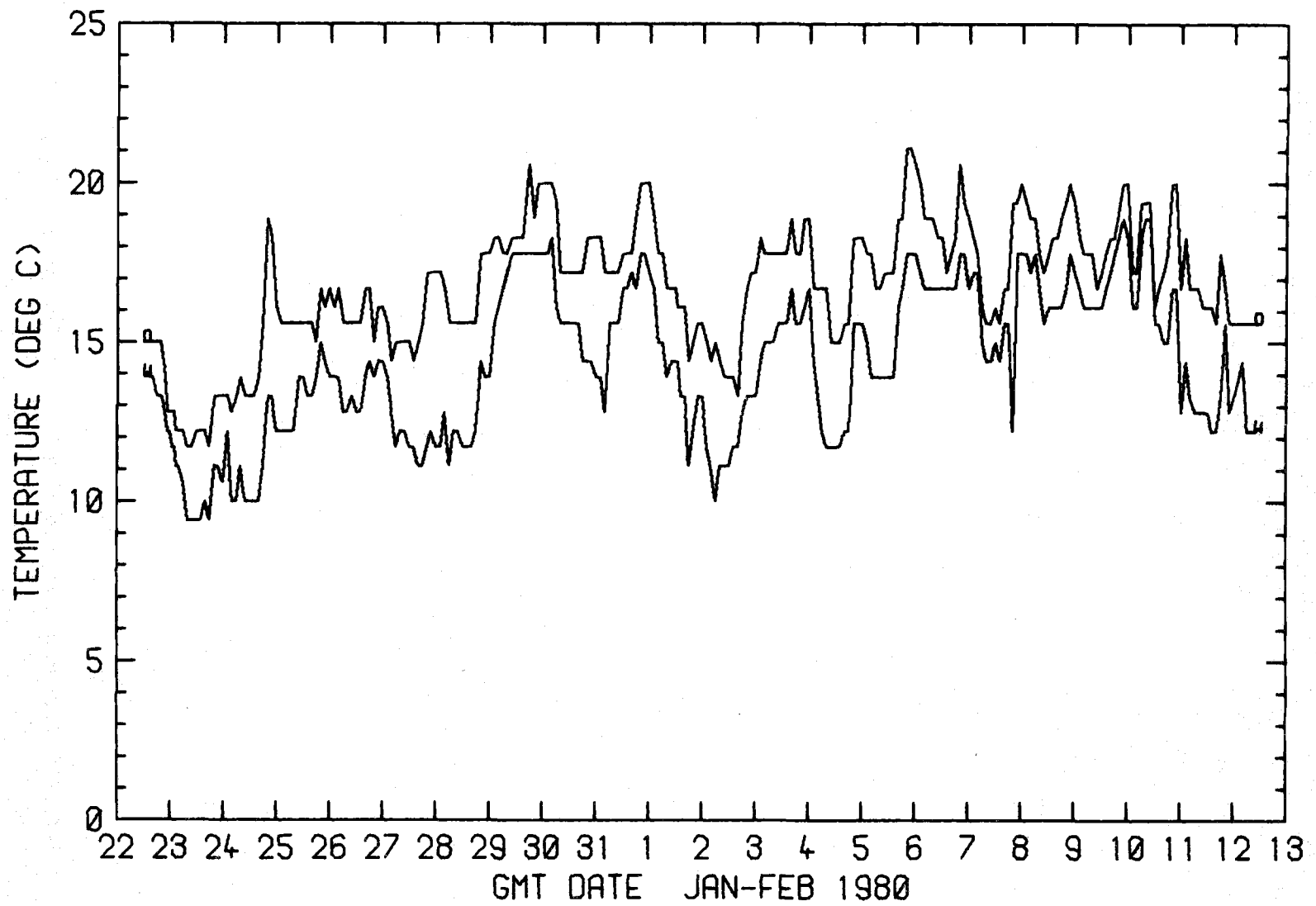


Figure 9. Observations from the R/V THOMAS WASHINGTON of dry bulb and wet bulb temperature.

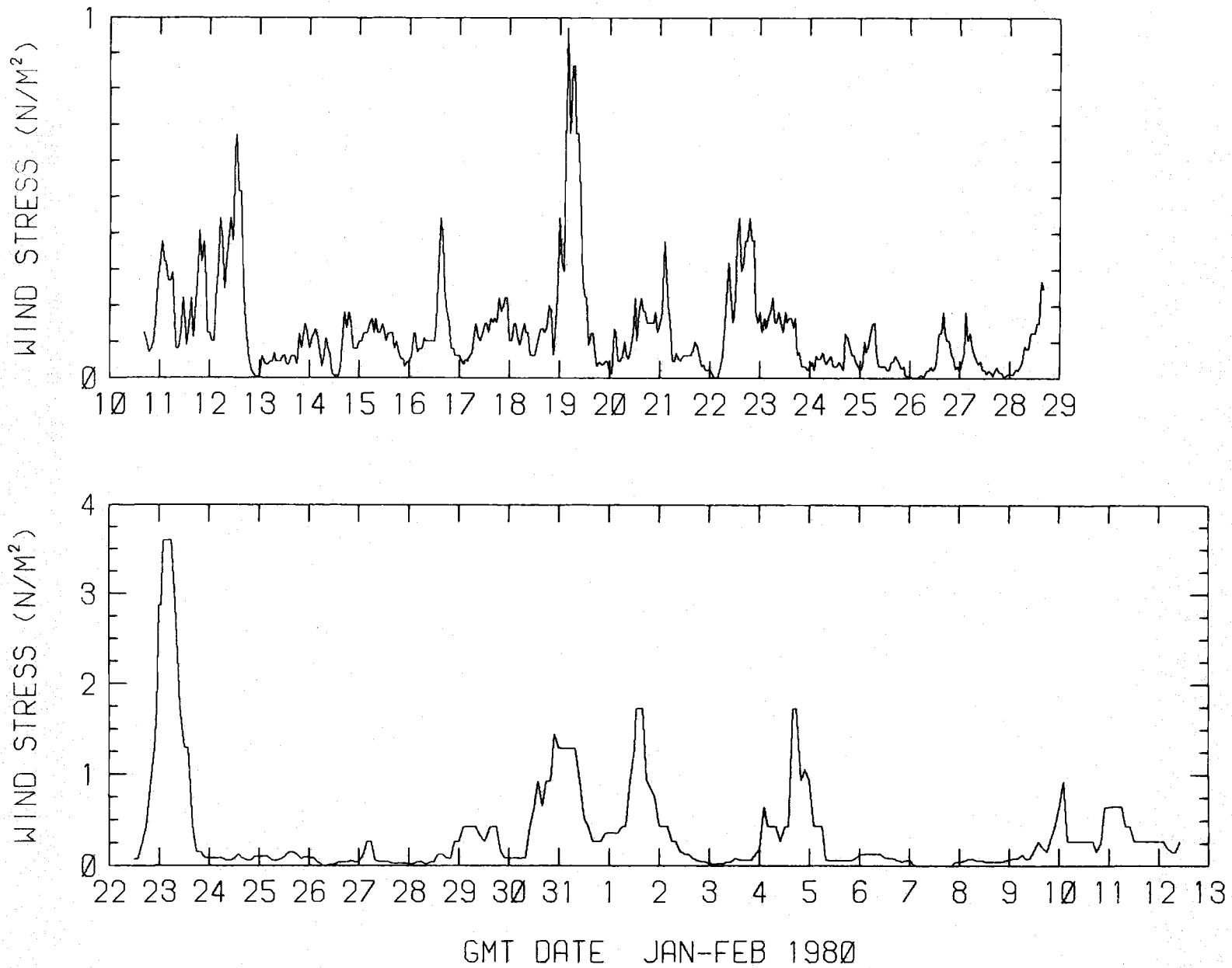


Figure 10. Wind stress estimated from observations aboard the NOAA Ship OCEANOGRAPHER (upper) and the R/V THOMAS WASHINGTON (lower).

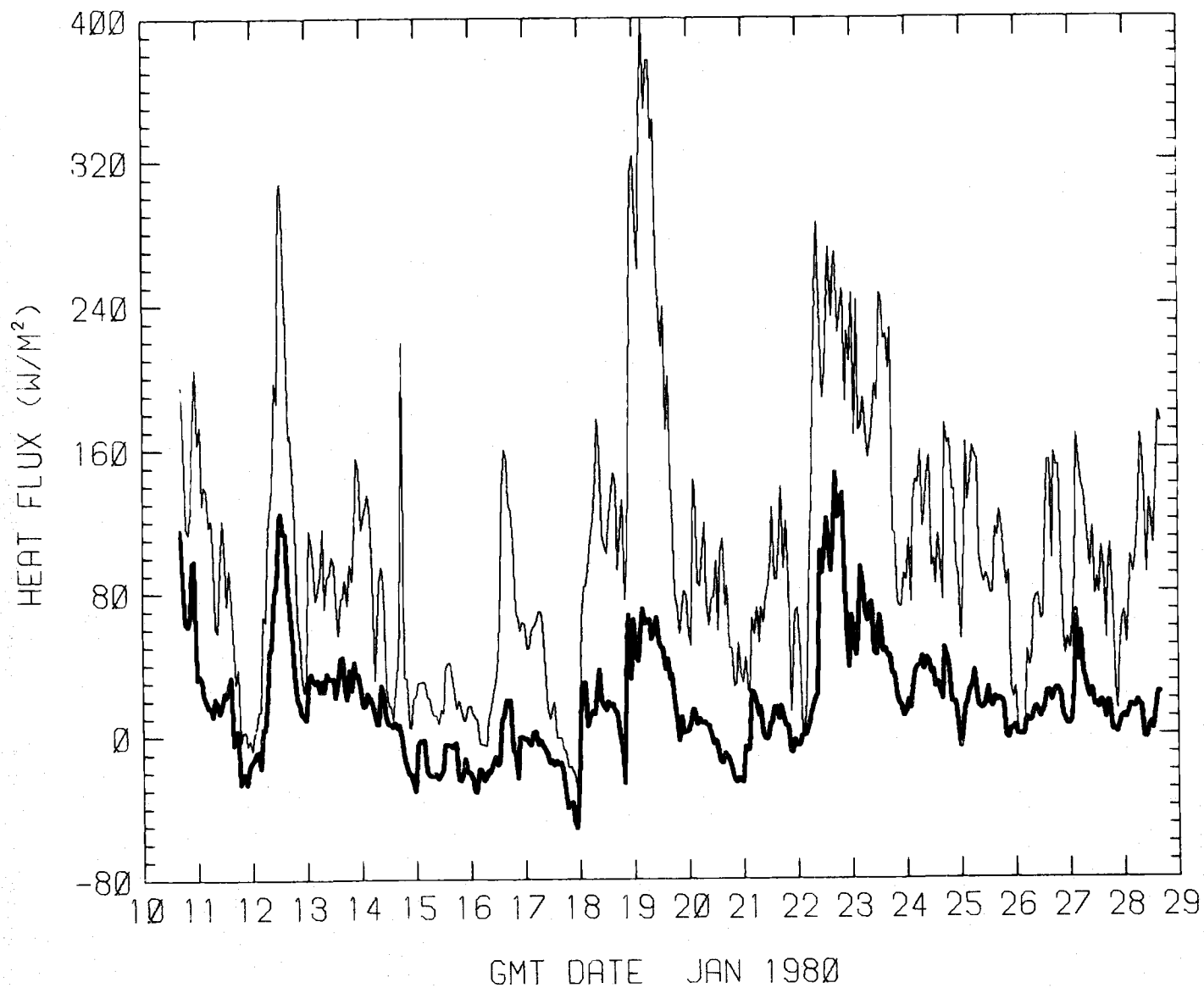


Figure 11. Estimates of fluxes of sensible (thick line) and latent (thin line) heat from observations aboard the NOAA Ship OCEANOGRAPHER.

## Doppler-Acoustic Velocity Profiles

by

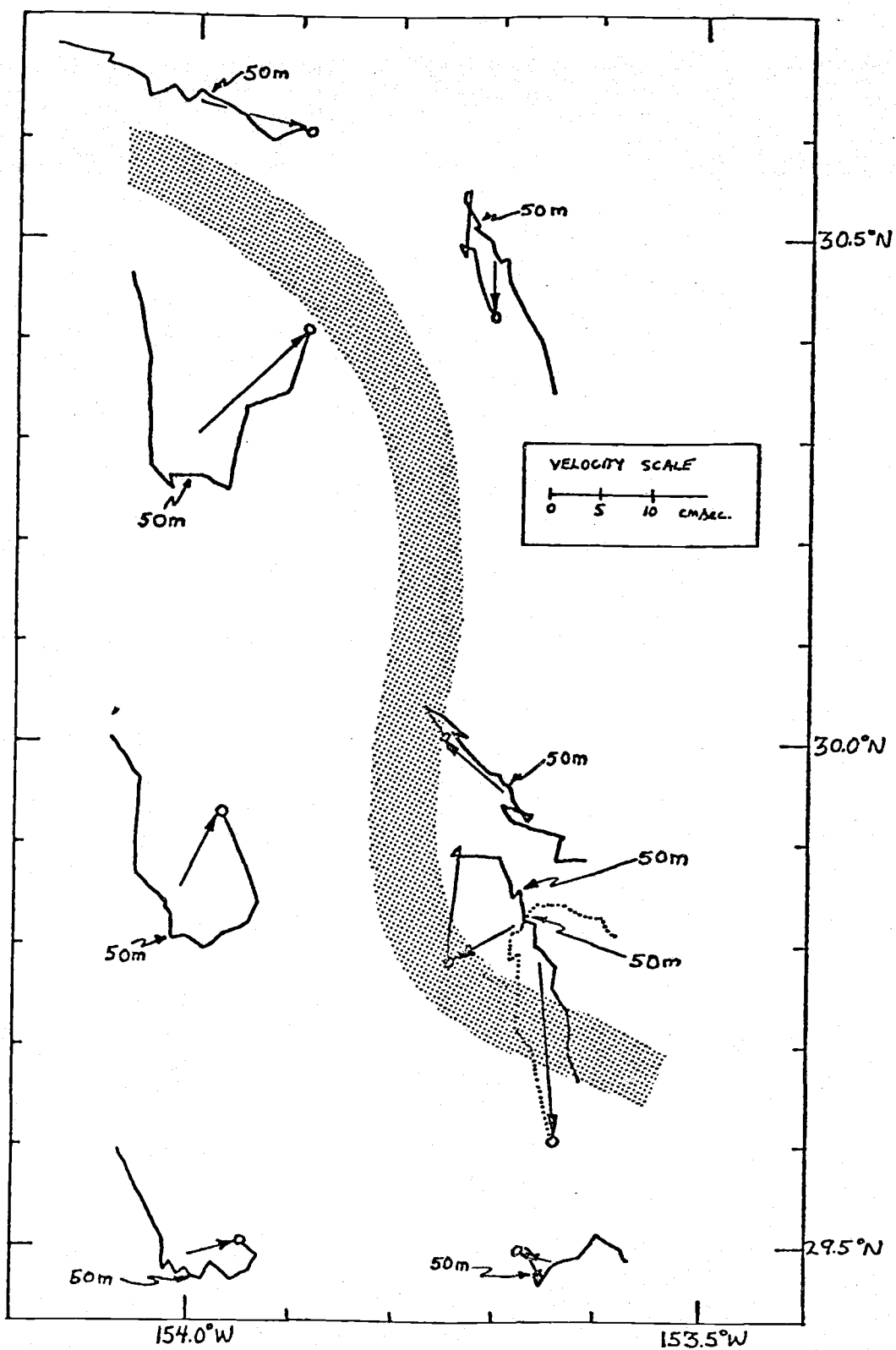
Lloyd Regier and Russ Davis

Scripps Institution of Oceanography

A Doppler-acoustic profiling current meter was employed on R/V THOMAS WASHINGTON to measure vertical profiles of horizontal currents throughout the FRONTS Experiment. This instrument transmits a short pulse of 300 kHz sound along four acoustic beams and measures the Doppler shift of energy reflected from zooplankton drifting in the water, thereby allowing the determination of the relative velocity (vector) between the ship and the water at 6.5 m intervals to a depth of 200 meters. The acoustic transducer is fixed to the hull, therefore measurement of the ship's heading is required to rotate the relative velocity profile to geographic components; if the ship's velocity over the earth is known (from the distance traveled between sequential fixes) the profile of absolute currents may be computed.

Data were taken continuously throughout operations in the FRONTS region and on both steaming legs to and from San Diego. The acoustic log functioned well throughout, consistently yielding profiles to 120 m even in high seas. The ship's gyro was quite erratic, failing frequently at unknown times; we are currently identifying these failures and doing what is possible to edit the data. Satellite fixes were obtained at an average interval of two hours resulting in a resolving distance of 30-50 km for the horizontal structure of absolute currents. We are examining the data for problems and developing algorithms to edit and compact the data. Profiles of vertical shear will be computed at a horizontal interval of perhaps 10 km. Merging of these profiles with the satellite fixes, we will produce maps of absolute current structure in the upper 100 m with a vertical resolution of 6.5 m and a horizontal resolution of 30-50 km. The shear profiles will be examined on much shorter horizontal scales in the region of the front.

A preliminary study of the current structure near a temperature front is shown in the accompanying figure. The velocity shear seen during the period 3-5 February is shown in this figure. The data has been averaged between satellite fixes and thus represent both a time and space average of the currents experienced by the ship. The lines at each station present a plan view of the profile of current relative to the mean velocity from the top to 100 m. For each profile the surface flow relative to the mean is shown by the open circle and by the vector extending from the origin to the circle. The tail of the vector is placed at the coordinates of the ship at the midpoint of the averaging interval. The shaded area is the approximate location of a 1°C jump in the surface temperature as measured by a thermistor in the acoustic transducer. The shear profiles are rather different on opposite sides of the front. The front is apparently marked by a convergence of surface water and must therefore be accompanied by a downward velocity. Note the prevalence over much of the region of a clockwise shear as one descends in the water column. According to the ship log, the ship was experiencing 45 degree rolls at the time of the measurements.



Acoustically measured current shears near a temperature front. See text for explanation.

## Expendable Temperature-Velocity-Pressure (XTVP) Measurements

by

Thomas B. Sanford and Eric Kunze

University of Washington

Objectives. The scientific objectives of our program in FRONTS were:

1. To measure low-frequency and internal-wave shears on velocity profiles as a function of distance from and structure of the front.
2. To obtain a profile time series within the front in order to quantify the temporal structure and statistics of the vertical shear field.
3. To relate the shear field over vertical scales of 10 - 100 m to the finer-scale mixing processes.
4. To provide velocity measurements in support of other measurement programs and joint experiments.

It appears from preliminary analysis that the above operational goals were achieved.

Operations. Aboard the OCEANOGRAPHER on 9 January were 56 of our probes, our deck and launching equipment and Tom Sanford, John Dunlap and Art Bartlett. Twenty-four additional probes did not arrive in time and were delivered to us by Gunnar Roden on the THOMAS WASHINGTON. Bob Drever remained aboard for several hours helping us test and secure equipment, and was sent ashore while we were in Puget Sound.

