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Subduction in the Subtropical Gyre: Seasoar Cruises Data Report

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Technical Report

Funding was provided by the Office of Naval Research through Grants Nos. N00014-91-J-1585, N00014-90-J-1425 and N00014-90-J-1508.

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Philip L. Richardson, Chair
Department of Physical Oceanography

Abstract

The overall objective of the Subduction Accelerated Research Initiative (ARI) was to bring together several techniques to address the formation and evolution of newly formed water masses. The Seasoar component provided surveys of temperature and salinity to help determine the spatial variability of the temperature, salinity and density fields in both the active frontal regions and in the vicinity of subducting water tagged by bobbers. Data were collected in the eastern North Atlantic Ocean in spring 1991, winter 1992, winter 1993 and spring 1994. "Star" patterns were used to study the mesoscale variability. Temperature, pressure and thickness for each pattern were objectively mapped on potential density surfaces of 26.5, 26.7 and 26.9 kg/m^3. Acoustic Doppler Current Profiles (ADCP) maps were also created for the two shallower density surfaces. We describe the Seasoar data collected during the four cruises. A CD-Rom includes 1- and 3-second conductivity-temperature-depth (CTD), cruise navigation, ADCP and Seasoar engineering data, as well as color figures of these data. This data report can also be viewed using an internet information browser (i.e., Mosaic, Netscape) using the provided CD-Rom.

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1. Introduction

Seasoar conductivity-temperature-depth (CTD) data were collected during the Subduction Experiment in the eastern North Atlantic during the period of May 1991–May 1993. The Seasoar work is part of the Subduction Accelerated Research Initiative (ARI) supported by the Office of Naval Research. The overall objective was to bring together several techniques to address the formation, evolution and subduction of newly formed water masses over a two year period. Other activities include synoptic mesoscale sampling of tracers, including potential vorticity in the upper pycnocline, and direct tagging of water parcels with bobber floats, as well as independent Eulerian velocity and meteorological measurements from surface moorings. The Seasoar provides well-resolved surveys to help determine the spatial variability of the temperature, salinity and density fields in both the active frontal regions and in the vicinity of subducting water tagged by the bobbers.

The Seasoar, manufactured by Chelsea Instruments, Ltd., is a towed vehicle equipped with impeller-forced wings that can be adjusted to undulate in the upper ocean. The wings are controlled by signals from the ship, and moved by an hydraulic unit. The Seasoar undulates between 0–450 dbars while being towed at about eight knots, cycling to the surface approximately every 12 minutes. The Seasoar group participated in four cruises during the experiment (Table 1). On the initial cruise in May 1991, 18 bobbers were deployed, three mesoscale surveys ("star patterns") and a frontal survey were completed (Luyten, 1991). In February 1992, a second frontal survey was completed (Rudnick, 1992). The following November, six star patterns near bobbers and two long transects were executed (Joyce, 1992). The final cruise, May 1993, surveyed near four bobbers and towed along three long transects (Luyten, 1993) (Figure 1, Table 2). In conjunction with four star patterns (two on the first and two on the last cruise), a series of closely spaced CTD stations, using a profiling CTD, were made overlaying the star pattern in an L-shaped pattern for the tracer studies. We used the CTD data from these stations to augment the Seasoar dataset. All cruises were on the R/V *Oceanus*.

Table 1: Dates corresponding to the cruises during the Subduction Experiment.

Subduction 1 (OC240 Leg 2)	5 May 1991–3 June 1991	J. Luyten
Subduction 2 (OC250 Leg 3)	2 March 1992–20 March 1992	D. Rudnick
Subduction 3 (OC254 Leg 4)	24 November 1992–16 December 1992	T. Joyce
Subduction 4 (OC258 Leg 3)	18 May 1993–16 June 1993	J. Luyten

Table 2: This table includes the mean locations, start and end times for all the star patterns surveyed on the Subduction cruises. In addition, it includes the start and end locations and times for the sections presented in this data report.

Cruise	Star	Start Time	End Time	Latitude	Longitude
1	1	05/16/91	05/20/91	22.8655 N	−27.0472 E
1	2	05/23/91	05/27/91	29.0139 N	−23.5313 E
1	3	05/31/91	06/02/91	29.9845 N	−21.6587 E
3	1	11/28/92	11/30/92	20.3393 N	−29.6893 E
3	2	12/01/92	12/02/92	22.8685 N	−27.0472 E
3	3	12/02/92	12/04/92	22.7953 N	−28.6941 E
3	4	12/04/92	12/06/92	23.2972 N	−29.4279 E
3	5	12/08/92	12/11/92	25.1120 N	−24.4478 E
3	6	12/11/92	12/12/92	26.9678 N	−24.9349 E
4	1	05/24/93	05/27/93	18.9862 N	−31.9748 E
4	2	05/30/93	05/31/93	24.2855 N	−37.4544 E
4	3	06/02/93	06/03/93	23.5120 N	−31.6550 E
4	4	06/05/93	06/08/93	28.1707 N	−26.3902 E

Cruise	Sect	Start Time	End Time	Start Latitude	Start Longitude	End Latitude	End Longitude
3	1	12/06/92	12/08/92	23.2020 N	−29.0249 E	24.6882 N	−24.6651 E
3	2	12/12/92	12/14/92	26.8574 N	−24.8574 E	32.6342 N	−24.7439 E
4	1	05/27/93	05/30/93	19.0518 N	−32.0232 E	24.6200 N	−24.6200 E
4	2	06/04/93	06/05/93	26.3285 N	−28.2048 E	27.8200 N	−26.1847 E
4	3	06/08/93	06/09/93	28.9257 N	−25.8696 E	28.8426 N	−23.0890 E
4	4	06/09/93	06/10/93	28.8509 N	−23.0497 E	30.4189 N	−23.8573 E
4	5	06/10/93	06/11/93	30.4394 N	−23.8296 E	32.9475 N	−21.5498 E

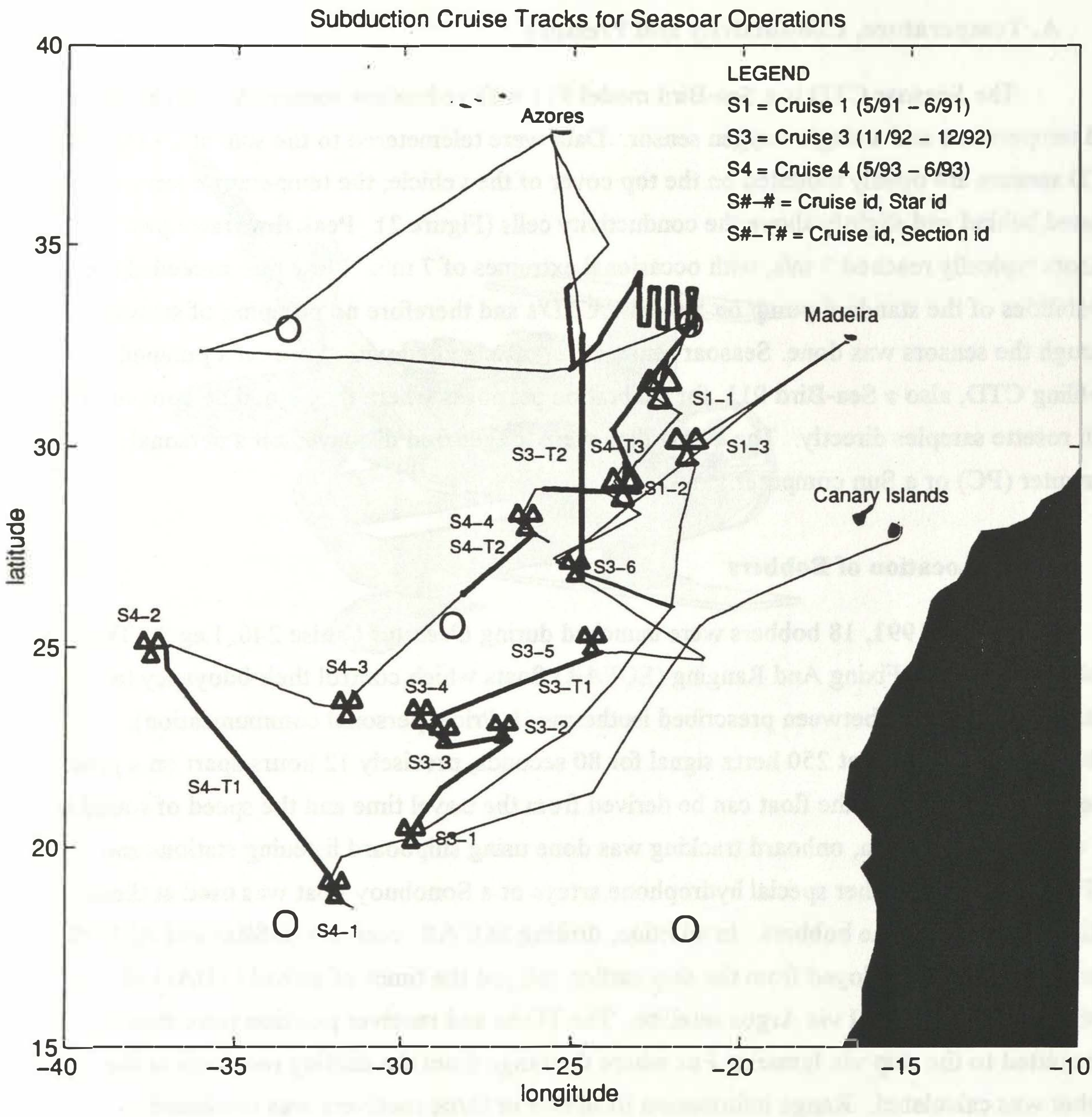


Figure 1: Seasoar Cruise Track: May 1991–May 1993. Heavy lines denote when Seasoar was actually being towed. Heavy circles are location of Subduction moorings.

2. Methods

A. Temperature, Conductivity and Pressure

The Seasoar CTD is a Sea-Bird model 911 with redundant sensors for conductivity and temperature and a single oxygen sensor. Data were telemetered to the ship at 24 Hz. The CTD sensors are openly mounted on the top cover of the vehicle, the temperature sensors are located behind and slightly above the conductivity cells (Figure 2). Peak flow rates past the sensors typically reached 5 m/s, with occasional extremes of 7 m/s. Flow rate exceeded the capabilities of the standard pump on Sea-Bird CTD's and therefore no pumping of seawater through the sensors was done. Seasoar sensors were exchanged with those on a pumped profiling CTD, also a Sea-Bird 911, for calibration purposes where they could be compared with rosette samples directly. The 24 Hz data were logged and displayed on a personal computer (PC) or a Sun computer.

B. Location of Bobbers

In May 1991, 18 bobbers were launched during *Oceanus* Cruise 240, Leg 2. The bobbers are SOund Fixing And Ranging (SOFAR) floats which control their buoyancy to cycle every other day between prescribed isotherms (J. Price, personal communication). Bobbers transmit a swept 250 hertz signal for 80 seconds, precisely 12 hours apart on a preset schedule. The range to the float can be derived from the travel time and the speed of sound in the water. While at sea, onboard tracking was done using shipboard listening stations and SOFAR receivers. Either special hydrophone arrays or a Sonobuoy float was used at these stations to listen for the bobbers. In addition, drifting SOFAR receivers (DSRs) and ALFOS floats, which were deployed from the ship earlier, relayed the times of arrival (TOAs) of bobber signals to WHOI via Argos satellite. The TOAs and receiver position were then transmitted to the ship via Inmarsat Fax where the range from the drifting receivers to the bobber was calculated. Range information from two or three receivers was combined to locate the bobbers by triangulation. On the final cruise, the moored autonomous listening stations (ALS), which had been recording TOAs from the bobbers since May 1991, were recovered. The ALS data were decoded and actual positions were determined for the bobbers for the times of the Seasoar surveys (Figure 3 – a. Subduction 3 and b. Subduction 4).

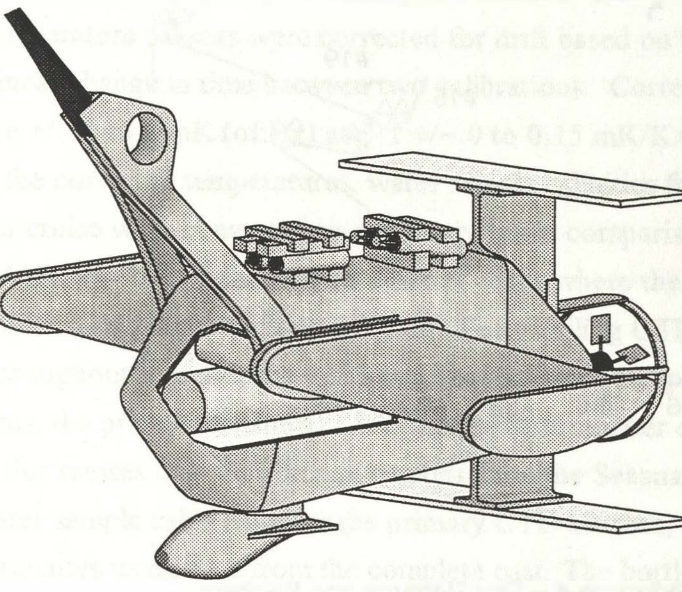


Figure 2: Seasoar vehicle with sensors

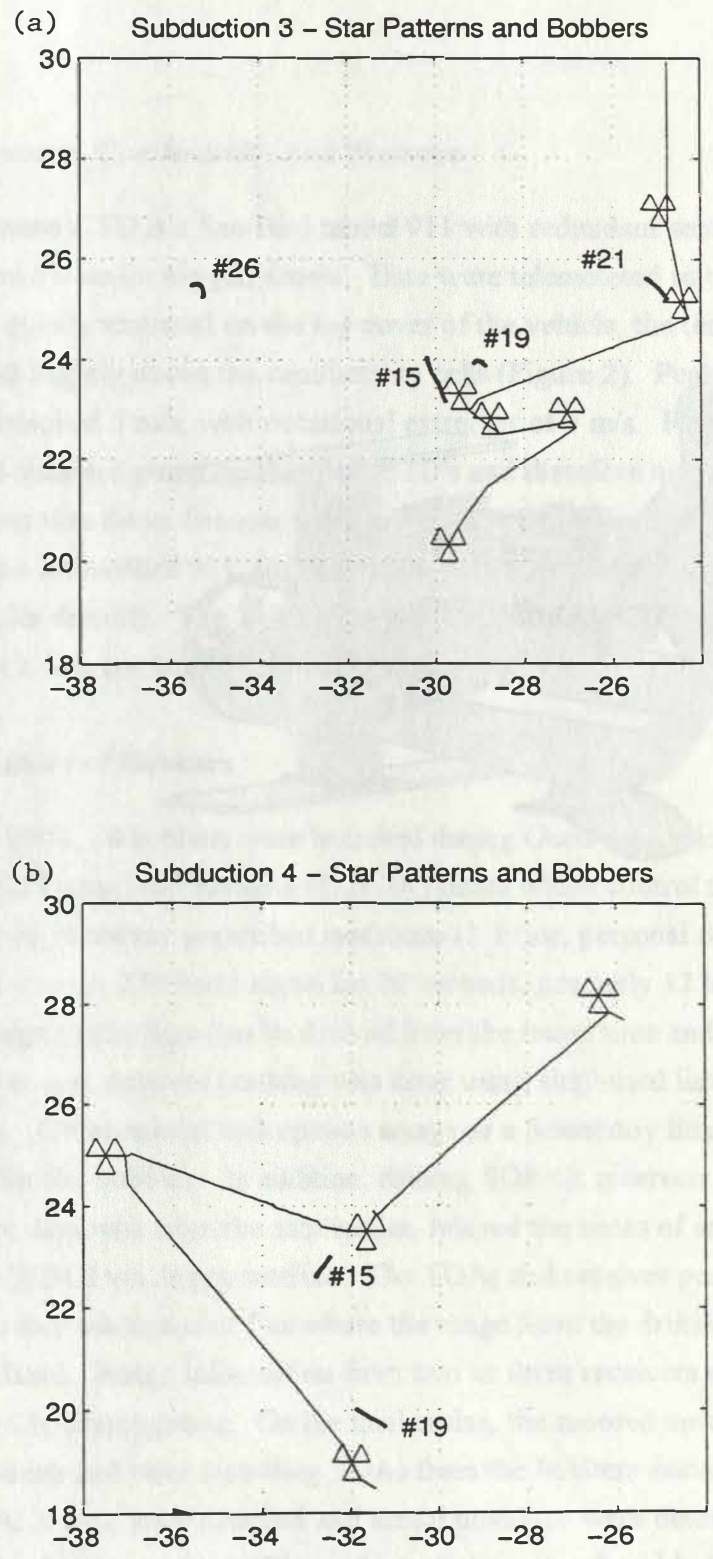


Figure 3: Bobber location at the time of Seasoar mesoscale survey determined from ALFOS data. (a) Subduction 3. (b) Subduction 4.

C. Data Processing

The CTD temperature and conductivity sensors were calibrated for each cruise using a combination of lab calibrations (done by Sea-Bird at the North-West Calibration Center) and comparisons with water samples collected on a profiling CTD. All sensors were calibrated before the initial cruise and following all subsequent cruises.

The temperature sensors were corrected for drift based on the lab calibrations alone, by assuming a linear change in time between two calibrations. Corrections to the laboratory calibrations were +/- 0 to 2 mK (offset) and 1 +/- 0 to 0.15 mK/K (slope).

Using the corrected temperatures, water sample salinities from approximately seven deep stations per cruise were converted to conductivity for comparison with the conductivity sensors. The calibration for conductivity in shallow water where the vertical gradients are large and spatially variable is particularly difficult. The profiling CTD maintained one sensor pair (primary) throughout a cruise, the secondary sensors were swapped with the Seasoar's for calibrations. Thus, the primary sensor pair had the greatest number of water samples to use for calibration. For cruises one and three, we determined the Seasoar sensor calibration by performing a water sample calibration for the primary CTD sensors, and then fit the secondary sensors to the primaries using data from the complete cast. The bottle data for the secondary sensors then served as a consistency check for the obtained calibration values. For Subduction 4, however, this approach generated a correction to the pre-cruise lab calibration that largely exceeded the post-cruise lab calibration. This can not occur if the sensors drift essentially linearly in time. We, therefore, relied only on the direct bottle comparison to calibrate the Seasoar conductivity sensors. Additionally, the vertical conductivity gradient during this cruise was at times so strong that the vertical separation of 1.5 meters between bottles and sensors introduced an error large enough to affect the calibration. To correct for the spatial difference, a polynomial fit of the conductivity gradient was determined for each station, and an offset was applied based on the polynomial and the distance between bottles and sensors. The conductivity gradients from the other cruises were not large enough to require this correction. Conductivity corrections ranged from -1.7 to +0.7 mS (offset) and 1 +/- 0 to 0.6 mS/S (slope). The remaining differences between calibrated CTD conductivity and bottle conductivities were of the order of 0.2 mS/m (deep samples) to 0.5 mS/m (shallow samples), corresponding to salinity differences of 0.002 to 0.005 psu.

The calibrated 24 Hz data were then screened for anomalous points using a 9-point median filter. To determine the proper relationship between temperature and conductivity sensors influenced by their physical separation and sensor response times, salinity was calculated for various lags of temperature and pressure relative to conductivity. A lag of 4 scans (1/6 second) was found to minimize salinity spiking across sharp gradients. This lag was consistent over the course of the experiment. The data were edited further by excluding data shallower than 1 dbar. This excludes salinity spikes due to air in the conductivity cell when the Seasoar breaks the surface. Summary figures for quality control were produced (Figure 4). The data were then binned into 1 and 3 sec datasets (available in ASCII and Matlab format on CD-Rom) of time, pressure, potential temperature, salinity, and potential density. Salinity and potential density were calculated after binning.

The 3 second averaged data were interpolated onto a uniform grid in depth/distance along the Seasoar track using a second order exponential filter with vertical and horizontal scales of 5 dbar and 4 km, respectively. Grid points for which the sum of weights were less than or equal to 0.1 were flagged (Figure 5). Data were then mapped onto density surfaces at intervals of 0.05 sigma-theta (Table 3, Figure 6). Where appropriate, CTD data from the L-shaped tracer surveys were combined with the Seasoar data and input into the objective mapping programs. We chose to focus on sigma-theta levels of 26.5, 26.7 and 26.9. The levels correlate with the isotherm boundaries and corresponding average densities of the bobbers when they were initially deployed (Figure 7). The thickness of each density surface is based on the density gradient centered on the density surface of interest with a fixed density difference of 0.05 sigma-theta. The mapping technique used a spatial correlation scale of 10 km, and a signal-to-noise ratio of 50 percent was assumed. Areas with errors exceeding 95 percent were not contoured. Data was objectively mapped for all Seasoar surveys on the above-mentioned density surfaces for potential temperature, salinity, pressure and thickness (Figures 8a–i).

Despite the variety of shipboard location tools for determination of bobber position, the actual location of bobbers during the experiment was problematic. In some instances, insufficient fixes were available to locate bobbers or two Seasoar surveys were carried out because of possible ambiguities in bobber location. Why post-experiment bobber tracks (using the moored ALS data) seem to be 'offset' from at-sea locations has not been resolved. Thus, the Seasoar maps around bobbers should be considered only to reflect the general characteristics of the water masses at that particular time.

Table 3: Mean and standard deviation of theta, pressure and thickness on density surfaces 26.5, 26.7, 26.9 for all star patterns surveyed. Not enough data were available for density level 26.9 for surveys 3 and 4 during Subduction 4.

SUBDUCTION 1 - STAR PATTERN 1:
DATES: 05/16/91 10:30 - 05/20/91 07:30
BOBBER #: 24,29,22,5,8,21,16,17,18,23,25
MEAN LAT: 31.4729 N
MEAN LONG: -22.4486 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.7702	16.2514	13.9505
Std. Theta	0.0201	0.0680	0.0206
Avg. Press	60.7186	240.5842	364.9566
Std. Press	10.9056	10.0753	4.1349
Avg. Thick	78.4115	31.4357	36.6801
Std. Thick	5.6687	1.5292	1.3638
# grid pts	86	469	223

SUBDUCTION 1 - STAR PATTERN 2:
DATES: 05/23/91 06:00 - 05/27/91 20:00
BOBBER #: 19,14,11,12,26,20,15
MEAN LAT: 29.0139 N
MEAN LONG: -23.5313 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.8185	16.1601	13.9314
Std. Theta	0.1699	0.0929	0.0249
Avg. Press	124.4070	241.9765	366.1262
Std. Press	6.6596	6.3833	4.9197
Avg. Thick	41.0442	30.1820	35.9329
Std. Thick	8.8076	1.6768	1.3890
# grid pts	473	473	346

SUBDUCTION 1 - STAR PATTERN 3:
DATES: 05/31/91 06:30 - 06/02/91 01:30
BOBBER #:
MEAN LAT: 29.9845 N
MEAN LONG: -21.6587 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.7825	16.4236	13.9782
Std. Theta	0.2247	0.1287	0.0264
Avg. Press	51.0511	216.5273	340.1730
Std. Press	4.2587	15.9862	18.1612
Avg. Thick	45.1072	27.1940	36.2476
Std. Thick	5.5786	4.7615	1.0980
# grid pts	418	420	360

Table 3 (continued)

SUBDUCTION 3 - STAR PATTERN 1:
DATES: 11/28/92 22:00 - 11/30/92 14:00
BOBBER #: 26
MEAN LAT: 20.3393 N
MEAN LONG: -29.6893 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	17.6773	15.6800	13.5893
Std. Theta	0.1868	0.1361	0.0823
Avg. Press	163.4997	234.0999	342.2342
Std. Press	10.8143	11.4590	10.1150
Avg. Thick	13.0774	22.1654	30.2678
Std. Thick	0.8380	1.6846	1.5926
# grid pts	308	308	304

SUBDUCTION 3 - STAR PATTERN 2:
DATES: 12/01/92 01:00 - 12/02/91 18:30
BOBBER #: 15,25
MEAN LAT: 22.8685 N
MEAN LONG: -27.0472 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.2682	16.0629	13.8362
Std. Theta	0.0742	0.0673	0.0426
Avg. Press	180.6118	262.3036	373.9740
Std. Press	5.6818	5.9471	5.1209
Avg. Thick	14.5908	24.6175	28.2718
Std. Thick	0.6068	1.1954	1.4681
# grid pts	308	308	308

SUBDUCTION 3 - STAR PATTERN 3:
DATES: 12/02/92 19:00 - 12/04/92 19:30
BOBBER #: 19
MEAN LAT: 22.7953 N
MEAN LONG: -28.6941 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.3048	16.0337	13.8438
Std. Theta	0.0858	0.0732	0.0374
Avg. Press	191.6362	271.8771	376.0974
Std. Press	6.4222	5.5544	5.1748
Avg. Thick	14.3554	23.5976	24.8414
Std. Thick	0.7220	0.8780	1.5926
# grid pts	312	312	30

Table 3 (continued)

SUBDUCTION 3 - STAR PATTERN 4:
DATES: 12/04/92 20:00 - 12/06/92 01:00
BOBBER #: 15
MEAN LAT: 23.2972 N
MEAN LONG: -29.4279 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.1389	15.8712	13.7206
Std. Theta	0.2898	0.2891	0.1830
Avg. Press	187.0571	268.6239	374.4001
Std. Press	5.9160	8.1597	9.1982
Avg. Thick	14.3723	24.3347	25.0590
Std. Thick	0.8294	1.0564	1.4868
# grid pts	301	301	298

SUBDUCTION 3 - STAR PATTERN 5:
DATES: 12/08/92 09:30 - 12/11/92 13:30
BOBBER #: 21
MEAN LAT: 25.1120 N
MEAN LONG: -24.4478 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.5389	16.2373	13.9424
Std. Theta	0.0331	0.0267	0.0070
Avg. Press	176.1963	268.6849	387.1770
Std. Press	4.8472	4.9632	6.2923
Avg. Thick	18.6155	28.0117	30.1917
Std. Thick	1.3784	0.8609	1.1335
# grid pts	272	272	272

SUBDUCTION 3 - STAR PATTERN 6:
DATES: 12/11/92 13:30 - 12/12/92 18:30
BOBBER #: 20
MEAN LAT: 26.9678 N
MEAN LONG: -24.9349 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.2821	16.1338	13.9678
Std. Theta	0.0512	0.0342	0.0164
Avg. Press	164.3603	256.8055	362.1923
Std. Press	3.9648	4.1351	3.9743
Avg. Thick	19.5107	28.0923	33.5705
Std. Thick	0.7727	1.1078	0.8828
# grid pts	265	265	265

Table 3 (continued)

SUBDUCTION 4 - STAR PATTERN 1:
DATES: 05/24/93 07:30 - 05/27/93 12:00
BOBBER #: 19
MEAN LAT: 18.9862 N
MEAN LONG: -31.9748 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	17.8358	15.6538	13.5999
Std. Theta	0.1302	0.0988	0.1453
Avg. Press	199.7486	261.7677	361.3810
Std. Press	10.6113	11.6073	8.3183
Avg. Thick	11.1412	20.6743	28.2127
Std. Thick	0.8561	0.9830	2.1628
# grid pts	306	306	279

SUBDUCTION 4 - STAR PATTERN 2:
DATES: 05/30/93 02:00 - 05.31.93 13:30
BOBBER #: 26
MEAN LAT: 24.2855 N
MEAN LONG: -37.4544 E

Sigma-Theta	26.5	26.7	26.9
Avg. Theta	18.0407	16.0338	13.9275
Std. Theta	0.0810	0.0271	0.0122
Avg. Press	224.9581	318.8388	389.9046
Std. Press	8.3322	9.2240	4.6894
Avg. Thick	18.3139	27.8029	30.8733
Std. Thick	1.4372	1.4772	1.5640
# grid pts	335	335	132

SUBDUCTION 4 - STAR PATTERN 3:
DATES: 06/02/93 01:30 - 06/03/93 14:00
BOBBER #: 15
MEAN LAT: 23.5120 N
MEAN LONG: -31.6550 E

Sigma-Theta	26.5	26.7	
Avg. Theta	18.1924	16.0873	
Std. Theta	0.0251	0.0184	
Avg. Press	192.4304	281.1632	
Std. Press	5.9920	5.0778	
Avg. Thick	17.1146	26.1395	
Std. Thick	1.3808	1.8345	
# grid pts	306	306	

Table 3 (continued)

SUBDUCTION 4 - STAR PATTERN 4:
DATES: 06/05/93 15:00 - 06/08/93 17:30
BOBBER #: 21
MEAN LAT: 28.1707 N
MEAN LONG: -26.3902 E

Sigma-Theta	26.5	26.7	
Avg. Theta	18.4098	16.0449	
Std. Theta	0.0979	0.0424	
Avg. Press	183.8366	292.0272	
Std. Press	11.0004	10.4090	
Avg. Thick	31.0742	28.0224	
Std. Thick	3.0547	1.4874	
# grid pts	366	362	

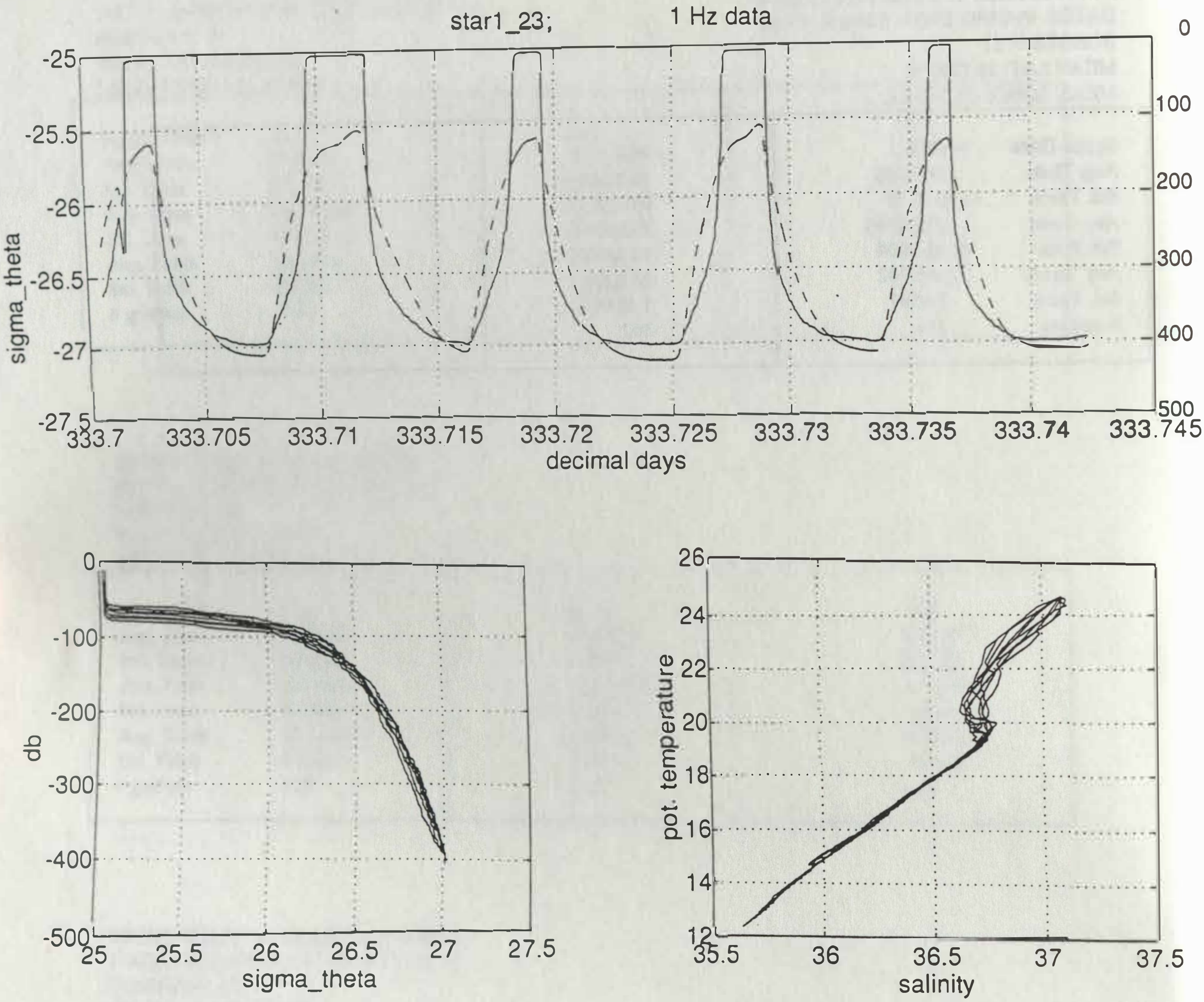


Figure 4: One hour summary plots of Seasoar track. In the upper plot, the dotted line represents pressure over a 0–500 db range vs time. The solid line represent sigma-theta over range of 25–27.5.

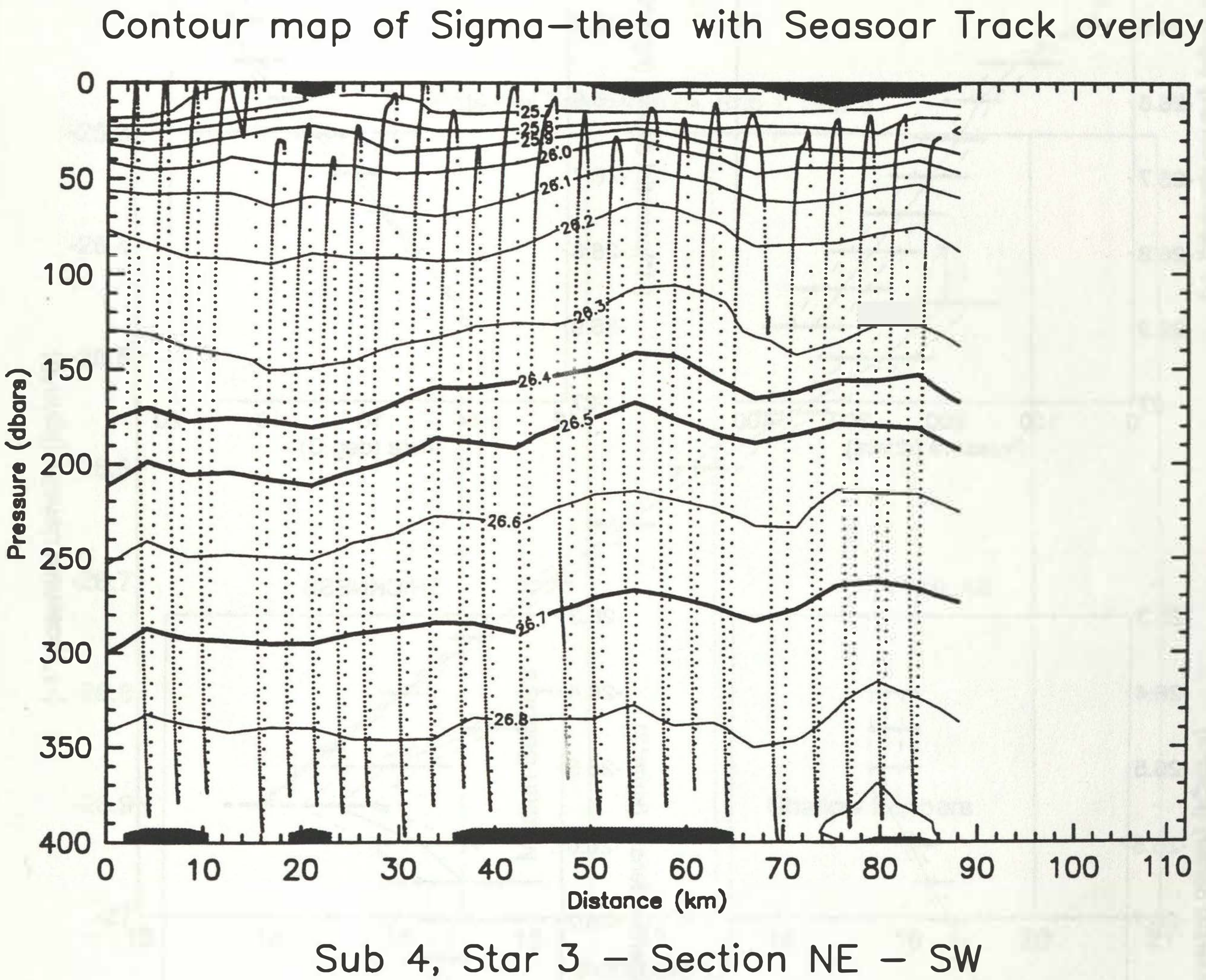


Figure 5: Theta contour plot of gridded Seasoar data along transect 2 of Cruise 3. Gray areas denote unavailable data. The darker lines represent average sigma-theta, during Subduction 1, where the bobbers were deployed (see Figure 7).

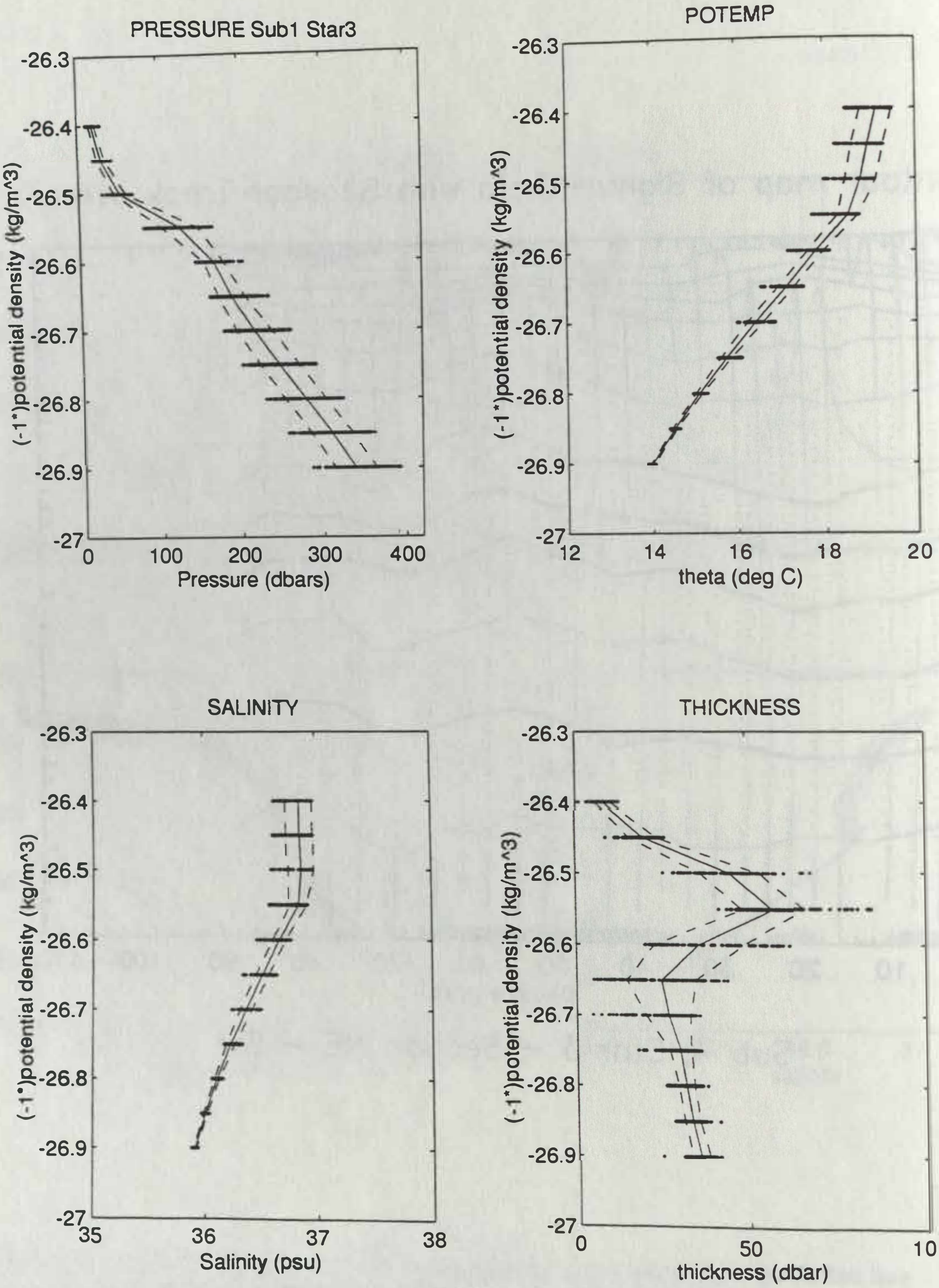


Figure 6: Example Summary plot of pressure, theta, salinity and thickness vs. Sigma-theta. See Appendix A.