The launcher was a 16' Lexan tube with one end attached with shock cord to the weather deck rail while the other end dangled outboard and aft supported from above by a line to a pole sticking about 12' out from the upper deck. The outboard end of the Lexan tube had a housing into which the probe and its buoyancy collar fitted and were secured. Once in place, the probe was shut-off by a surrounding ring of permanent magnets. The buoyancy collar was a specially-made pair of cylindrical shells of styrofoam which enveloped the forward end of the probe and was secured with rubber bands held together by a clock mechanism.

The operational procedure was to inset a probe into the hand launcher, a standard Sippican hand launcher, bring the Lexan tube aboard the ship (i.e., swing in the outboard end), place the probe into the inboard end of the tube, release the probe and allow it to slide down to the housing on the outboard end. There, the buoyancy collar and clock release mechanism was installed. The clock was set to go off at a preset time (here about 72 sec, enough time for the ship to get far enough away from the probe). The whole unit, probe and buoyancy was secured in the housing, automatically turning off the probe electronics. The probe could be released, turning on the electronics and clock, at any time. Generally, we tried to launch when the crest of the swell reached the housing.

The launch scheme and hardware performed well in most respects. The first operation was to make three profile sections across the front at  $1/4$  inertial period intervals. The winds were about 30 kn and the sea and swell were 12-15' in height. We experienced no difficulties in launch or probe performance due to weather and sea state. We learned that the beads of water inside the Lexan tube acted as effective brakes or drag on the outgoing XBT wire, preventing it from being wafted out by the wind and thereby causing a premature end to our data as the wire fetched up and broke. The buoyancy collar worked well. The only difficulty we experienced was with the clock mechanisms purchased from EOTEC. They were not reliable. We tested them as much as possible before use but they still failed on launch once every 5-7 times. As a result, we lost about 10 probes simply because they did not release. With an improved timing mechanism, the surface release should be more reliable.

After the three sections (Fig. 1) we obtained a short section oriented N-S just east of our work area. Somewhat farther to the north, we obtained four profiles in conjunction with Rolf Lueck using the velocity microstructure profiler CAMEL from the THOMAS WASHINGTON.

Additional profiles were taken in conjunction with Paulson's thermistor tows, Hayes' TOPS profiles and Caldwell and Dillon's profiles.

Analysis. Preliminary analysis of the 27 usable profiles taken in the FRONTS area has confirmed the essentially inertial nature of the internal wave signature and suggested the presence of a geostrophic flow that increases northward with depth.

A comparison of profile pairs taken at the same position but a half inertial period apart (Fig. 3) shows mirror imaging of the larger-scale, larger-energy features, confirming that the internal waves are inertial. Features on the order of a meter do not show clear mirror imaging, suggesting noninertial frequencies or rapid formation and dissipation. These features may not be internal wave signatures, but may be due to turbulence.

The velocity structure can be seen to change across the front. In the east (Pair 374-397), the largest feature in U is broad and at a depth of 400 m. This feature moves upward in the water column toward the west. At  $153^{\circ}36'W$  (Pair 381-401), the character of the velocity structure changes, as can be seen by the appearance of a feature at 300 m depth in V and a more complicated structure at the same depth in U. This structure across the front was not significantly distorted over the one-day period of investigation.

The mean of the linear fit to the half-inertial period pairs (Figs. 4 and 5) has a uniform slope across the front. This noninertial shear is a first approximation to the geostrophic shear. The flow is seen to increase to the north with depth while there is little east-west shear. The XBT isotherms in the area slope downward to the west which would provide a northward geostrophic shear, provided the temperature gradient isn't compensated by a salinity gradient as is characteristic of the North Pacific subarctic front.

In Fig. 6, the linear fit was removed from the profiles and then they were rotated to a common time. The correlation between the half inertial period pairs is almost exact. In the west, there is an apparent vertical motion downward of the near-surface features.



Polynomial fits were also made to order 2 and 3. Both the quadratic and cubic fits showed a predominantly inertial behavior, confirming the idea that the geostrophic shear is approximately linear.

It is hoped that by adding together and subtracting the profiles of half inertial period pairs, a separation of the geostrophic and internal wave motions can be made.

Table 1. XTVP FRONTS area log.

<u>XTVP</u>	<u>Date</u>	<u>Launch time</u>	<u>Down time</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Comments</u>
371	Jan 20	1925:14	1825:14	30 19.9	153 37.4	fair
LEG 1:						
372	Jan 21	0138:38	0138:38	30 23.81	153 16:31	good to 200 m, then fair
373	Jan 21	0217:22	0217:22	20 23.65	153 20.32	fair to 150 m, then poor
374	Jan 21	0253:34	0254:40	30 23.16	153 23.81	good to 150 m, then poor
375	Jan 21	0327:02	0328:12	30 22.22	153 26.17	bad to 600 m, then poor
376	Jan 21	0356:51	0358:03	30 21.39	153 28.26	good to 400 m, then poor
377	Jan 21	0426:17	0427:20	30 20.64	153 30.14	very poor
378	Jan 21	0456:16	0457:24	30 20.64	153 30.14	good
379						no drop
380	Jan 21	0539:16	0540:22	30 19:41	153 35.43	bad
381	Jan 21	0555:34	0555:34	30 20:19	153 37:00	fair
382						no drop
383	Jan 21	0639:24	0639:24	30 21.61	153 41.25	good
384	Jan 21	0656:25	0659:25	30 21.53	153 42.95	good to 500 m
385						no drop
386	Jan 21	0743:43	0743:43	30 22:41	153 47.29	good after 100 m
LEG 2:						
387	Jan 21	1005:48	1010:26	30 21:89	153 24.76	bad
388	Jan 21	1015:04	1015:04	30 21.78	153 25.91	bad
389	Jan 21	1044:48	1045:31	30 21.43	153 29.74	good
390	Jan 21	1115:57	1116:40	30 21.07	153 33.69	good
391	Jan 21	1147:22	1147:48	30 20.71	153 37.65	fair
392	Jan 21	1215:49	1216:59	30 20:37	153 41.35	good to 150 m, poor after 600 m
393						no drop
394	Jan 21	1236:28	1237:34	30 20.13	153 43.90	good
395						no drop
396	Jan 21	1327:27	1327:27	30 21.38	153 49.28	good
LEG 3:						
397	Jan 21	1549:46	1550:10	30 19.88	153 24.32	good
398	Jan 21	1615:30	1616:10	30 20.05	153 26.90	good
399	Jan 21	1645:00	1645:45	30 20.27	153 29.92	poor
400	Jan 21	1715:18	1715:58	30 20.52	153 33.14	intermittently good
401	Jan 21	1745:39	1746:09	30 20.75	153 36.80	good
402	Jan 21	1815:30	1816:15	30 20.97	153 40.34	good
403	Jan 21	1847:52	1848:24	30 21.20	153 44.13	poor
404	Jan 21	1915:45	1916:27	30 21.36	153 46.14	fair
405						no drop
406	Jan 21	1948:18	1949:07	30 21.53	153 47.61	fair
407	Jan 21	2015:02	2015:46	30 21.67	153 48.85	poor
408	Jan 21	2044:52	2045:51	30 21.82	153 50.23	good
OTHERS						
419	Jan 24	2025:58	2026:48	30 20.2	153 37.0	good
420	Jan 24	2242:05	2242:54	30 20.2	153 35.0	good
421	Jan 25	0015:57	0016:37	30 21.8	153.33.9	good to 550 m

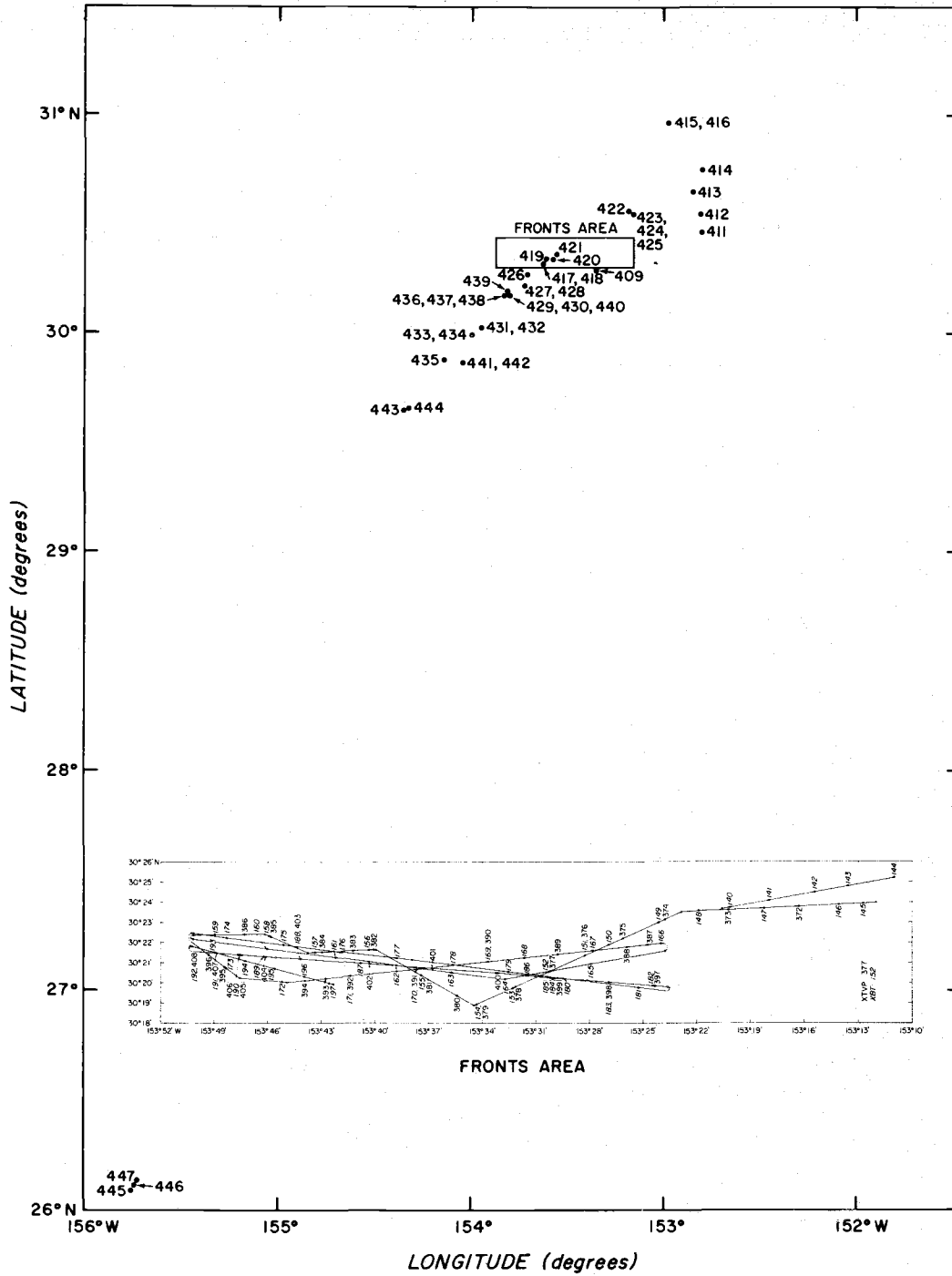


Figure 1. XTVP Drops During 1980 FRONTS Experiment

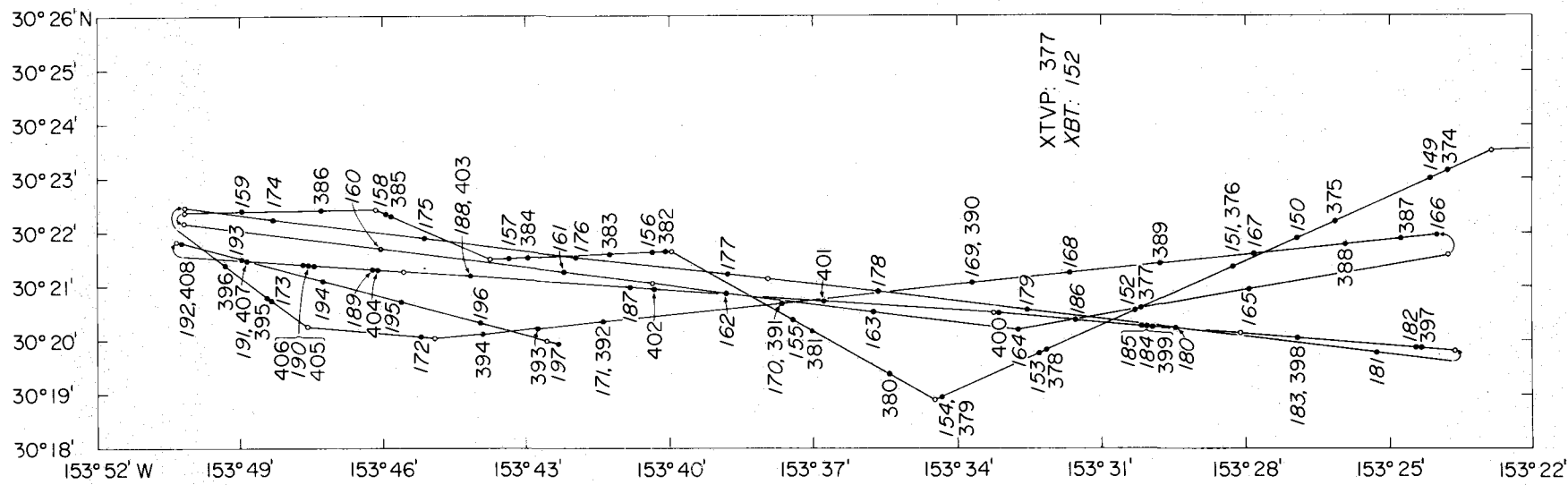
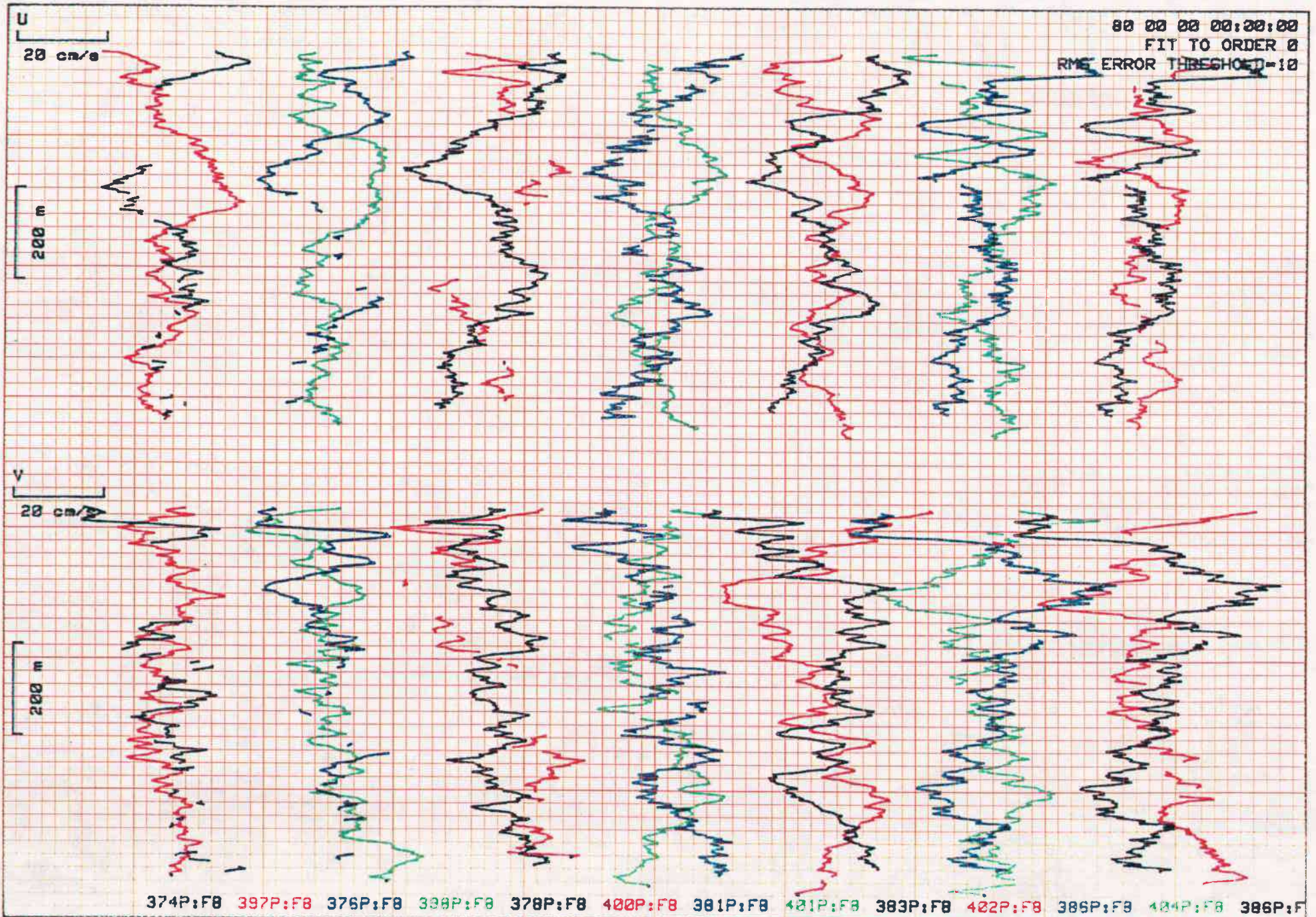


Figure 2. XTVP and XBT Drops in FRONTS Area



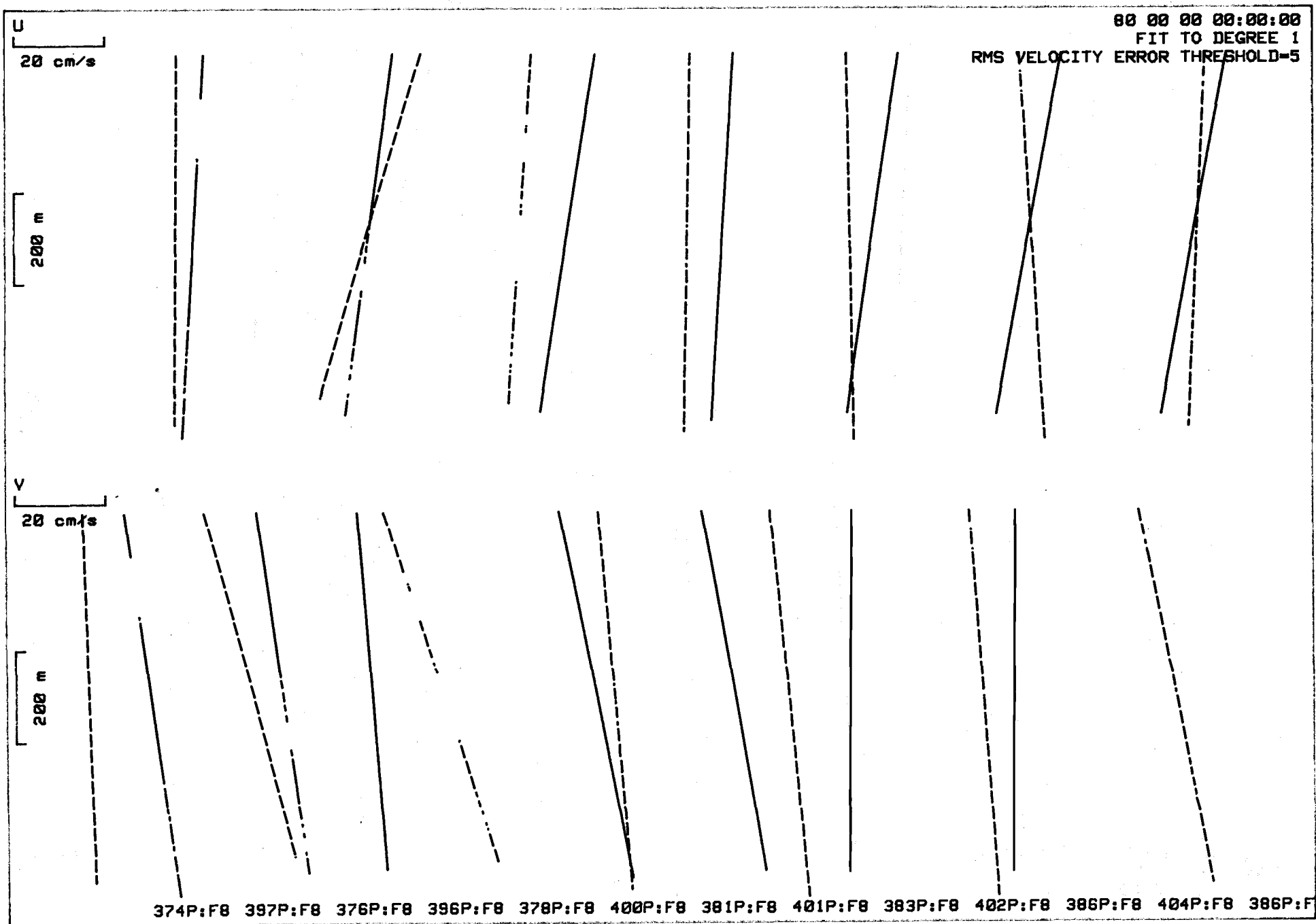


Fig 4: Linear Fits of Half - Inertial Period Pairs

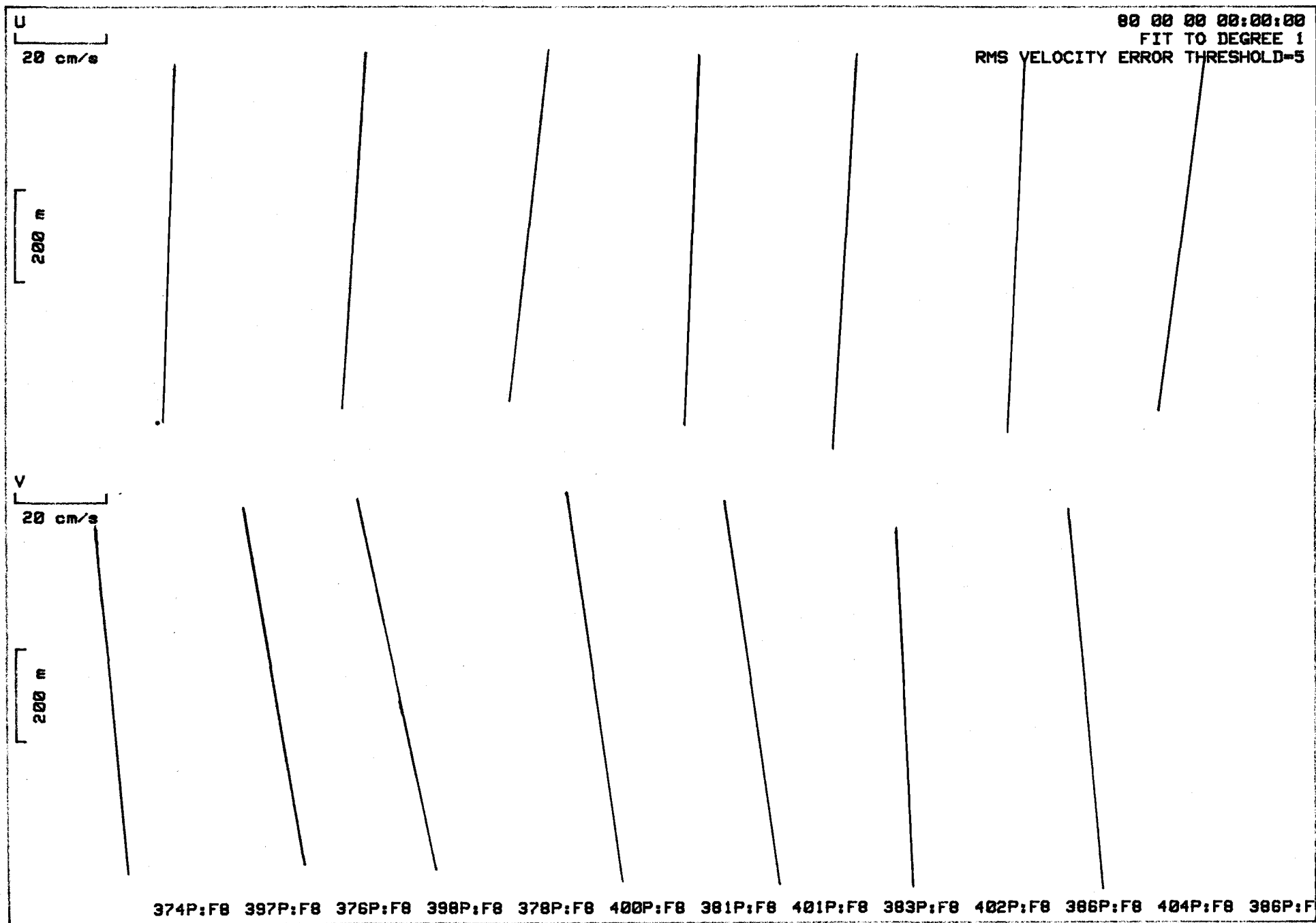


Fig 5: Averages of Linear Fits: Shear Across Front

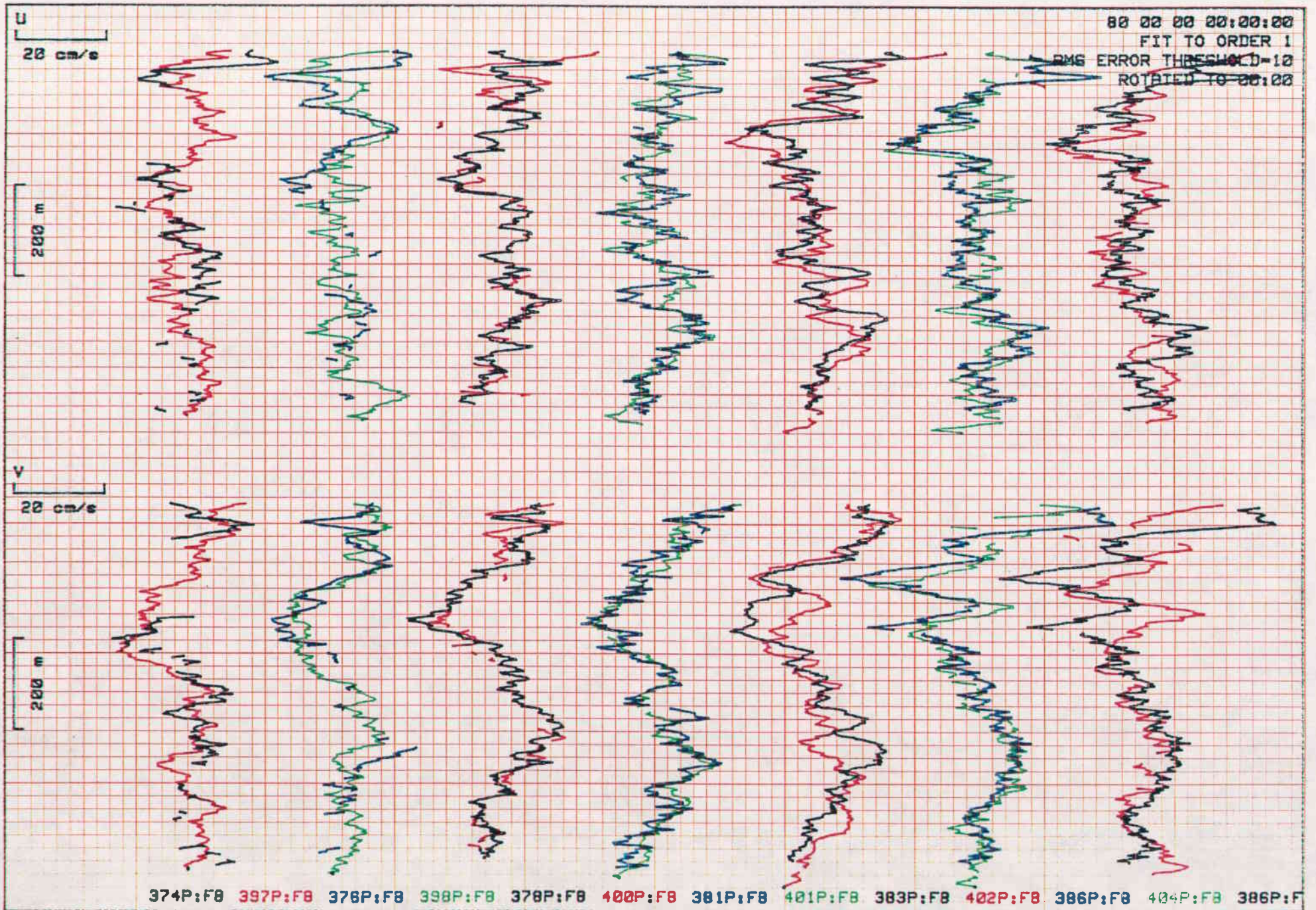


Figure 6. Rotated Half-Inertial Period Pairs



## CTD/Velocity Finestructure Measurements

by

Stanley P. Hayes

Pacific Marine Environmental Laboratory/NOAA

The main objectives of this study were:

- Define large-scale thermohaline structure across the frontal region to provide background data for small-scale studies.
- Study T-S and velocity finestructure in the frontal region in terms of intrusive interleaving and internal waves.
- Compare finestructure observations with microstructure measurements of other investigations.

CTD/O<sub>2</sub> measurements from the NOAA ship OCEANOGRAPHER were made with an NBIS CTD system. Casts were made during thermistor tow and microstructure profiling operations. During severe weather when other observations programs were not possible, a small scale (~ 10 km) CTD section was made across the front. In addition, repeated CTD profiles (Yo-Yo's) from 0 to 200 m were made during several of the microstructure profiling stations. This operation was discontinued after the CTD and MSP wires became entangled. A total of 41 CTD/O<sub>2</sub> casts and 6 time series Yo-Yo's were made.

Velocity measurements were made using the profiler TOPS (Total Ocean Profiling System) which consists of an acoustically-tracked dropsonde with on-board NBIS velocimeter and CTD. The acoustic tracking portion of the instrument failed so that only relative velocity measurements were obtained. Profiles were made in the frontal zone and north and south of the front at 34°N and 26°N. Intercomparison with the XTVP (see Sanford and Kunze in this report) were made at several stations. A total of 18 drops were made.

Figs. 1 and 2 show temperature and salinity profiles obtained during one Yo-Yo (cast 32). Both up and down profiles are plotted; the time difference between profiles is about 5 min. An XTVP drop was made prior to this Yo-Yo and microstructure profiling was conducted during the Yo-Yo. The features seen in the profiles are fairly typical. The weakly stratified mixed layer extended to about 120 m depth. The pycnocline was temperature-stabilized. Numerous small-scale salinity inversions occurred in the mixed layer and down into the pycnocline. In our analysis we will be studying the possibility of double diffusive effects in the dynamics of these intrusions and the role of these features in heat and salt transport.

Figure 3 shows profiles of temperature, salinity, and velocity obtained from TOPS 14 taken at 29°40'N, 154°20'W. The measured relative velocity has been integrated assuming that the vehicle dynamics are similar to those discussed by Evans *et al*, 1979. This technique yields a baroclinic velocity profile. The zero velocity was arbitrarily set so that both U and V were approximately zero at depth. Velocity profiles were started at 50 m to eliminate surface launch transients. The plotted data has been smoothed by a 1 dbar (approximately 10 point) boxcar average. The velocity difference across

the thermocline was about 35 cm/sec. Below this level flow was to the north-east relative to the deep water. Numerous small-scale velocity features are seen; the correlations between these features and the T,S structures are being studied.

Much of our effort so far has been spent on understanding the vehicle motions and attempting to improve the algorithm for calculating true water velocity from measured relative velocity. Accelerometer measurements on TOPS and comparison of reconstructed velocity profiles with Sanford's XTVP profiles are used to test the techniques. A crude intercomparison of the velocity measured by the velocimeter on TOPS (i.e. the velocity relative to the body) and the XTVP data was obtained at sea by high-pass filtering the XTVP profiles. This intercomparison was chosen since basically the TOPS body acts as a high-pass filter as it falls through the water (i.e. over long scales the body follows the flow). Fig. 4 shows the high-pass-filtered XTVP velocity (dashed) and TOPS-14-relative velocity smoothed by a 20 point (~ 2 m) boxcar average. The overall agreement between the two measurements is excellent. Even small-scale features (< 10 m) are seen by both instruments which indicates high vertical resolution for the XTVP. The deep water discrepancy between the two profiles is probably caused by the time delay between them. At the surface the two profiles are nearly simultaneous; however, since the XTVP falls six times faster than TOPS, there is a time lag of about 20 minutes at the bottom. The TOPS relative velocity measurements in Fig. 4 were processed through an algorithm similar to Evans *et al* 1979 to determine the water velocity. The results are shown in Fig. 5 and they are compared with the unfiltered XTVP profile. Again the agreement is quite good and gives us added confidence in our understanding of the essential dynamics of the TOPS vehicle.

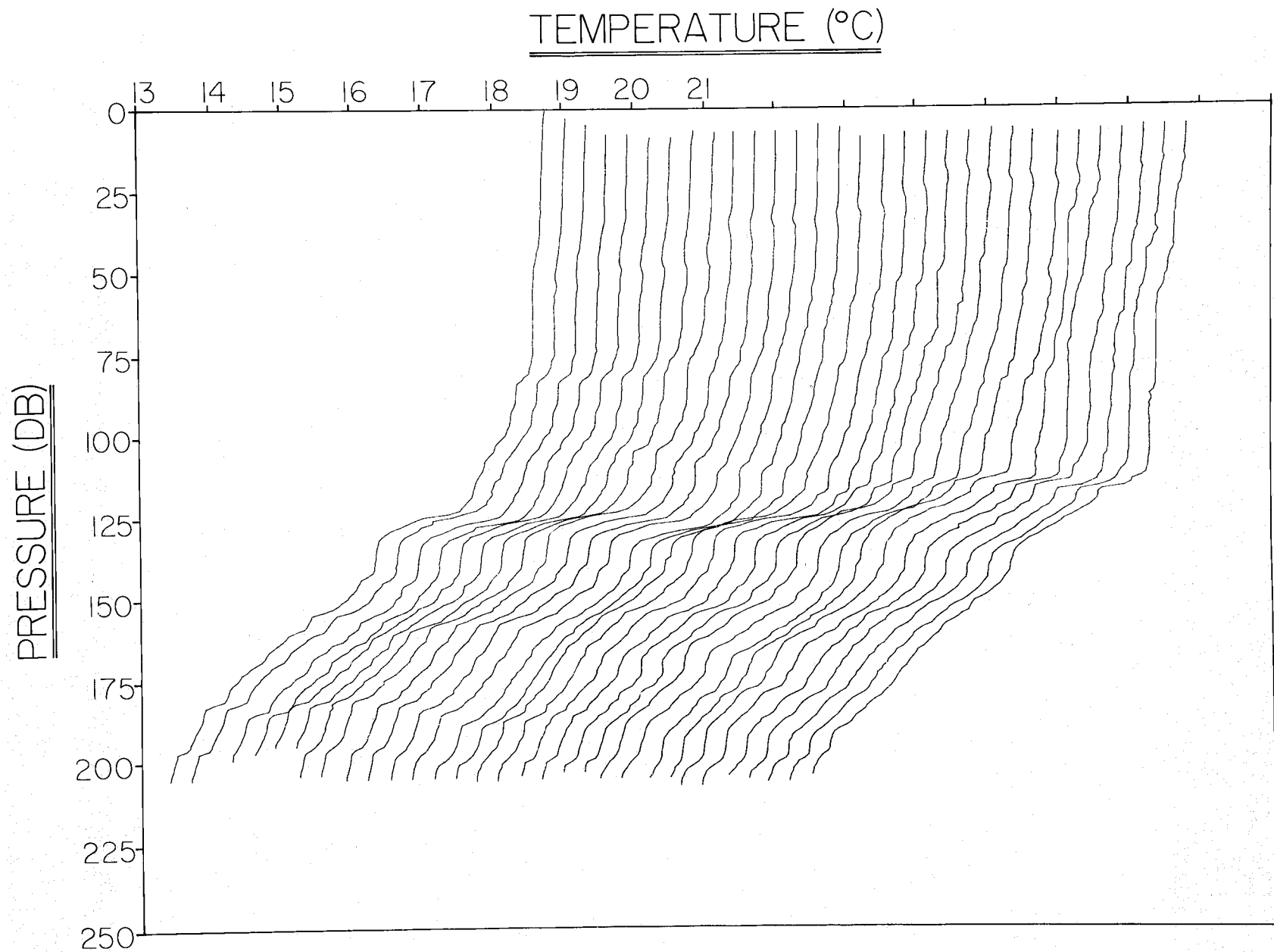


Figure 1. Temperature profiles for CTD 32 yo-yo cast at 29°56'N, 154°W.  
The time difference between profiles was approximately 5 minutes.