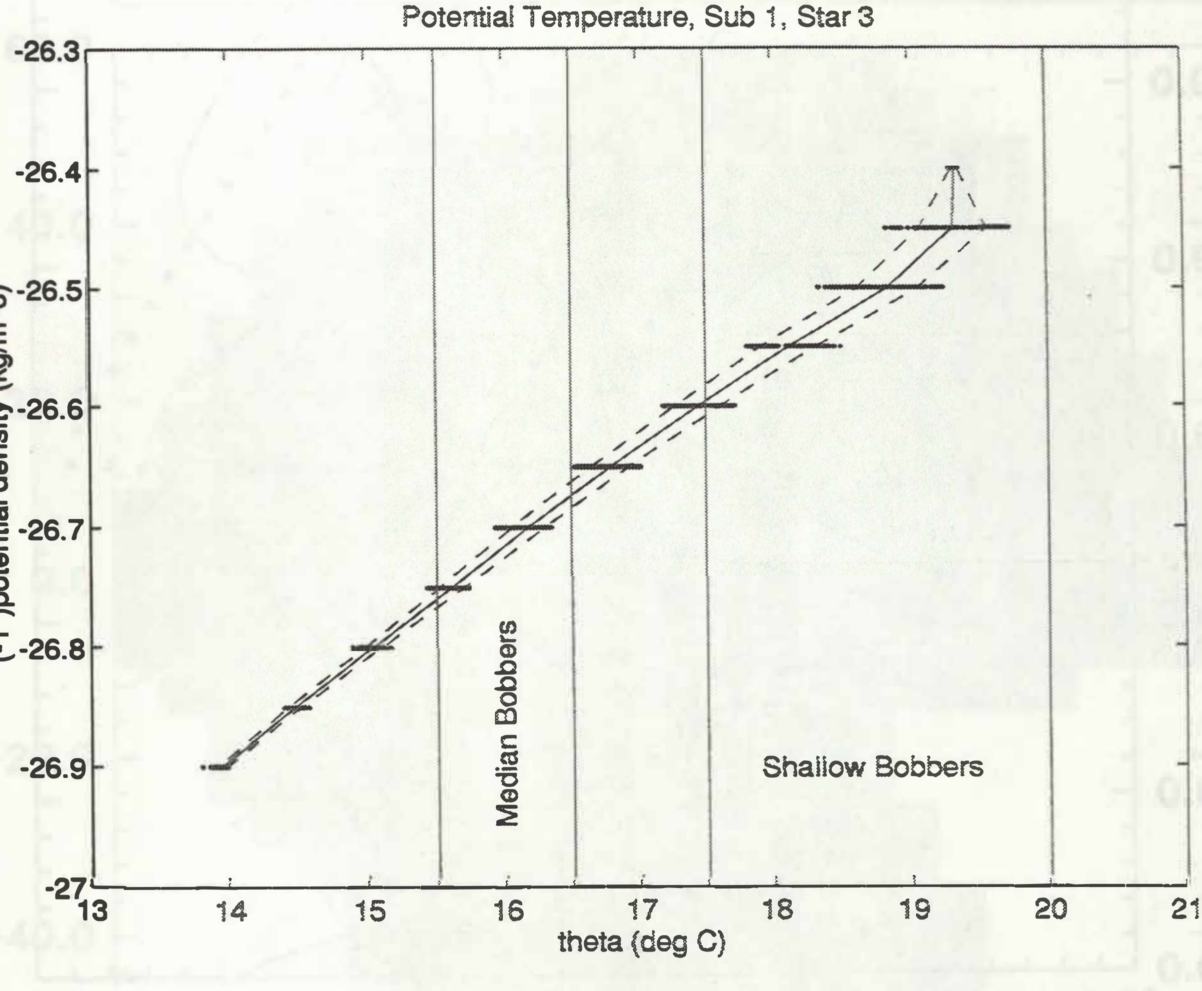


Figure 7: Representative range of bobber movements during Subduction 1.

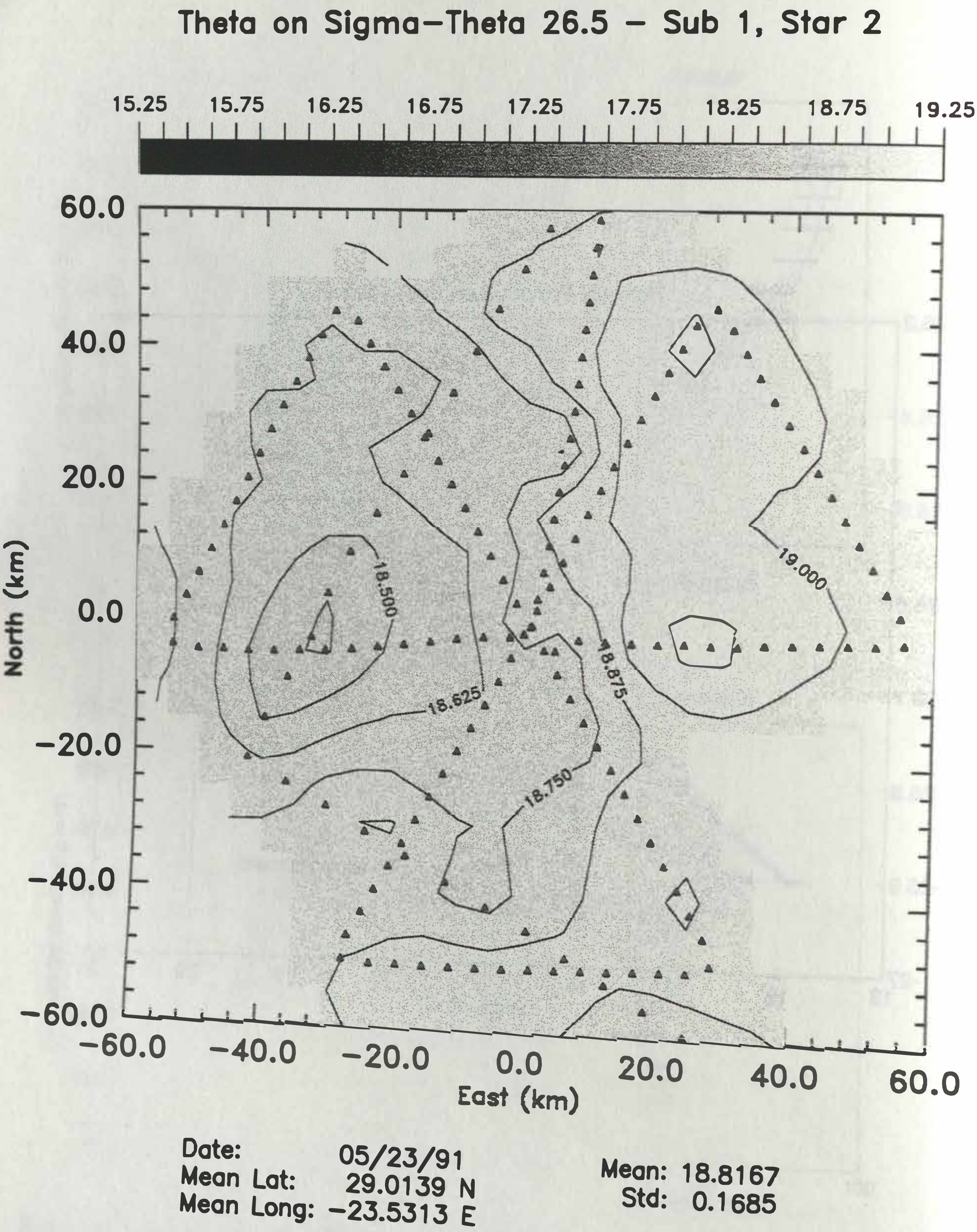
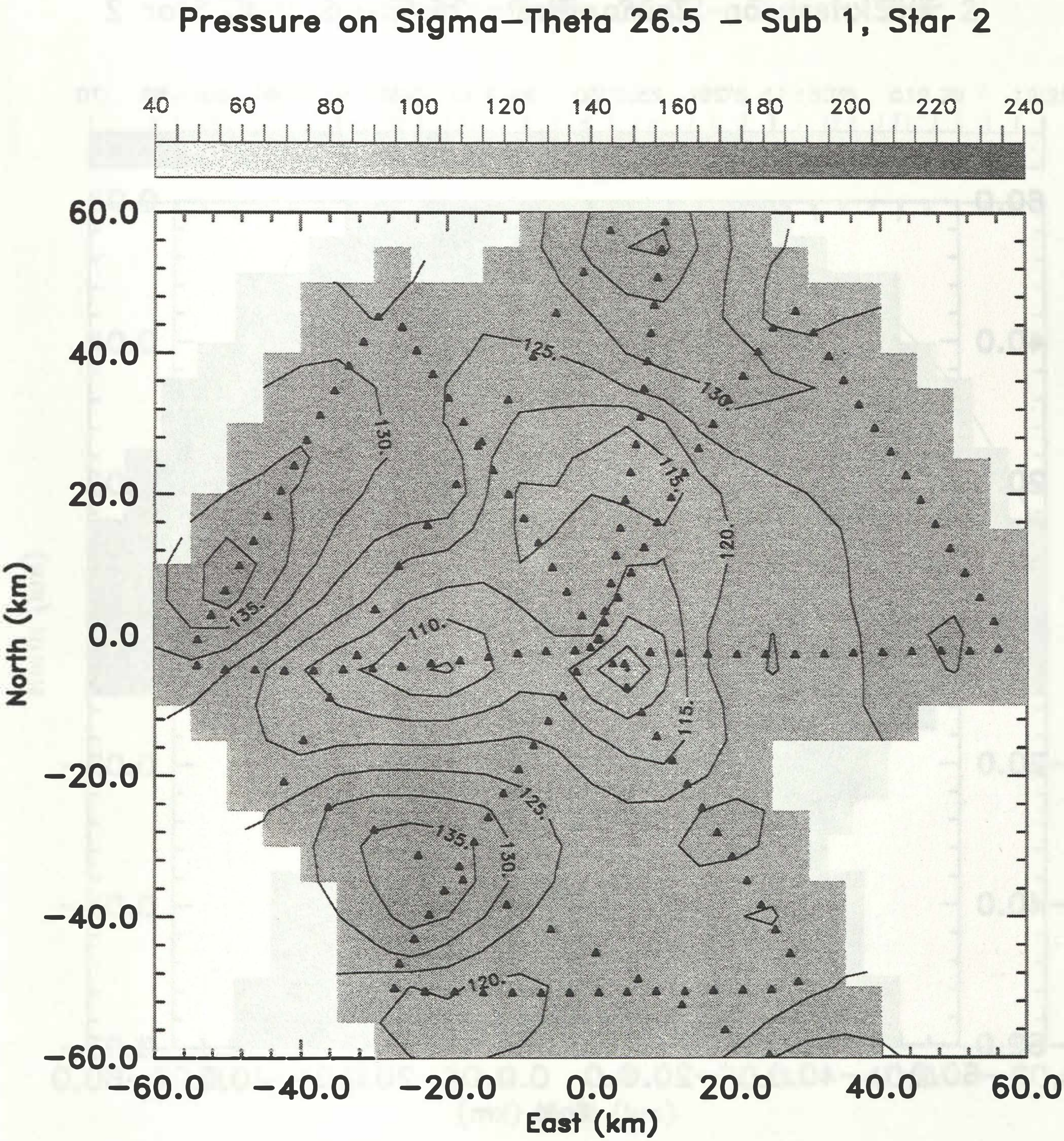


Figure 8a–i: Representative contour maps of theta, pressure and thickness for density levels 26.5, 26.7, 26.9. Each map contains a mean and standard deviation (STD) of the observed property over the entire star pattern. See Appendix D.



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 124.4070
Std: 6.6596

Figure 8b

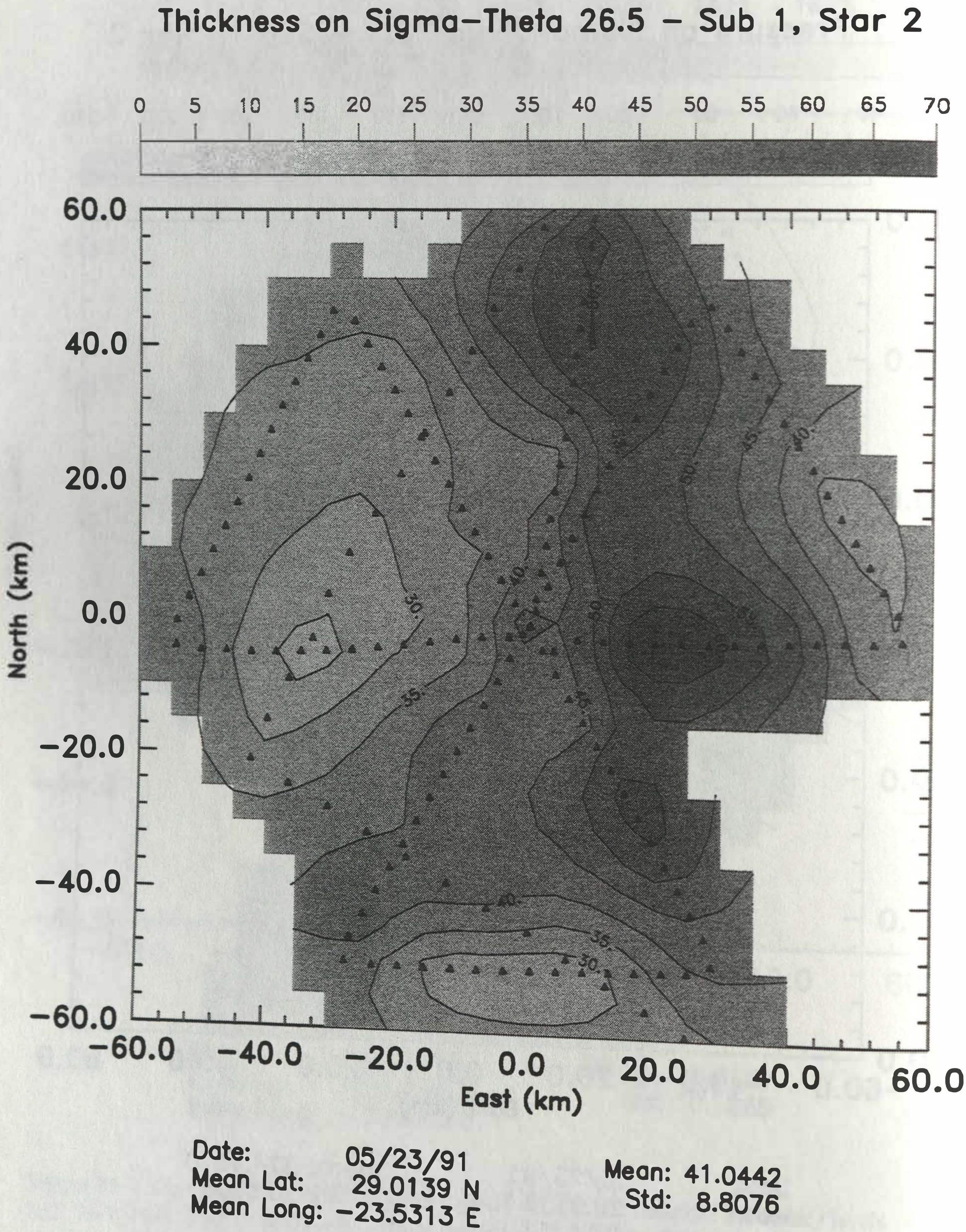

Thickness on Sigma-Theta 26.5 - Sub 1, Star 2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 41.0442
Std: 8.8076

Figure 8c

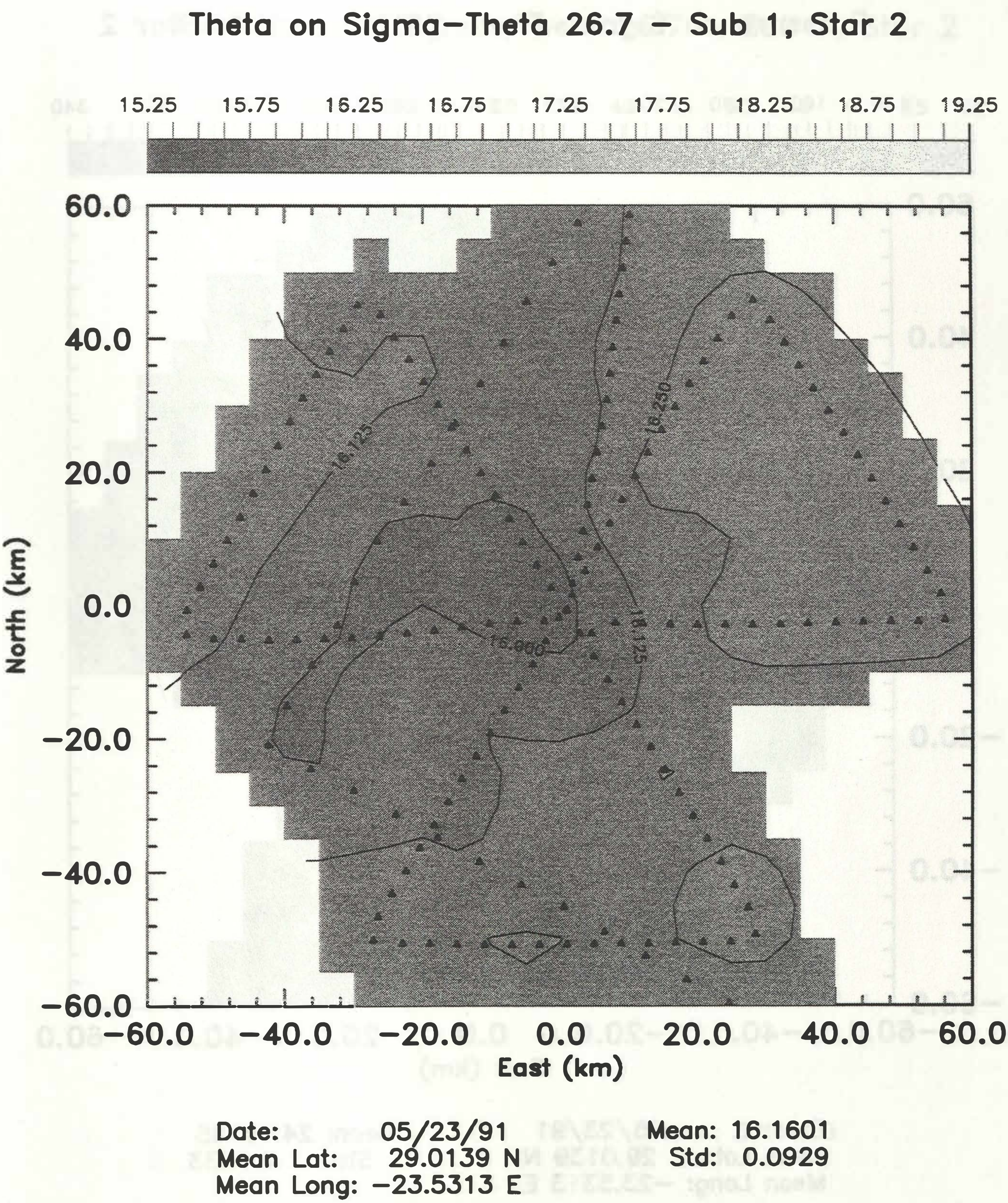
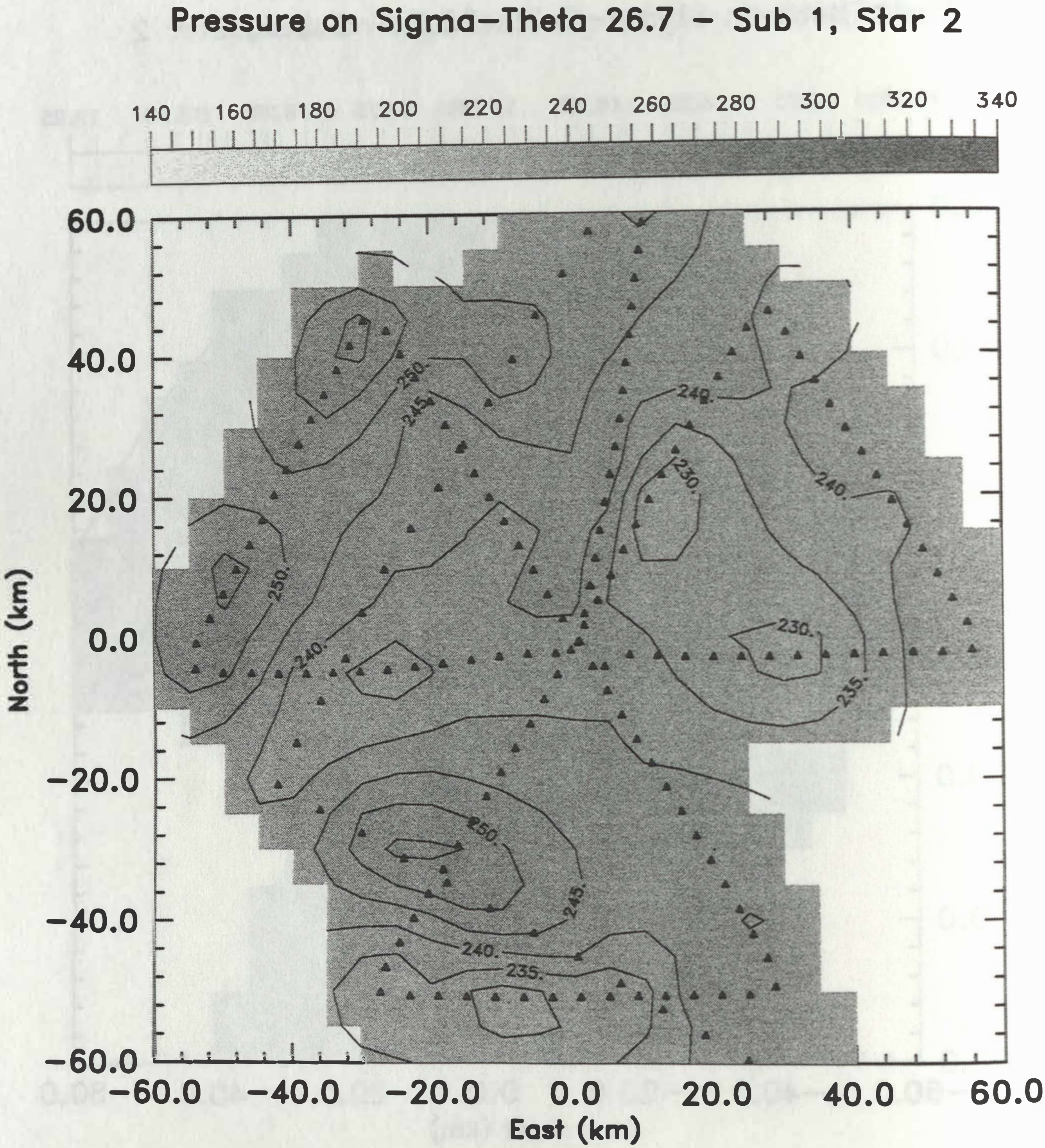

Theta on Sigma-Theta 26.7 - Sub 1, Star 2
15.25 15.75 16.25 16.75 17.25 17.75 18.25 18.75 19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
16.125
16.250
16.000
16.125
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 16.1601
Std: 0.0929

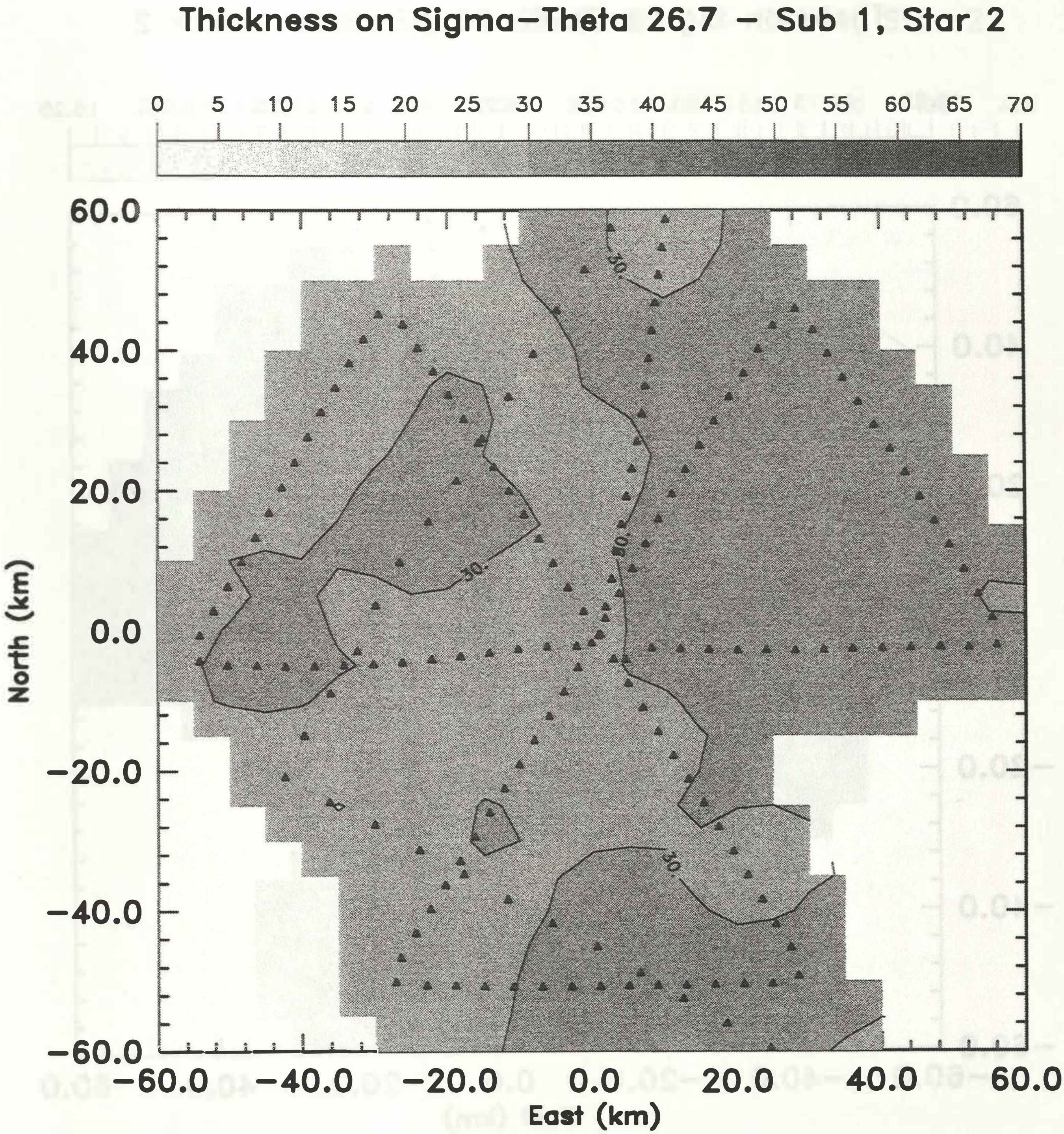
Figure 8d



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E

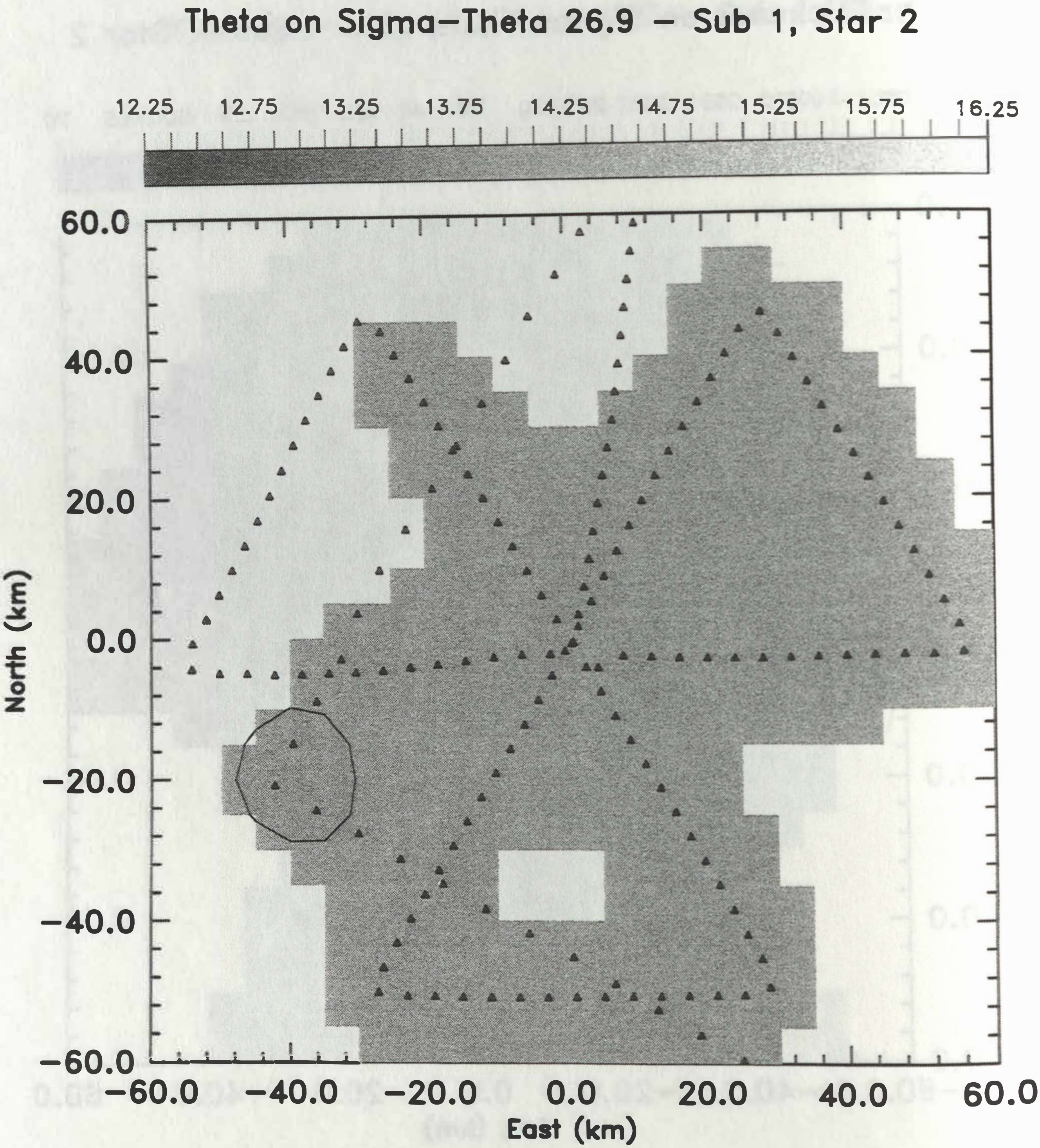
Mean: 241.9765
Std: 6.3833

Figure 8e



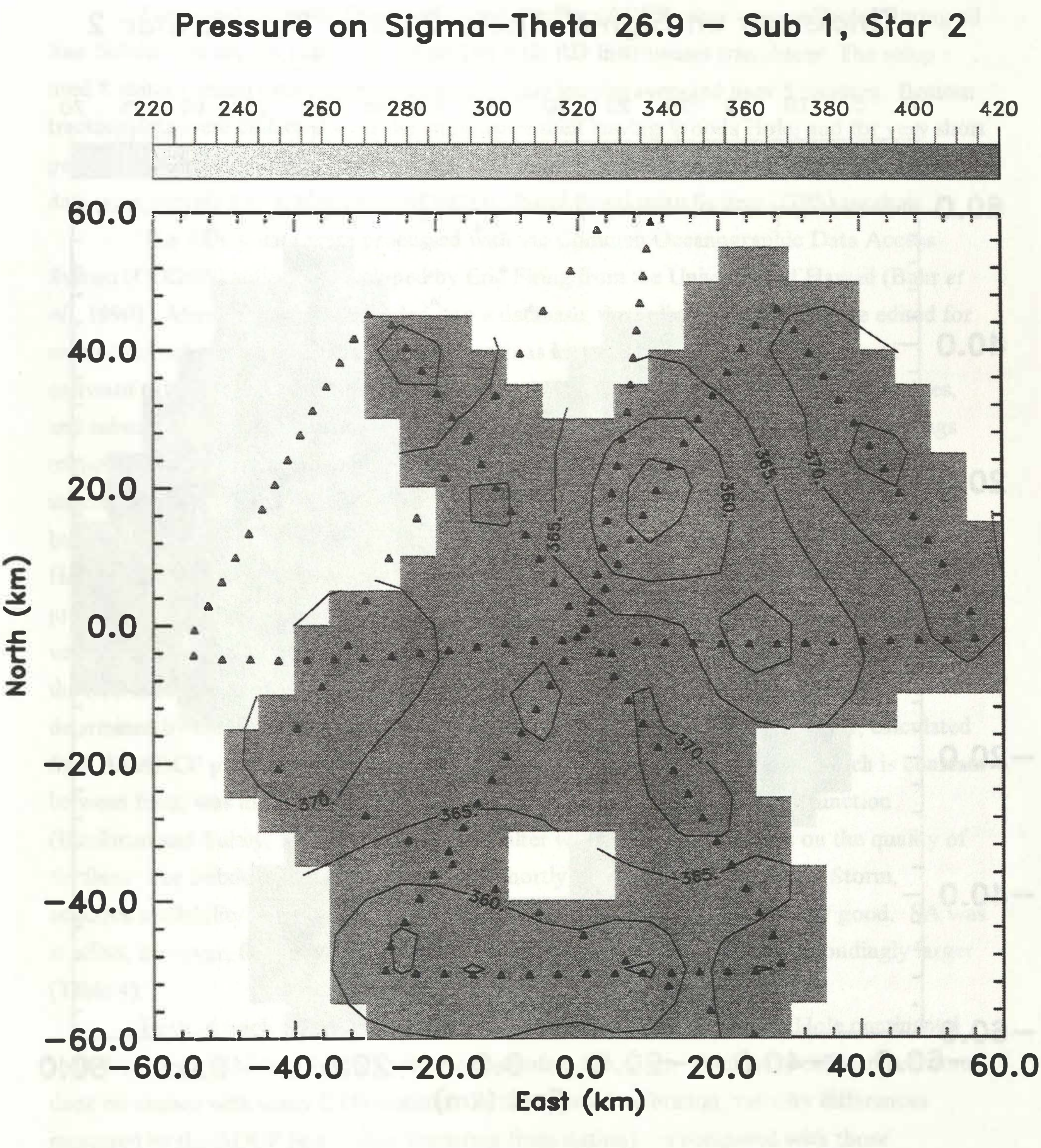
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 30.1820
Std: 1.6768

Figure 8f



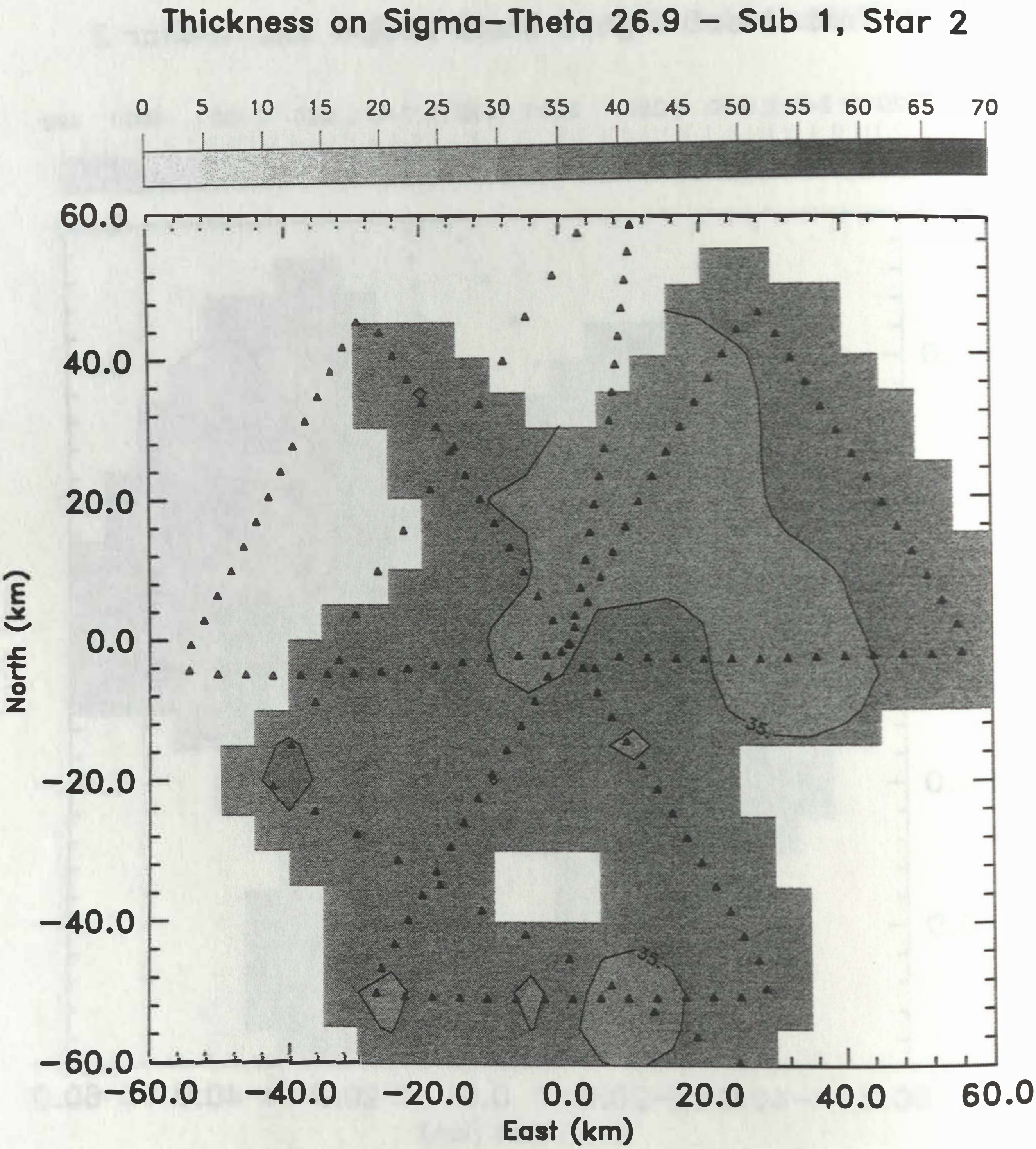
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 13.9314
Std: 0.0249

Figure 8g



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 366.1262
Std: 4.9197

Figure 8h



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E

Mean: 35.9329
Std: 1.3890

Figure 8i

D. Underway Currents – ADCP

Shipboard Acoustic Doppler Current Profiler (ADCP) data were collected during all four Subduction cruises using a standard 150 KHz RD Instruments transducer. The setup used 8 meter vertical bins with 8 or 16 meter pulse lengths averaged over 5 minutes. Bottom tracking data were collected over the continental shelf leaving Woods Hole, and for very short periods over the slopes of the Azores, Madeira, and Gran Canaria. One-second navigation data were provided by a Magnavox MX4200 Global Positioning System (GPS) receiver.