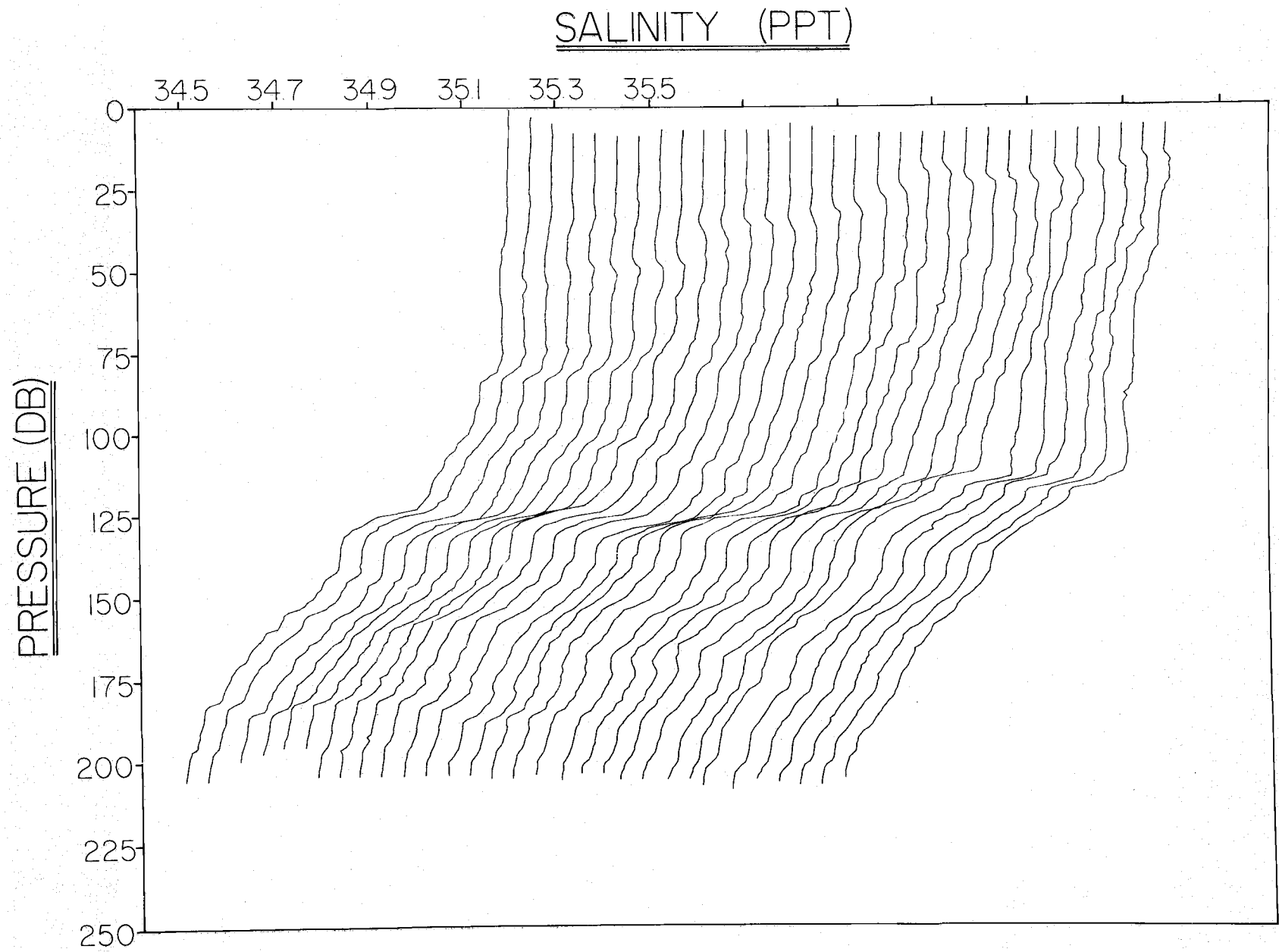


Figure 2. Salinity profiles for CTD 32 yo-yo cast.

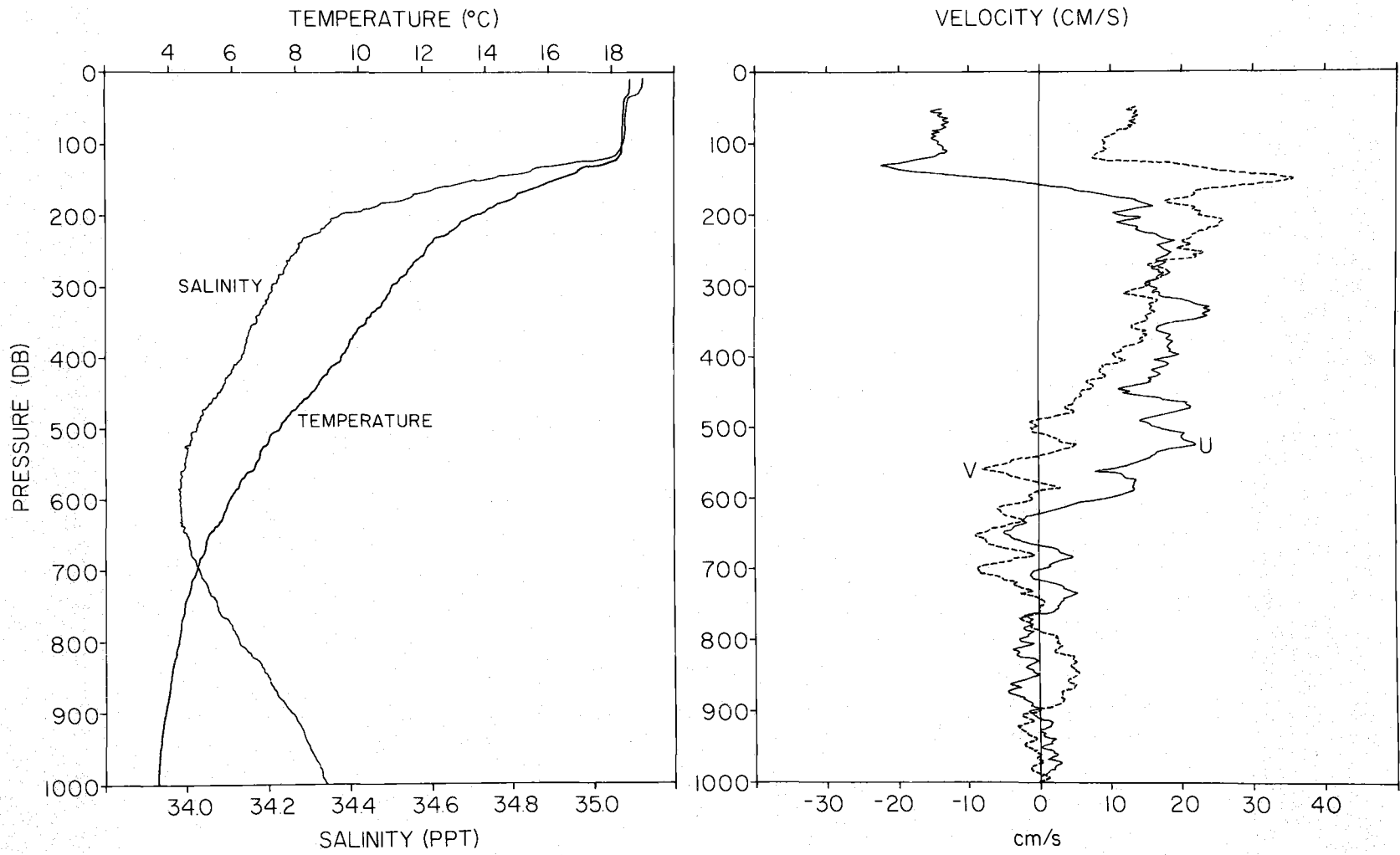


Figure 3. Temperature, salinity, and velocity profiles for TOPS 14 at 29°40'N, 154°20'W.

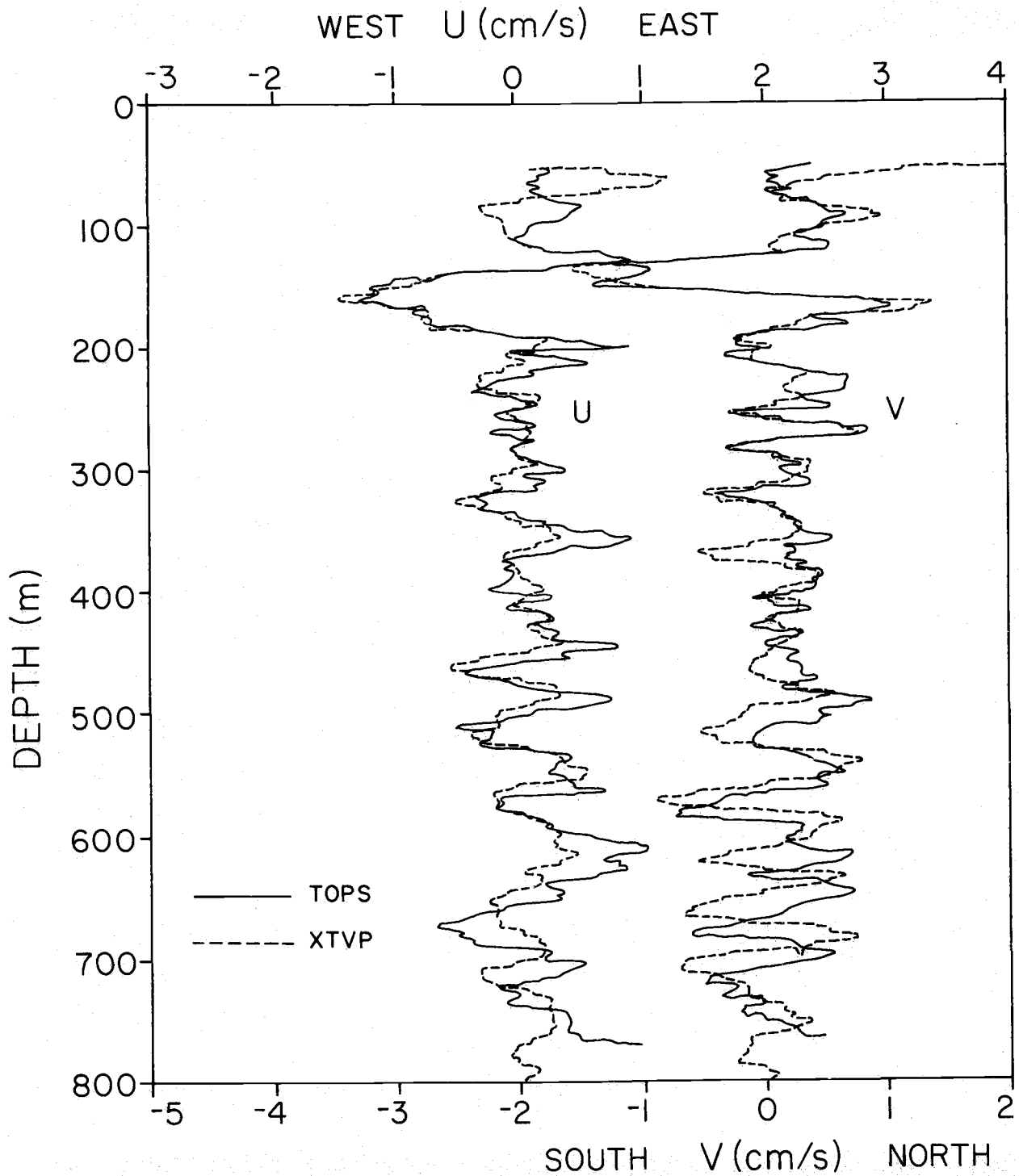


Figure 4. Velocity profile measured by NBIS velocimeter onboard TOPS (solid). Since TOPS is a free-fall profiler this measurement is the velocity of the water relative to TOPS. For comparison, a high-pass-filtered velocity profile taken with Sanford's XTVP is shown.

## COMPARISON OF TOPS AND XTVP VELOCITY PROFILES

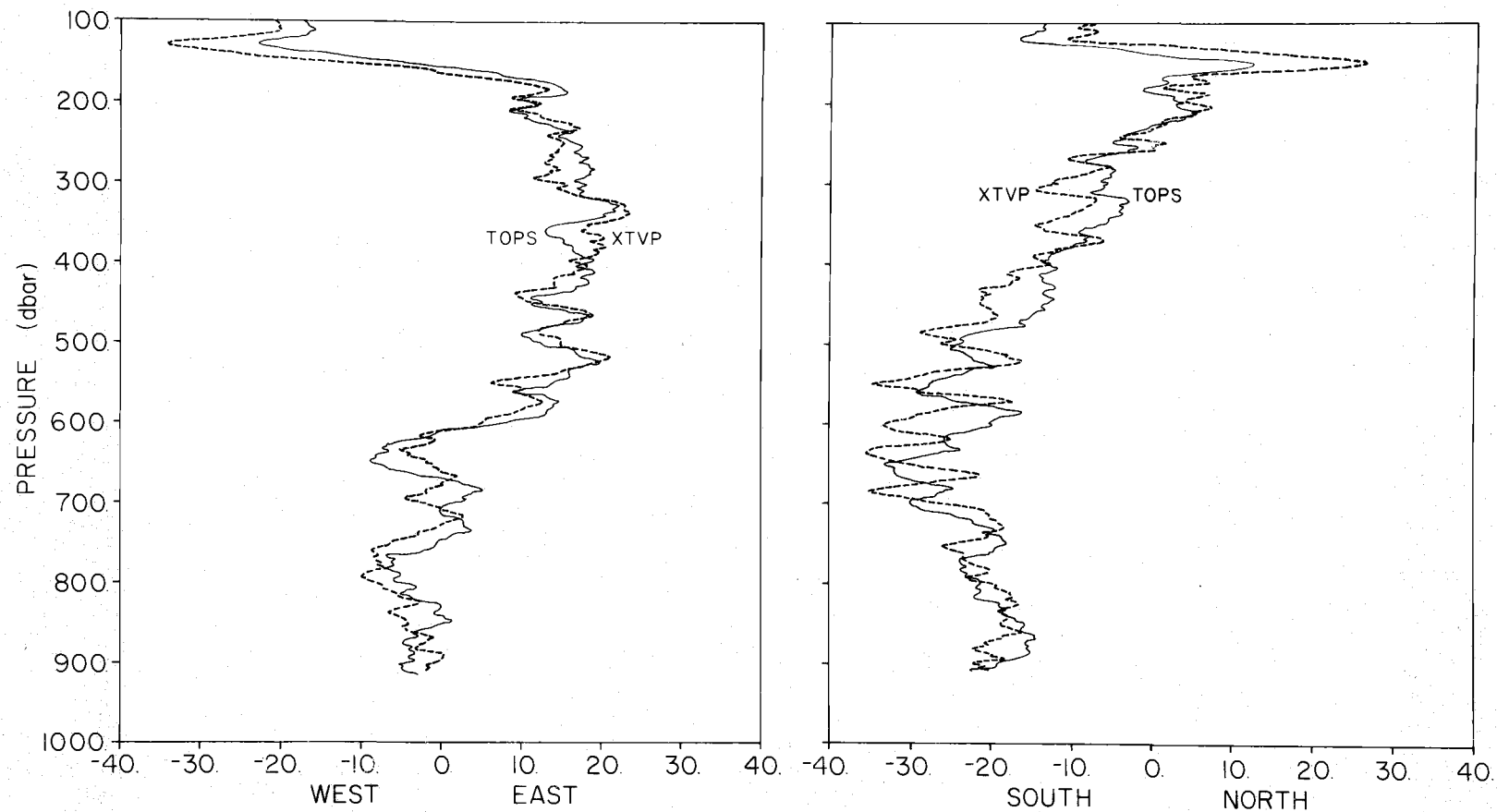


Figure 5. Baroclinic velocity profile computed from the relative velocity shown in Fig. 4 (solid) compared with XTVP velocity profile.

## Towed Temperature Cross-Sections

by

Clayton A. Paulson

Oregon State University

During the FRONTS experiment we towed a thermistor chain from the NOAA Ship OCEANOGRAPHER. The chain had 27 thermistors distributed over 90 m of faired cable. We also had several prototype conductivity sensors installed on the chain but they did not function properly. The chain was towed along the tracks shown in Figs. 1 and 2 at speeds ranging from 4 to 11 knots.

Three examples of frontal structure observed during the experiment are shown in Figs. 3-5. The measurements show that the surface expression of the North Pacific subtropical front is composed of multiple regions having large horizontal temperature gradients. Horizontal gradients of surface temperature occasionally exceeded  $0.1^{\circ}\text{C}/100\text{ m}$ . The magnitude of the temperature difference across the surface fronts ranged up to  $2^{\circ}\text{C}$ . There was usually temperature stratification associated with the surface fronts and occasionally, as shown in Fig. 3, temperature inversions in the upper 95 m.

The analysis of surface frontal structure will be continued along the following lines:

- Examine the surface salinity record from the OCEANOGRAPHER to determine salinity and density changes across fronts.
- Investigate the relationship between the location and magnitude of surface fronts and the large-scale structure observed by AXBT, CTD and satellite surveys.
- Investigate mixing in fronts from analysis of high-frequency temperature fluctuations.



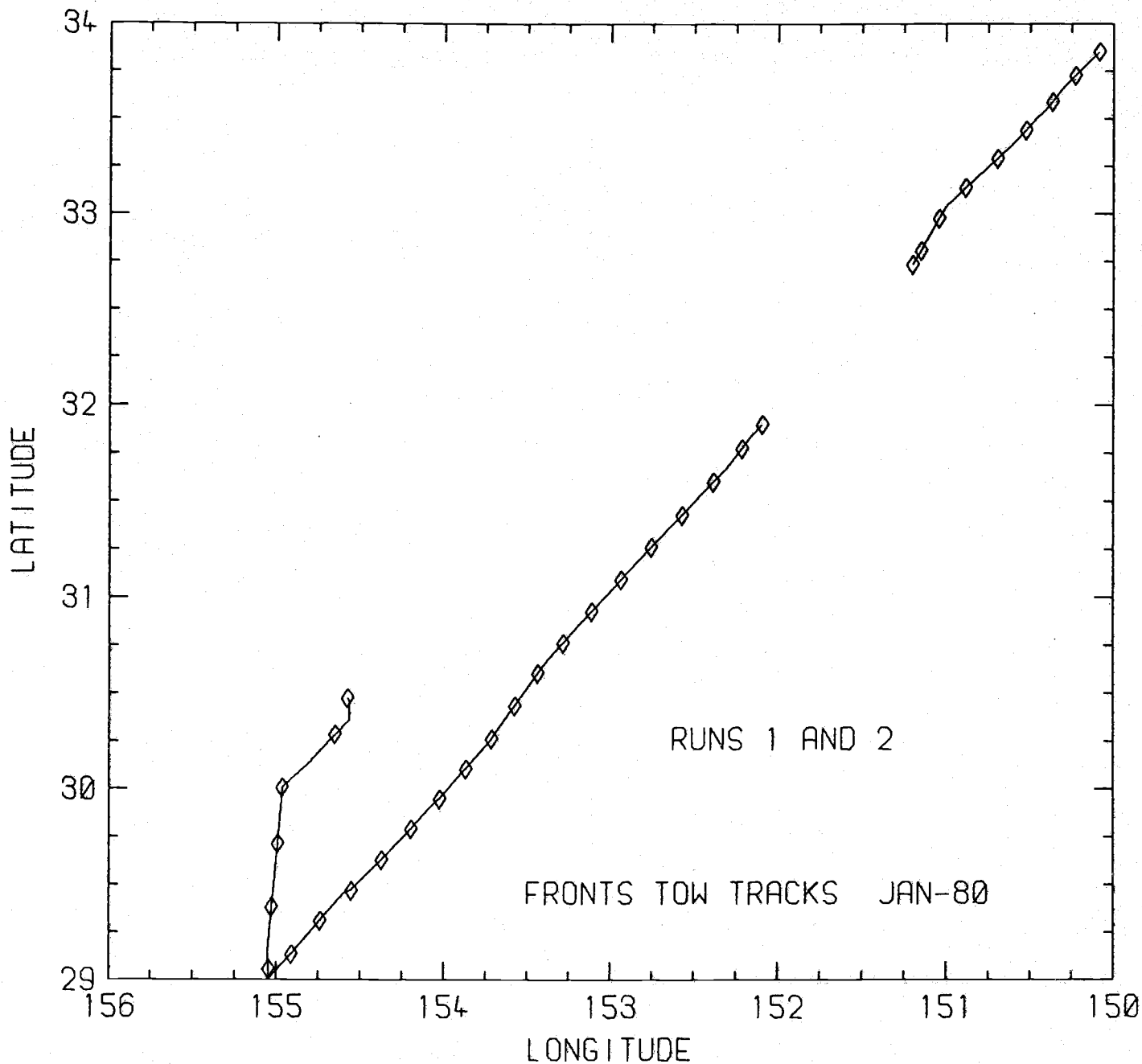


Figure 1. Track of the towed thermistor chain during Runs 1 and 2. Run 1 began near 34N, 150W at 0040 GMT, 16 January 1980, and ended at 1600 on the same date. Symbols (diamonds) are plotted at the beginning and end of the track and in two-hour intervals from the beginning. Run 2 began near 32N, 152W at 0520 GMT, 17 January 1980 and ended at 0245, 18 January. As in Run 1, symbols are plotted at the beginning and end of the track and in two-hour intervals from the beginning. The turn to the north at 29N occurred at 1655 GMT, 18 January 1980.

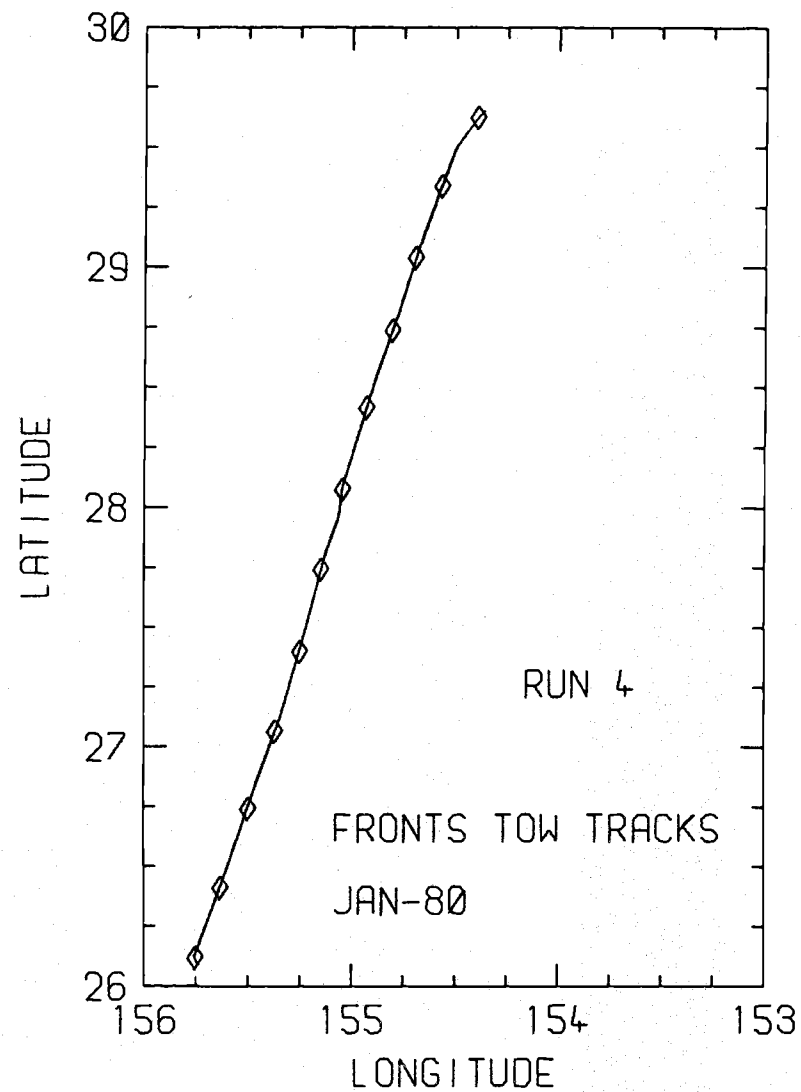
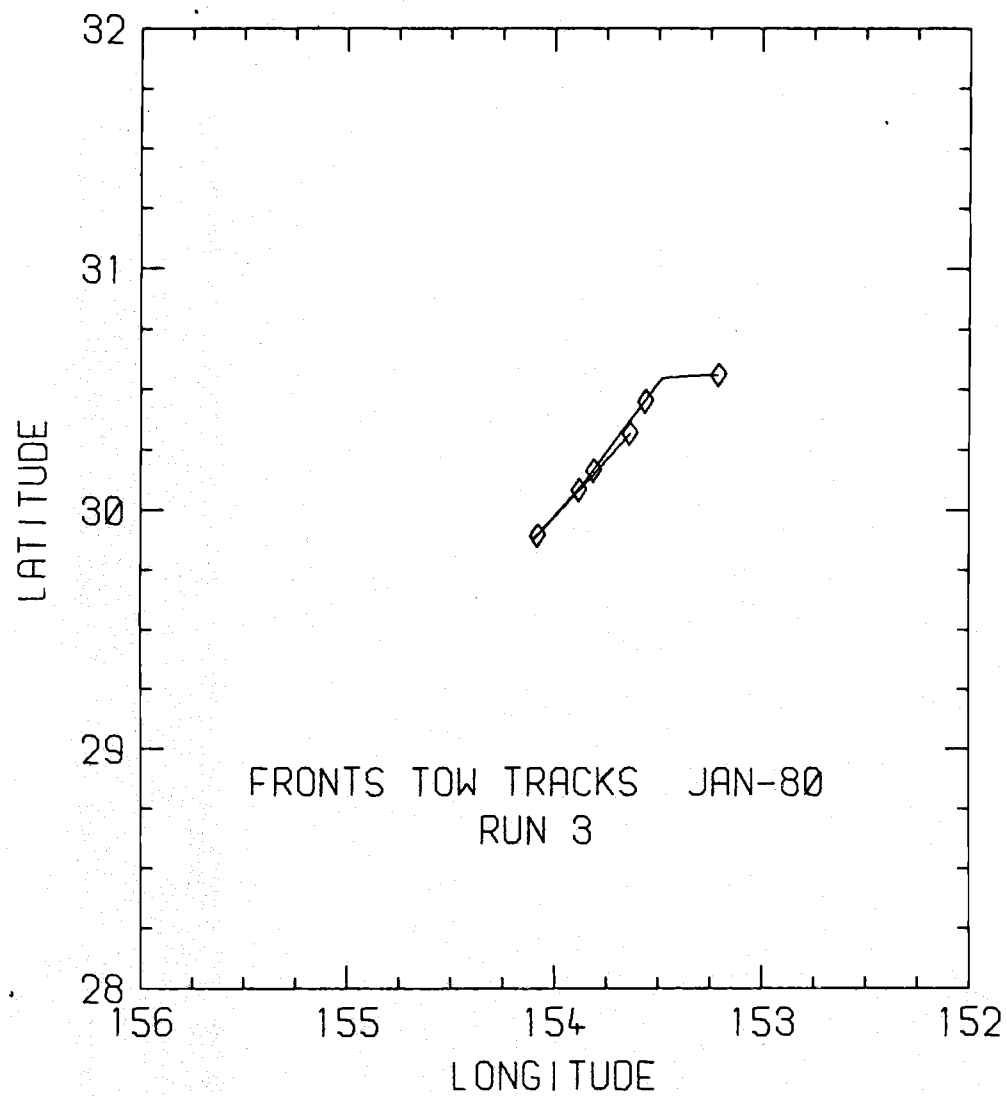


Figure 2. Track of the towed thermistor chain during Runs 3 and 4. Run 3 began near 30.5N, 153.2W at 0700 GMT, 25 January 1980, and ended at 1700 on the same date. The turn toward the southwest occurred at 0820 GMT. A course change of 180° was made at 1312 GMT. Run 4 began near 20.6N, 154.4W at 1900 GMT, 27 January 1980 and ended at 1650, 28 January. The symbols in both tracks are plotted at the beginning and end of each track and at intervals of two hours from the beginning.

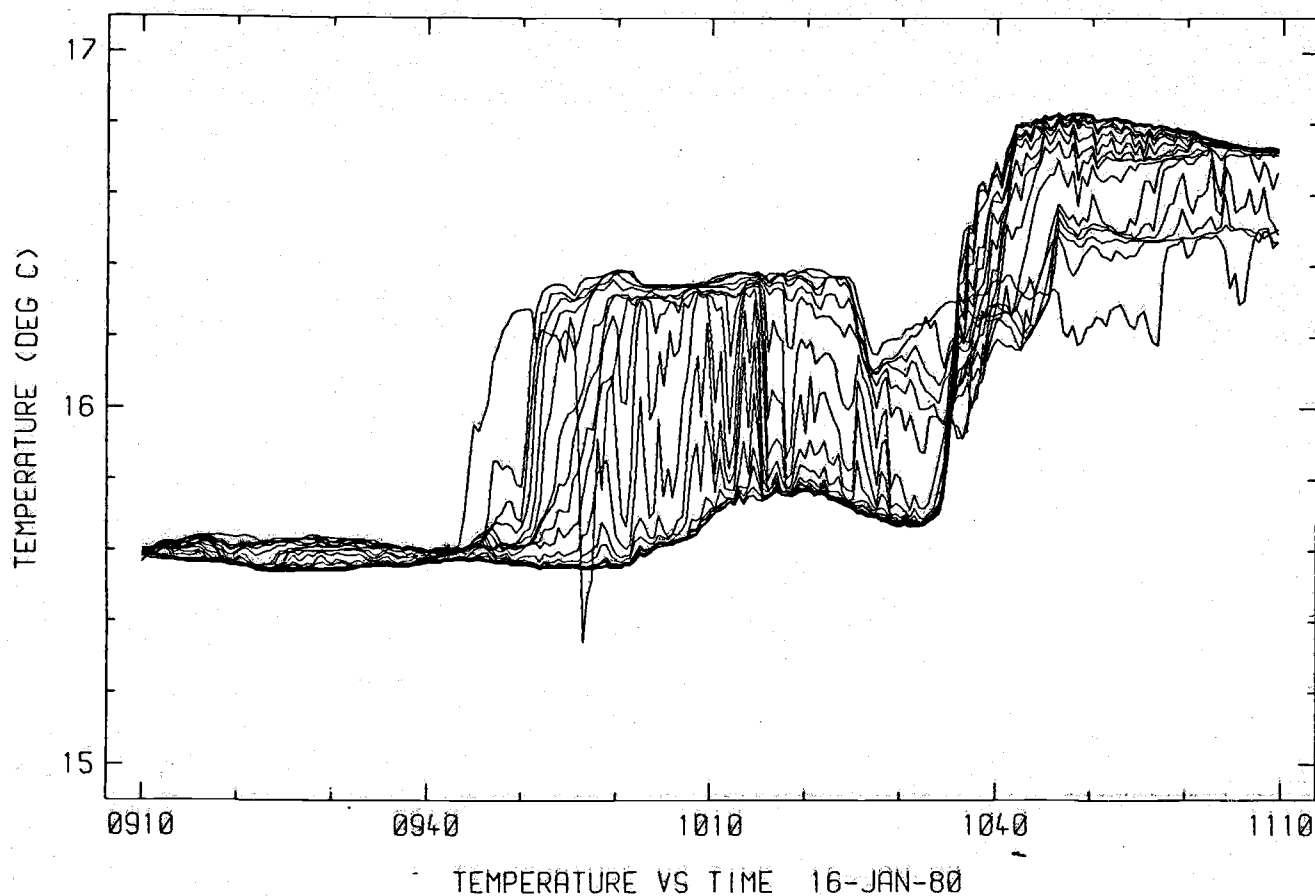


Figure 3. An example of frontal structure observed near 33.3N,150.0 during the FRONTS experiment. The observations were obtained by the towed chain with temperature sensors distributed between depths of 13 and 92 m. The plotted temperature records are sequential 30 s averages. The tow speed was 3.2 m/s yielding a distance traveled of 23 km over the two-hour period shown. At the beginning of the record, the temperature is nearly uniform in the upper 92 m. Just after 0940, warming begins at a depth of 92 m and progresses upward. An isothermal layer remains near the surface. Following 1030, warming occurs near the surface and the temperature gradient changes sign with warm water now overlying colder water. The rapid change in temperature shown at 1035 occurs at a rate of about  $0.5^{\circ}\text{C}$  in 300 m. The cold spike at 0955 occurs at a depth of 92 m and is believed to be caused by the upward displacement of cold water. Many surface fronts were observed during the experiment. Most were not as complex as the example shown here in that they did not exhibit a reversal of vertical temperature gradient.

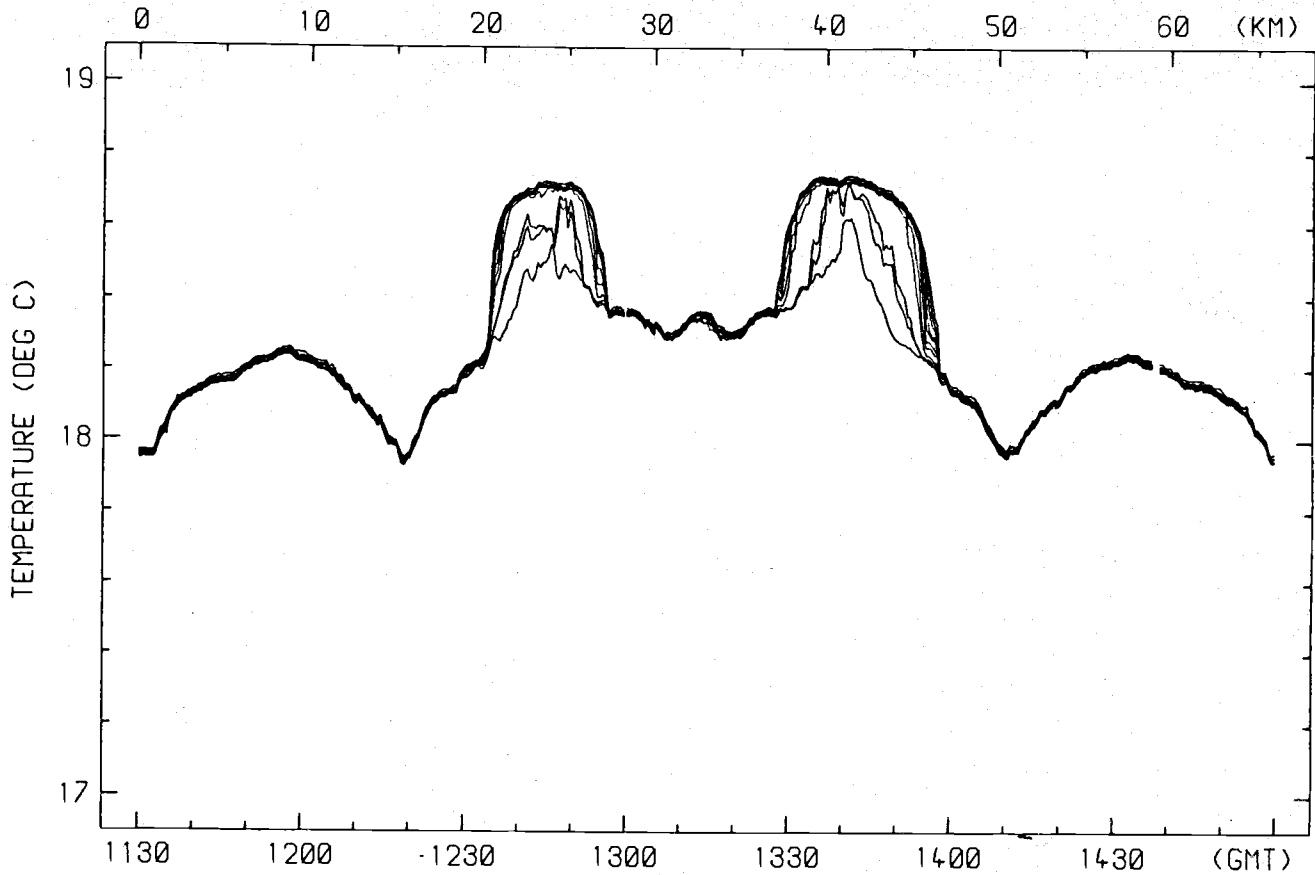


Figure 4. Frontal structure observed during Run 3. The towed chain had temperature sensors distributed between depths of 5 and 73 m. As shown in Figure 2, the tow direction at 1130 GMT was toward the southwest. Sudden warming together with stratification was encountered at 1236. This was followed by sudden cooling and vanishing stratification at 1255. A course change of  $180^\circ$  was made at 1312 and the same warm dome was observed while towing toward the northeast. The temperature structure is remarkably symmetric with respect to 1312 GMT. The width of the warm dome is a little greater on the tow toward the northeast, but this might be at least partly accounted for by variation in tow speed. A constant speed was assumed in constructing the space scale on the upper abscissa.

regions with sharp temperature steps, such as feature 7, are also sharp boundaries for the dissipation patches. The temperature inversion, feature 10 in Fig. 6, does not have any enhanced dissipation associated with it and is typical of the few inversions observed. Features 11 and 12 in Fig. 6 show two patches 6 and 8 meters deep respectively that have temperature variations of less than  $0.2^{\circ}\text{C}$  and low rms temperature gradients. The upper feature is a site of large dissipation whereas the lower feature does not have any enhanced dissipation. Velocity microstructure in the surface mixed layer was substantially higher than in the seasonal thermocline and had temporal variations that appear correlated with the wind speed.