The ADCP data were processed with the Common Oceanographic Data Access System (CODAS) software developed by Eric Firing from the University of Hawaii (Bahr *et al.*, 1990). After the data were loaded into a database, the individual profiles were edited for anomalous points based on editing criteria such as large second vertical derivatives of eastward (*u*) and northward (*v*) velocity components, large vertical (*w*) and error velocities, and subsurface maxima of backscatter amplitude. Aside from the usual amplitude warnings triggered by either bottom interference or biological scattering layers, we found occasional interference from the hydrowire when the CTD package had drifted into one of the ADCP beams. Next the GPS fixes were screened for outliers based on number of satellites used and Horizontal Dilution of Precision (HDOP) values, and then merged with the ADCP data to provide absolute velocities. This step involved the intermediate calculation of the absolute velocity of a reference layer (e.g., Kosro, 1985; see Table 4 for layer range). The velocity of the reference layer is the difference between the velocity of the ship over the ground, determined by the fixes, and the velocity of the ship relative to the reference layer, calculated from the ADCP profiles. This initial estimate of the reference layer velocity, which is constant between fixes, was then smoothed by convolution with a Blackman window function (Blackman and Tukey, 1959). The choice of filter width generally depends on the quality of the fixes. For Subduction 1, which occurred shortly after the Gulf war Desert Storm, selective availability (SA) was not in effect, and the fix quality was accordingly good. SA was in effect, however, for Subduction 3 and 4, and the filter needed to be correspondingly larger (Table 4).

Bottom track calibration was performed using mostly the Woods Hole continental shelf data, since the island bottom tracking was often too short. Underway calibrations were done on cruises with many CTD stations. In this type of calibration, velocity differences measured by the ADCP (e.g., when departing from station) are compared with those measured by the satellite navigation. This method has a large uncertainty associated with each individual calibration point and a large number of points need to be taken. Calibration values

Table 4: ADCP processing parameter settings.

	Subduction 1	Subduction 3	Subduction 4
Reference layer range	bins 5–20 (50–170 m)	bins 5–17 (50–145 m)	bins 5–20 (50–170 m)
Smoothing filter half width	20 minutes	30 minutes	30 minutes
Calibration (amplitude; phase)	1.007; -1.32 degrees	1.005; -1.5 degrees	1.005; -1.7 degrees

were computed for each cruise from a combination of bottom track and water track information (Table 4).

In order to produce maps of velocity on density surfaces, temperature and salinity profiles were generated from 15-minute averages of the Seasoar data. Using this database, the ADCP data were vertically regridded on density, and 30-minute averaged vectors over the two shallower density intervals were calculated (Figures 9a–b). In addition, 30-minute averages of ADCP velocity along the original depth bins were produced in ASCII format (available on CD-Rom).

4. Discussion

The initial deployment cruise for the bobbers, in May 1991, came just as the water column began to stratify. The remnant mixed layer was deep and reflected the characteristics of late winter conditions. The density modes for the first two star patterns indicated that the initial winter mixed layer depth was between 100 and 150 meters (see Appendix B: Figures. Sub 1, Star 1 — Section SE–NW and Sub 1, Star 2, Section SE–NW). The Subduction bobber cruises were distributed in time in such a way as to cover a two year lifespan. However, due to the concentration in the northern region near the Azores Front on the second cruise (February 1992), no Seasoar data were collected near any of the bobbers. Thus, the temporal sampling between the bobber cruises was uneven, with intervals of 18 and 6 months.

The 'star' patterns were carried out in order to map the variability around the bobber floats. During the initial cruise, the star patterns each consumed about 45 hours of shiptime. The long legs of the patterns were approximately 110 km in length. An analysis of temperature, pressure, and thickness variations on the individual legs indicated that the decorrelation scale was 8–10 km. Error maps made from the objective mapping of the data showed that the star pattern was too large: large areas within the pattern were poorly mapped. In subsequent cruises, the scale of the pattern was reduced so that the long legs of the pattern were approximately 80 km. Not only did this better 'map' the variability, it took less shiptime (27 hrs/survey)!

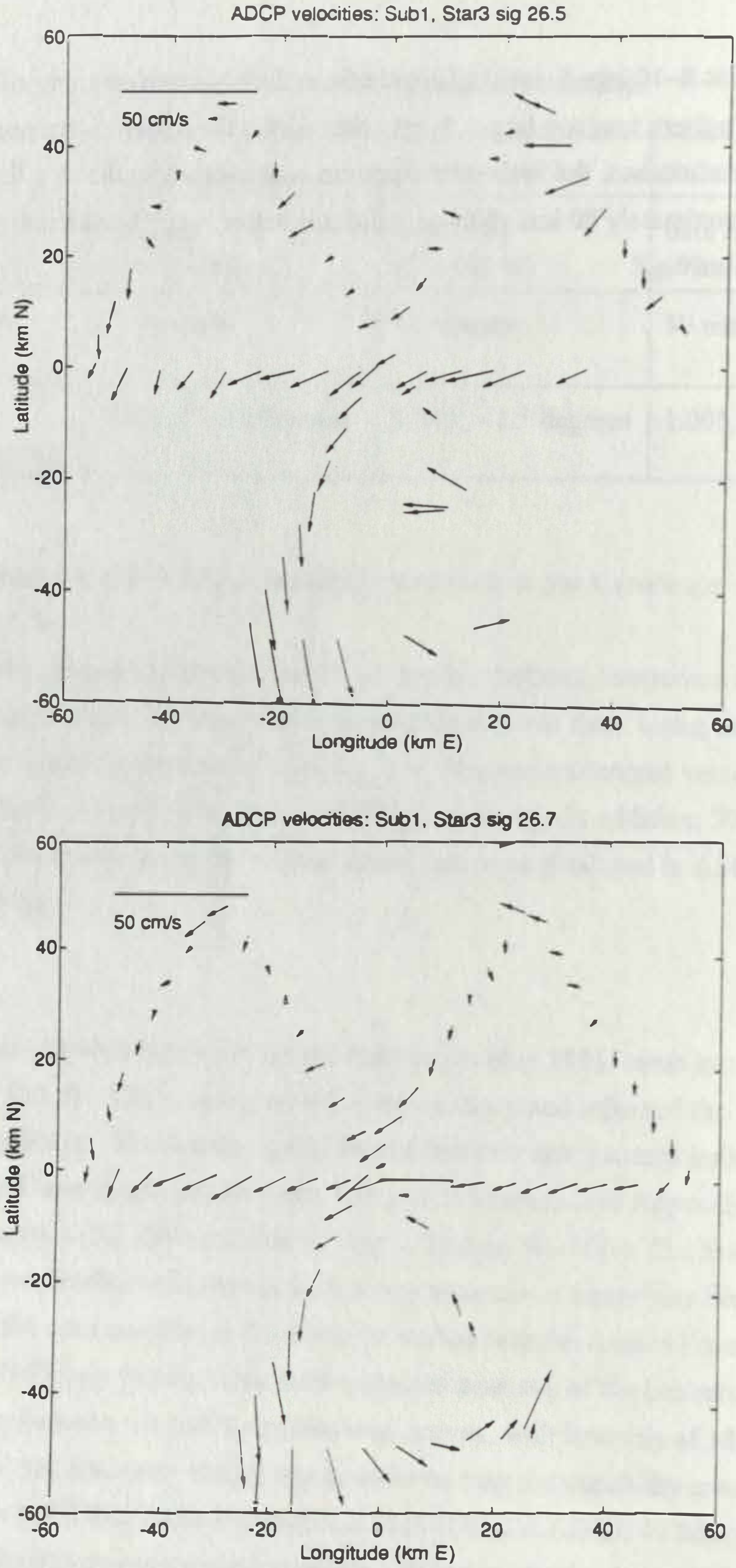


Figure 9: Representative map of ADCP velocities on a star pattern at density levels (a) 26.5 and level (b) 26.7. See Appendix E.

5. Acknowledgments

The Subduction ARI experiment was sponsored by the Office of Naval Research, grants N00014-91-J-1585 — Mesoscale Variablility of Subduction Waters (T. Joyce), N00014-91-J-1508 — Seasoar Operations in Subduction, and N00014-91-J-1425 — Subduction in the Subtropical Gyre (J. Luyten). We wish to thank the Captain and crew of the R/V *Oceanus*. Bobber locations were received from James Price and Christine Wooding.

6. References

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Appendix A: Star Pattern — Data Summaries

Seasoar data were summarized for each star pattern surveyed during the Subduction experiment. The gridded data were mapped onto density surfaces of 0.05 sigma-theta. Plots of pressure, potential temperature, salinity and thickness vs potential density for each survey are presented in Figures A-1 through A-13. Location and time of the survey is described in Figure 1 and Table 2.

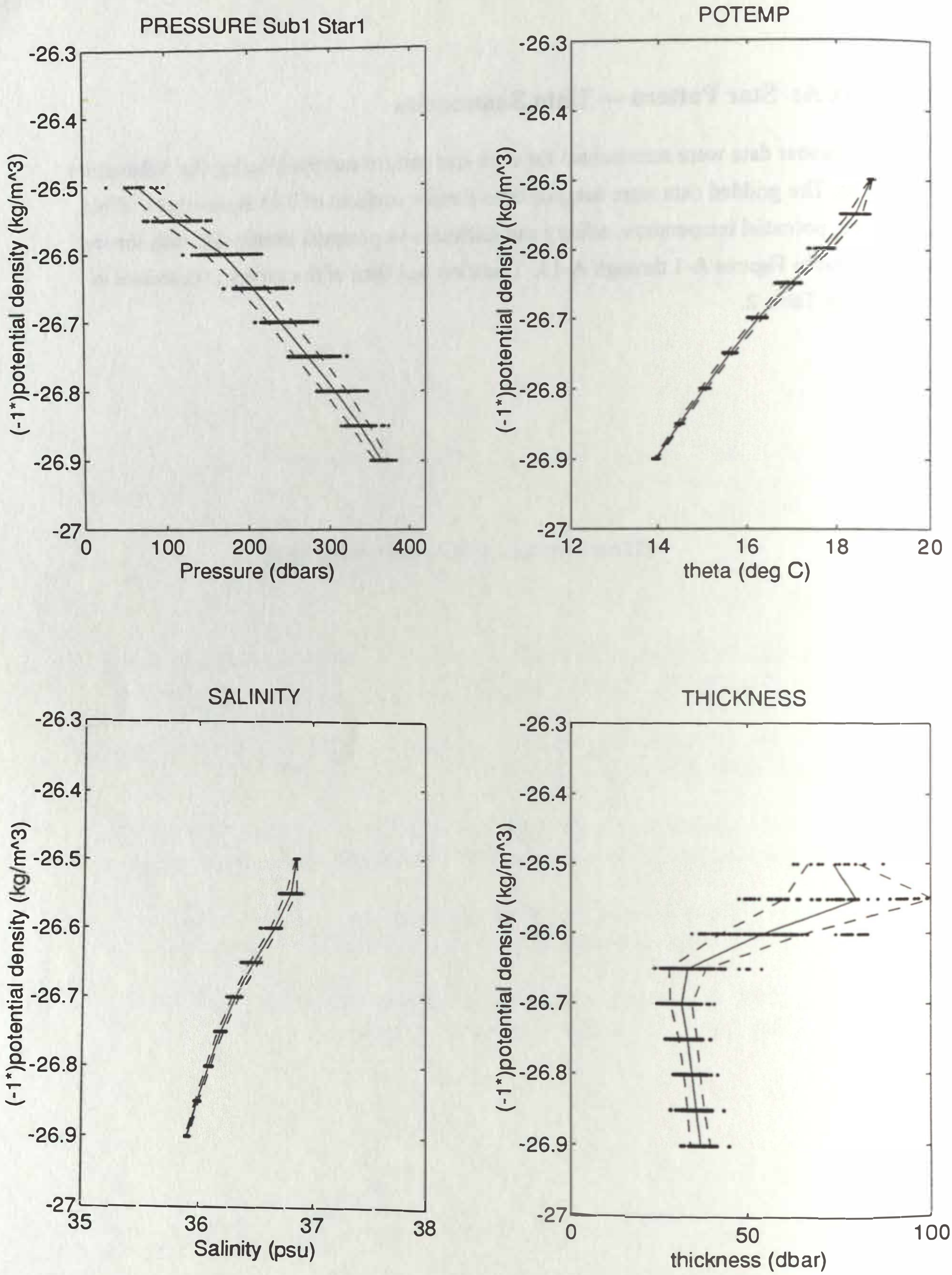

PRESSURE Sub1 Star1
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-1

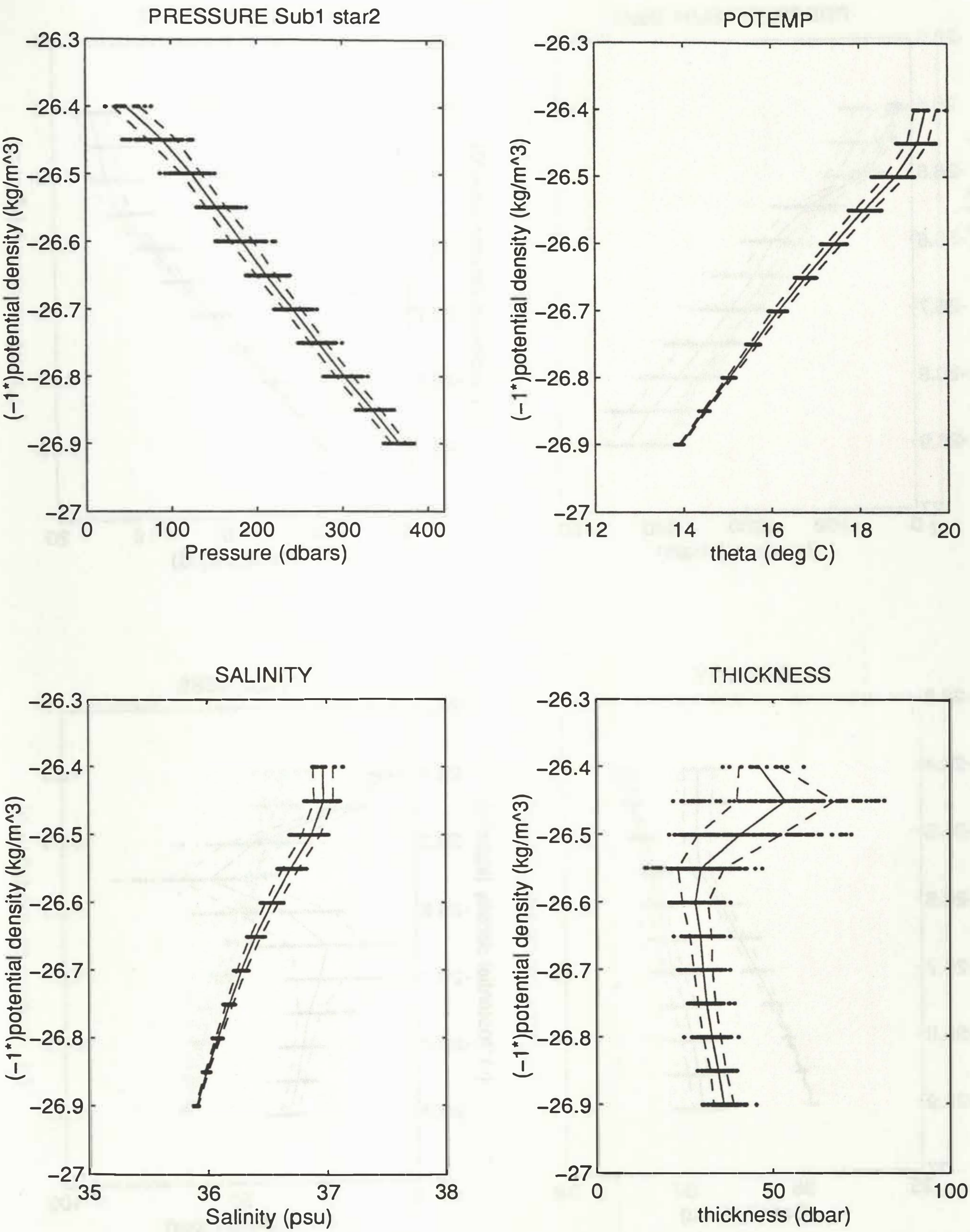

PRESSURE Sub1 star2
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-2

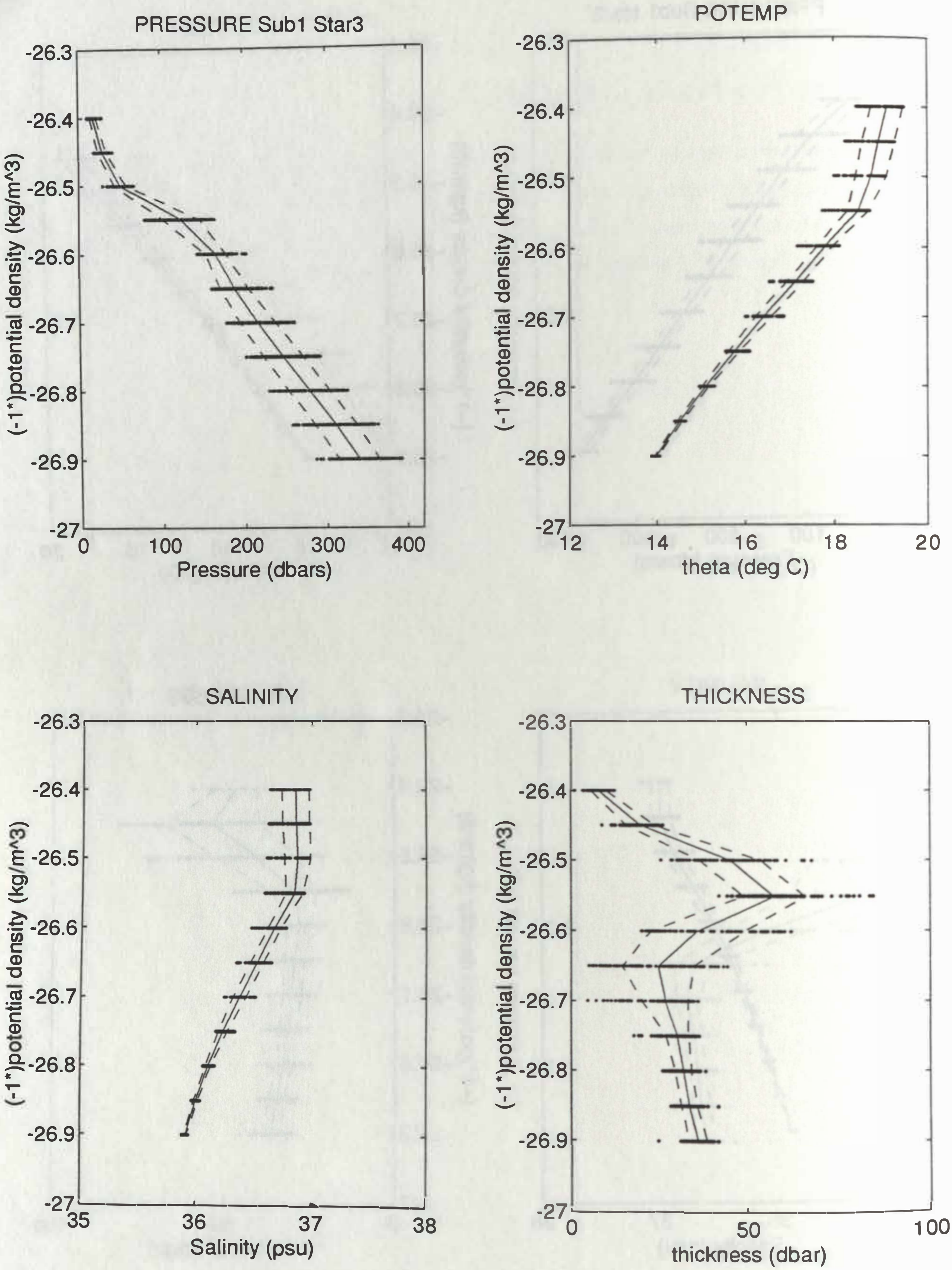

PRESSURE Sub1 Star3
(-1*)potential density (kg/m^3)
Pressure (dbars)
-26.3
-26.4
-26.5
-26.6
-26.7
-26.8
-26.9
-27
0
100
200
300
400
POTEMP
theta (deg C)
12
14
16
18
20
SALINITY
Salinity (psu)
35
36
37
38
THICKNESS
thickness (dbar)
0
50
100

Figure A-3

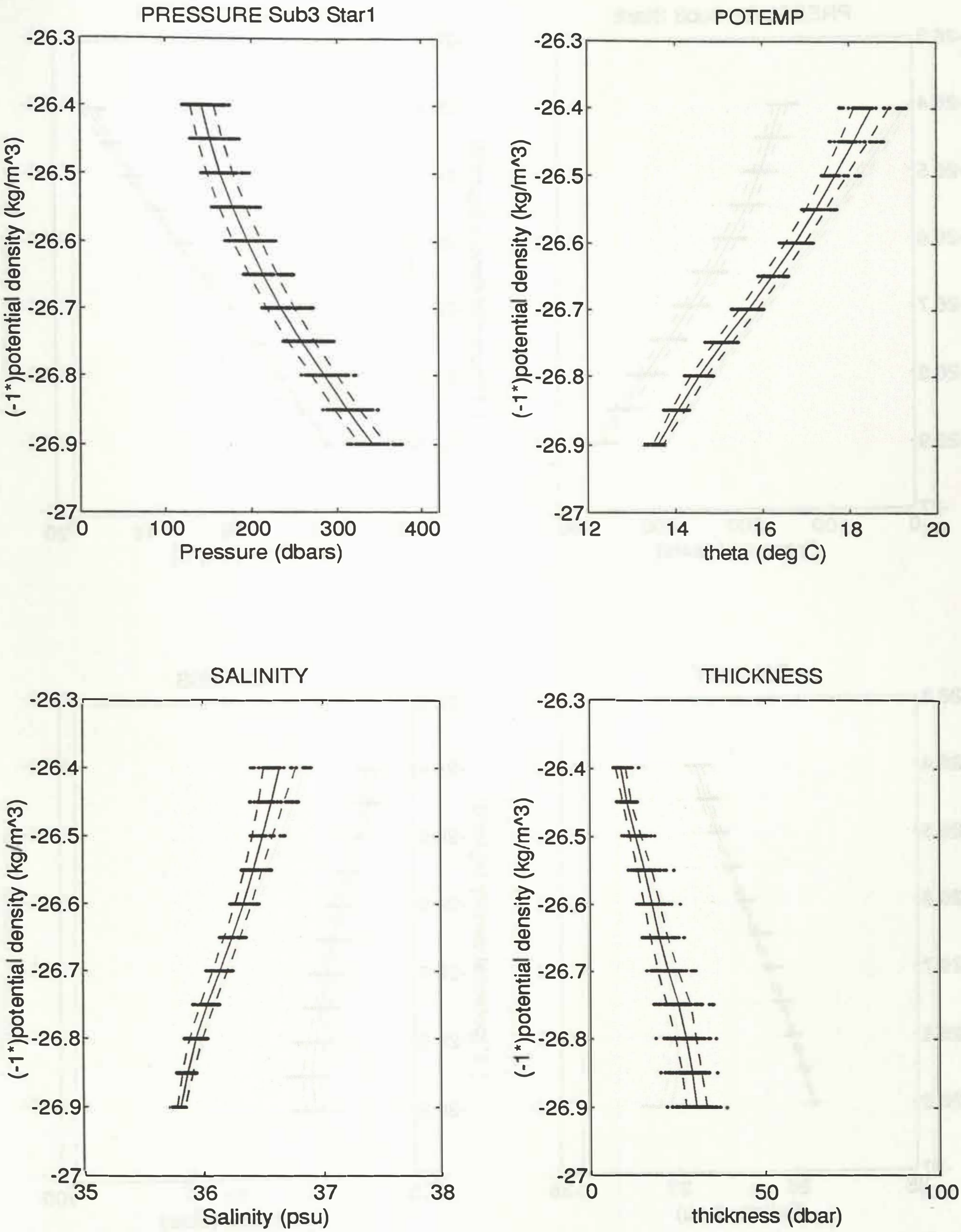

PRESSURE Sub3 Star1
Pressure (dbars)
(-1*)potential density (kg/m^3)
-26.3
-26.4
-26.5
-26.6
-26.7
-26.8
-26.9
-27
0
100
200
300
400
POTEMP
theta (deg C)
12
14
16
18
20
SALINITY
Salinity (psu)
35
36
37
38
THICKNESS
thickness (dbar)
0
50
100

Figure A-4

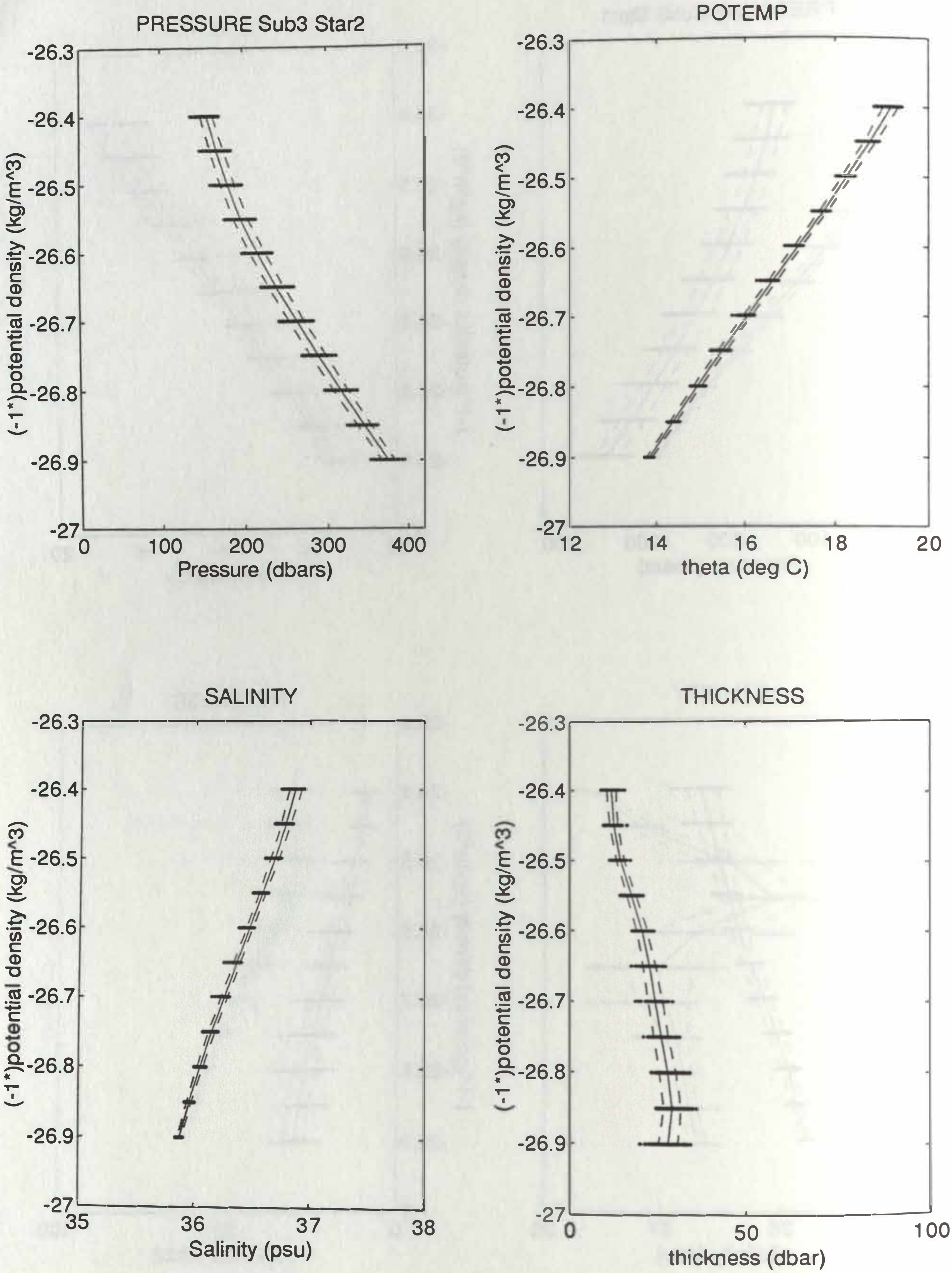
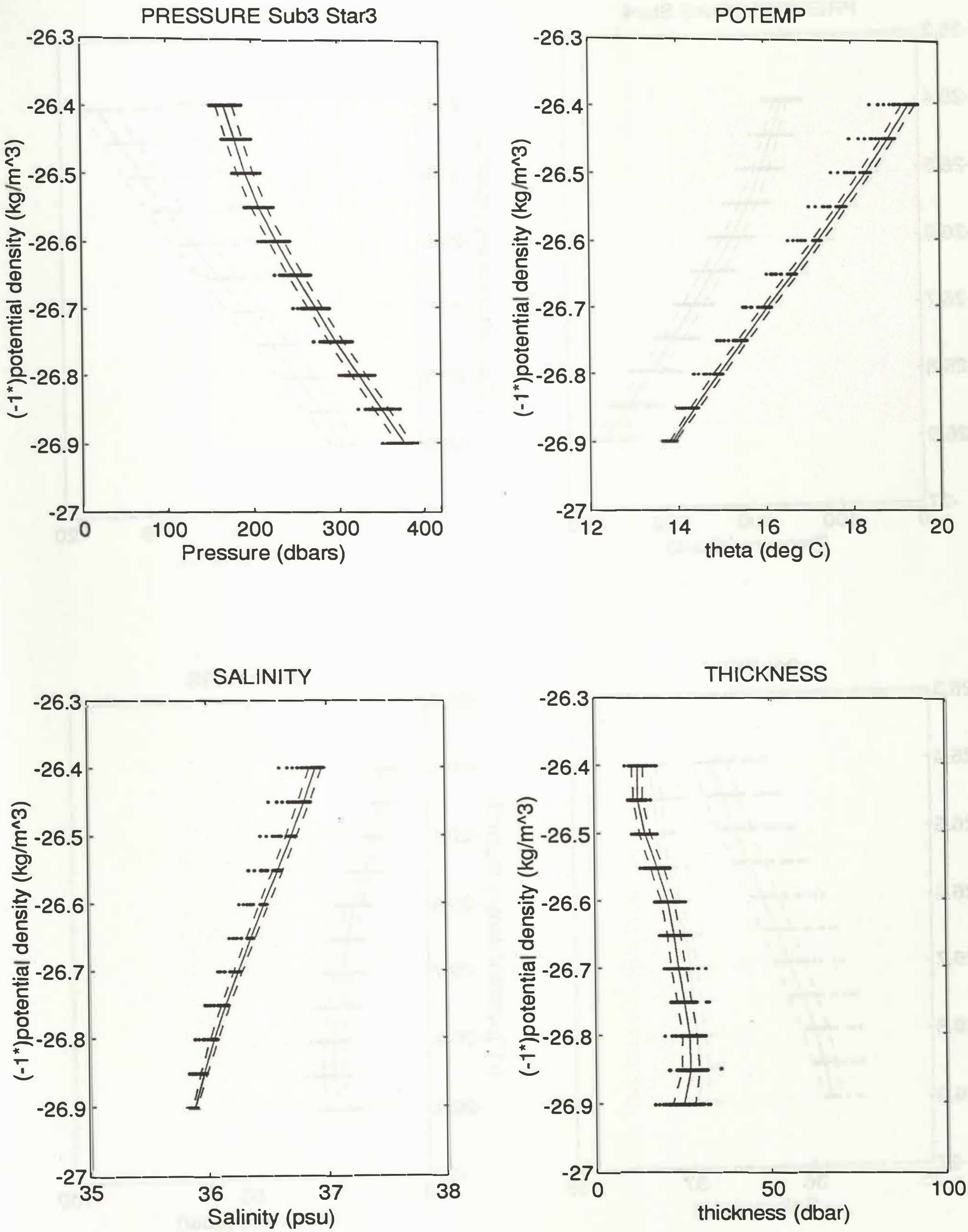

PRESSURE Sub3 Star2
(-1*)potential density (kg/m^3)
-26.3
-26.4
-26.5
-26.6
-26.7
-26.8
-26.9
-27
0
100
200
300
400
Pressure (dbars)
POTEMP
12
14
16
18
20
theta (deg C)
SALINITY
35
36
37
38
Salinity (psu)
THICKNESS
0
50
100
thickness (dbar)

Figure A-5



PRESSURE Sub3 Star3
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-6

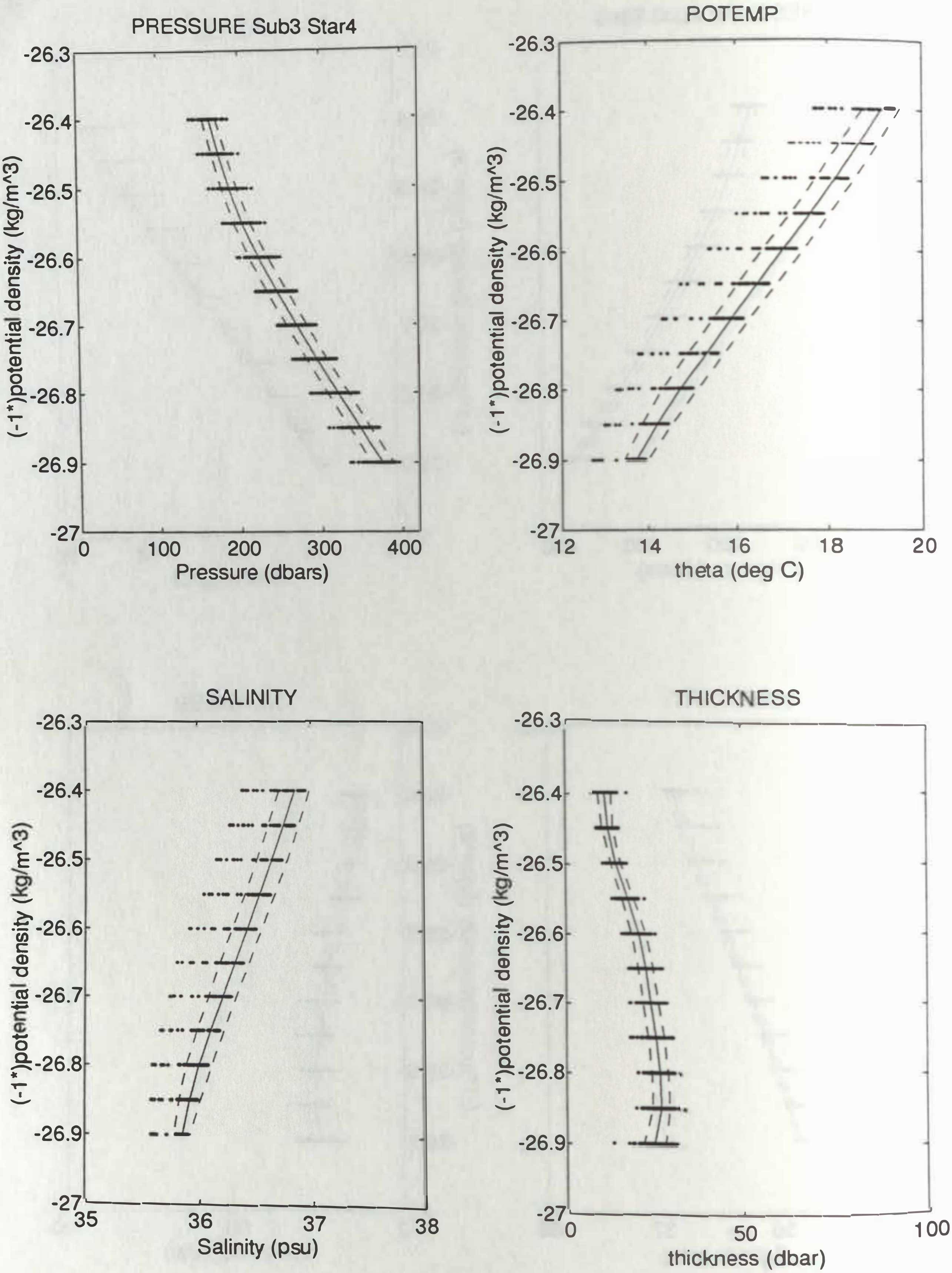
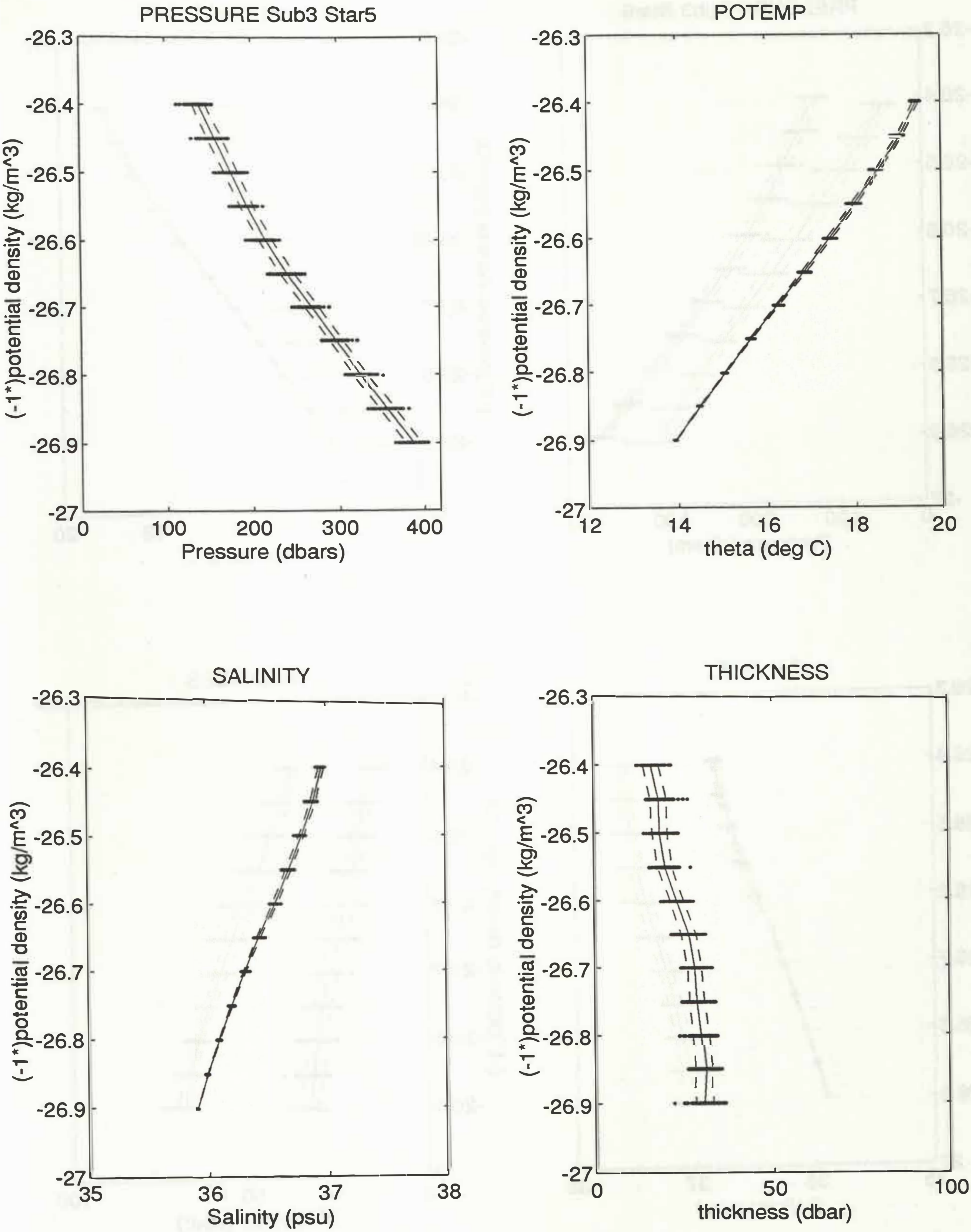