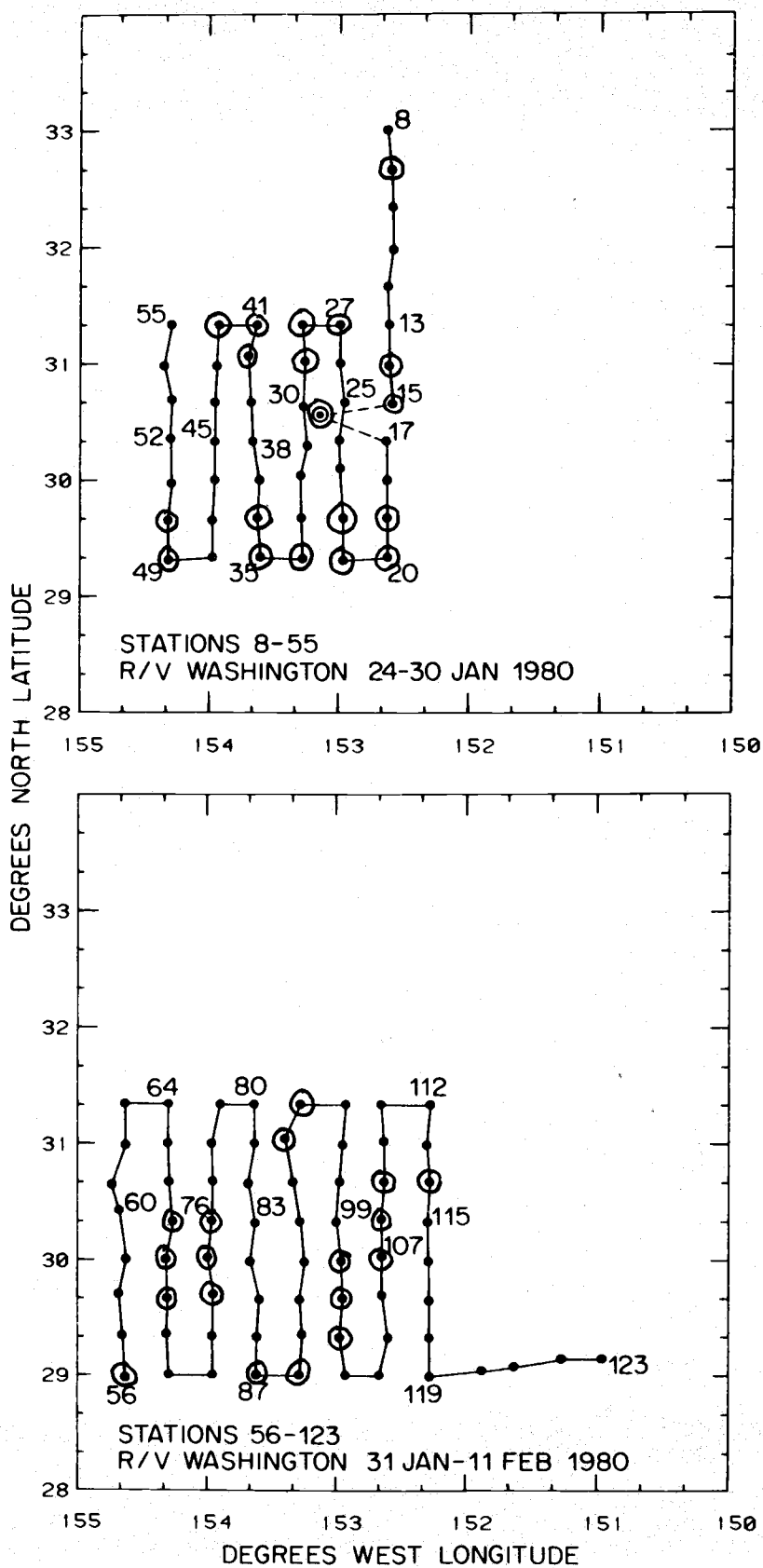


Figure 1. Gunnar Roden's CTD station pattern. Circled dots denote the location of one or more Camel II launchings.

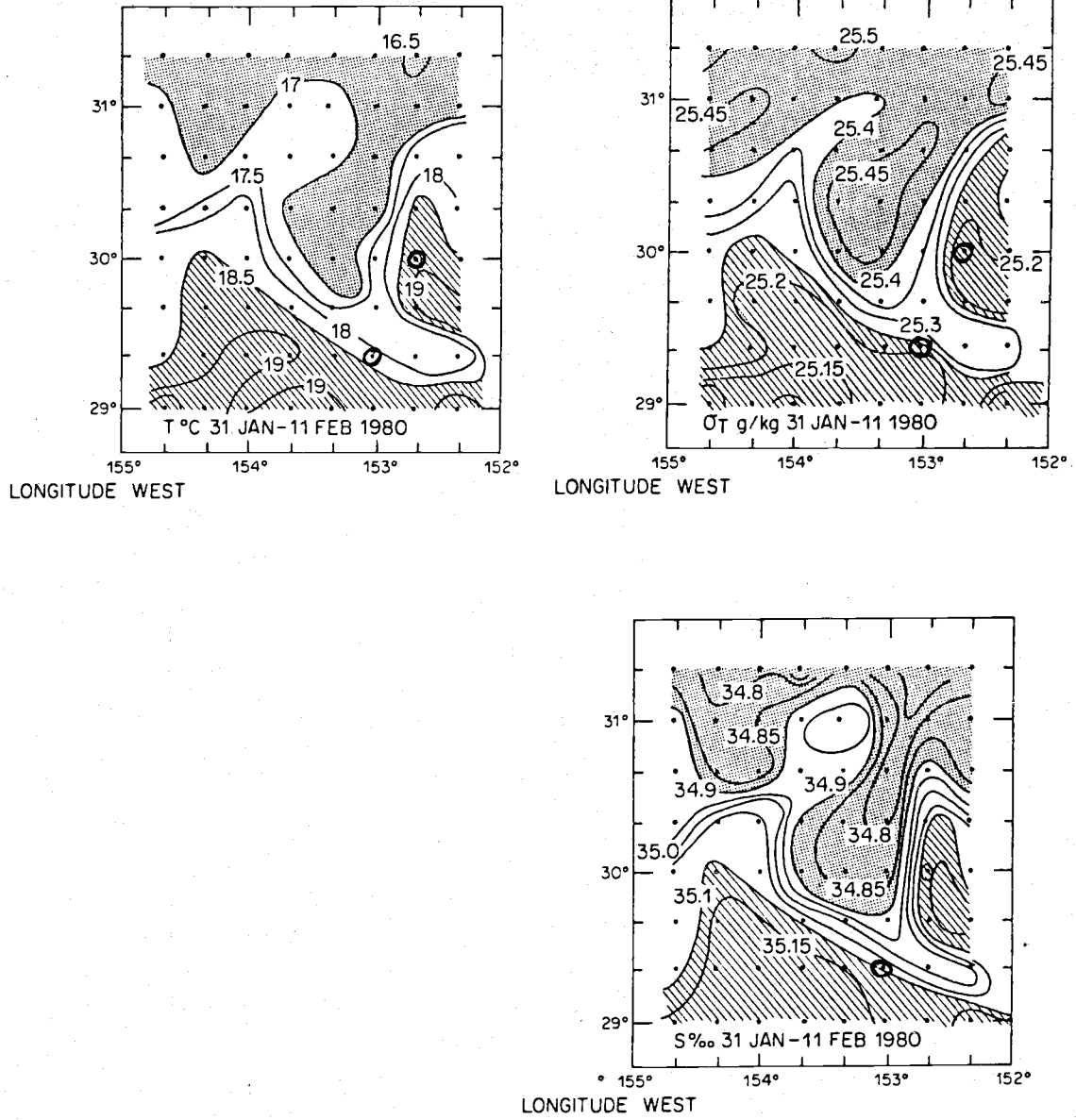


Figure 2. Surface salinity and temperature after Gunnar Roden. The two circled stations show the location of Camel II profiles depicted in Figures 3-6.

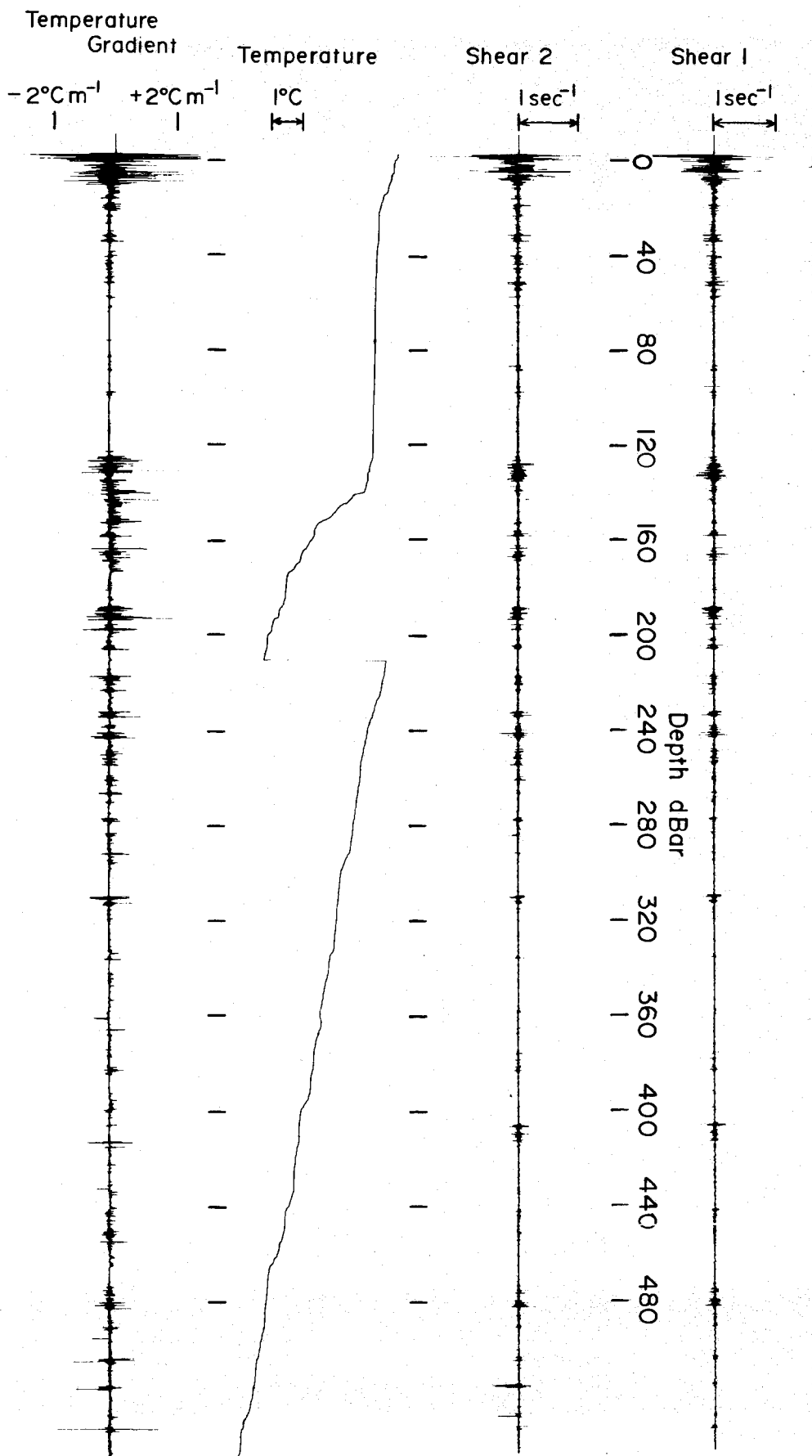
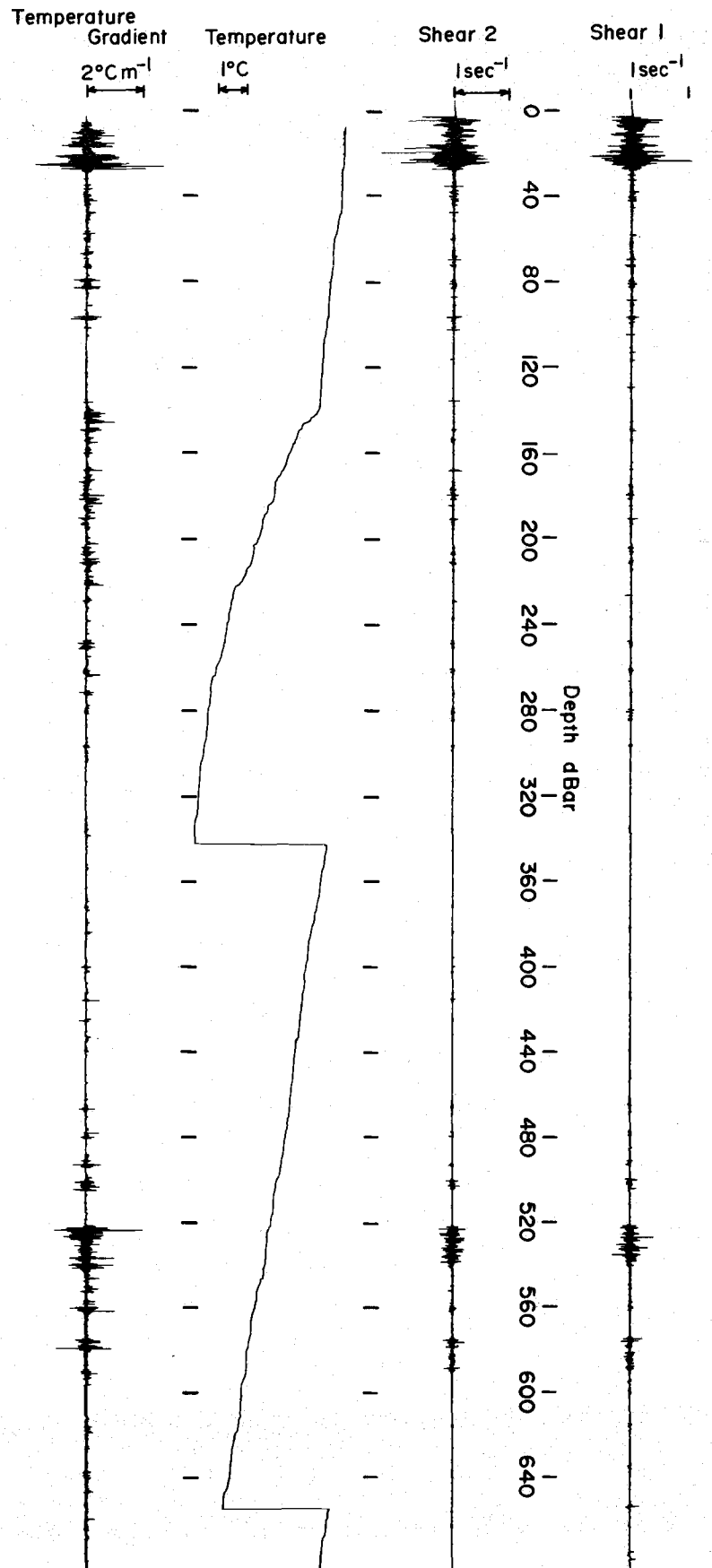


Figure 3. Unprocessed sample of Camel II data ( $153^{\circ}\text{W}, 29^{\circ}20'\text{N}$ ).



FRONTS-80-02-08-1906 St. # 107 Drop 41

Figure 4. Unprocessed sample of Camel II data ( $152^{\circ}40'\text{W}, 30^{\circ}\text{N}$ ).

FRONTS -80-02-08-0135 St. # 102 Drop 40

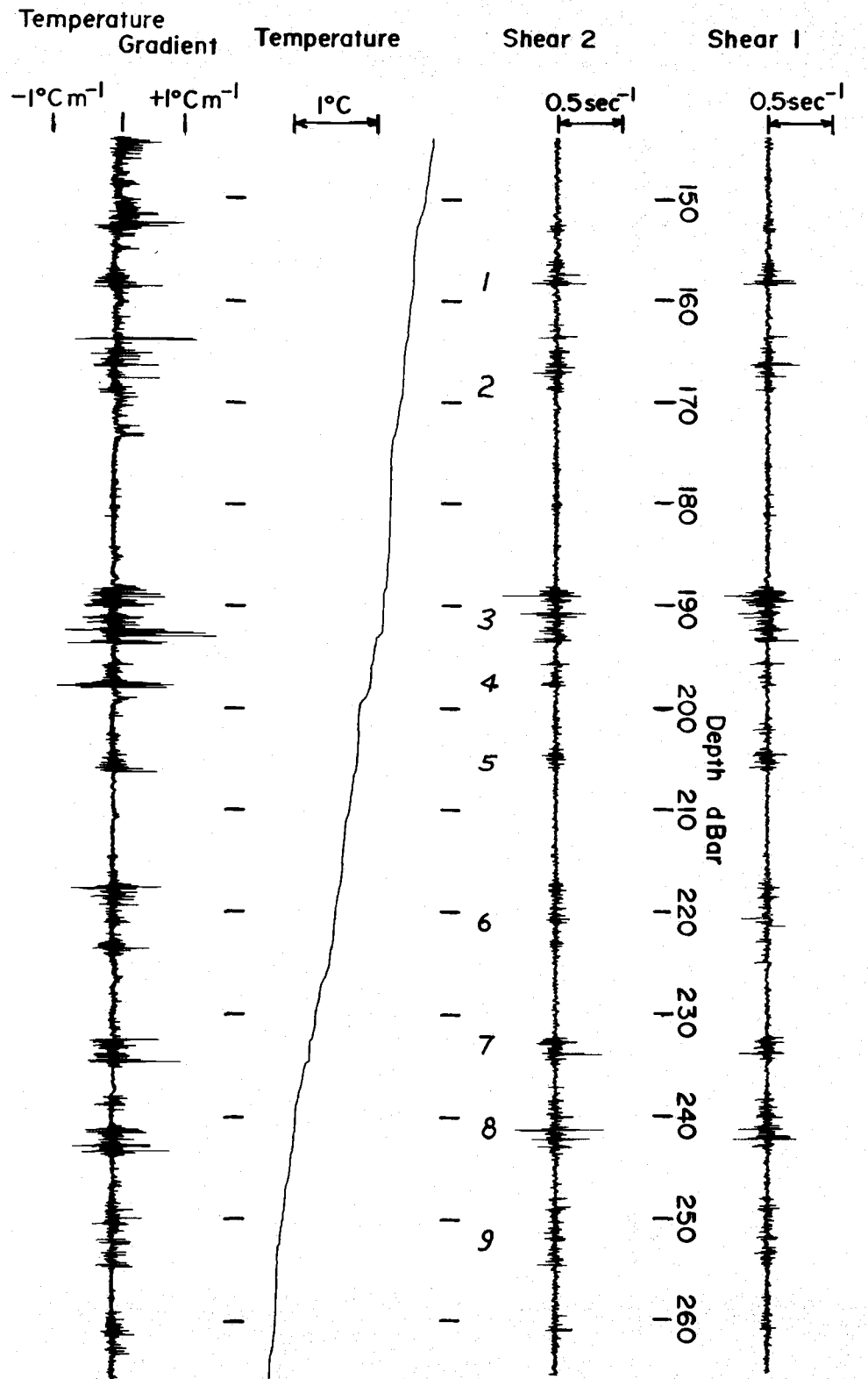


Figure 5. Detail of features in Figure 3.

FRONTS -80-02-08-0135 St.#102 Drop 40

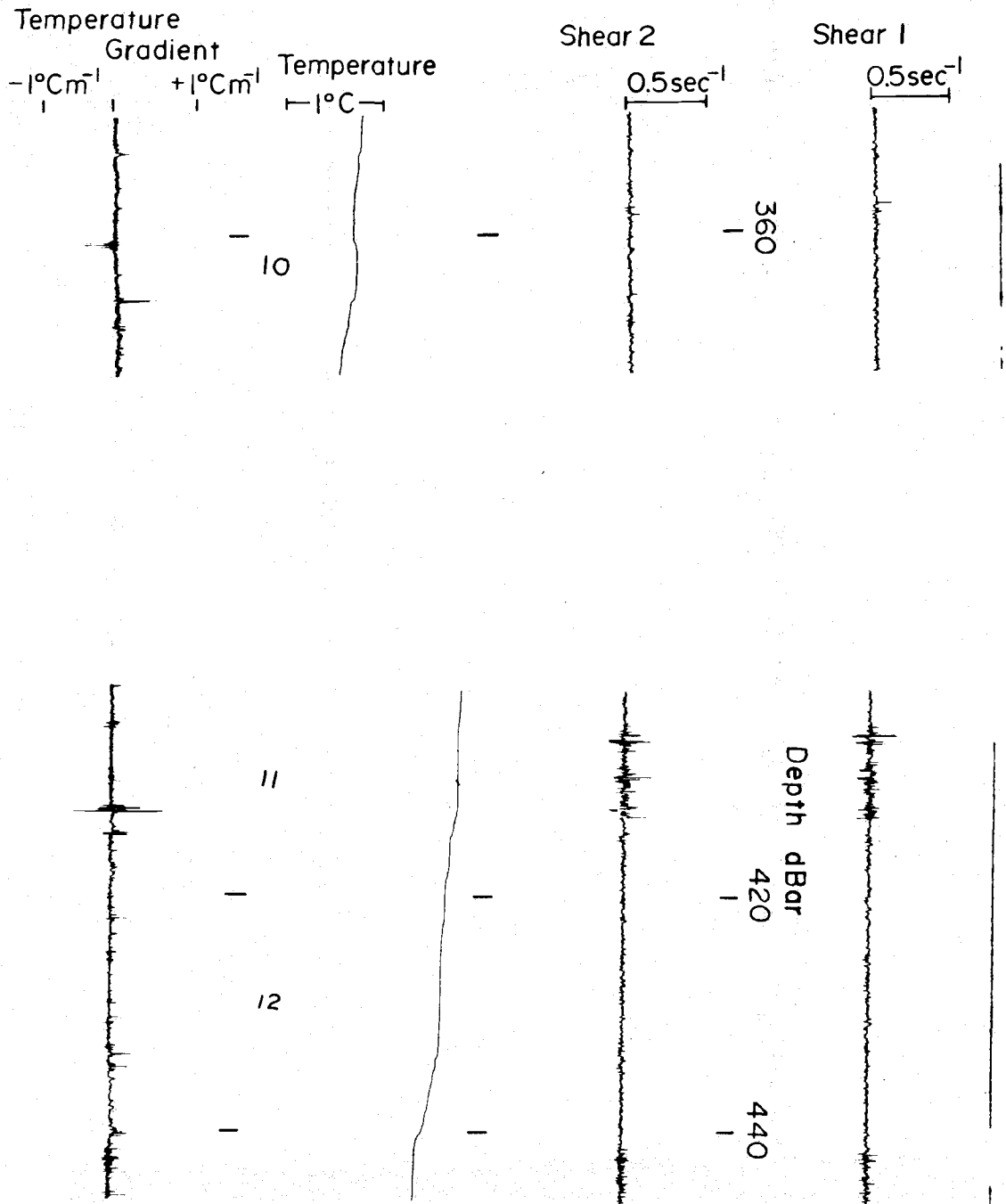


Figure 6. Detail of features in Figure 3.

## Temperature Microstructure

by

T. M. Dillon and D. R. Caldwell

Oregon State University

Measurements of the temperature microstructure in the surface layer and thermocline of the Pacific sub-tropical front were made in January 1980 from the NOAA Ship OCEANOGRAPHER. The most intensively studied area was along a line extending from 31°N-153°12'W to 29°52'N-154°08'W (Table 1, Fig. 1). In addition, two stations were occupied north (34°N-150°W) and south (26°N-155°W) of the frontal zone for comparison. Analysis of the data is proceeding.

The most notable feature of the casts at Station 1 (34°N-150°W) is the presence of a temperature inversion just above the seasonal thermocline (Fig. 2); as noted by others, this inversion is salinity-compensated. Some mixing is evident near the upper boundary of the inversion.

The transect (Station 5) casts showed a large variability in the upper 100 m. In cast F5A1 (Fig. 3) the surface layer was nearly uniform at 17.26°C, while in cast F5B1, 12 km to the southwest, the upper 30 m was 0.2°C warmer, and from 70-130 m was 0.1°C cooler (Fig. 4); moderate mixing was seen between 35-55 m where an appreciable temperature gradient was present. Also visible in this cast are a number of isothermal layers separated by temperature jumps of magnitude 0.01°C. Cast F5E2, 40 km southwest of F5B1, was characterized by a great deal of temperature structure, including numerous inversions of magnitude 0.04°C with several meters vertical scale (Fig. 5). No active mixing was observed in the 10-100 m zone, and it is presumed that the inversions were salinity-compensated and stable. The entire region of the transect could best be characterized as generally isothermal, or nearly so, in the upper 110 m, with pockets of water having different thermohaline properties randomly imbedded. The length scale of such features (~ 10-20 km) can best be seen in the towed thermistor chain data of Paulson.

Far south of the front (Fig. 6), the surface layer was nearly isothermal with the exception of a moderately active near-surface mixing layer.

In addition to the microstructure casts, temperature profiles were made while the ship was underway at 6 kts with a new instrument, the Rapid Sampling Vertical Profiler (RSVP). The RSVP performed well and successive casts resolved vertical temperature scales to 10 cm, and horizontal scales to 1 km in the upper 100 m.

TABLE 1

Latitude and Longitude of Microstructure Stations  
Occupied by the NOAA Ship OCEANGORAPHER

<u>Station No.</u>	<u>Latitude-Longitude</u>	<u>Date (Jan 80)/Time (GMT)</u>
F1	33°56'N-150°2'W	15/01:56-15/13:37
F2	31°00'N-153°00'W	23/18:13-24/04:12
F3	30°20.4'N-153°37.3'W	24/18:25-24/23:52
F5 (transect)	30°20.9'N-153°36.2'W	25/18:35-25/19:30
	30°16.1'N-153°42.6'W	25/20:40-25/21:01
	30°10.1'N-152°49.8'W	25/23:00-26/00:02
	30°01.6'N-153°57.2'W	26/00:54-26/02:58
	29°59.5'N-154°00.6'W	26/03:51-26/05:18
F6	29°58.5'N-154°00.3'W	26/18:35-27/00:21
F7	29°52.5'N-154°06.9'W	27/02:12-27/08:13
F8	26°05.8'N-155°45.1 W	28/19:58-29/02:45

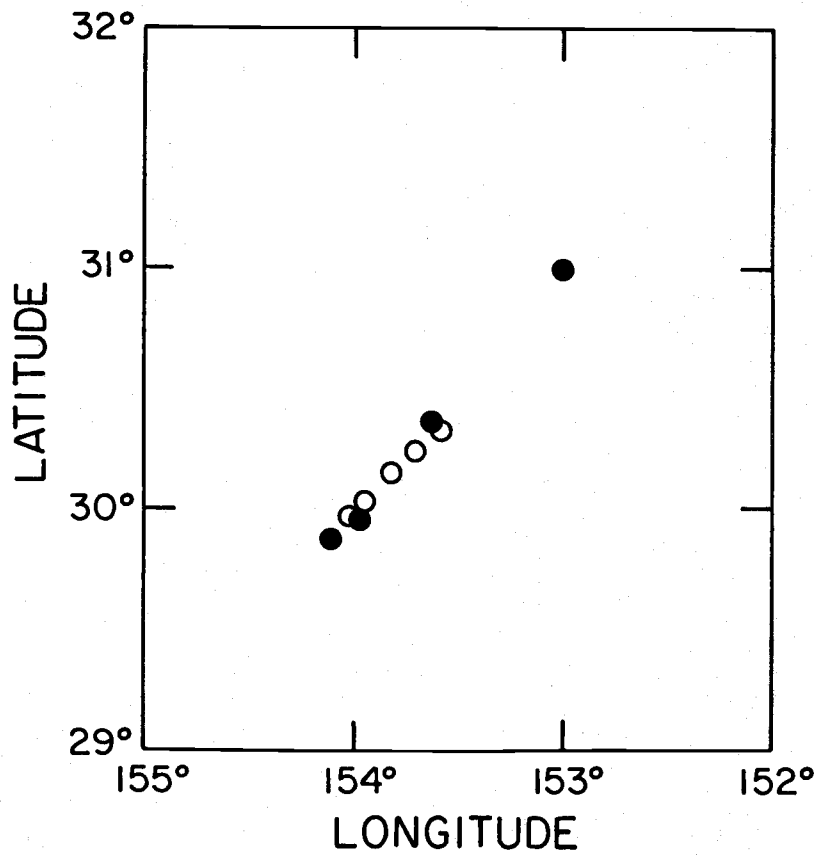


Figure 1. Map of the most intensively studied region, along a line extending from 31°N-153°W to the southwest. Solid circles are stations occupied for many casts, open circles are transect stations occupied only briefly.

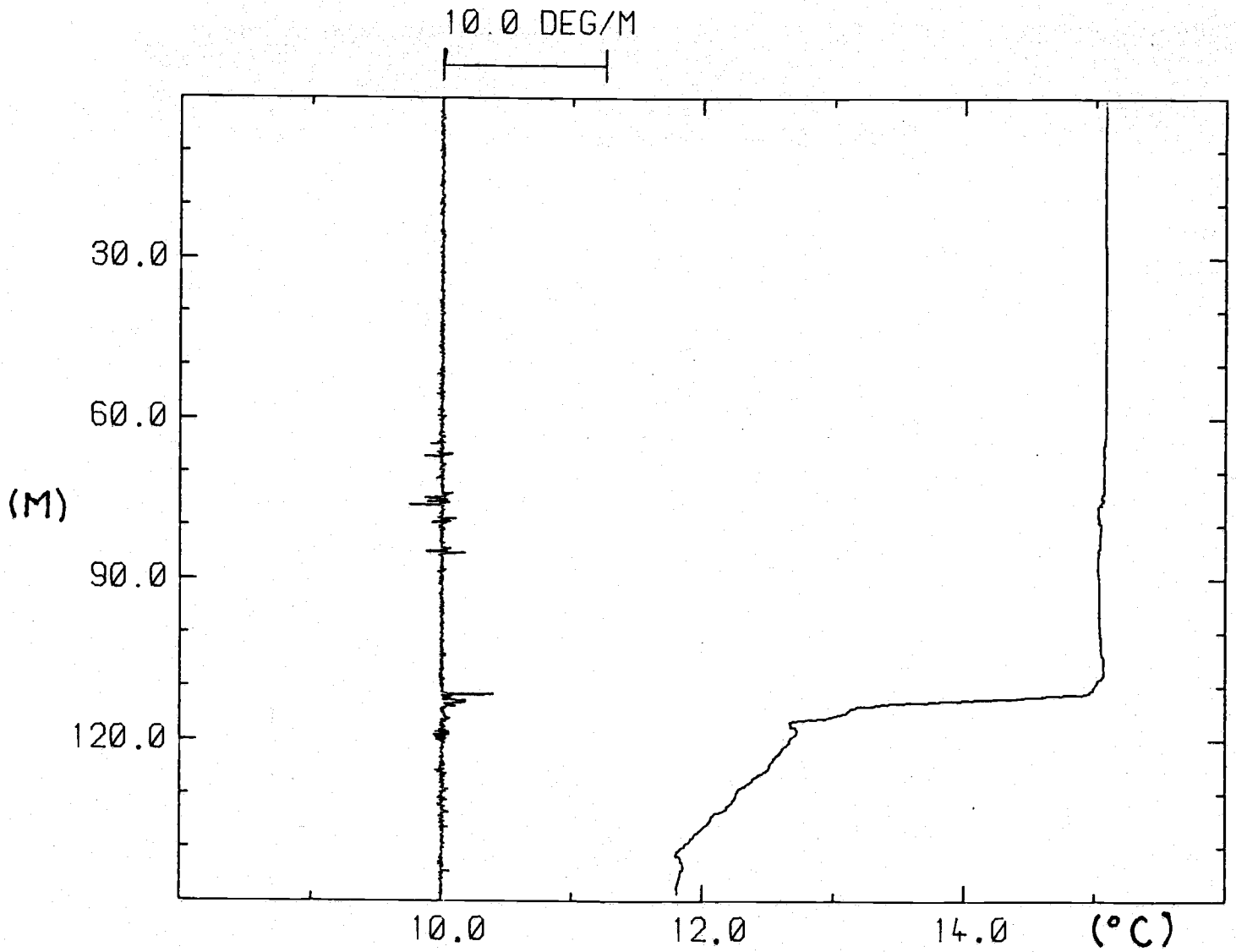


Figure 2. Temperature and temperature-derivative profiles from the northernmost station, 33°56'N, 152°02'W, cast F1J1. Temperature inversion from 90-110 m is salinity compensated.

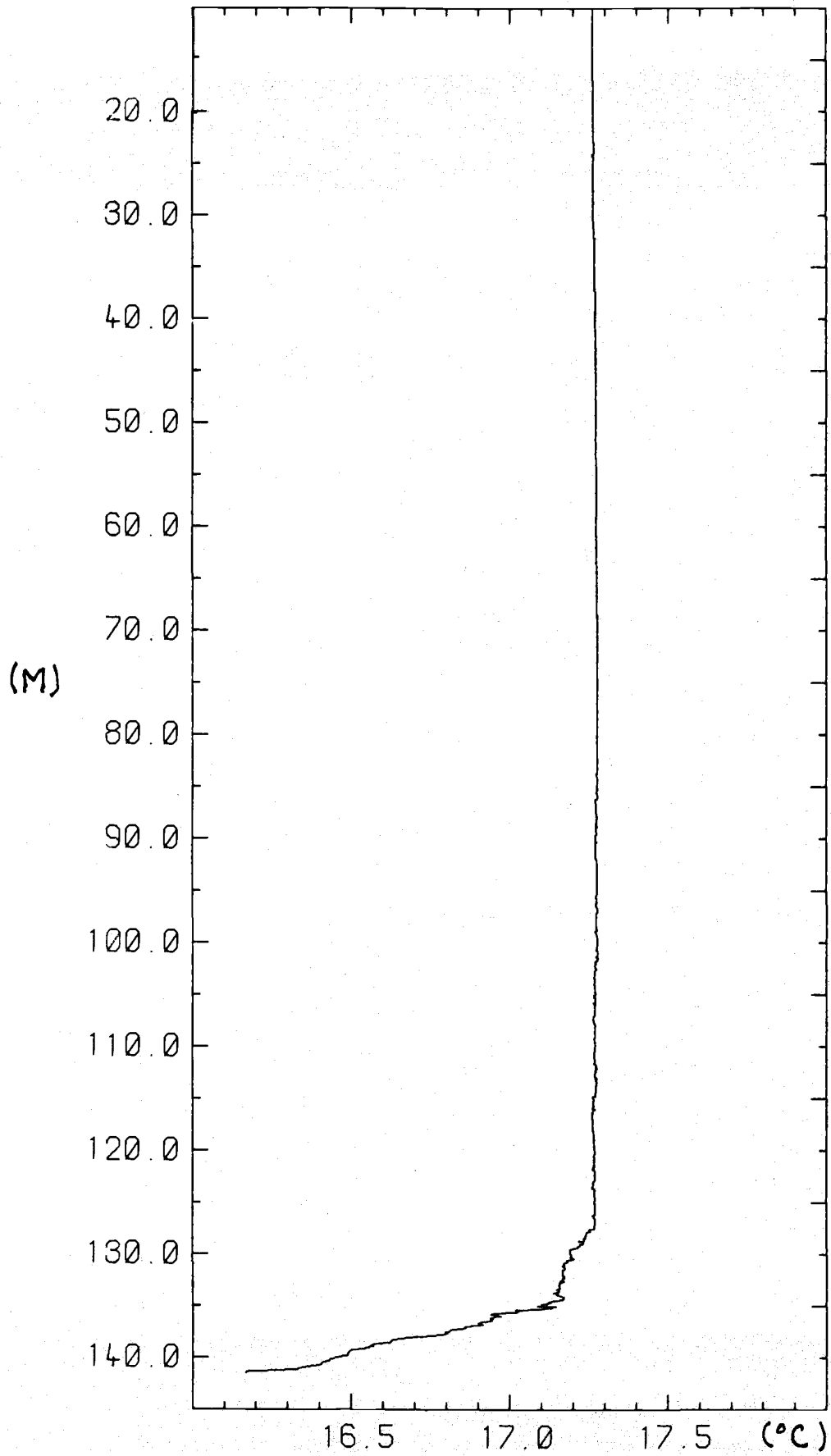


Figure 3. Temperature profile from cast F5A1,  $30^{\circ}20.9'N-153^{\circ}36.2'W$ . Surface layer is nearly isothermal above 120 m.



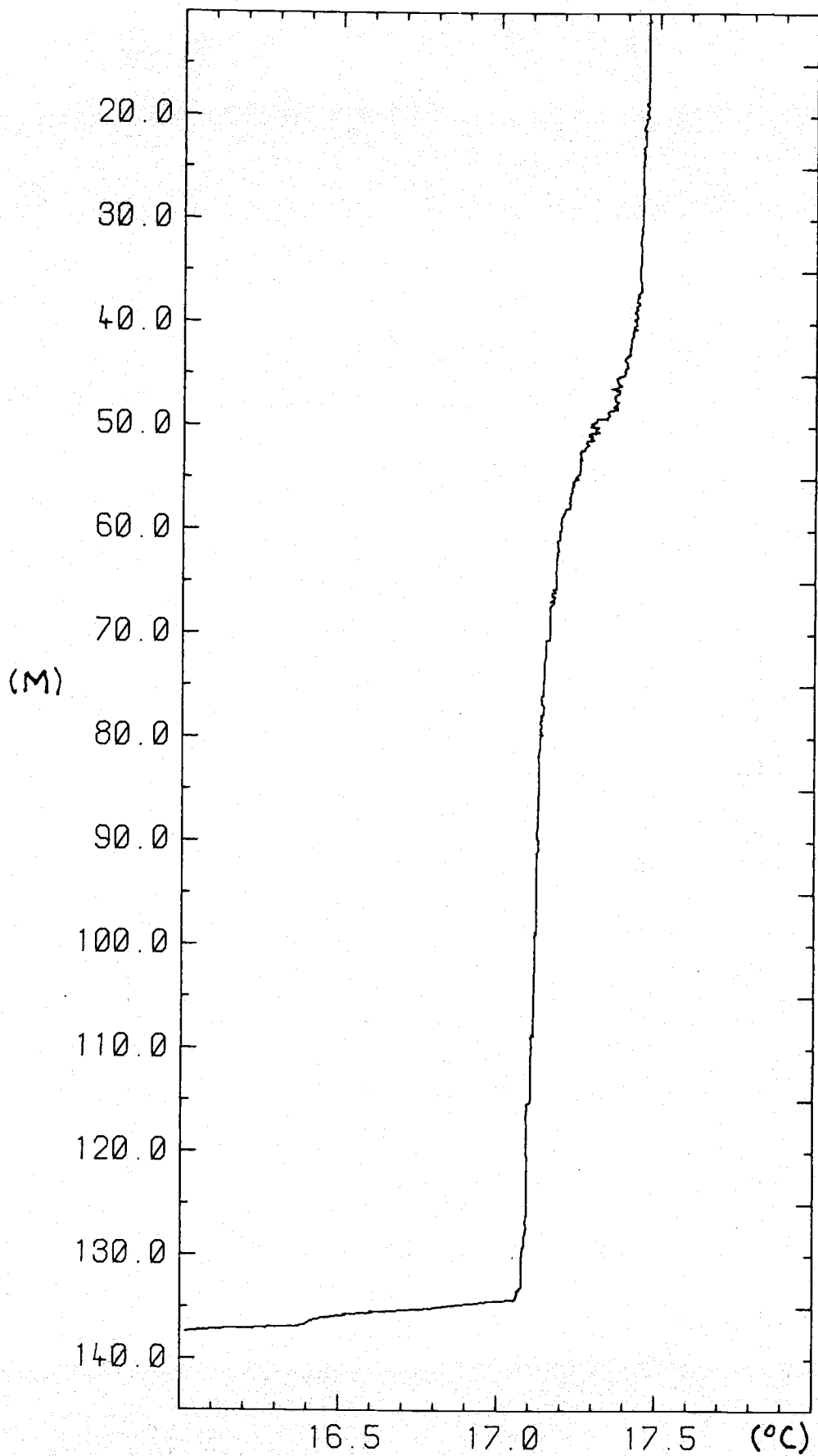


Figure 4. Temperature profile from cast F5B1, 30°16.1'N-153°42.6'W, 12 km southwest of profile in Fig. 3.