PRESSURE Sub3 Star4
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-7



PRESSURE Sub3 Star5
POTEMP
SALINITY
THICKNESS
(-1*)potential density (kg/m^3)
Pressure (dbars)
theta (deg C)
Salinity (psu)
thickness (dbar)

Figure A-8

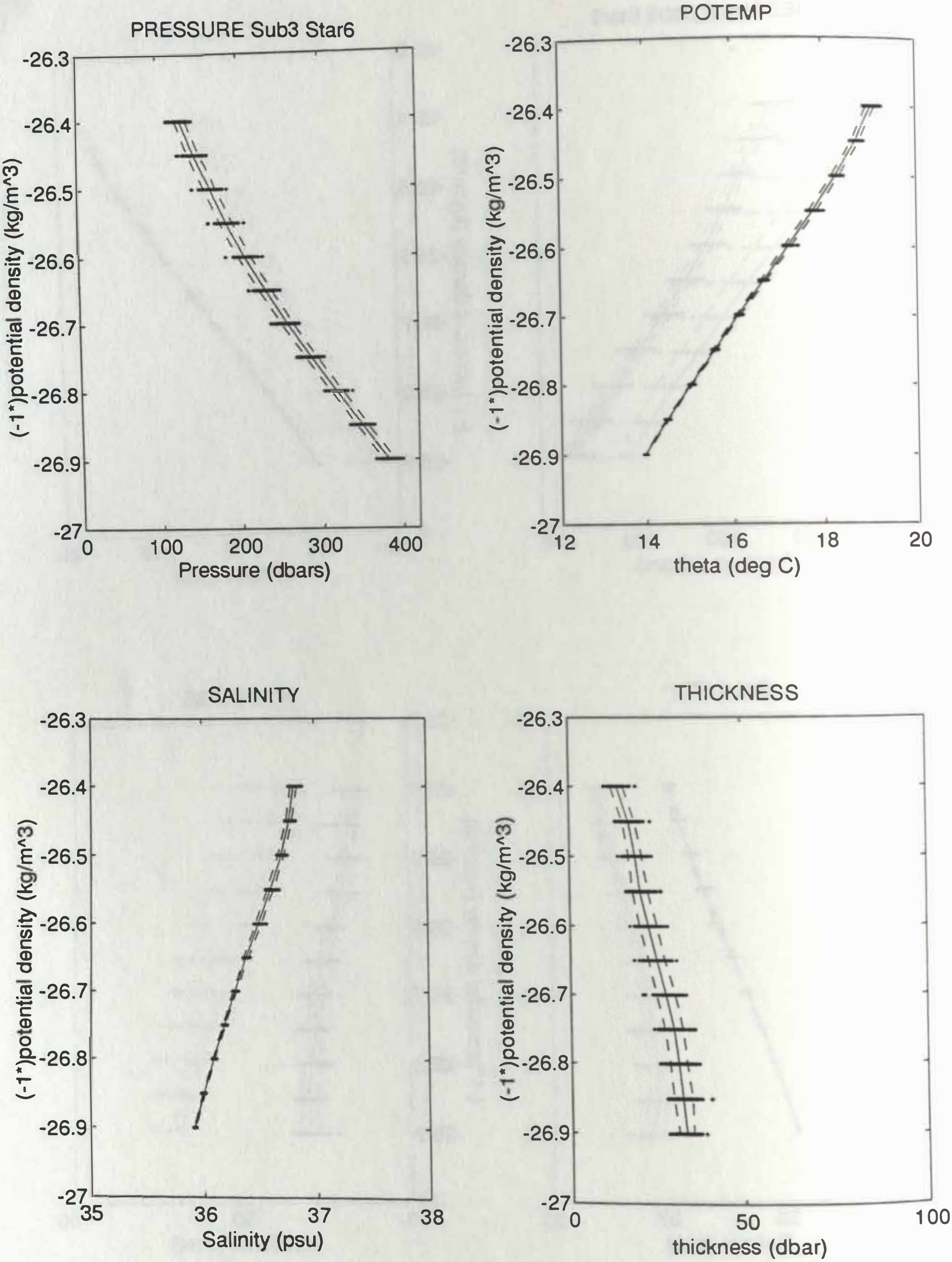

PRESSURE Sub3 Star6
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-9

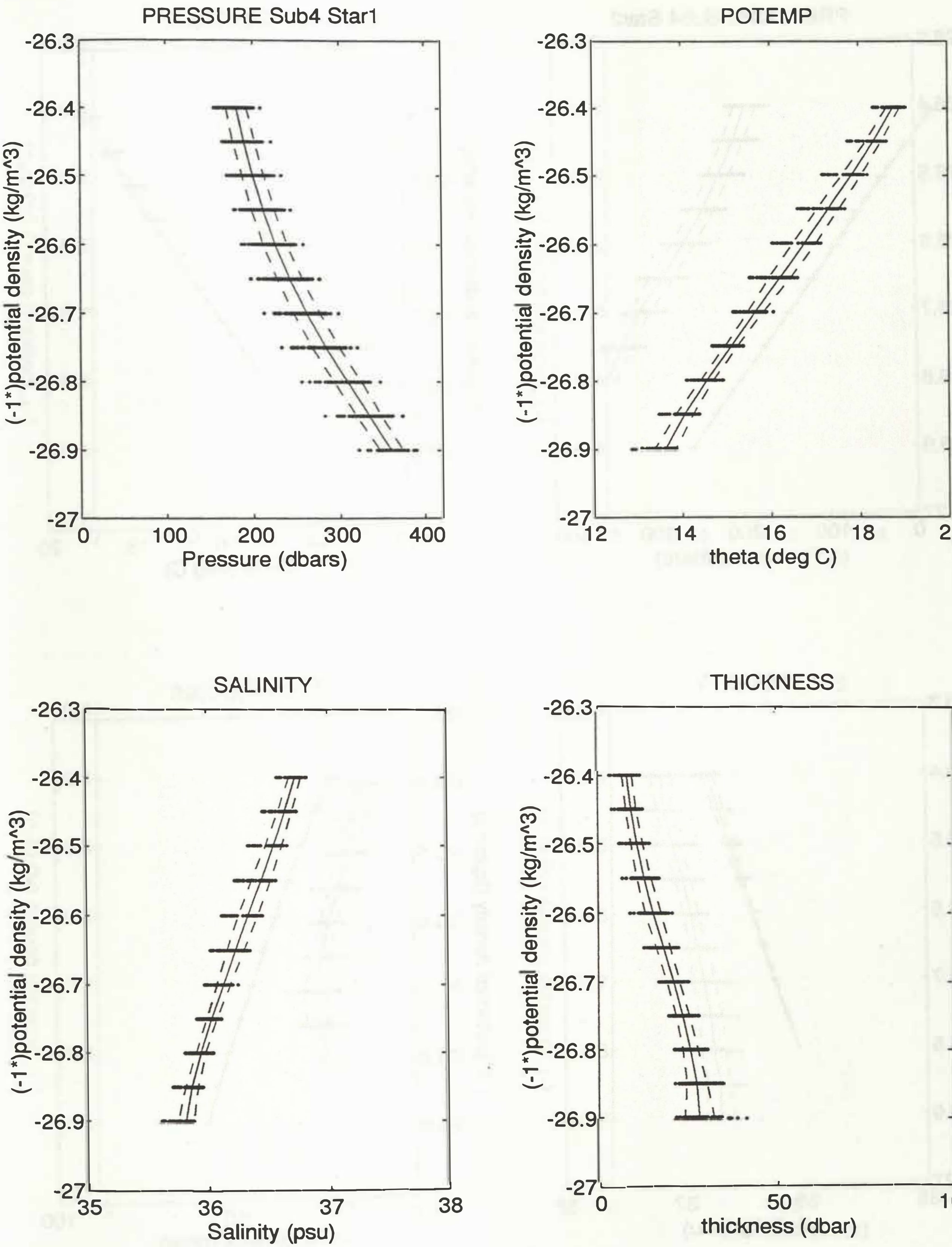

PRESSURE Sub4 Star1
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-10

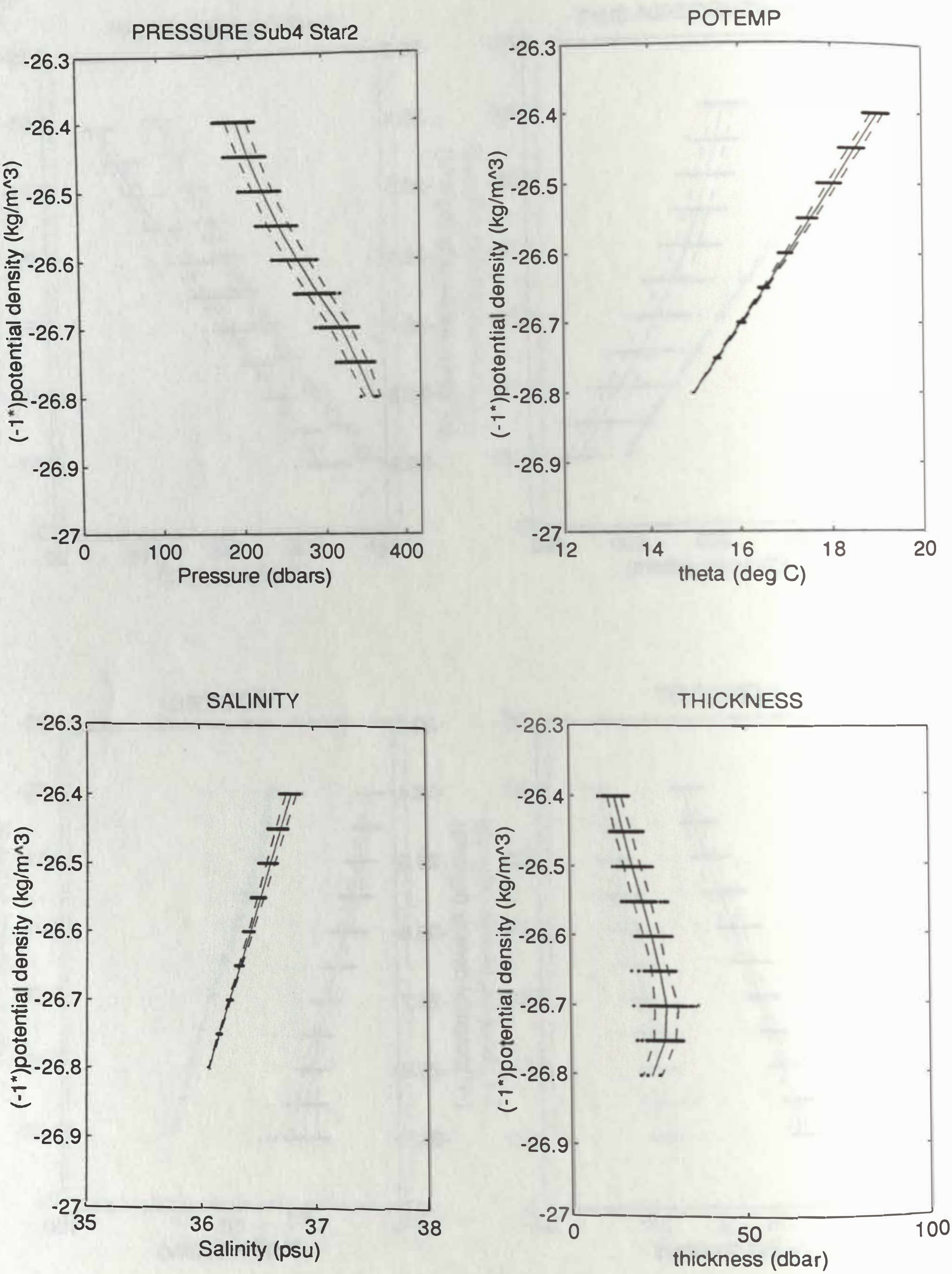

PRESSURE Sub4 Star2
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
(-1*)potential density (kg/m^3)
theta (deg C)
SALINITY
(-1*)potential density (kg/m^3)
Salinity (psu)
THICKNESS
(-1*)potential density (kg/m^3)
thickness (dbar)

Figure A-11

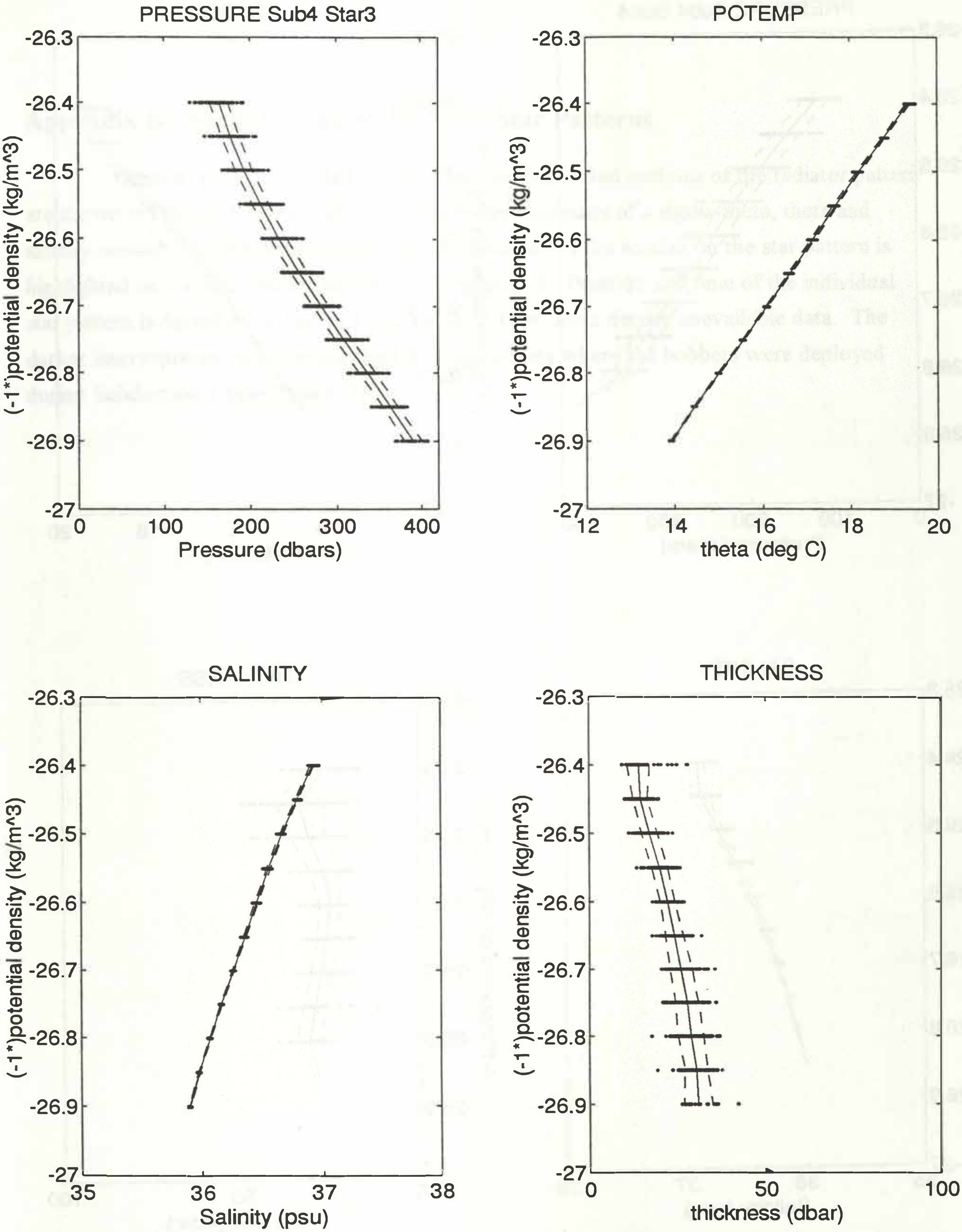

PRESSURE Sub4 Star3
POTEMP
SALINITY
THICKNESS
(-1*)potential density (kg/m^3)
Pressure (dbars)
theta (deg C)
Salinity (psu)
thickness (dbar)
-26.3
-26.4
-26.5
-26.6
-26.7
-26.8
-26.9
-27
0
100
200
300
400
12
14
16
18
20
35
36
37
38
50
100

Figure A-12

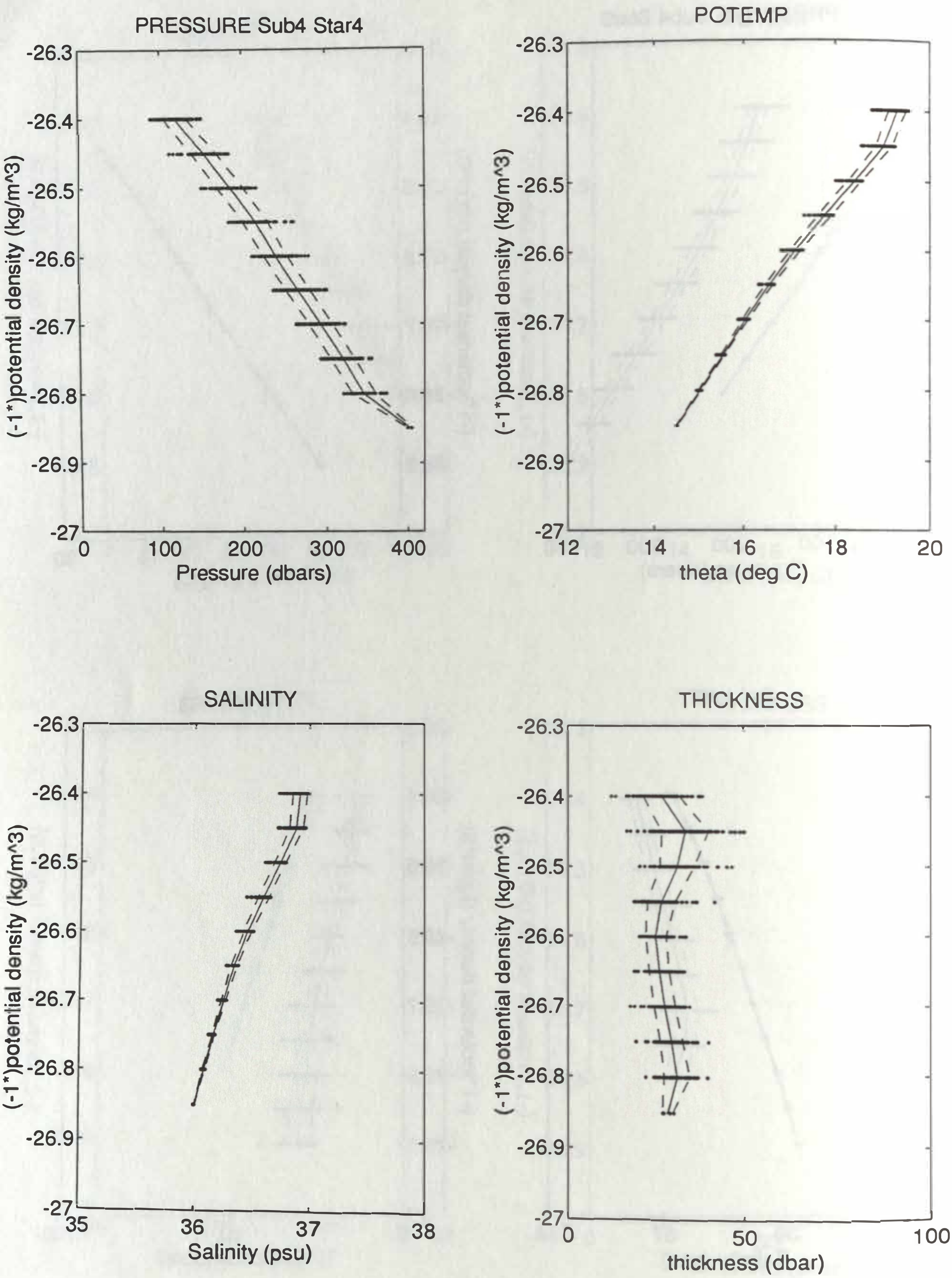

PRESSURE Sub4 Star4
(-1*)potential density (kg/m^3)
Pressure (dbars)
POTEMP
theta (deg C)
SALINITY
Salinity (psu)
THICKNESS
thickness (dbar)

Figure A-13

Appendix B: Section Contour Plots for Star Patterns

Contour plots of gridded Seasoar data along selected sections of the radiator pattern are shown in Figures B-2 through B-15. Each figure consists of a sigma-theta, theta and salinity contour plot for the specified section. Location of the section on the star pattern is highlighted on the star pattern shown in the Figure B-1. Position and time of the individual star pattern is described in Figure 1 and Table 2. Gray areas denote unavailable data. The darker lines represent the average theta and sigma-theta where the bobbers were deployed during Subduction 1 (see Figure 7).

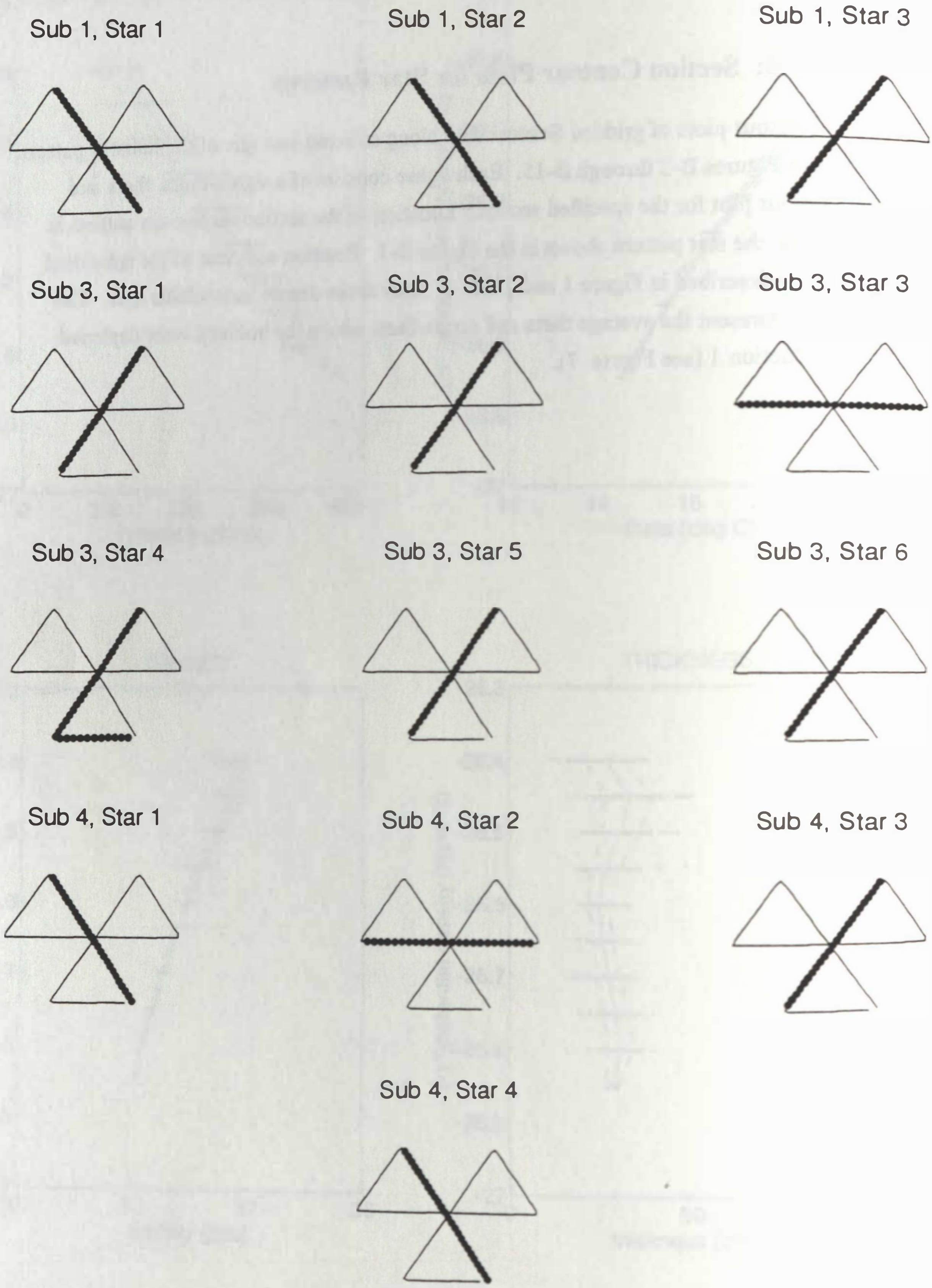


Figure B-1

Sections of Star Patterns Represented in Contour Maps

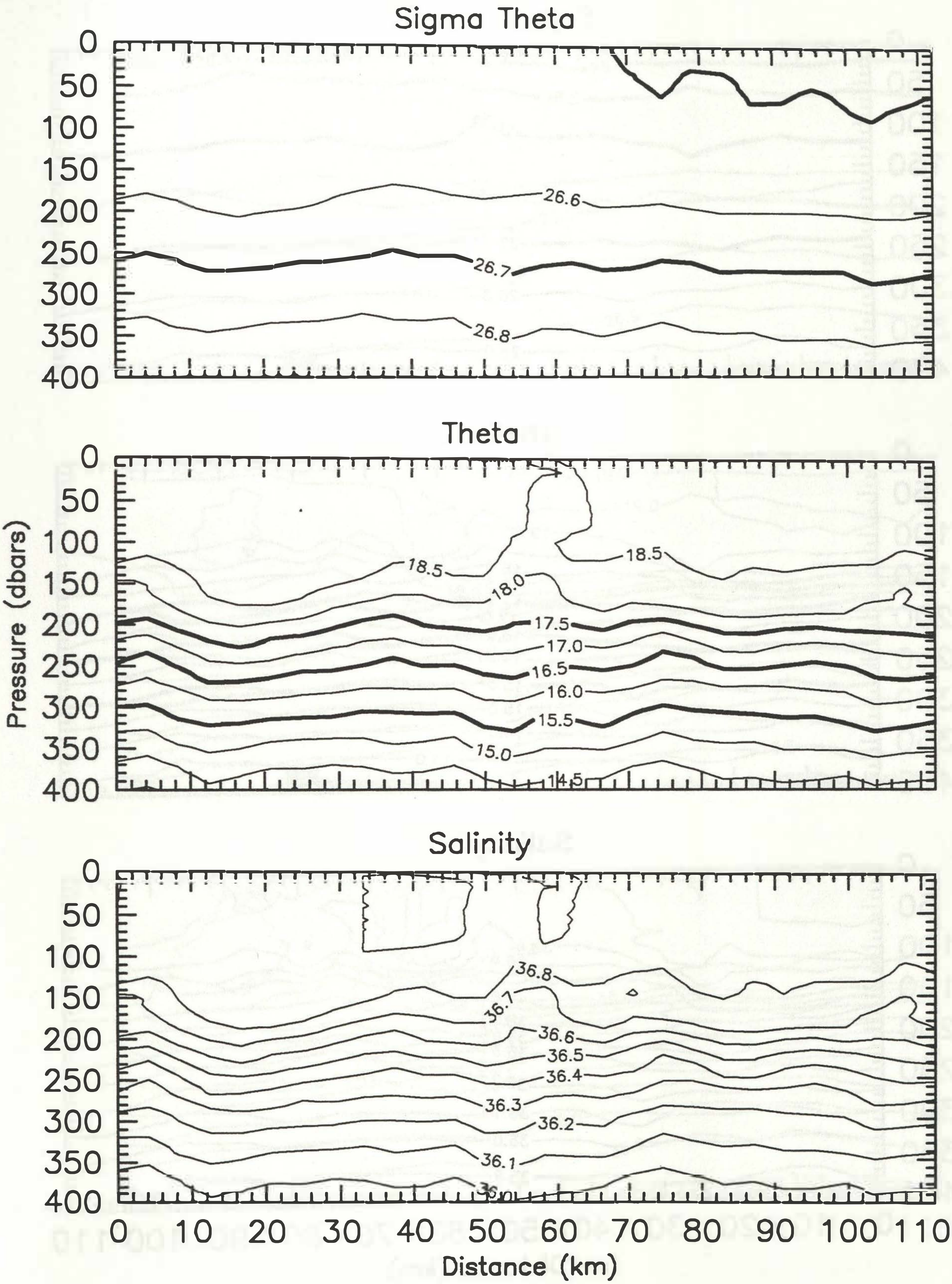


Figure B-2

Sub 1, Star 1 — Section SE — NW

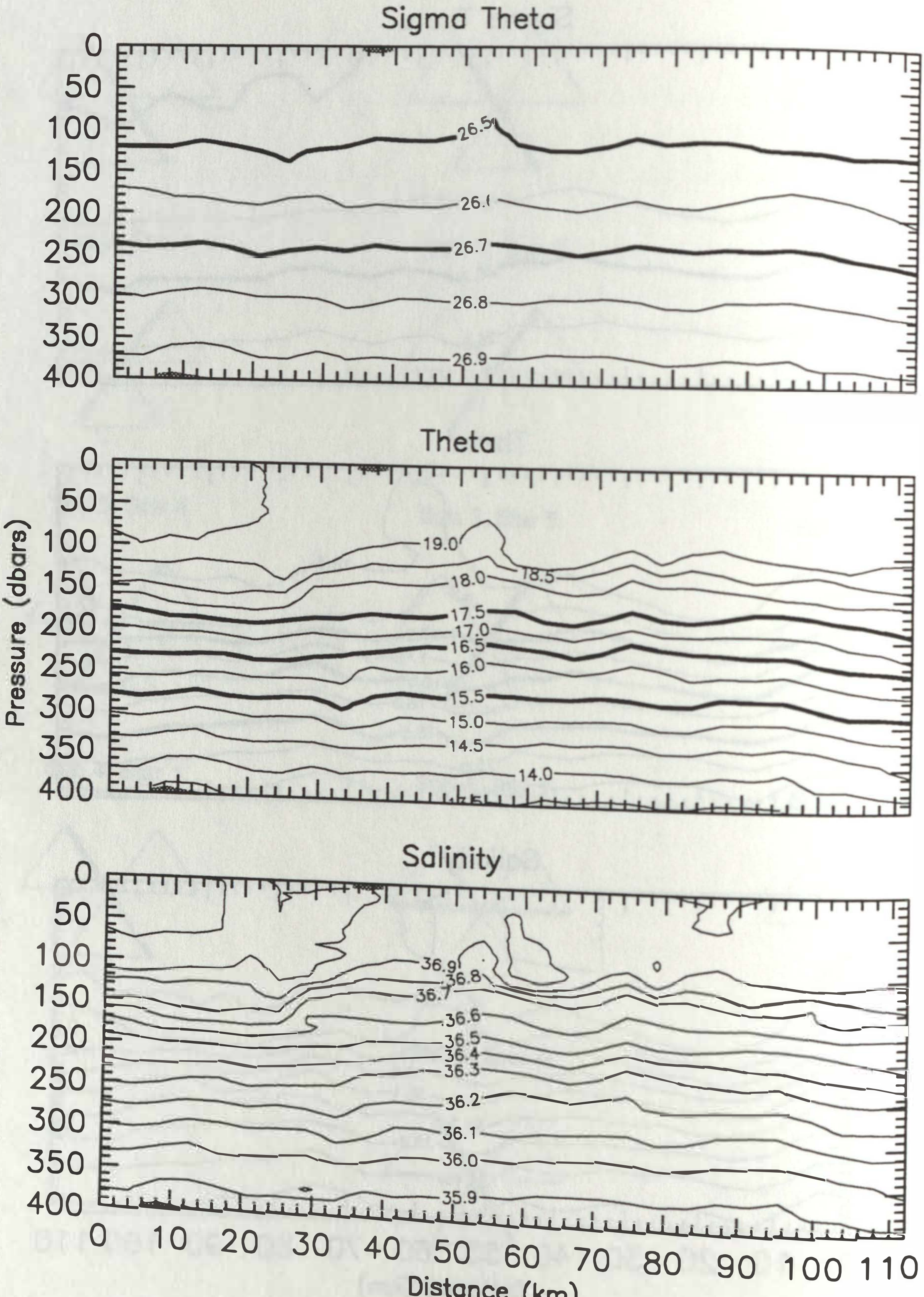


Figure B-3

Sub 1, Star 2 — Section SE — NW

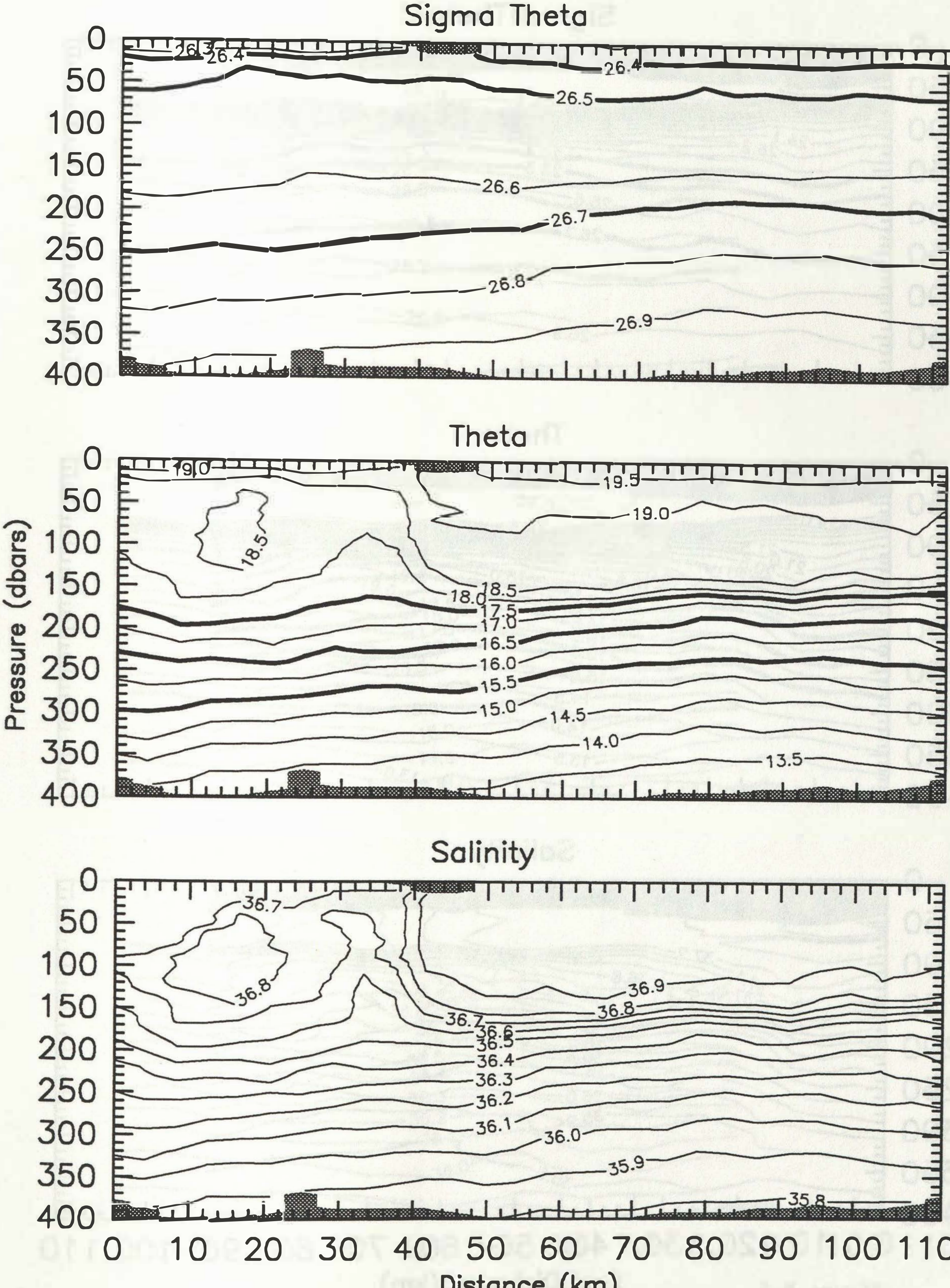


Figure B-4

Sub 1, Star 3 — Section NE — SW

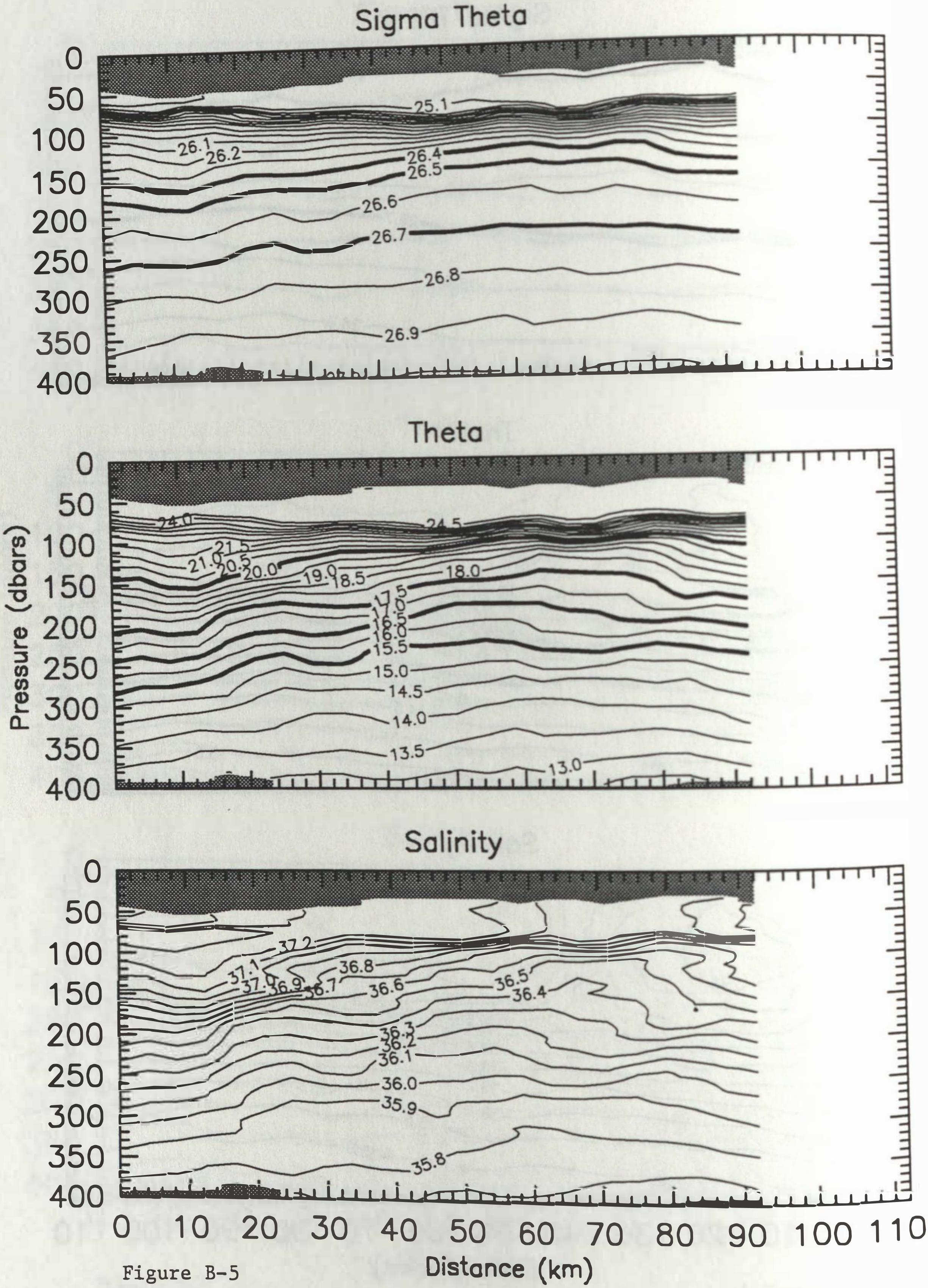


Figure B-5

Sub 3, Star 1 – Section SW – NE

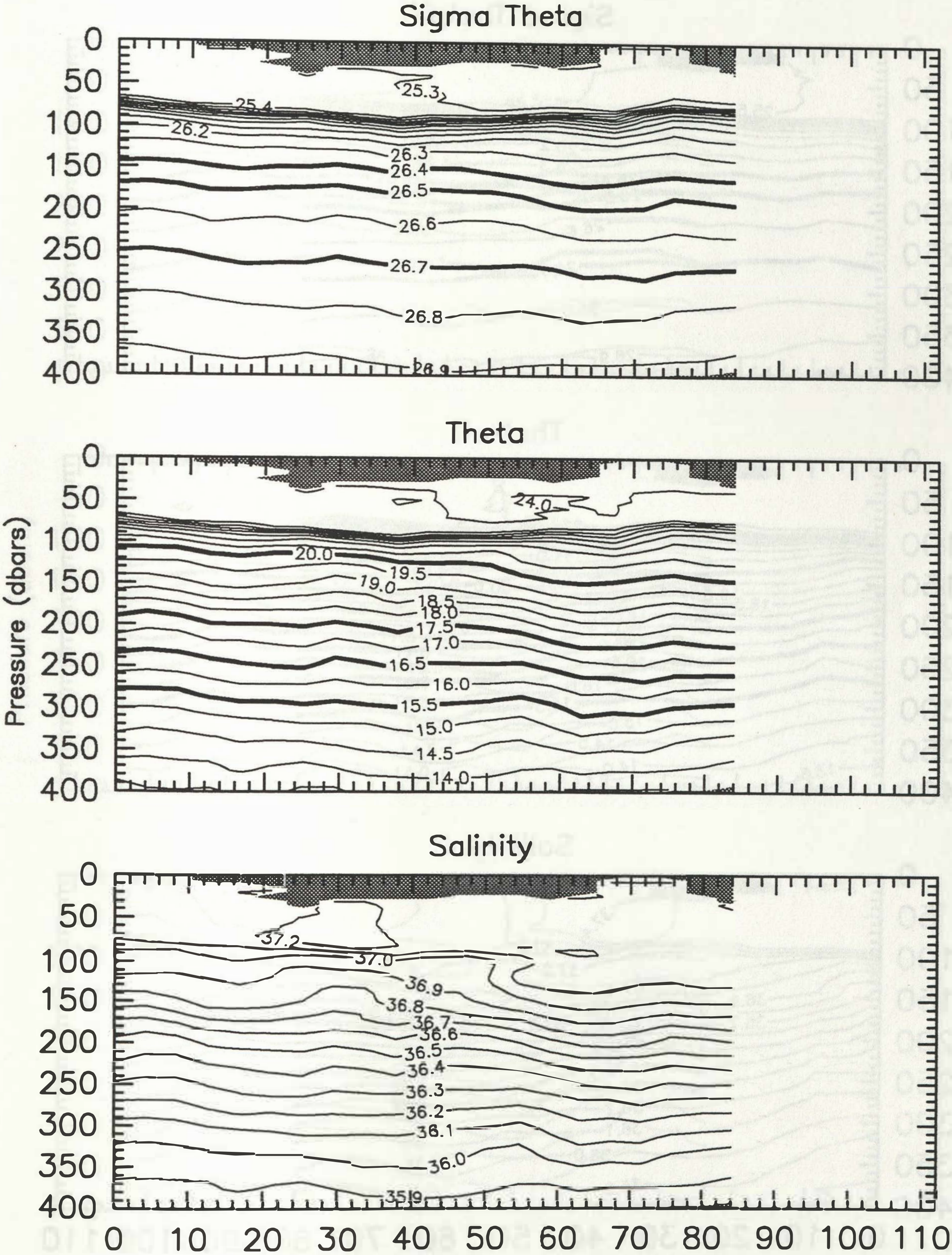


Figure B-6

Sub 3, Star 2 — Section NE — SW

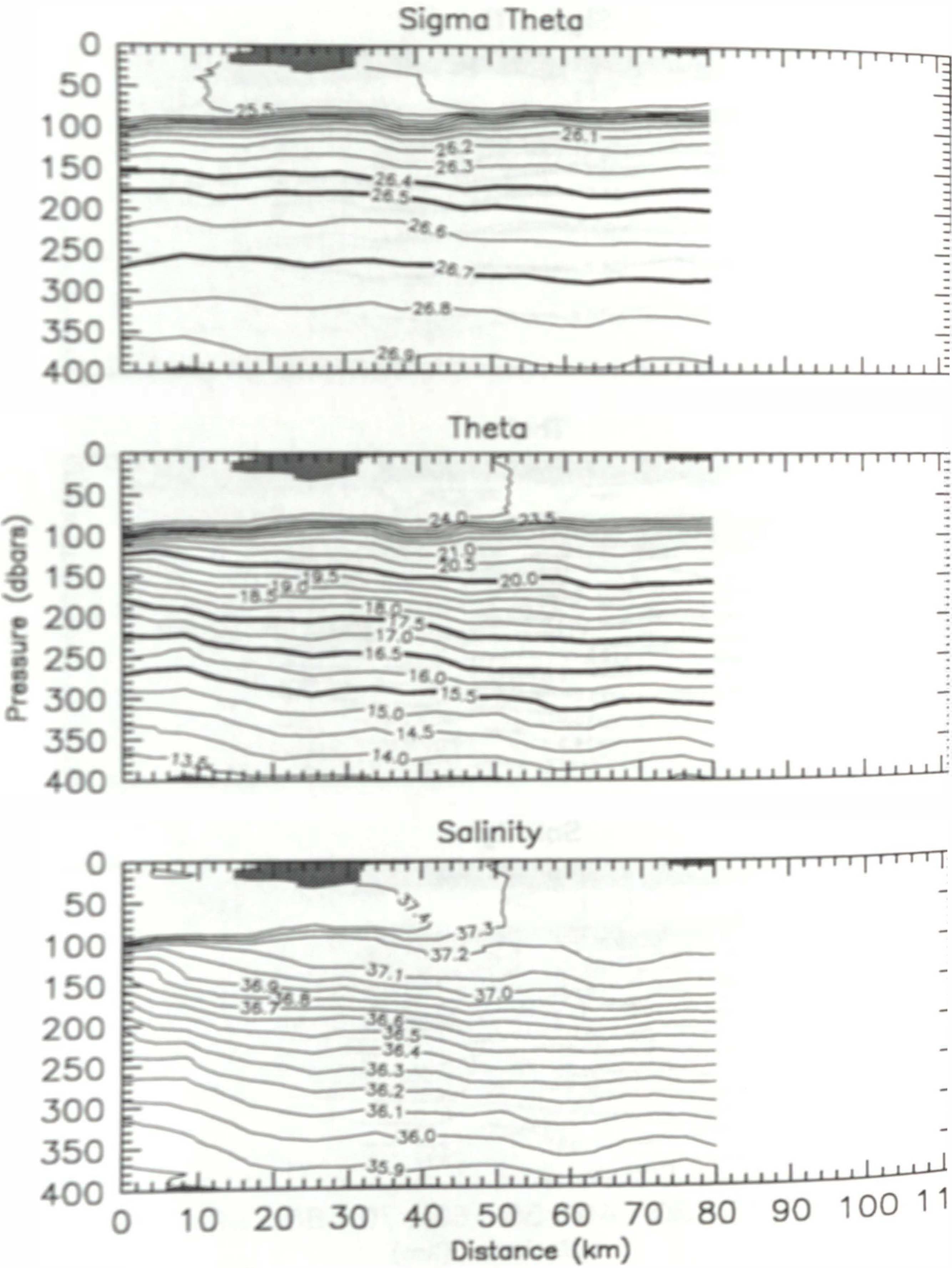


Figure B-7

Sub 3, Star 3 – Section E – W

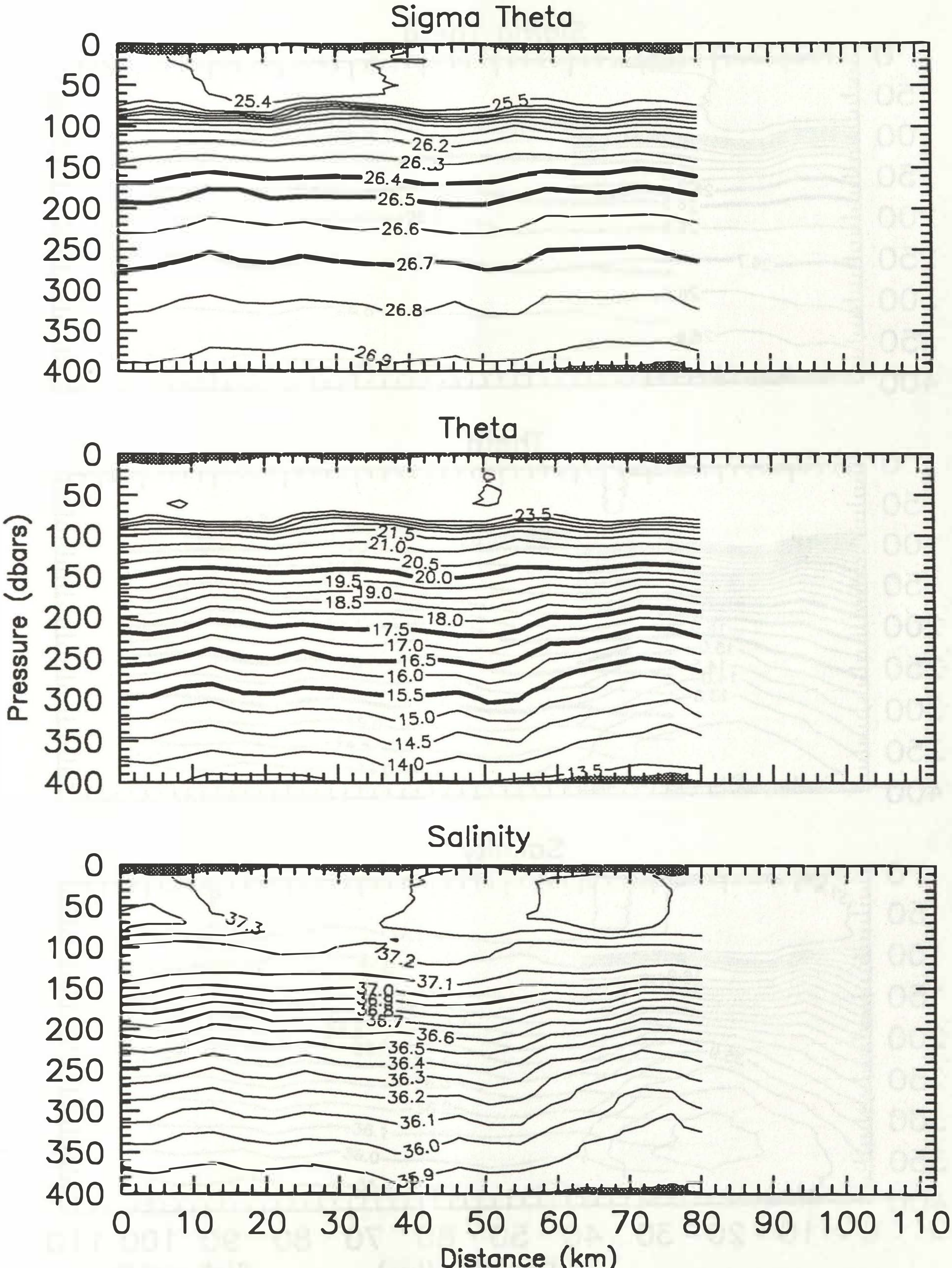


Figure B-8

Sub 3, Star 4 — Section NE — SW

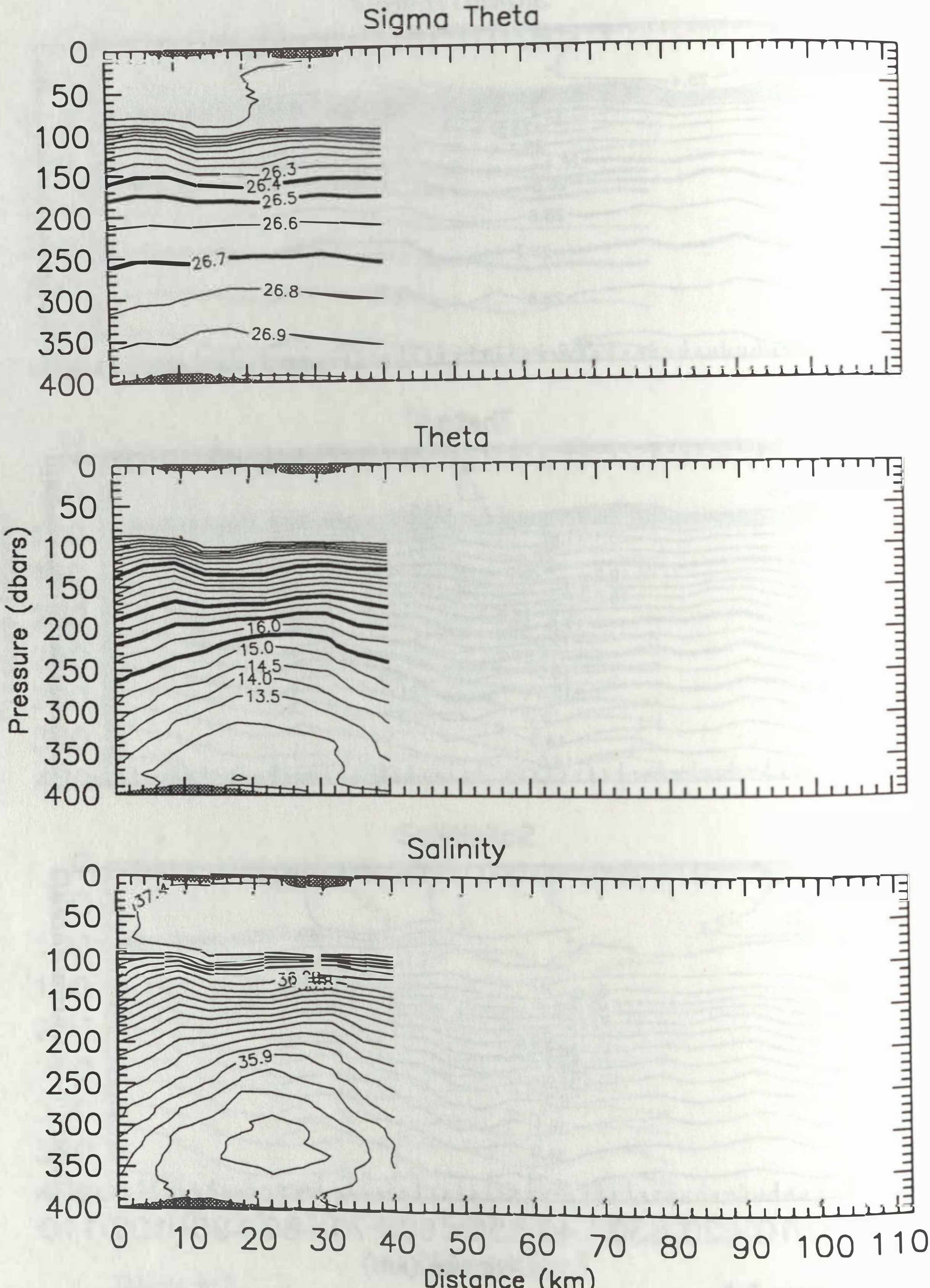


Figure B-9

Sub 3, Star 4 — Section E — W

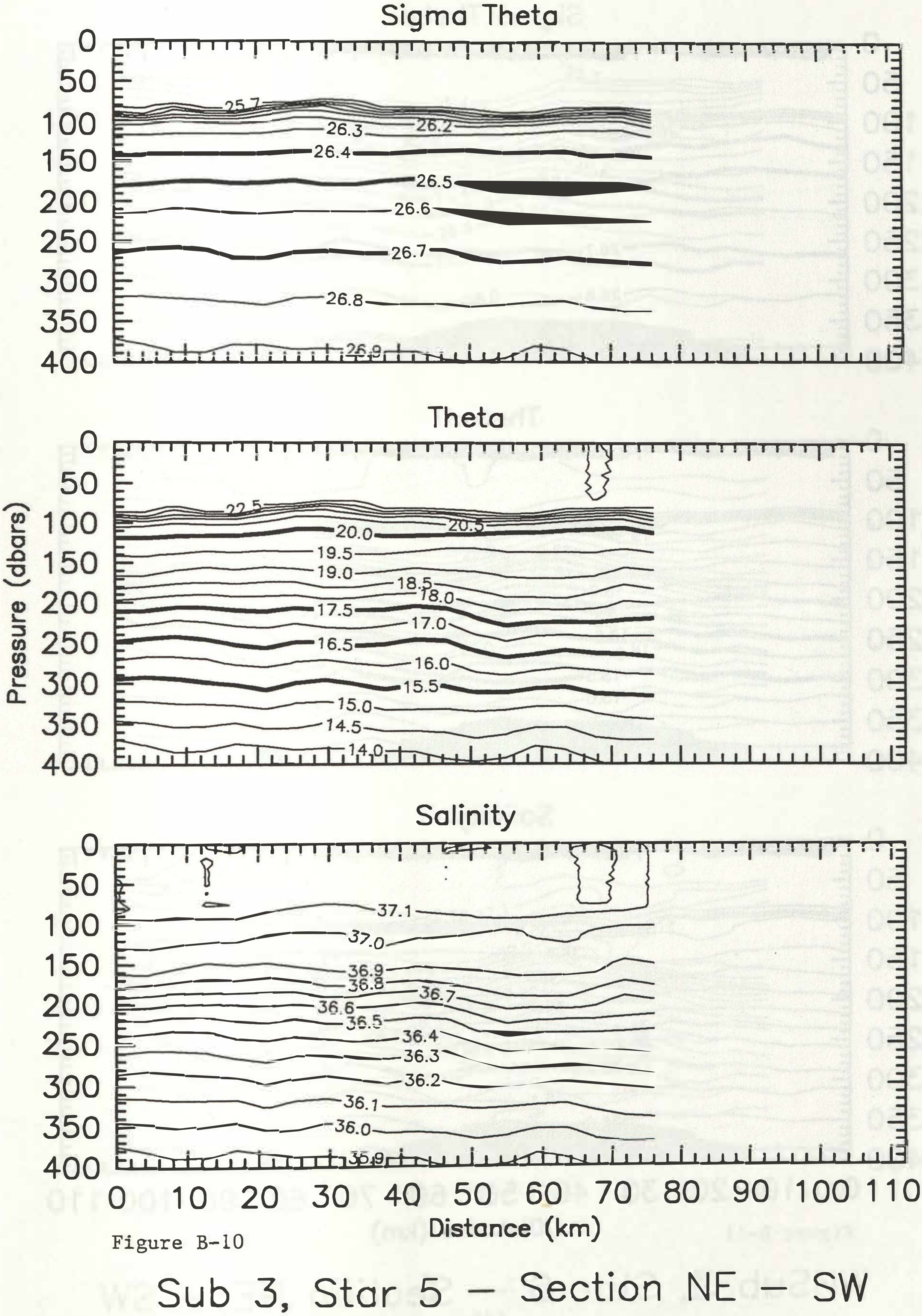


Figure B-10

Sub 3, Star 5 — Section NE— SW

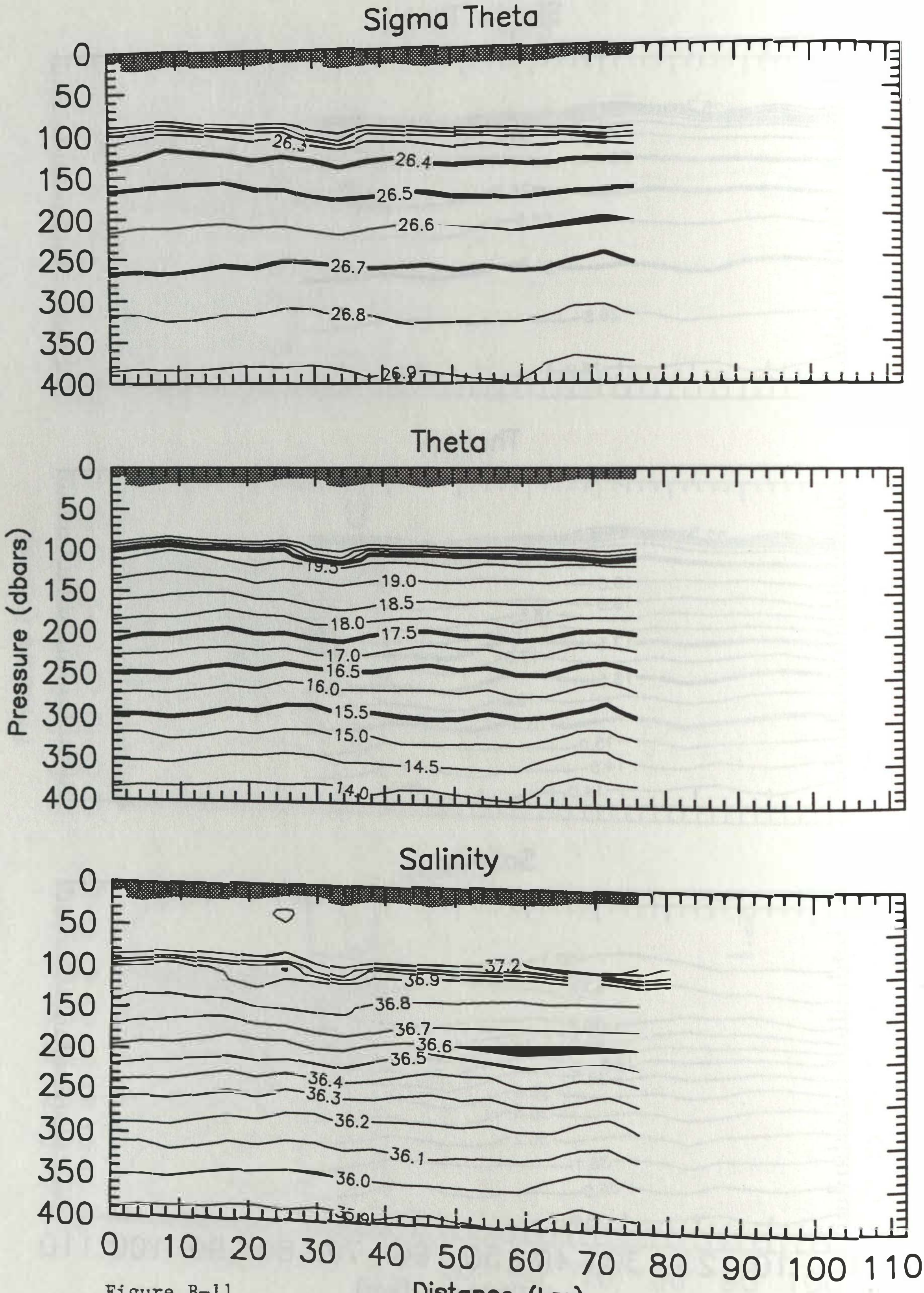


Figure B-11

Sub 3, Star 6 — Section NE — SW

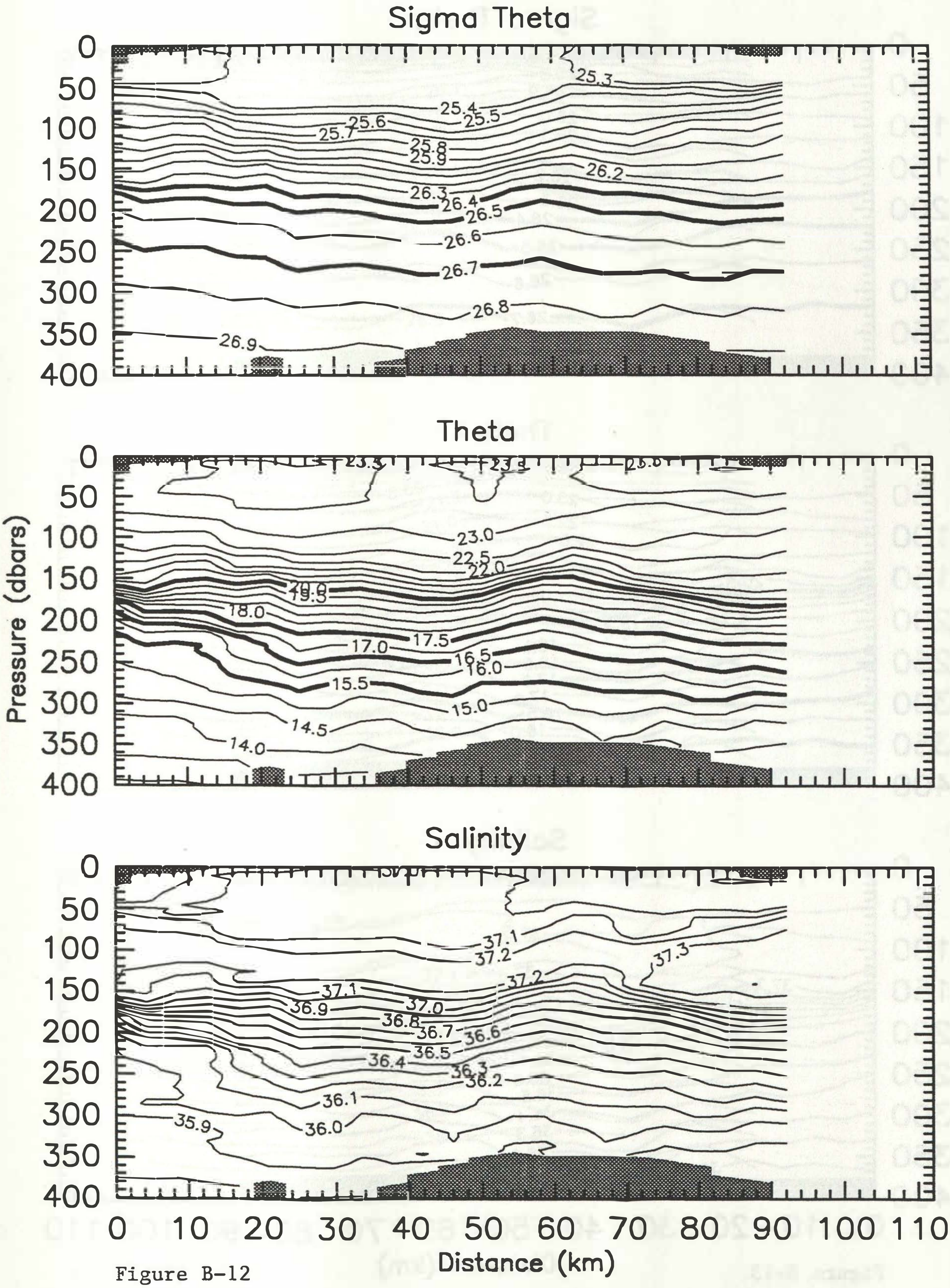


Figure B-12

Sub 4, Star 1 — Section SE— NW

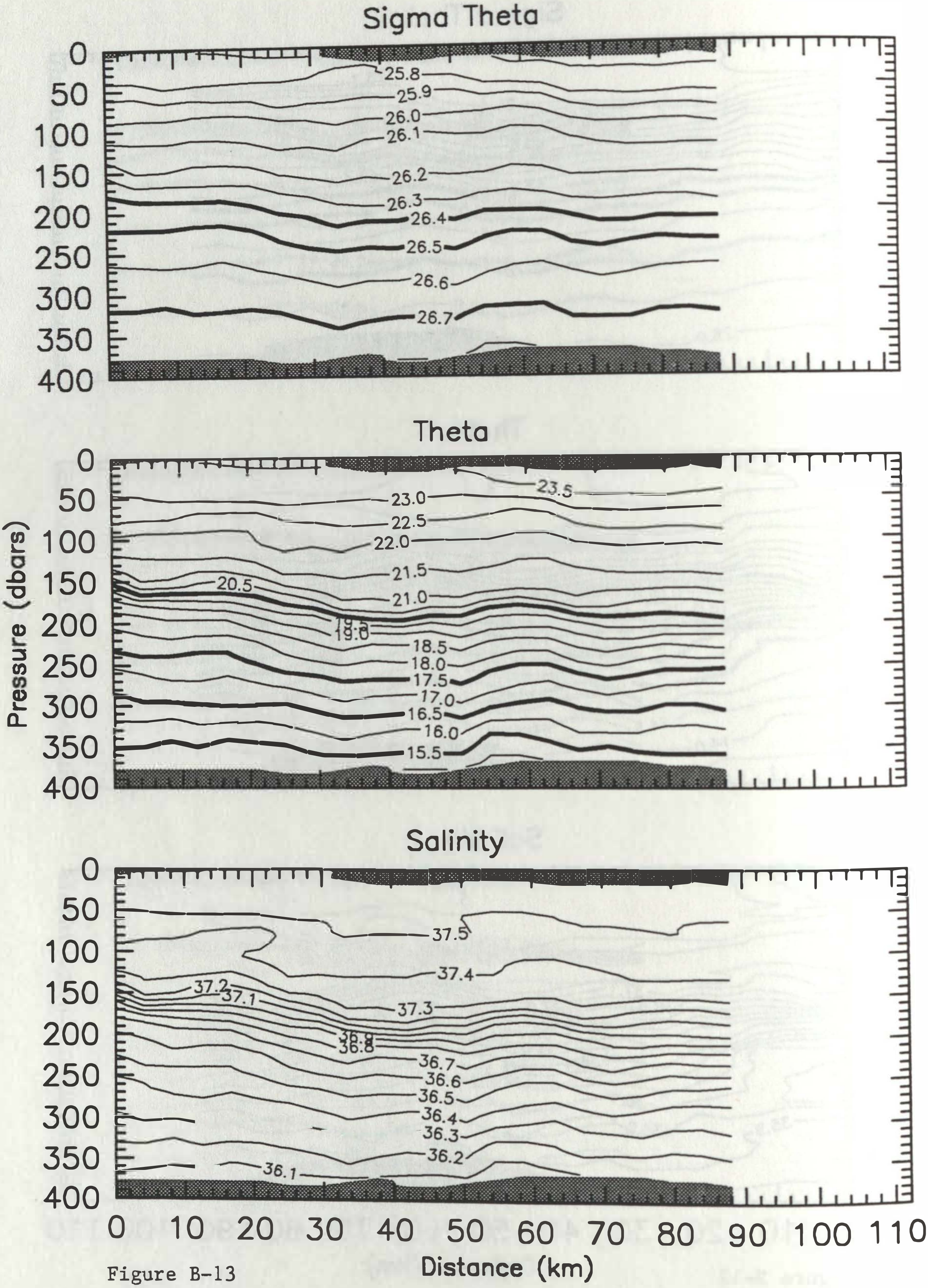


Figure B-13

Sub 4, Star 2 — Section E — W

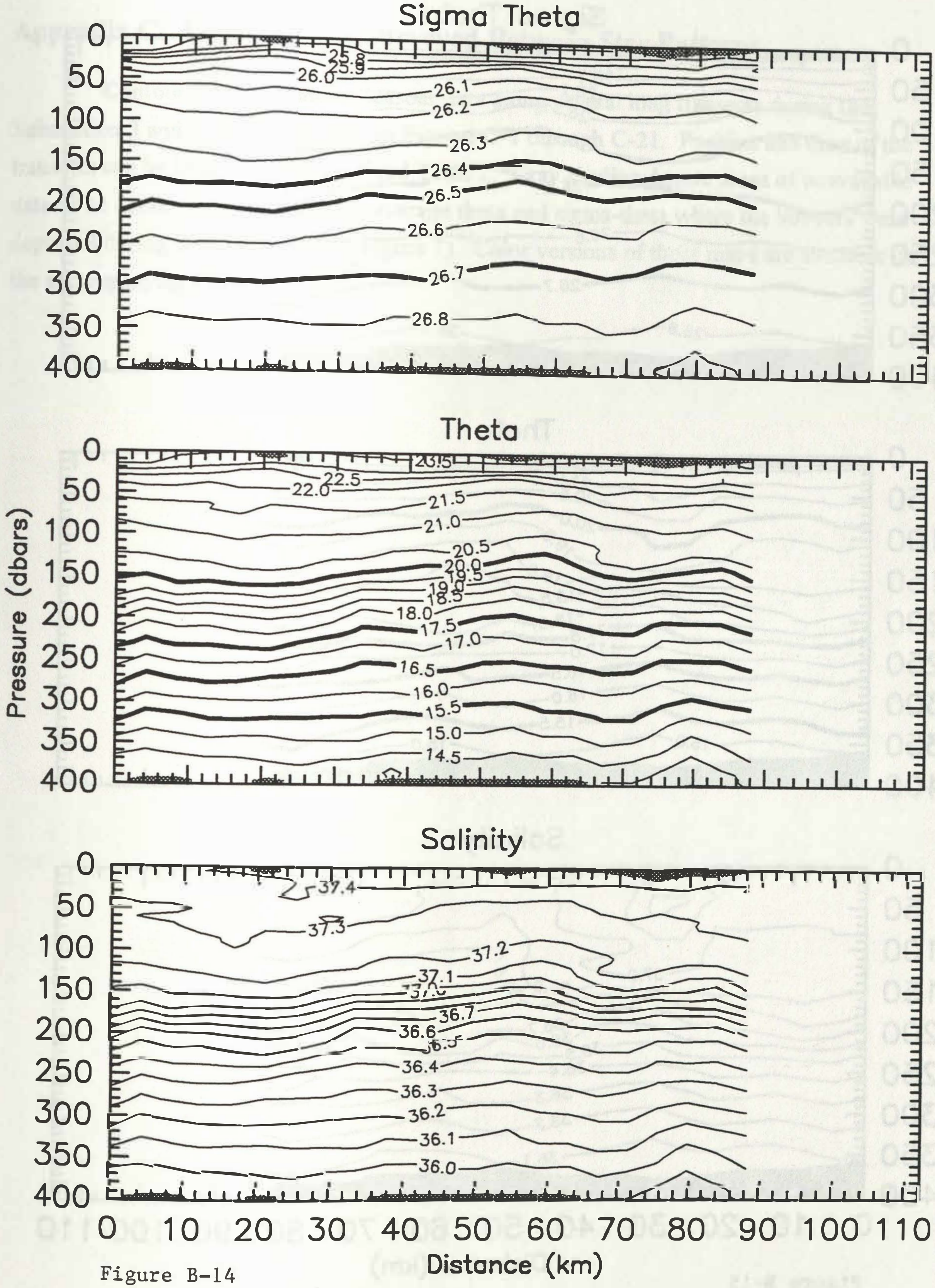


Figure B-14

Sub 4, Star 3 — Section NE — SW

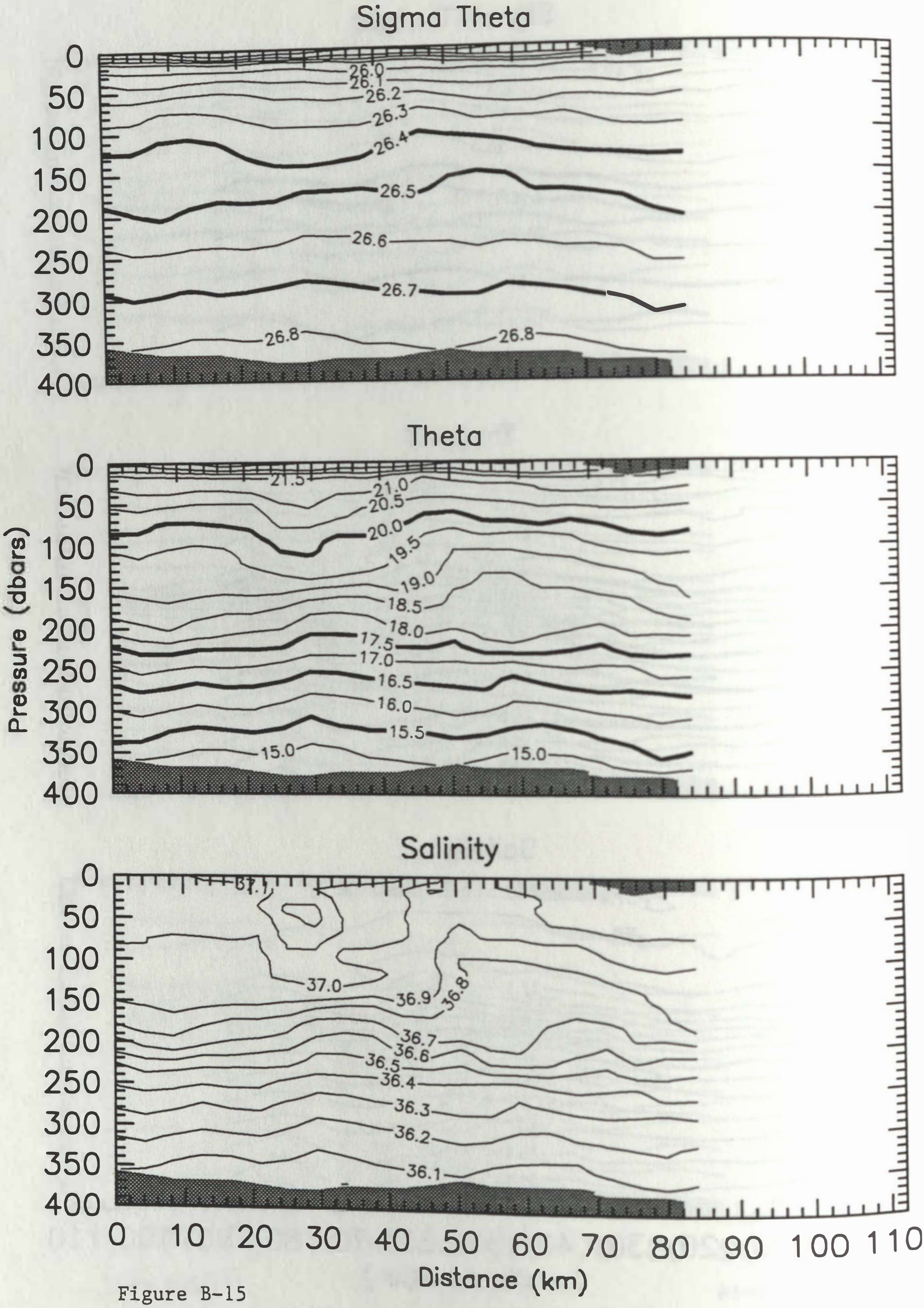
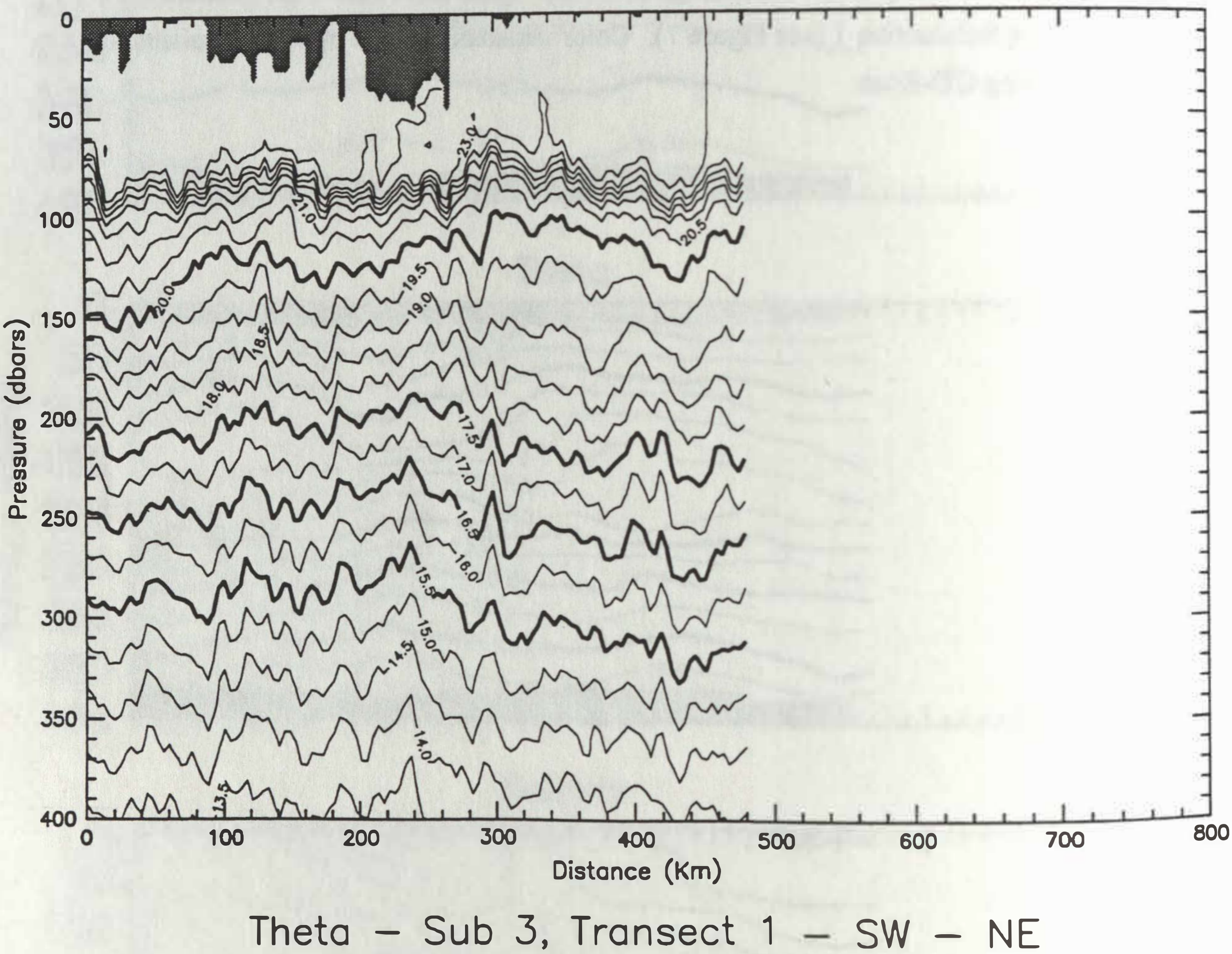