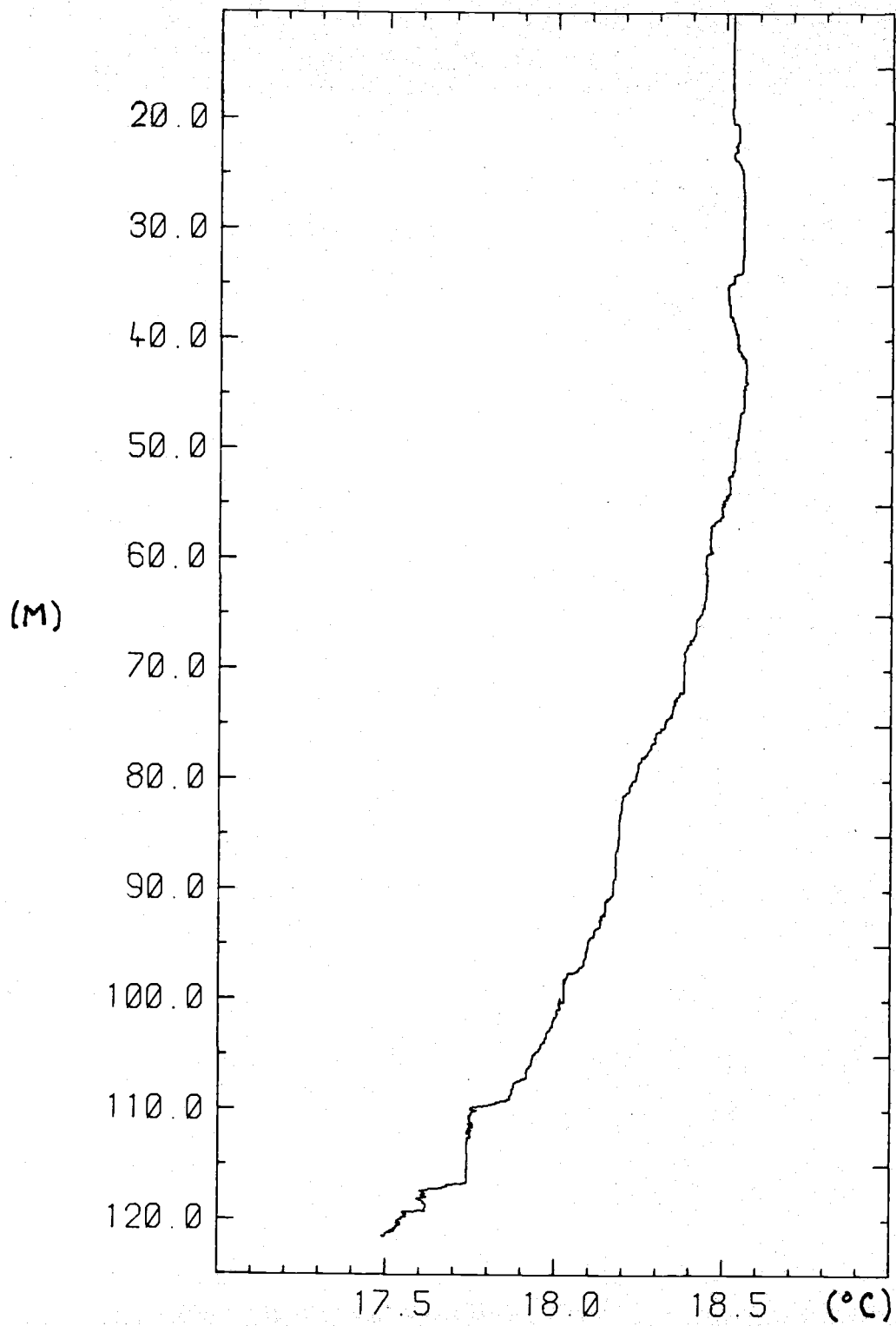


Figure 5. Temperature profile F5E2,  
29°59.5'N-154°00.6'W, 40 km southwest  
of profile in Fig. 3.

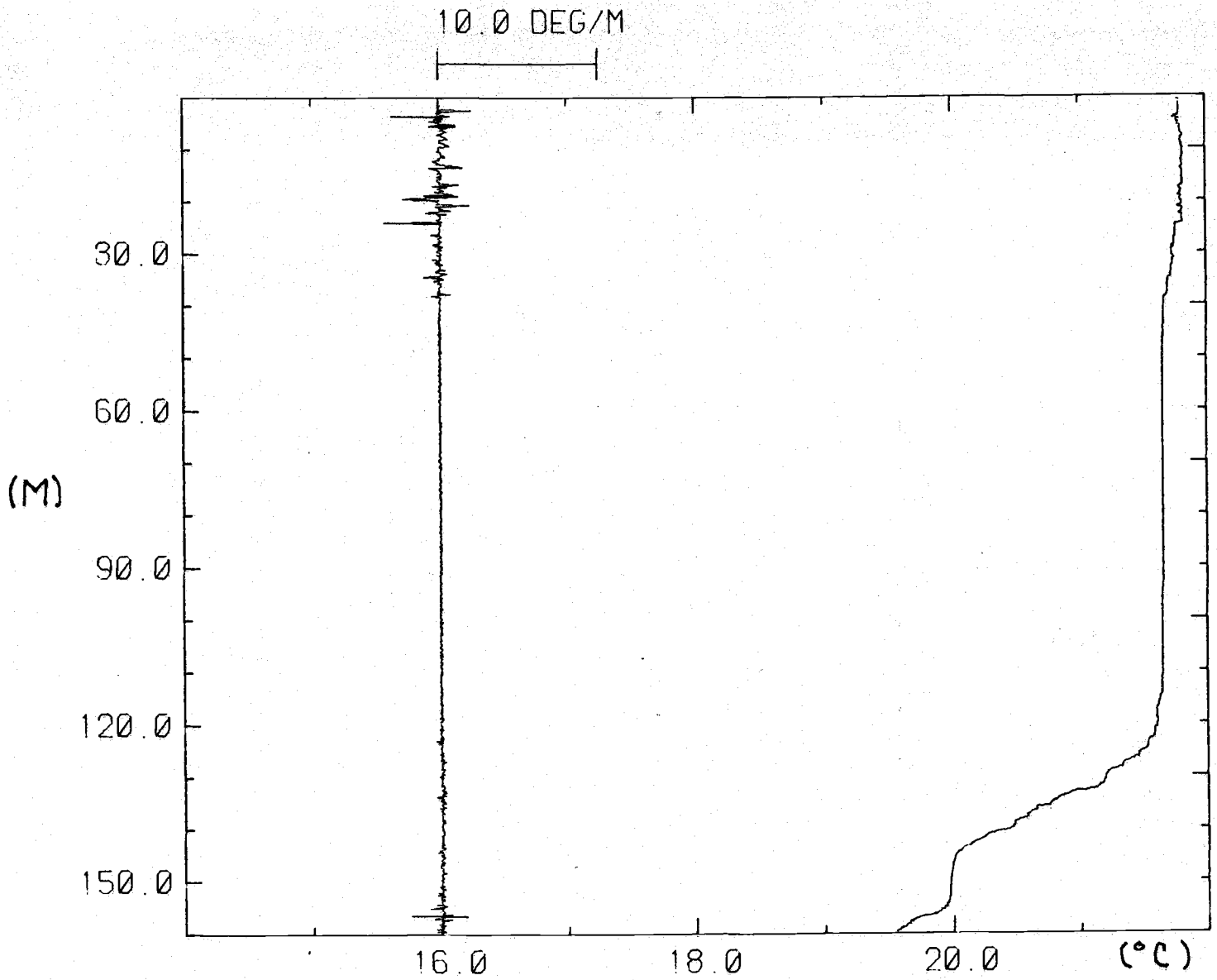


Figure 6. Temperature profile F8D3, south of frontal zone, at  $26^{\circ}05.8'N-155^{\circ}45.1'W$ . A moderately active surface mixing layer extends to 40 m depth.

## Mesopelagic Fishes

by

Mark D. Willis and W. G. Pearcy

Oregon State University

A total of 81 species of fishes were identified from fourteen 3-m Isaac-Kidd Midwater trawl (IKMT) tows to 200 m depth at night and twelve neuston tows made during FRONTS from the R/V THOMAS WASHINGTON.

Jaccard and Bray-Curtis similarity measures were calculated for fishes in all pairs of IKMT tows, but neither analysis showed any groupings of hauls which could be related to surface physical structure, or latitude. Many species occurred at most stations, and few species were restricted to the northern or southern stations. These preliminary results suggest only weak changes in species composition of fishes in the region sampled.

Some trends in species abundance were found, but they were inconsistently correlated with surface features. For example, the lanternfish Notolychnus valdiviae, one of the most abundant species captured, was most common in the region of an intrusion of low salinity, cold water from the northeast during 24-30 January (Fig. 1). During 31 January-11 February the highest catch was again found in the lower salinity water to the south (Fig. 2). Since almost all of the species captured by the IKMT are not surface-dwelling forms, their distributions may correlate better with subsurface features.

Future research will include correlation of species distributions with subsurface physical gradients measured during FRONTS, and comparison of the fish fauna with those reported from previous cruises within the eastern central North Pacific.

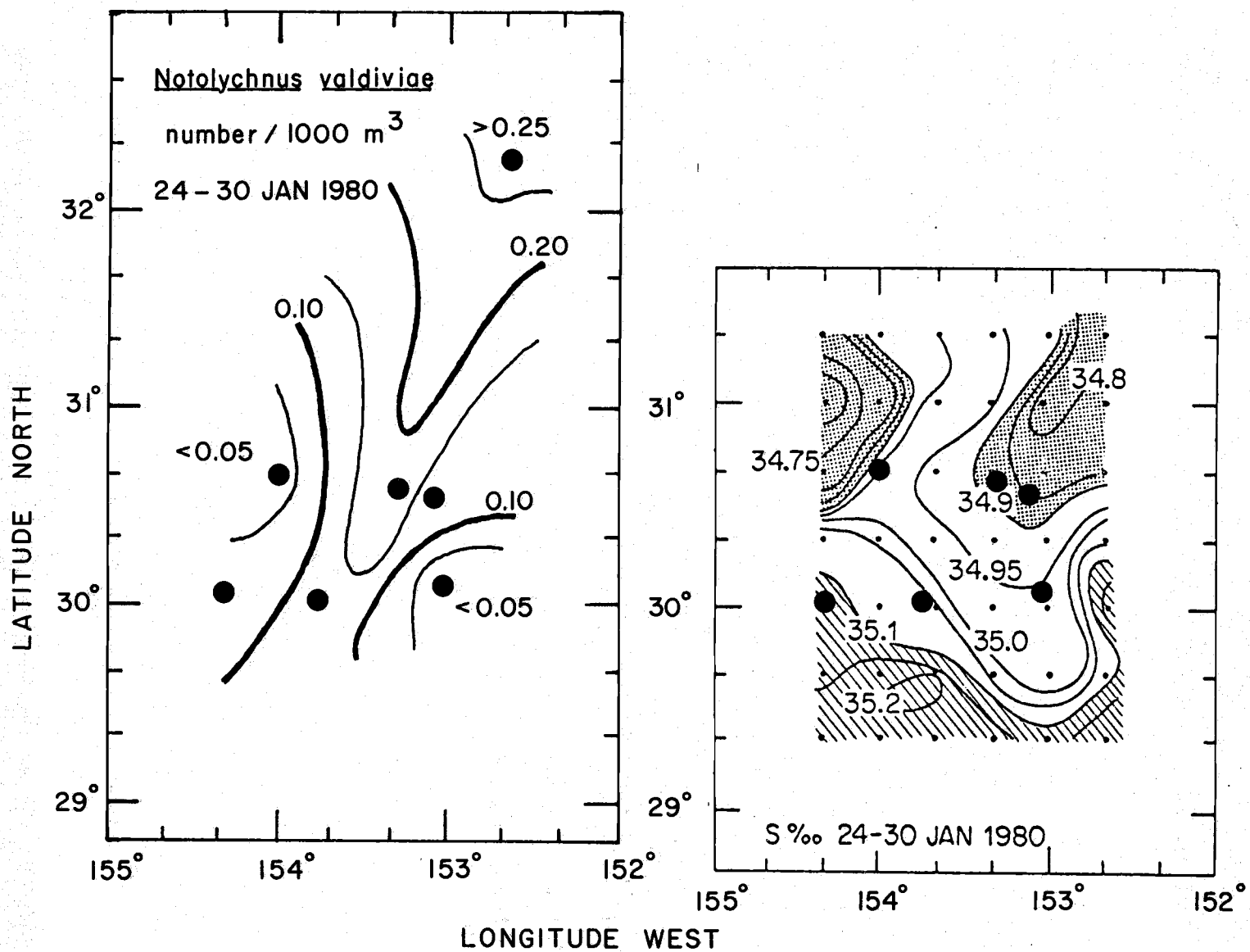


Figure 1. Contours of abundance (number per 1000 m<sup>3</sup>) of *Notolychnus valdiviae* (left), and contours of surface salinity (data from G. Roden, right) for 24-30 January, 1980.

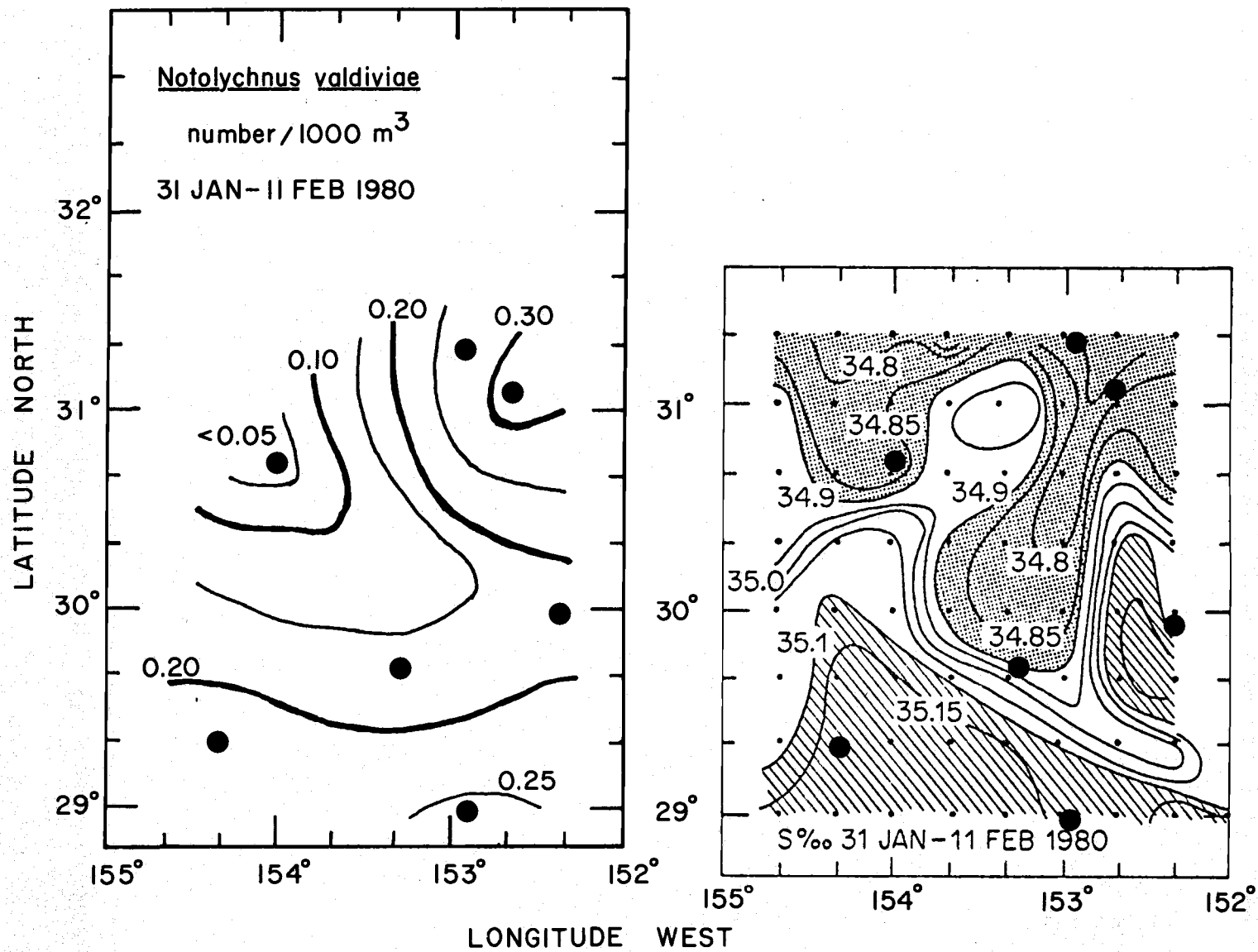


Figure 2. Contours of abundance (number per 1000 m<sup>3</sup>) of Notolychnus valdiviae (left), and contours of surface salinity (data from G. Roden, right) for 31 January-11 February 1980.

## REFERENCES

- Anderson, R. J. and S. D. Smith, 1980: Evaporation coefficient for the sea surface from eddy flux measurements. J. Geophys. Res. (submitted).
- Evans, D. L., H. T. Rossby, M. Mark and T. Gytre, 1979: YVETTE--A free fall shear profiler. Deep Sea Res., 26, 703-718.
- Large, W. G. and S. Pond, 1980: Open ocean momentum flux measurements in moderate to strong winds. J. Phys. Oceanog. (submitted).
- Roden, G. I., 1980: On the subtropical frontal zone north of Hawaii during winter. J. Phys. Oceanog., 10, 342-362.