Figure B-15

Sub 4, Star 4 – Section SE – NW

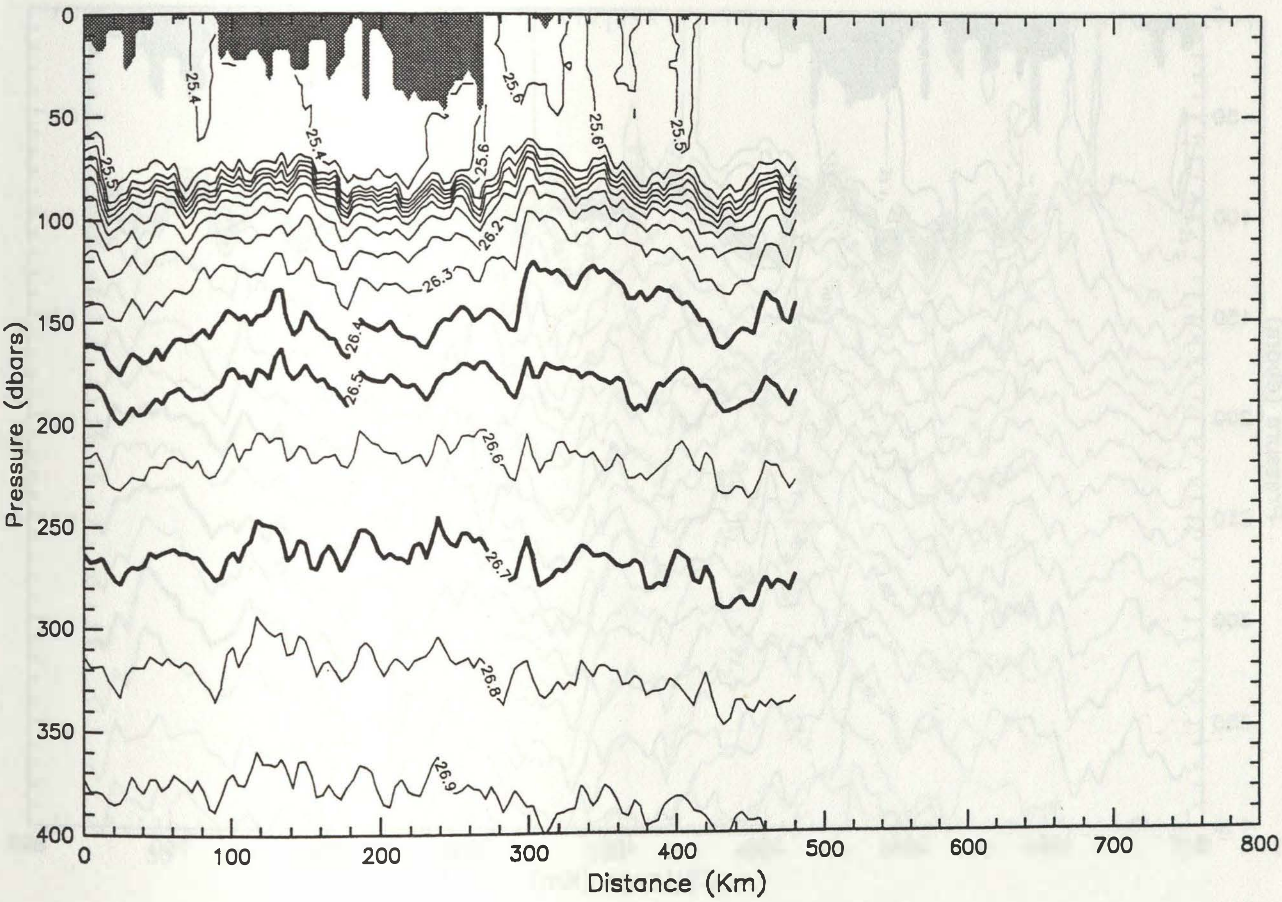
Appendix C: Long Sections Surveyed Between Star Patterns

Contour plots of gridded Seasoar data along several long transects during the Subduction 3 and 4 cruises proceed on Figures C-1 through C-21. Position and time of the transects can be located on Figure 1 and Table 2. Gray shading denote areas of unavailable data. The darker lines represent the average theta and sigma-theta where the bobbers were deployed during Subduction 1 (see Figure 7). Color versions of these maps are available on the accompanying CD-Rom.



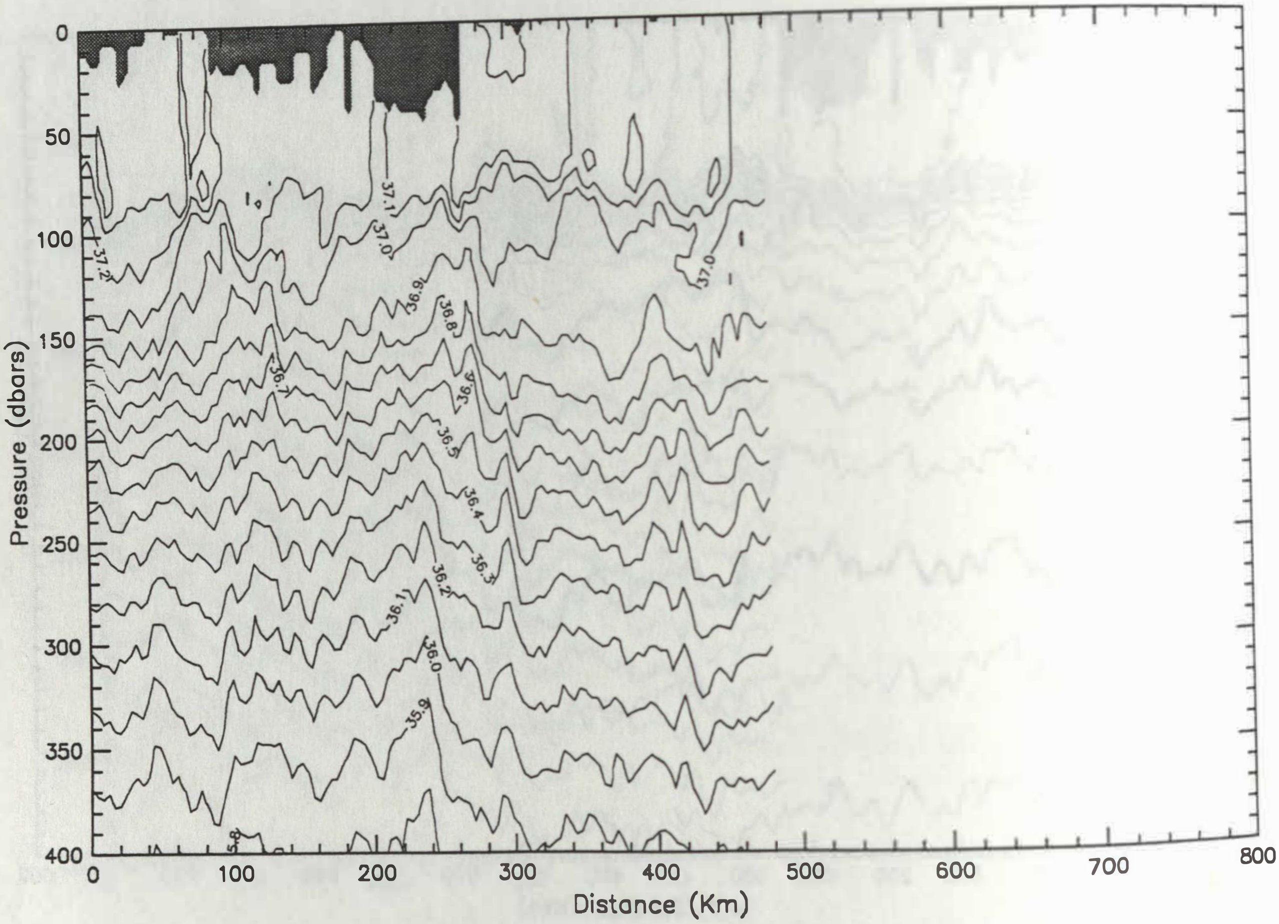
Pressure (dbars)
0
50
100
150
200
250
300
350
400
Distance (Km)
0
100
200
300
400
500
600
700
800
23.0
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
Theta – Sub 3, Transect 1 – SW – NE

Figure C-1



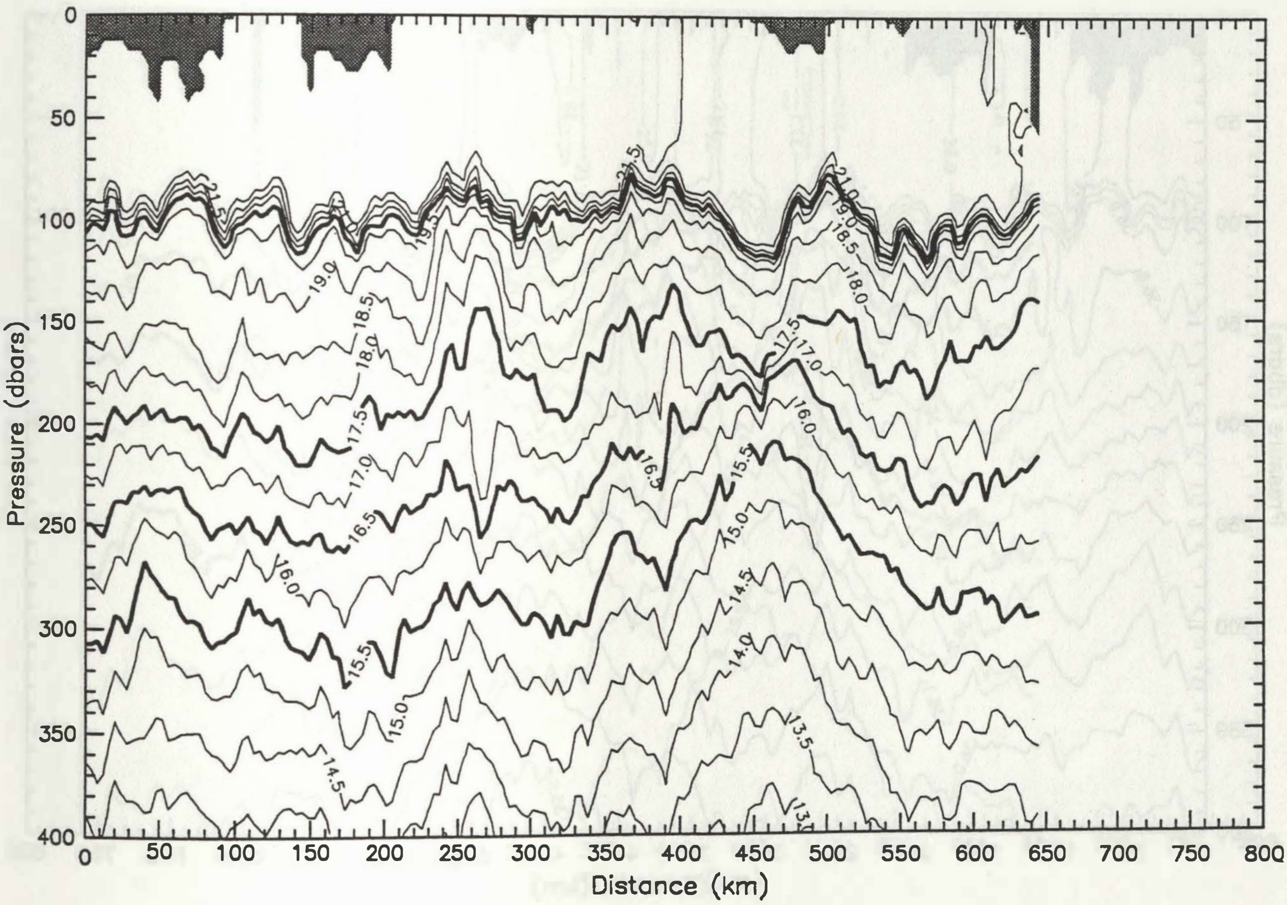
Sigma Theta — Sub 3, Transect 1 — SW — NE

Figure C-2



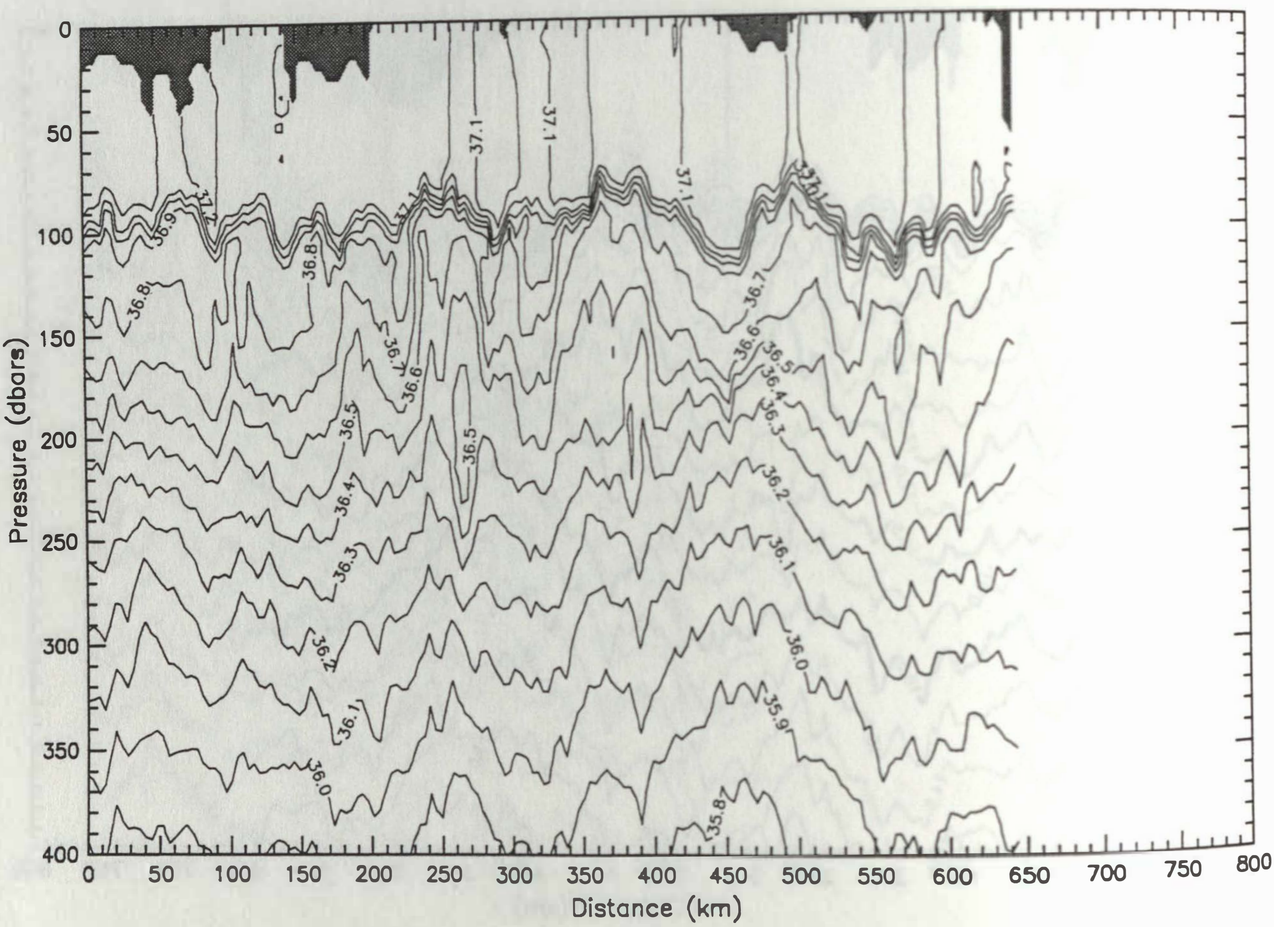
Salinity – Sub 3, Transect 1 – SW – NE

Figure C-3



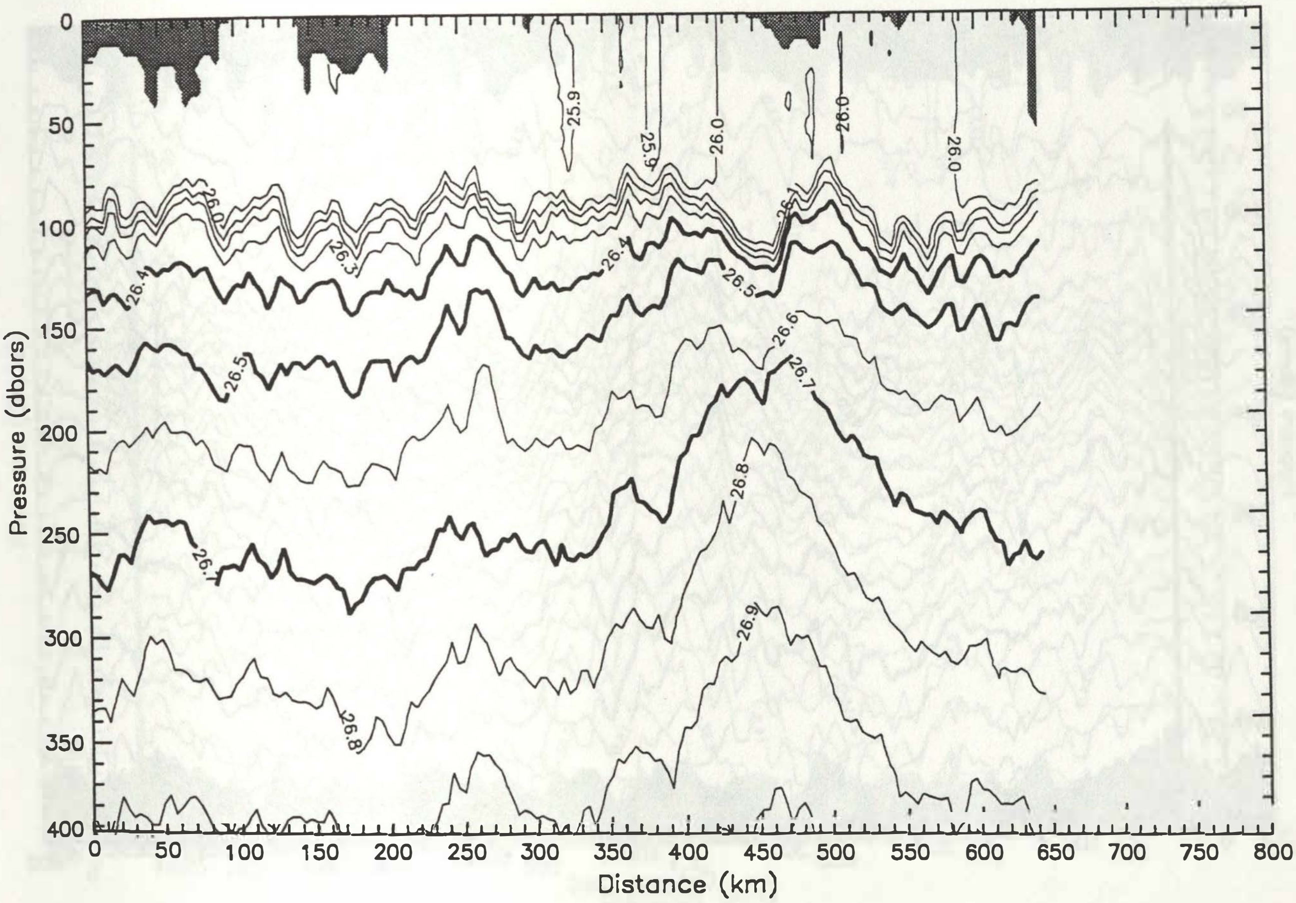
Theta — Sub 3, Transect 2 — S — N

Figure C-4



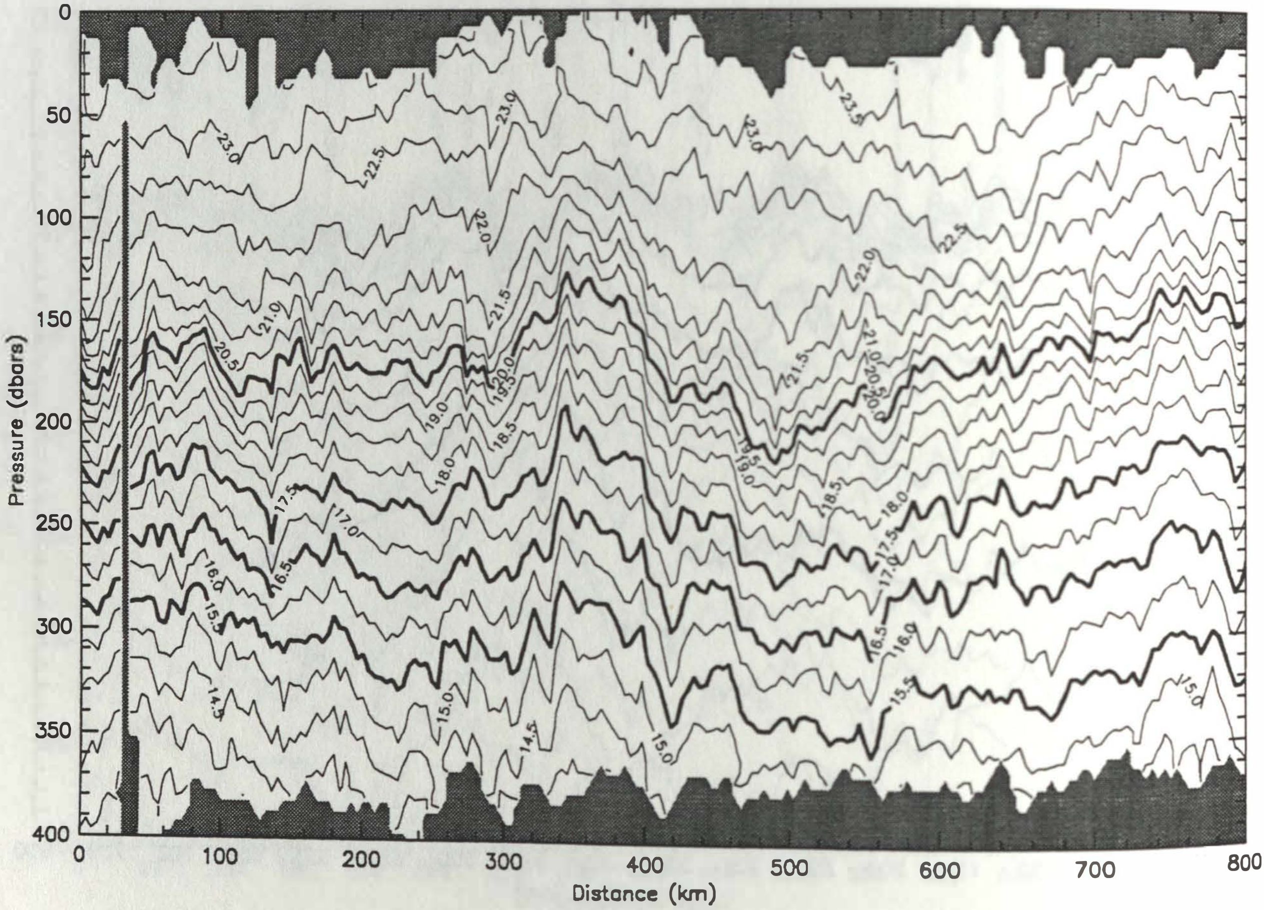
Salinity – Sub 3, Transect 2 – S – N

Figure C-5



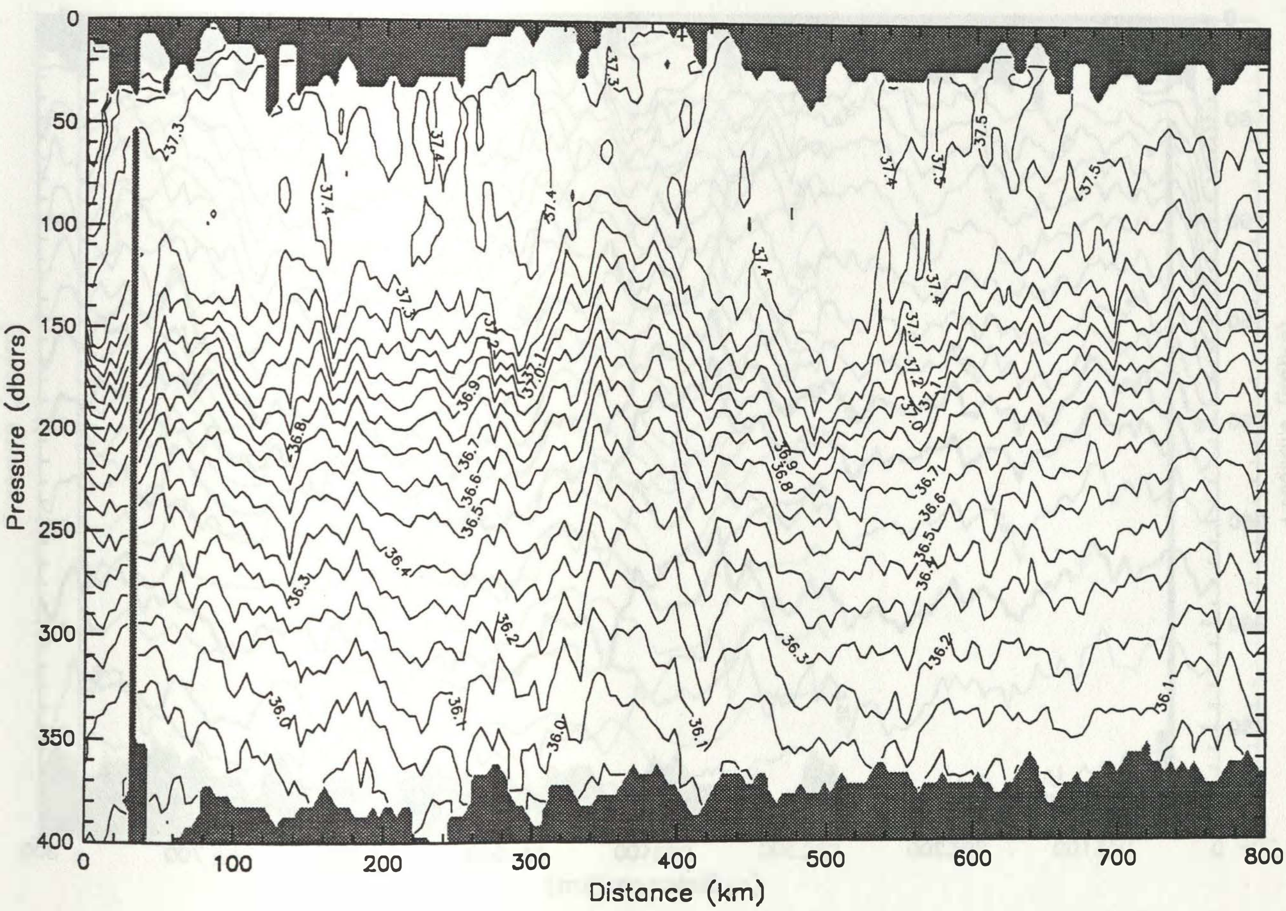
Sigma Theta — Sub 3, Transect 2 — S — N

Figure C-6



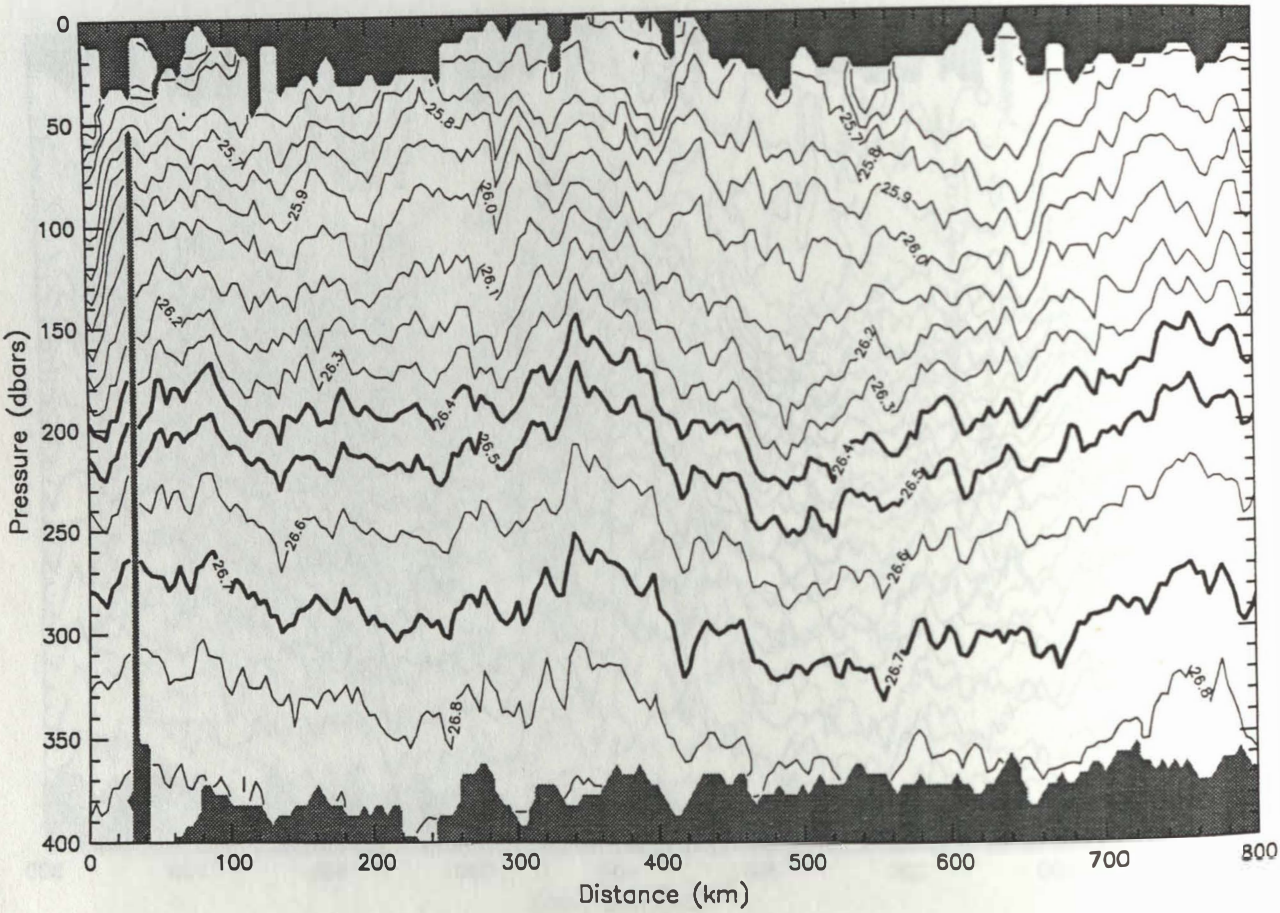
Theta – Sub 4, Transect 1 – SE – NW

Figure C-7



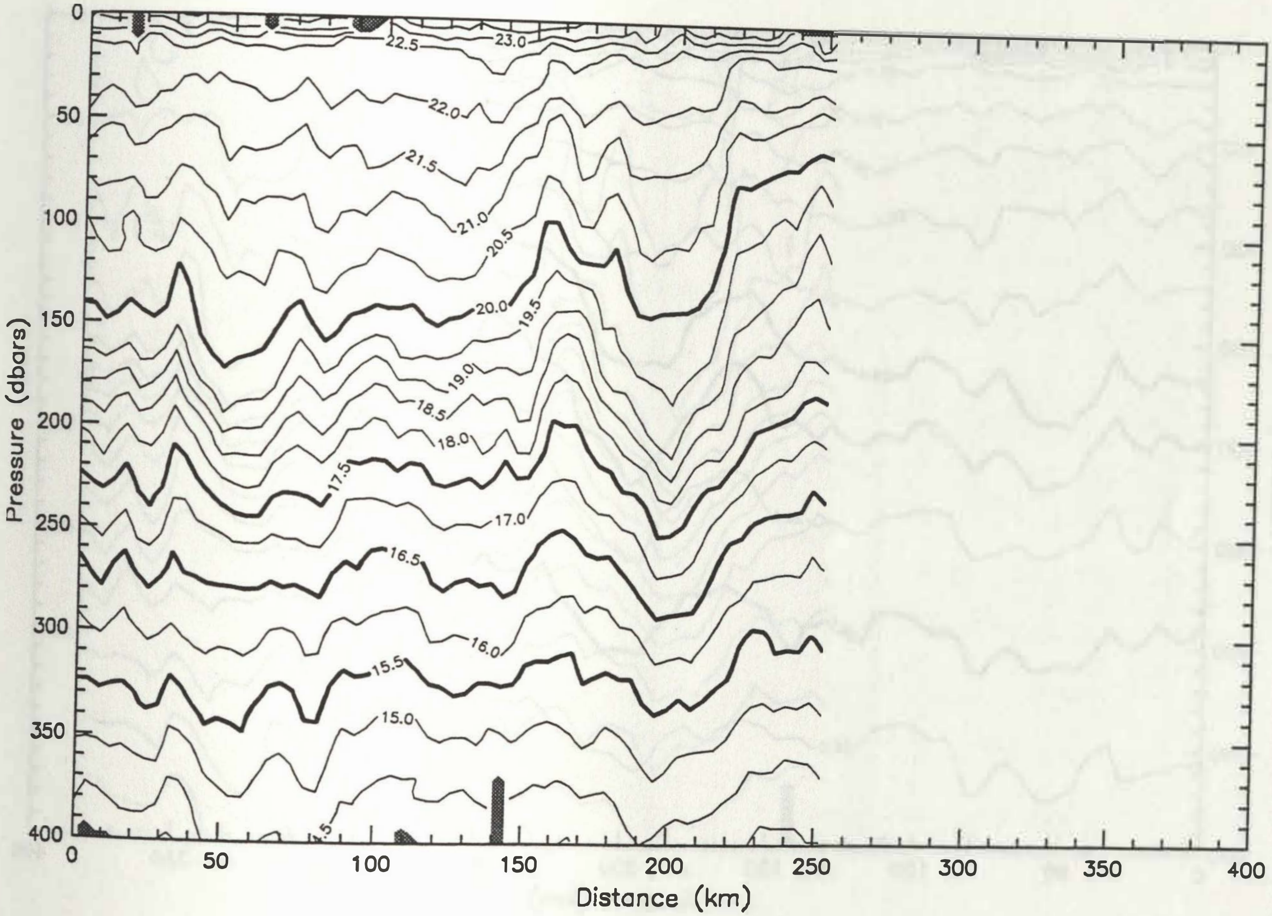
Salinity – Sub 4, Transect 1 – SE – NW

Figure C-8



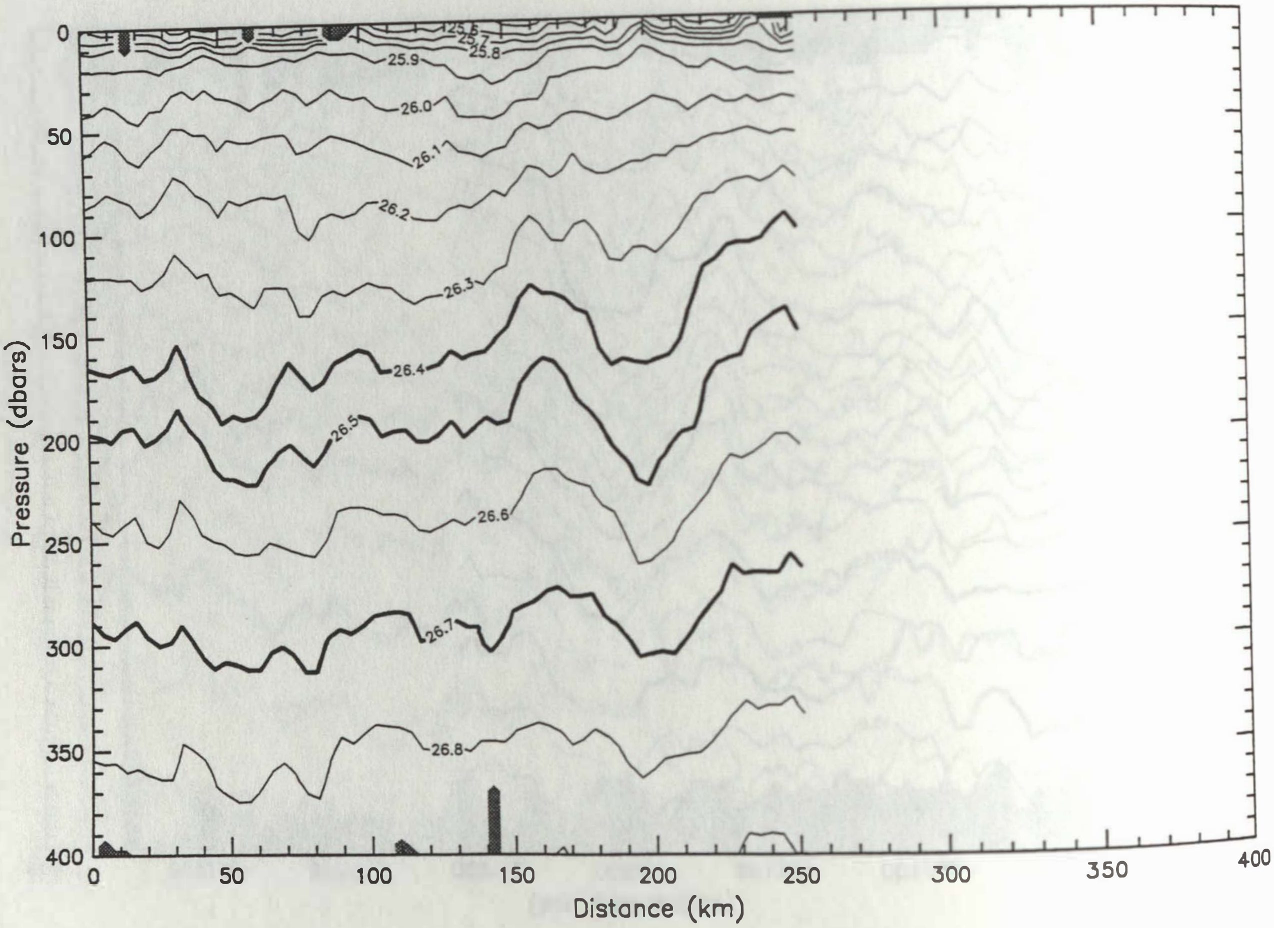
Sigma Theta – Sub 4, Transect 1 – SE – NW

Figure C-9



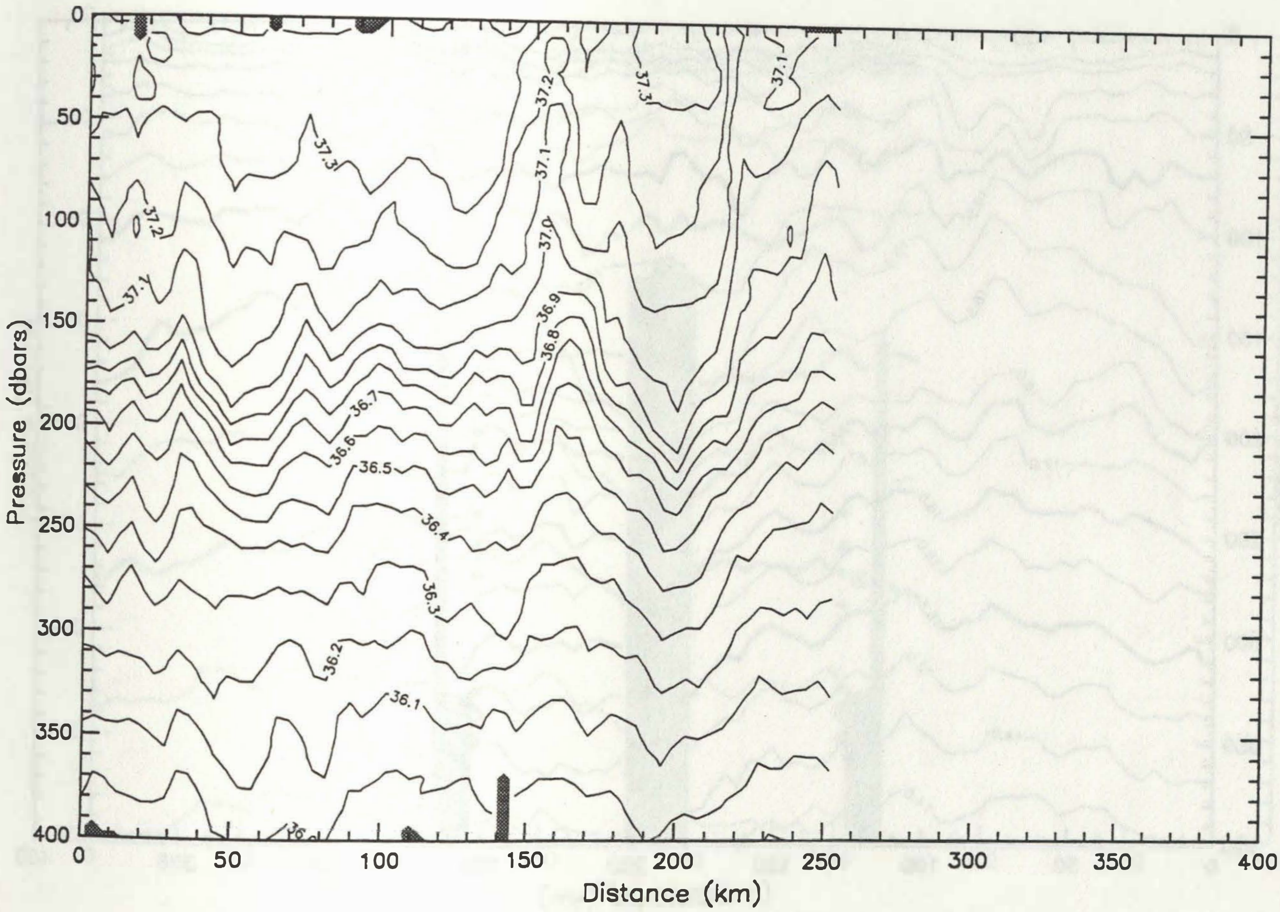
Theta — Sub 4, Transect 2 — S — N

Figure C-10



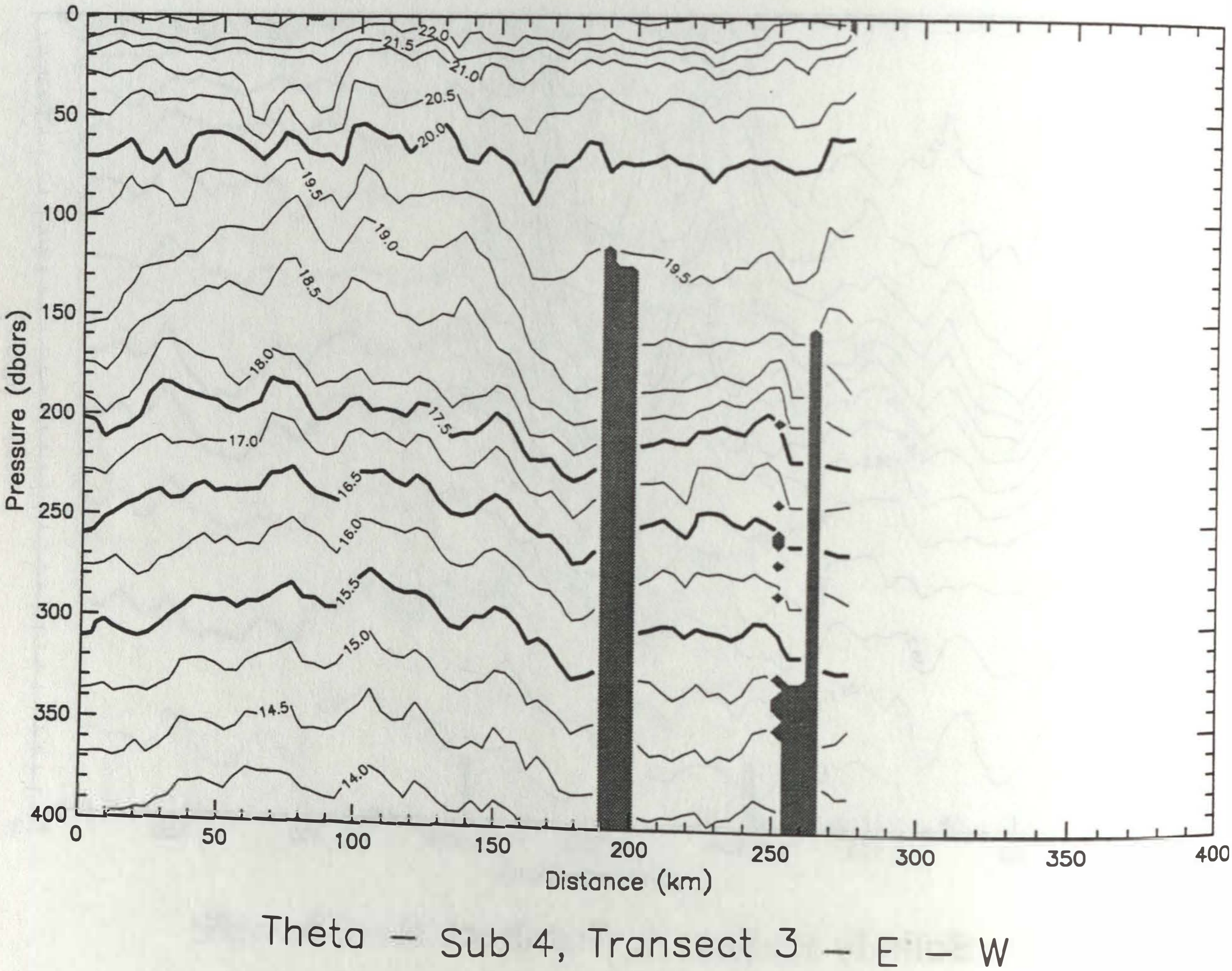
Sigma Theta – Sub 4, Transect 2 – S – N

Figure C-11



Salinity – Sub 4, Transect 2 – S – N

Figure C-12



Pressure (dbars)
Distance (km)
0
50
100
150
200
250
300
350
400
22.0
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
Theta — Sub 4, Transect 3 — E — W

Figure C-13

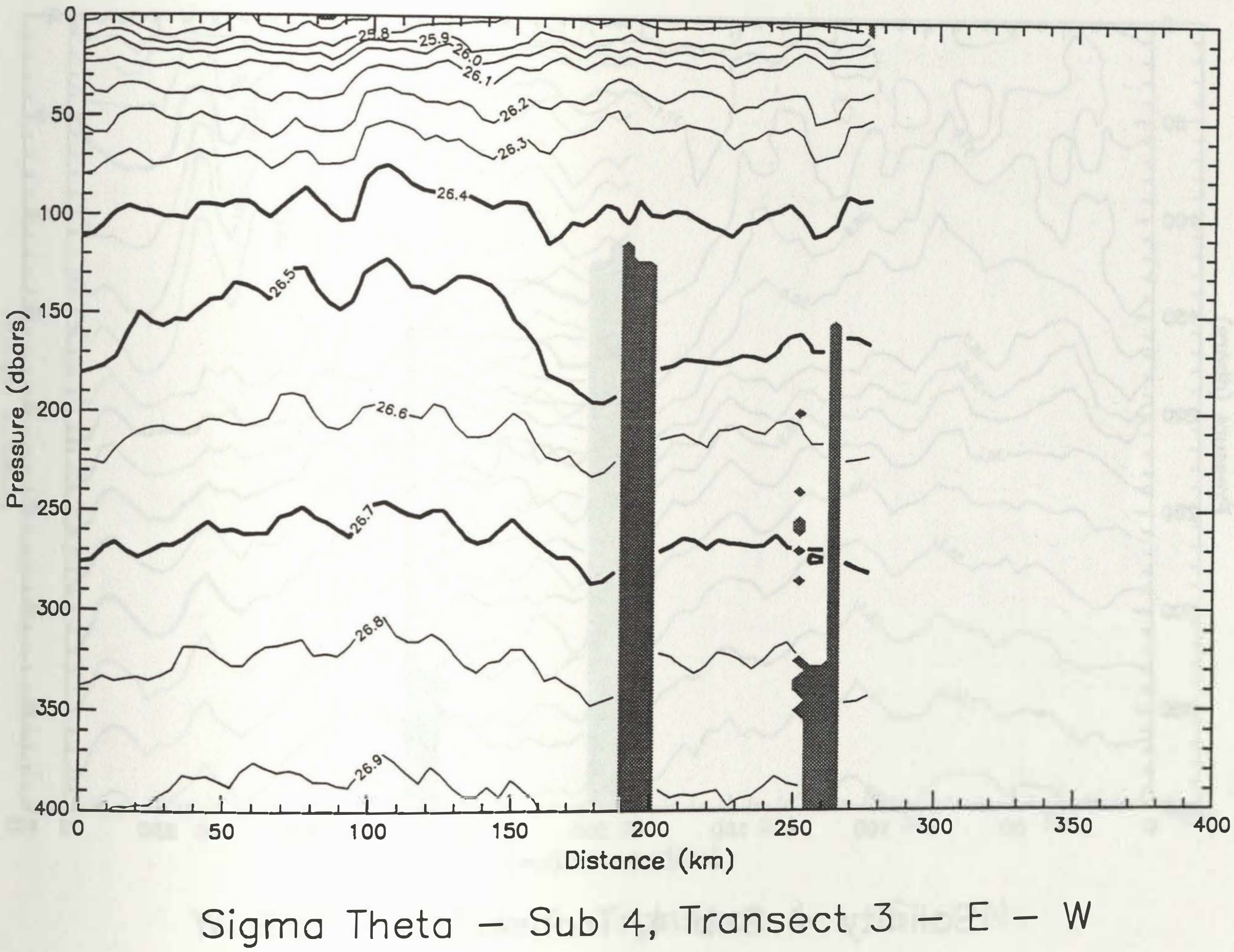

25.8
25.9
26.0
26.1
26.2
26.3
26.4
26.5
26.6
26.7
26.8
26.9
Pressure (dbars)
0
50
100
150
200
250
300
350
400
Distance (km)
0
50
100
150
200
250
300
350
400
Sigma Theta — Sub 4, Transect 3 — E — W

Figure C-14

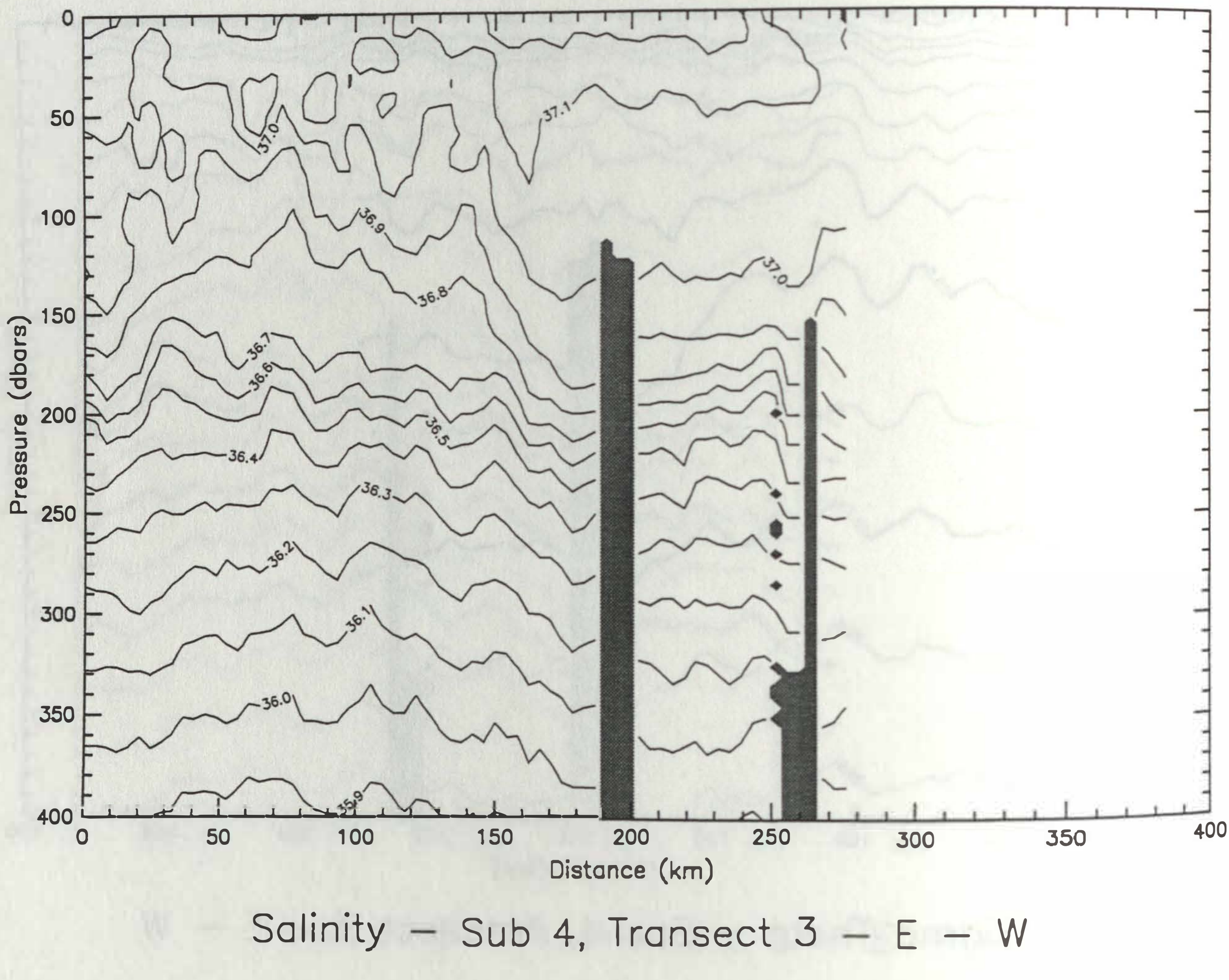
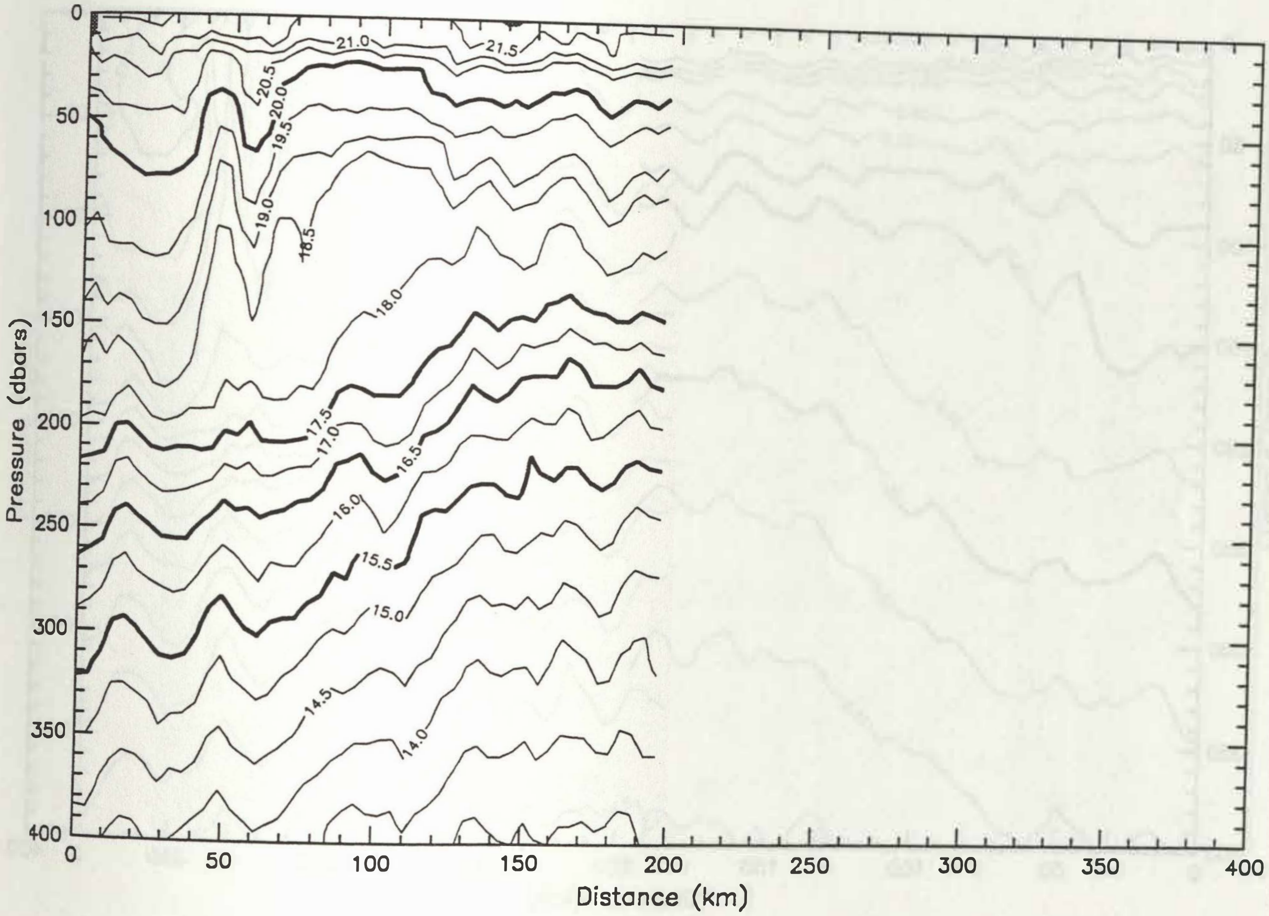
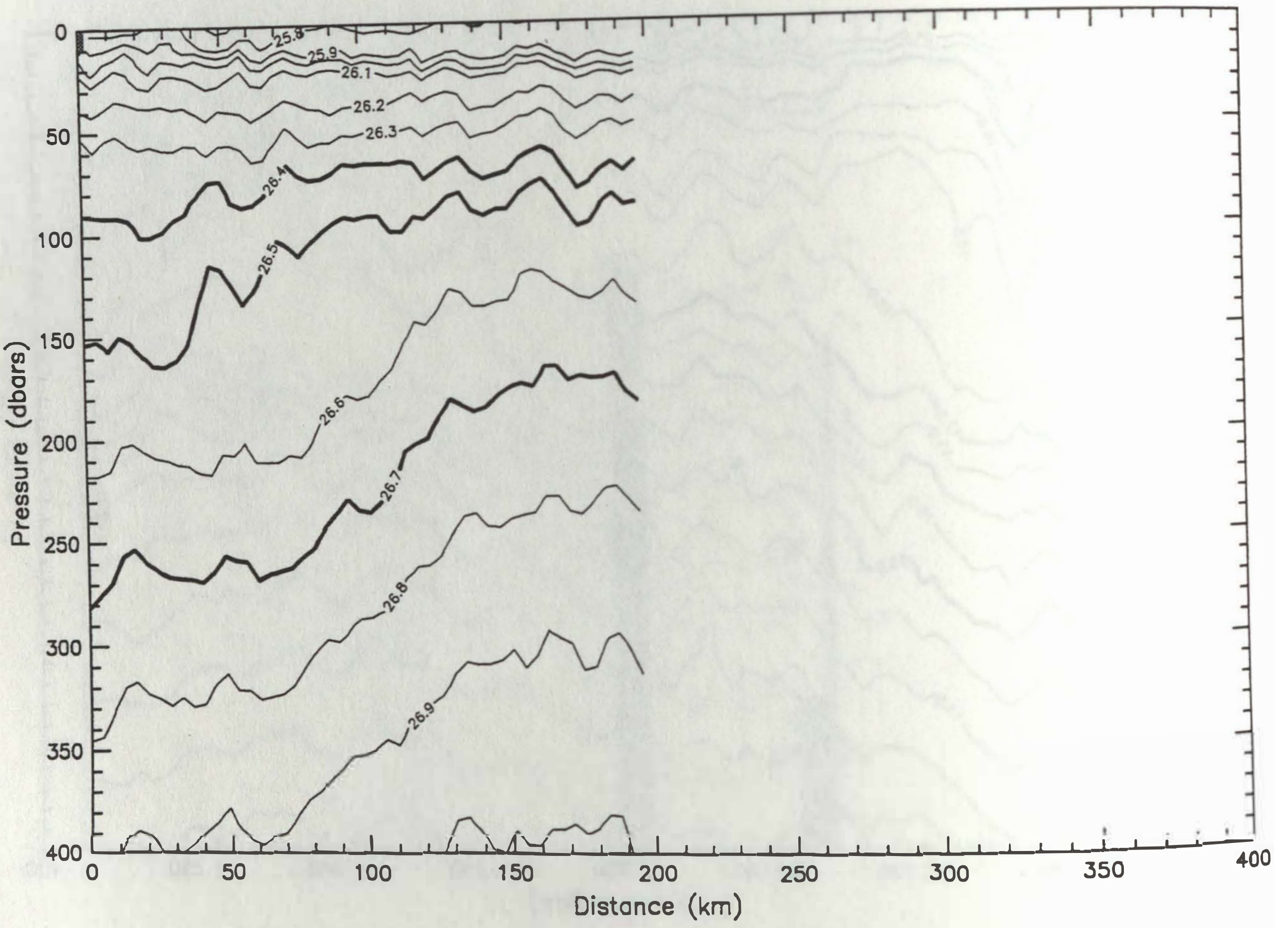

Pressure (dbars)
Distance (km)
0
50
100
150
200
250
300
350
400
37.1
37.0
36.9
36.8
36.7
36.6
36.5
36.4
36.3
36.2
36.1
36.0
35.9
Salinity – Sub 4, Transect 3 – E – W

Figure C-15



Theta – Sub 4, Transect 4 – S – N

Figure C-16



Sigma Theta – Sub 4, Transect 4 – S – N

Figure C-17

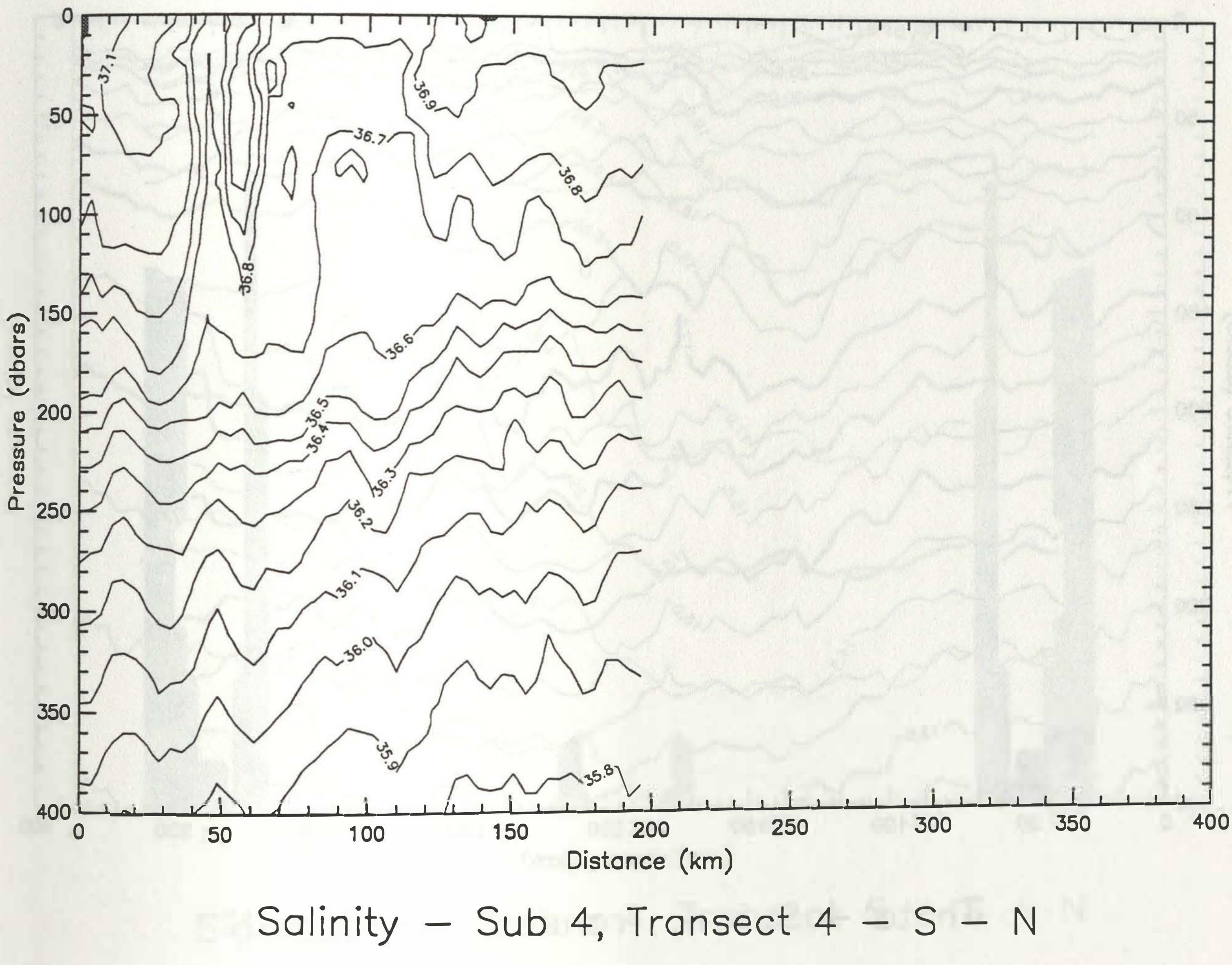
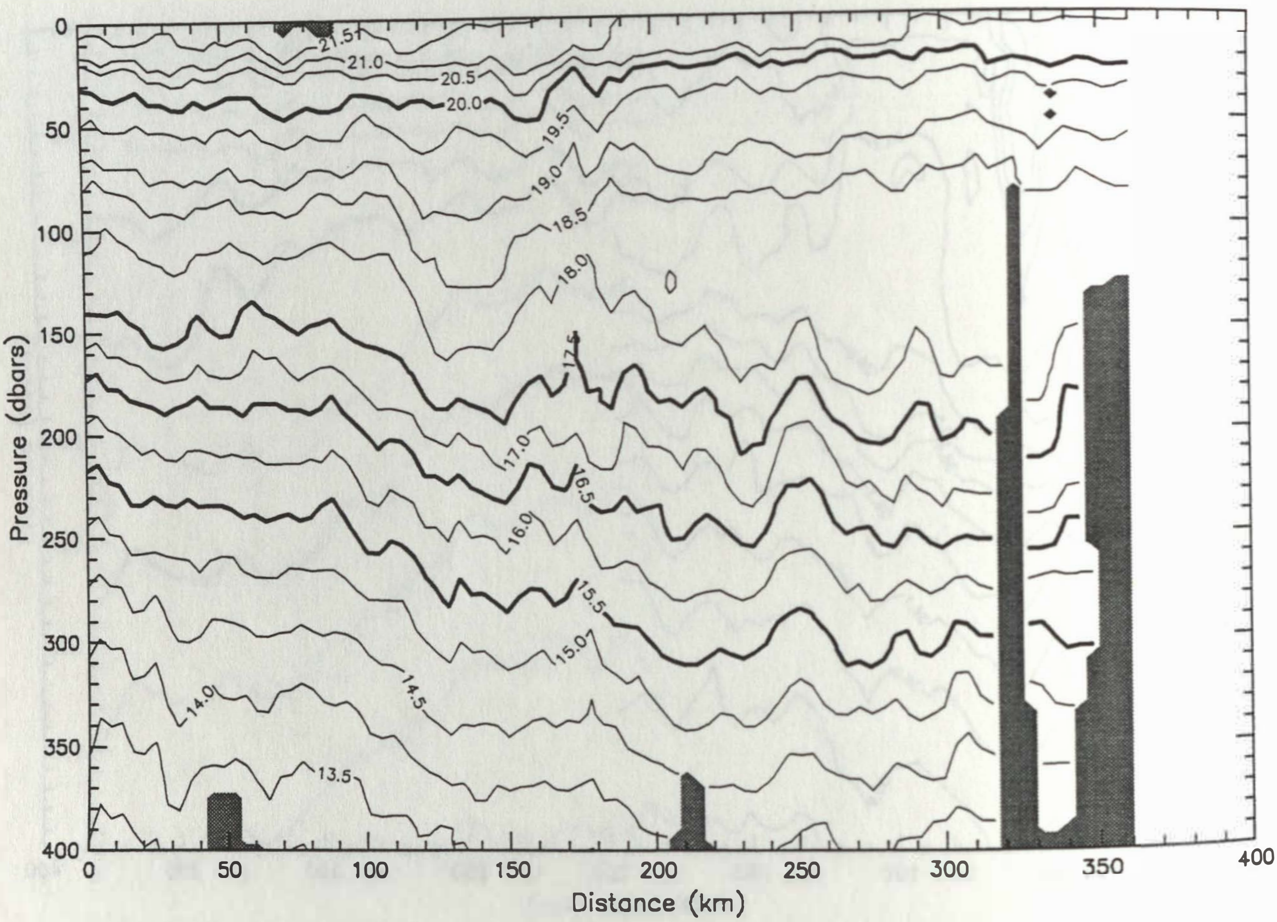
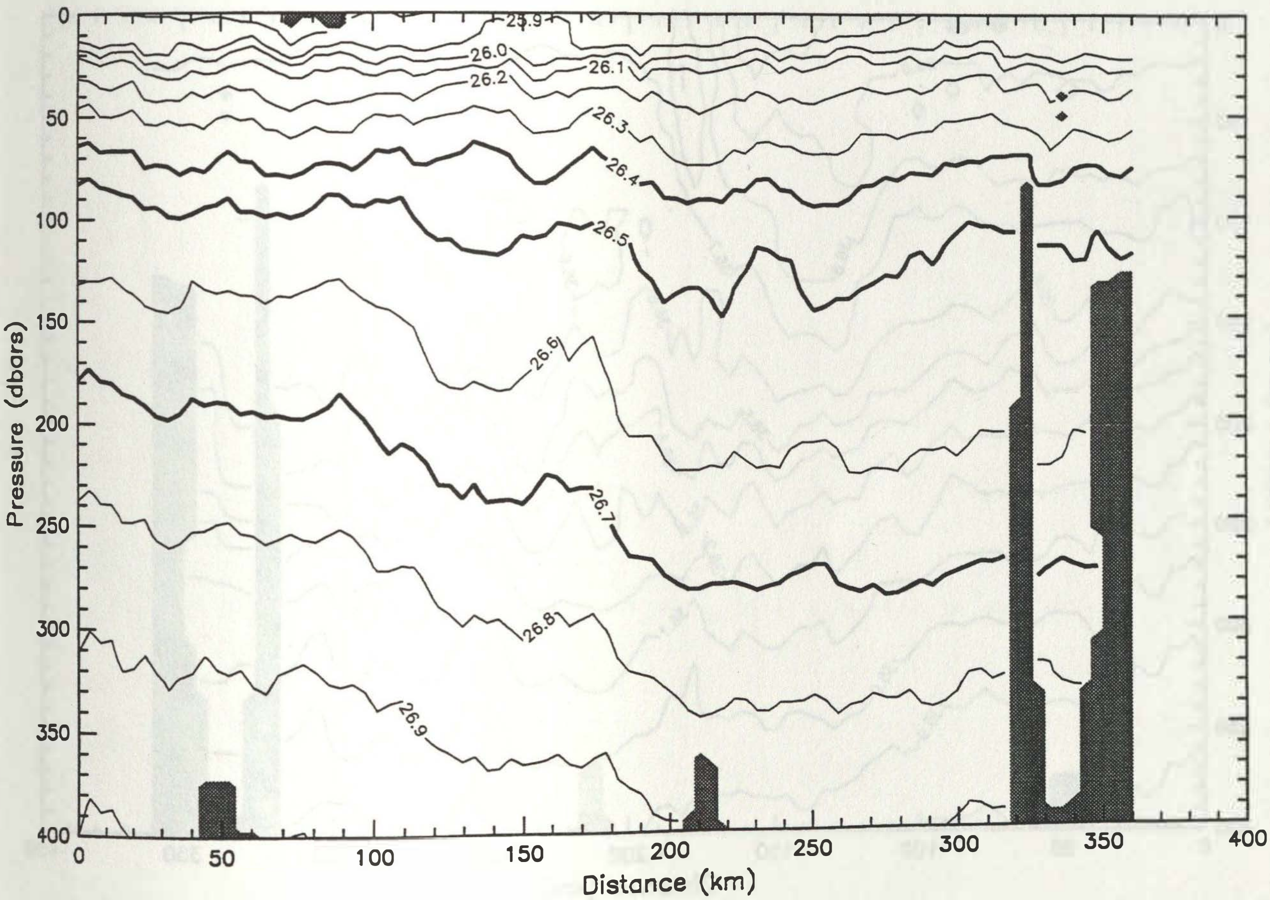

Pressure (dbars)
Distance (km)
37.1
36.9
36.7
36.8
36.8
36.6
36.5
36.4
36.3
36.2
36.1
36.0
35.9
35.8
Salinity – Sub 4, Transect 4 – S – N

Figure C-18



Theta – Sub 4, Transect 5 – S – N

Figure C-19



Sigma Theta — Sub 4, Transect 5 — S — N

Figure C-20

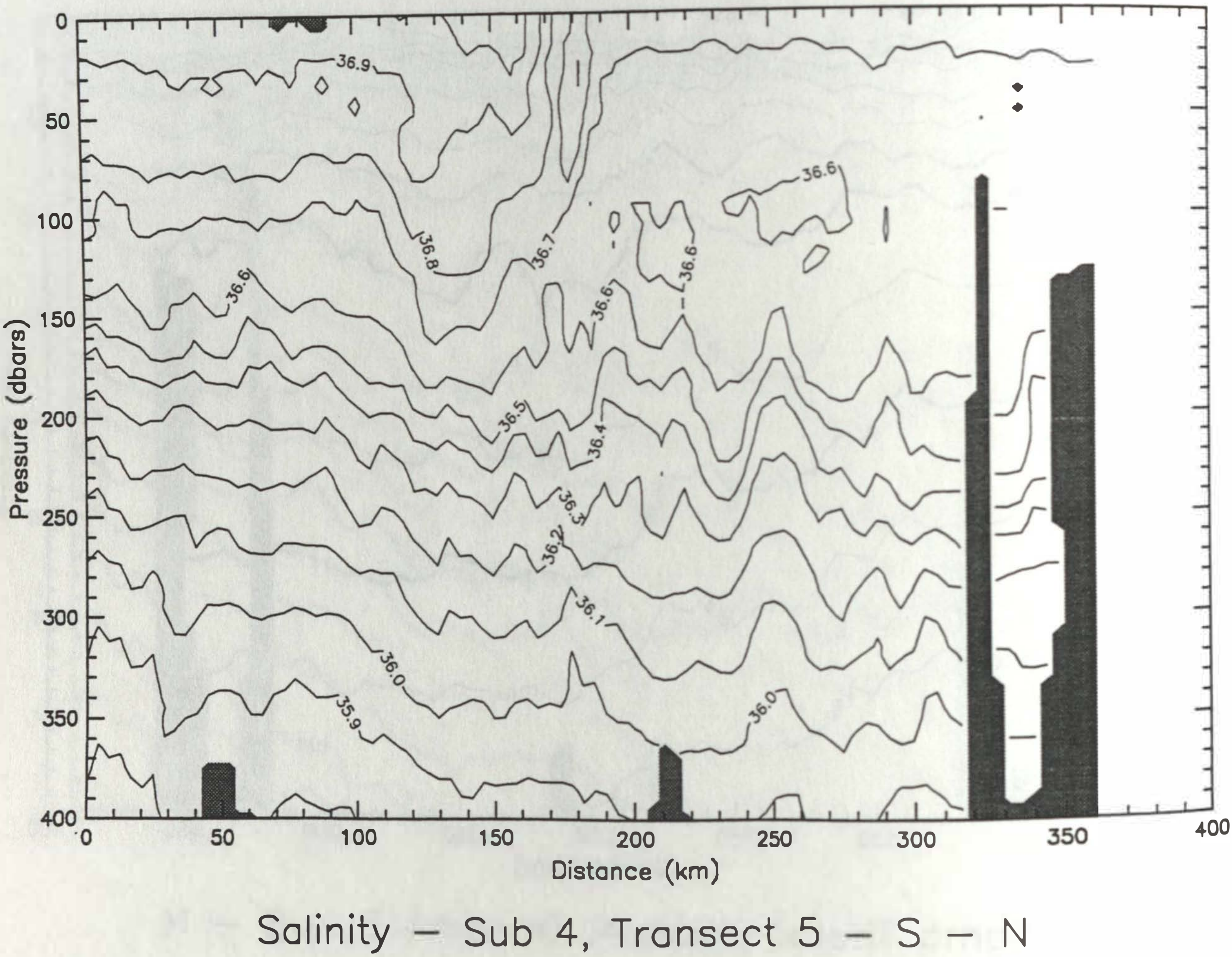
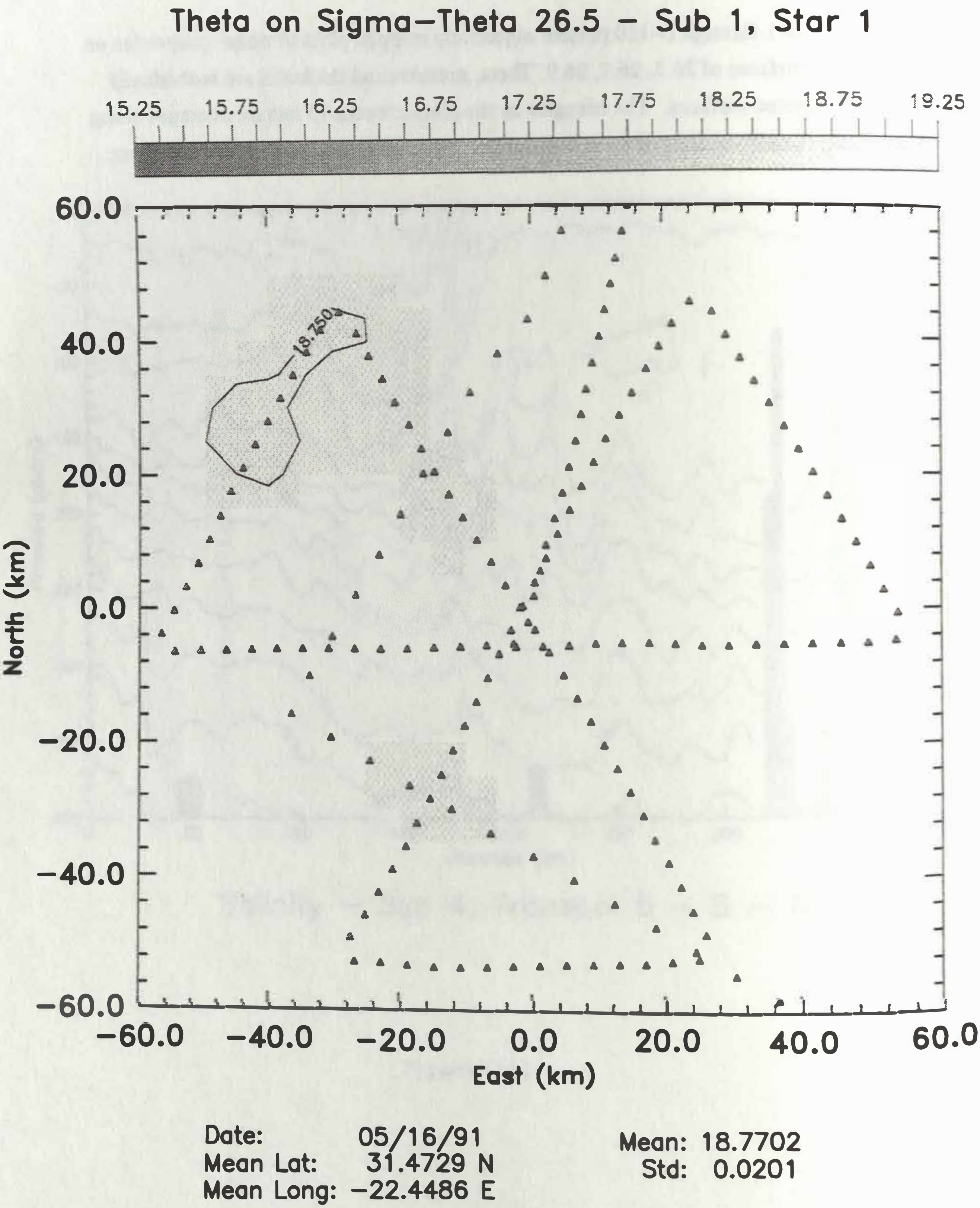

Pressure (dbars)
Distance (km)
0
50
100
150
200
250
300
350
400
36.9
36.8
36.7
36.6
36.5
36.4
36.3
36.2
36.1
36.0
35.9
Salinity - Sub 4, Transect 5 - S - N

Figure C-21

Appendix D: Star Pattern Objective Maps

Figures D-1 through D-110 present objectively mapped plots of ocean properties on potential density surfaces of 26.5, 26.7, 26.9. Theta, pressure and thickness are individually plotted on the selected surfaces. The triangles on the plots denotes 15 minute averages along the cruise track. Color versions of these maps are available on the accompanying CD-Rom.



Theta on Sigma-Theta 26.5 - Sub 1, Star 1
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
18.750
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E
Mean: 18.7702
Std: 0.0201

Figure D-1

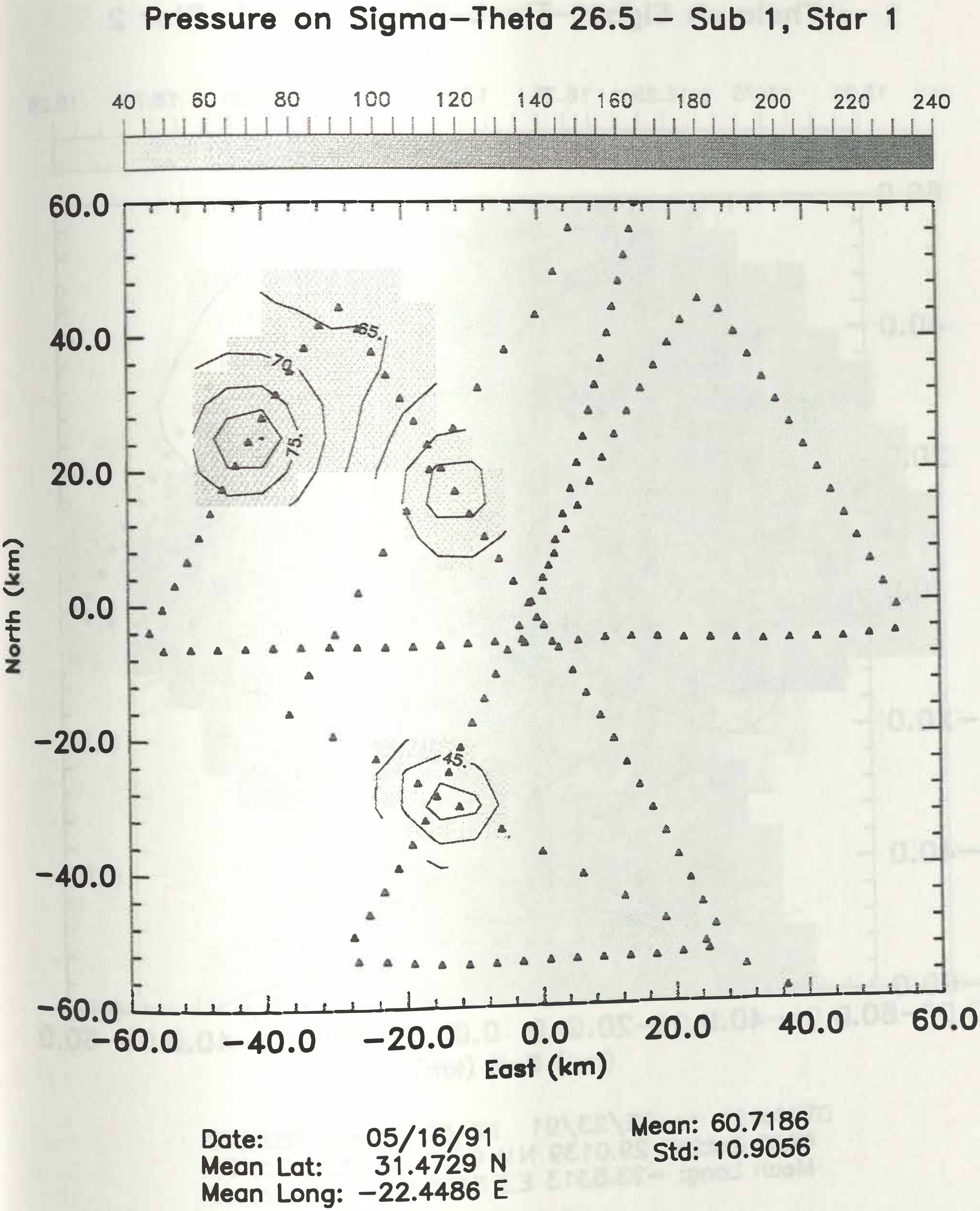
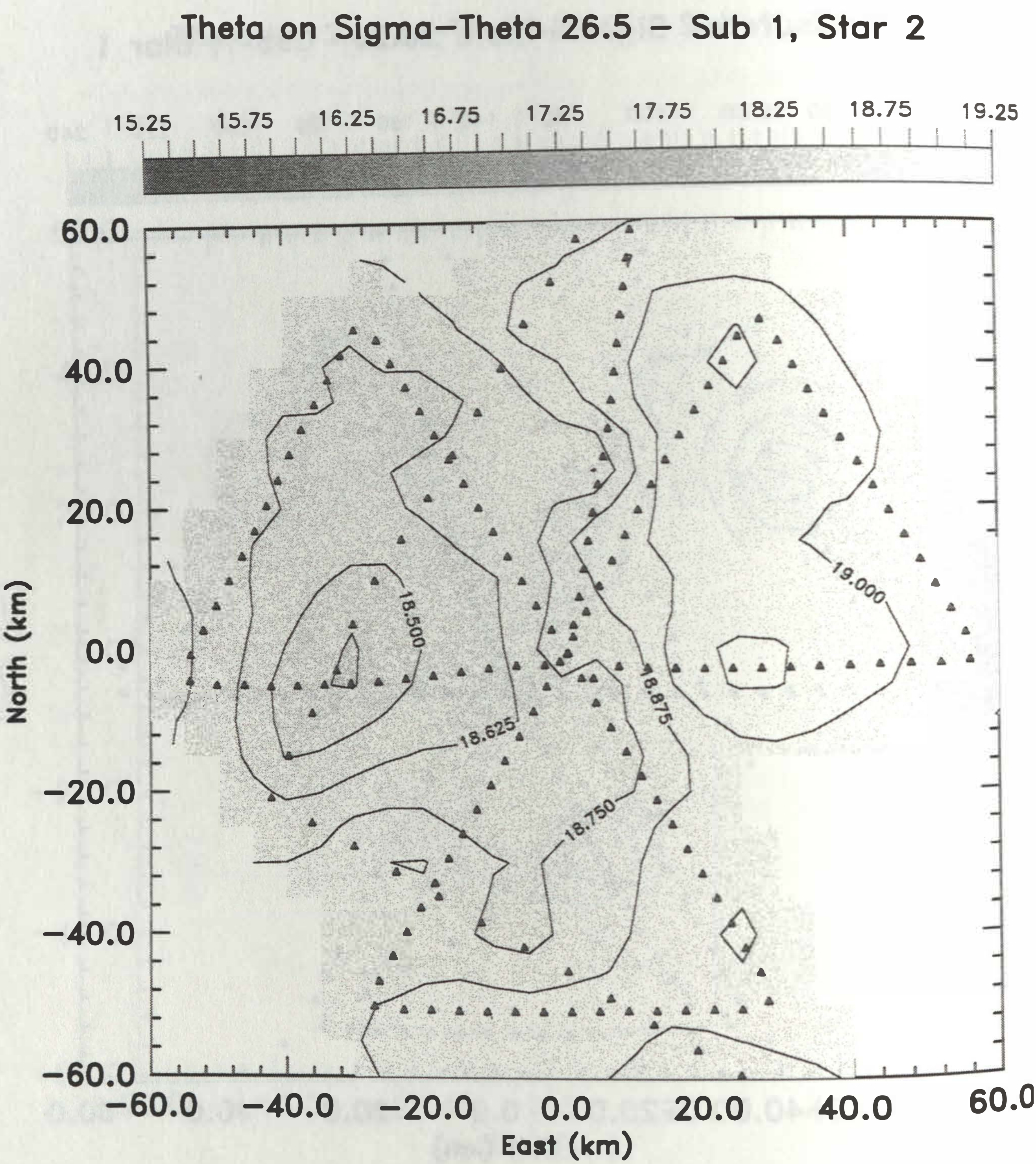

Pressure on Sigma−Theta 26.5 − Sub 1, Star 1
40
60
80
100
120
140
160
180
200
220
240
60.0
40.0
20.0
0.0
−20.0
−40.0
−60.0
North (km)
−60.0
−40.0
−20.0
0.0
20.0
40.0
60.0
East (km)
65.
70.
75.
45.
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: −22.4486 E
Mean: 60.7186
Std: 10.9056

Figure D-2



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 18.8167
Std: 0.1685

Figure D-3

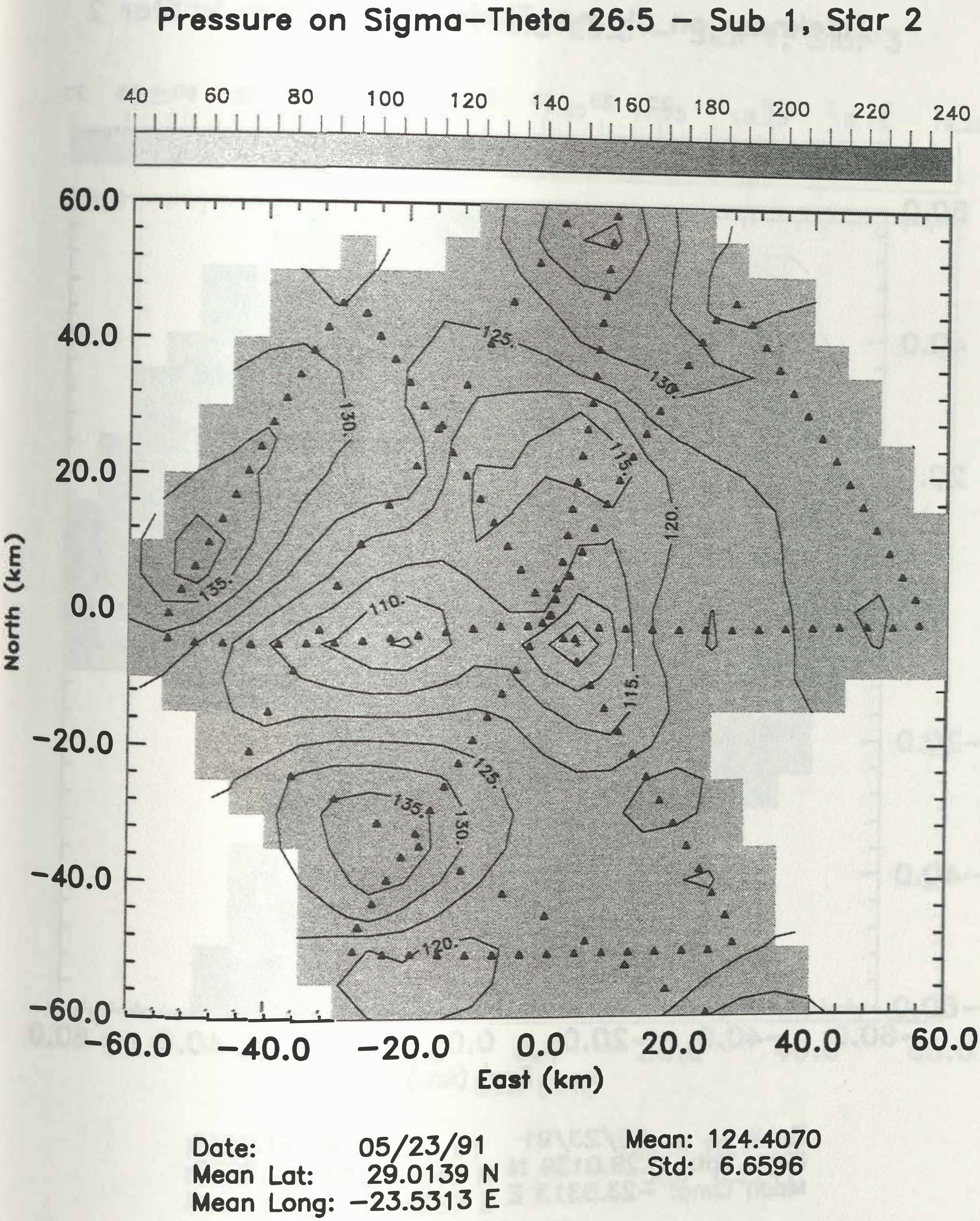

Pressure on Sigma-Theta 26.5 - Sub 1, Star 2
40
60
80
100
120
140
160
180
200
220
240
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
125.
130.
115.
120.
110.
135.
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 124.4070
Std: 6.6596

Figure D-4

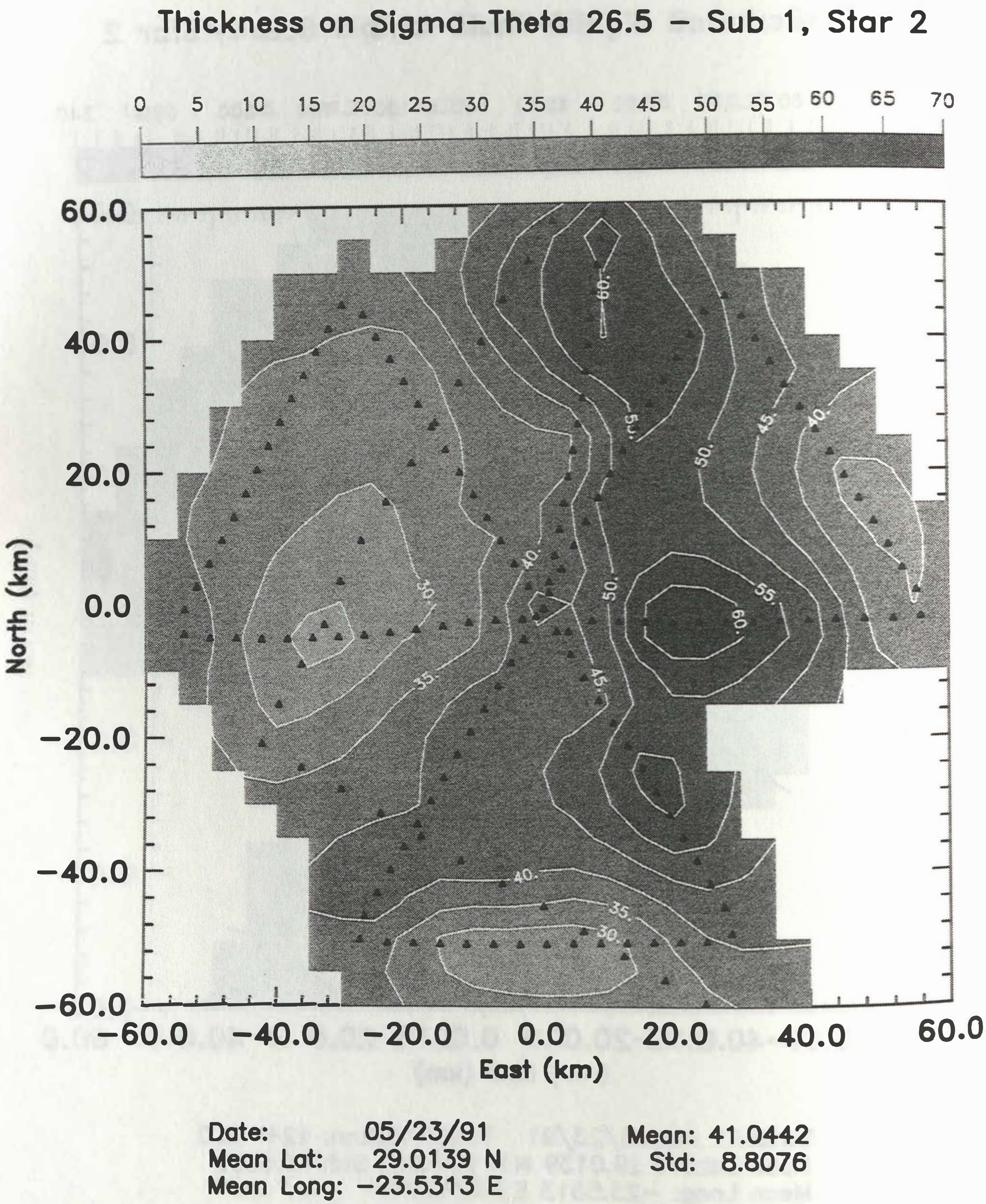

Thickness on Sigma—Theta 26.5 — Sub 1, Star 2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
−20.0
−40.0
−60.0
North (km)
−60.0
−40.0
−20.0
0.0
20.0
40.0
60.0
East (km)
60.
50.
45.
40.
50.
30.
40.
50.
55.
60.
35.
45.
40.
35.
30.
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: −23.5313 E
Mean: 41.0442
Std: 8.8076

Figure D-5

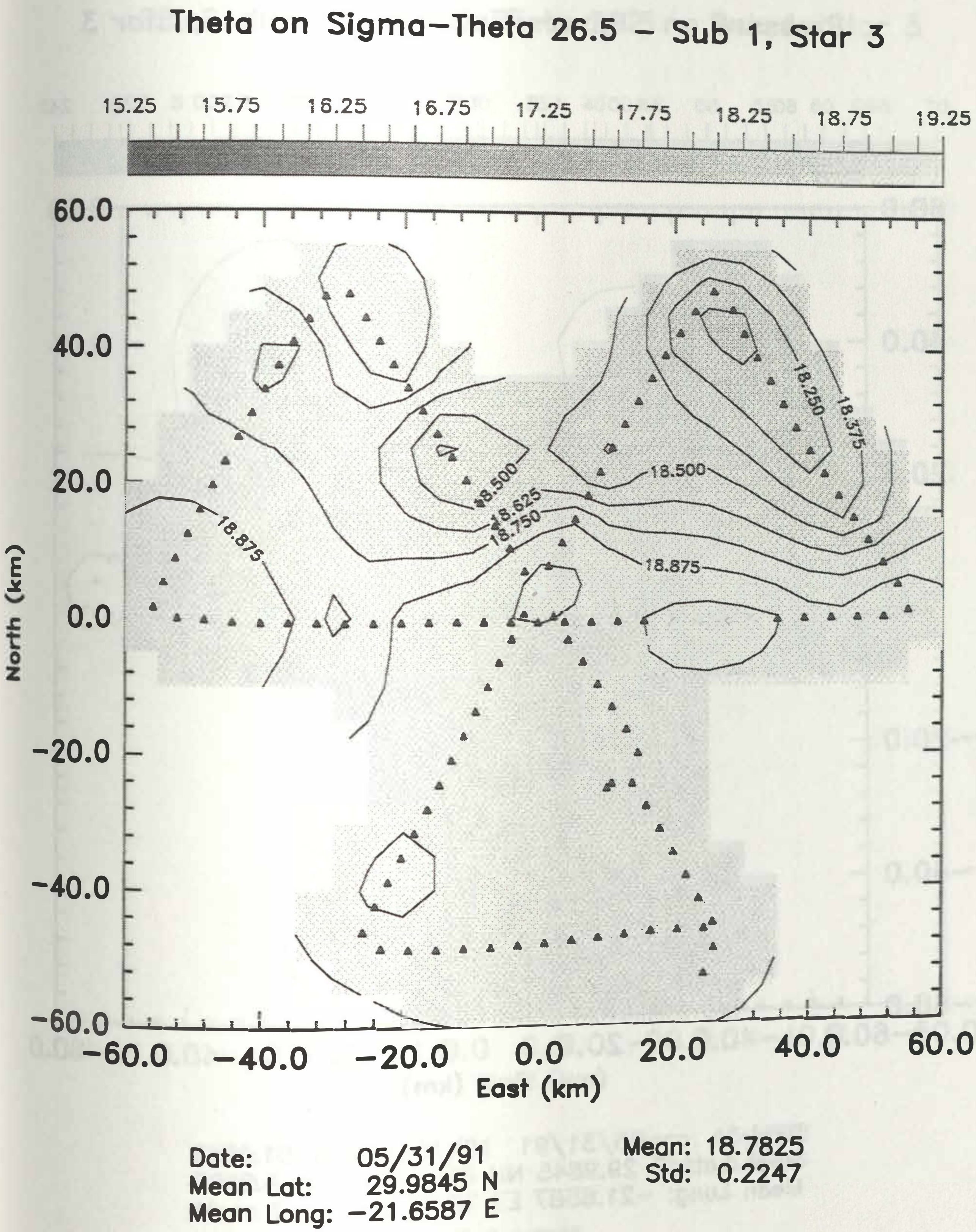
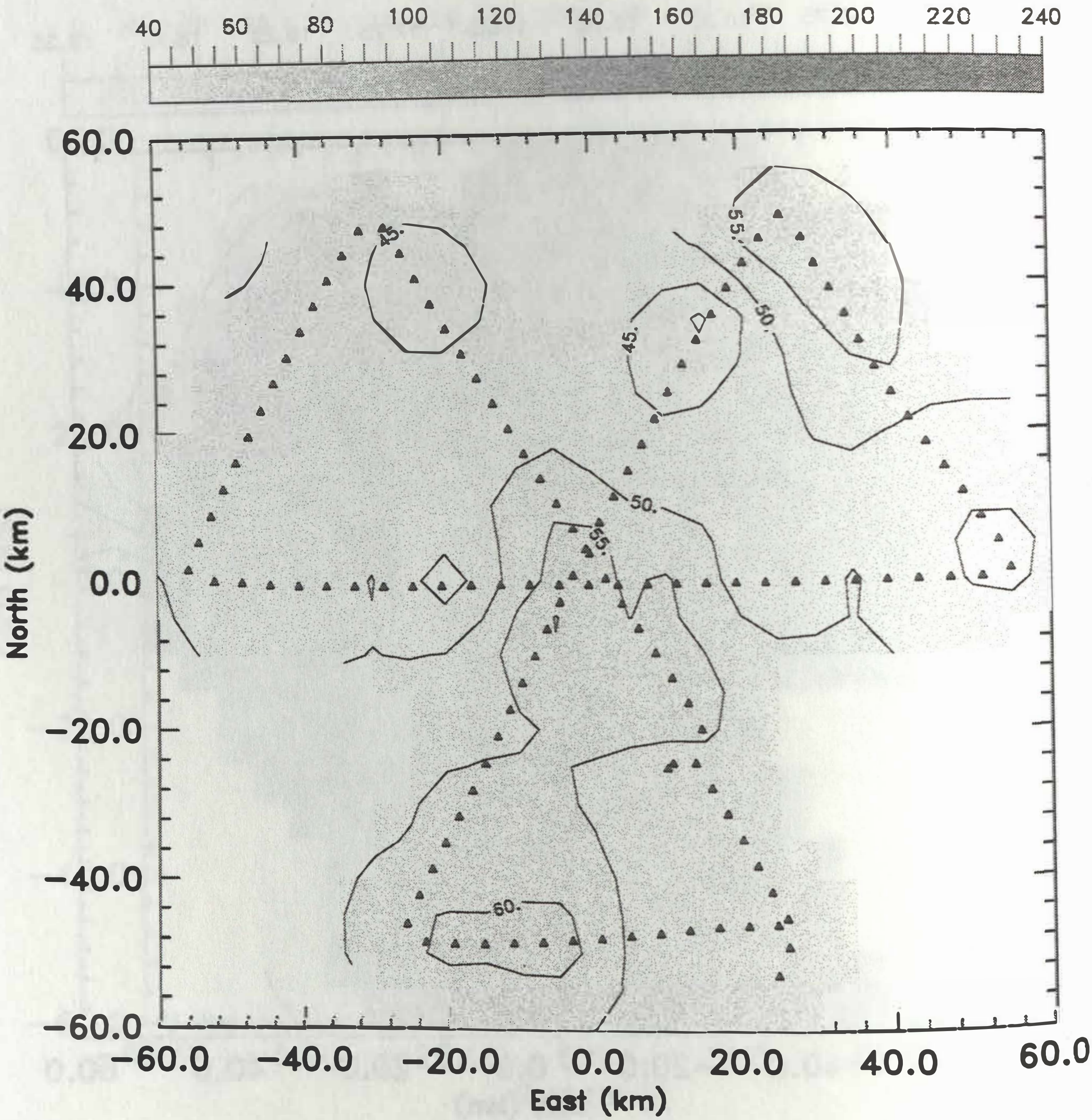

Theta on Sigma-Theta 26.5 - Sub 1, Star 3
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
18.250
18.375
18.500
18.500
18.625
18.750
18.875
18.875
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E
Mean: 18.7825
Std: 0.2247

Figure D-6

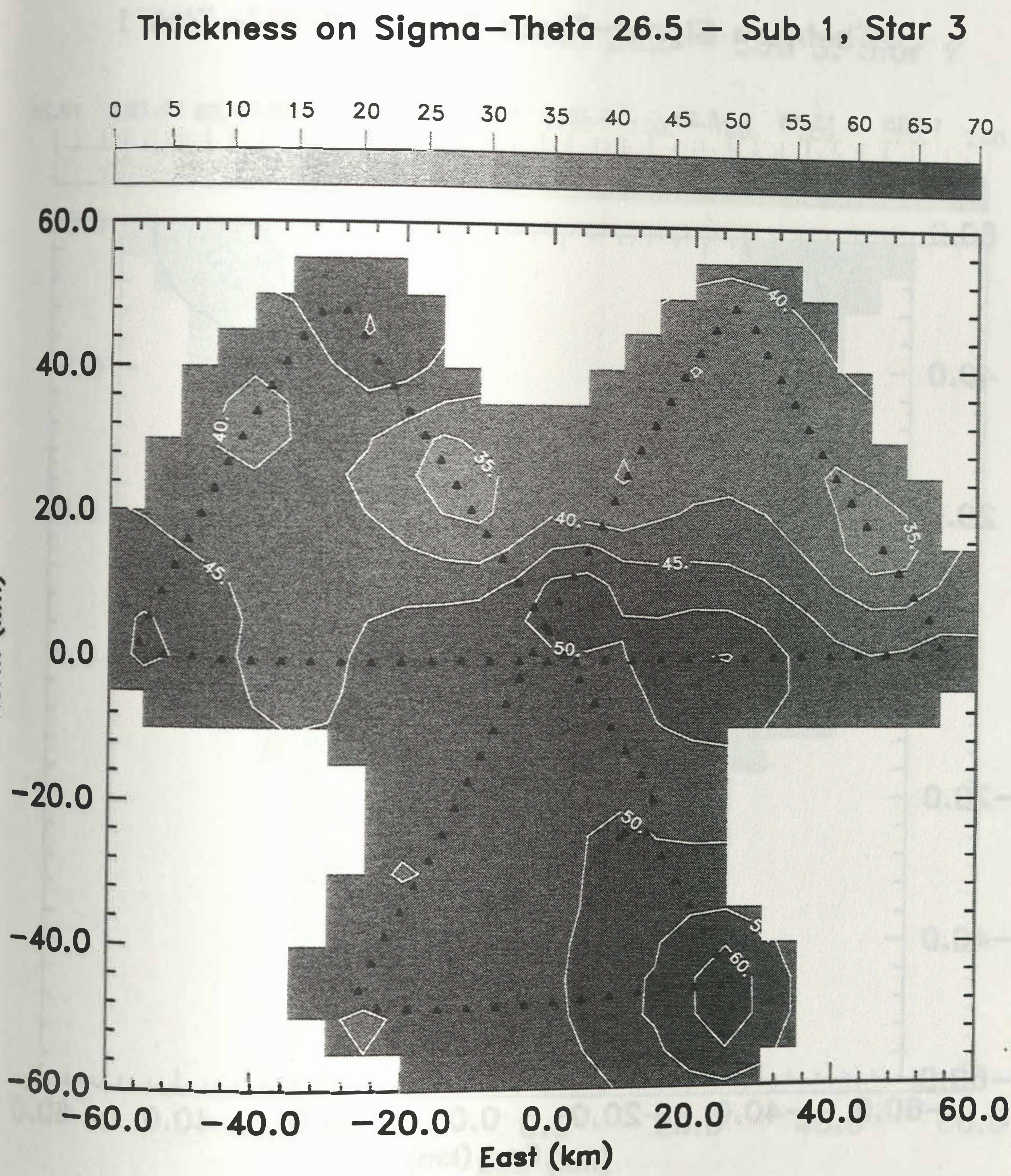
Pressure on Sigma-Theta 26.5 - Sub 1, Star 3



Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E

Mean: 51.0511
Std: 4.2587

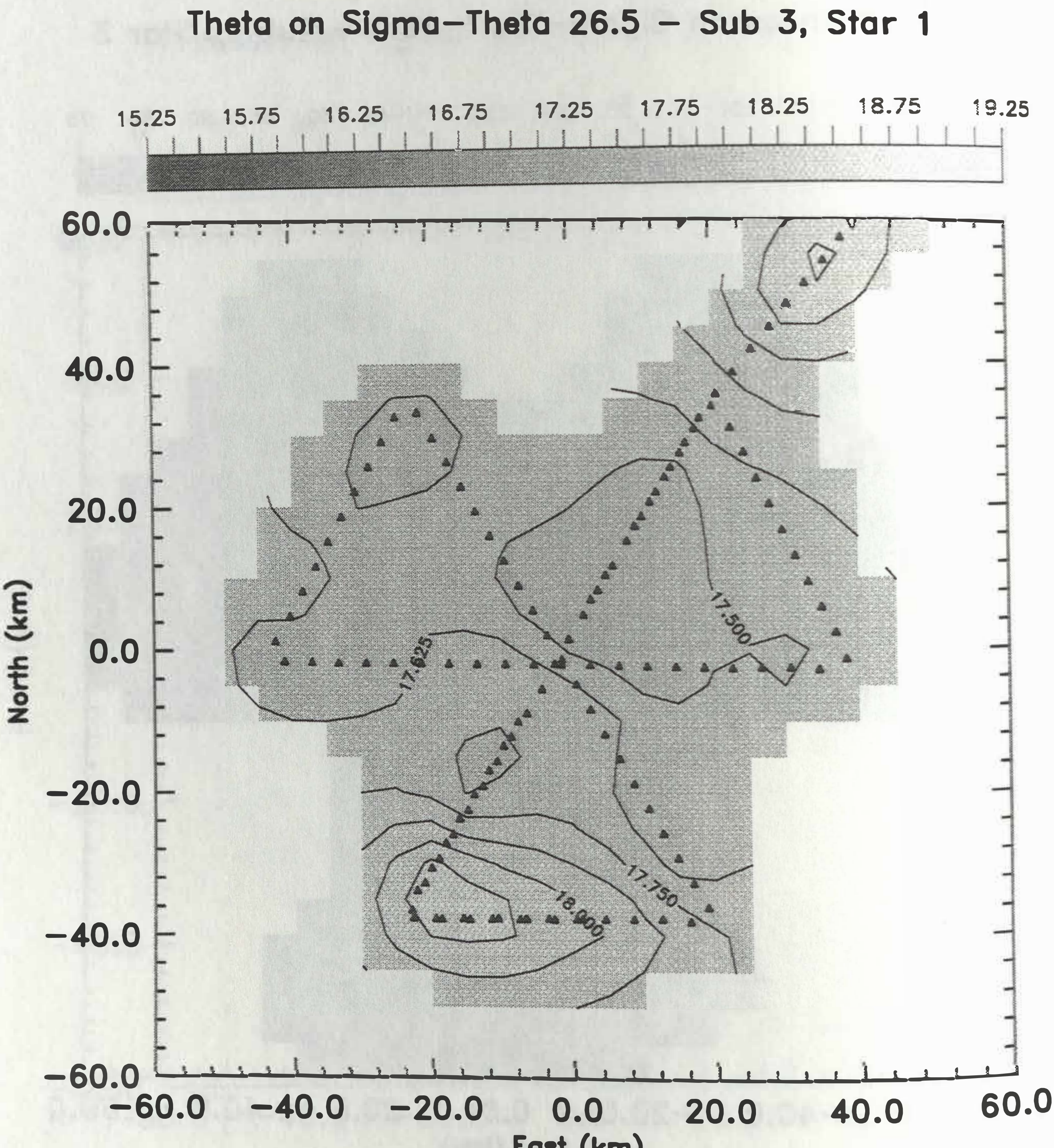
Figure D-7



Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E

Mean: 45.1072
Std: 5.5786

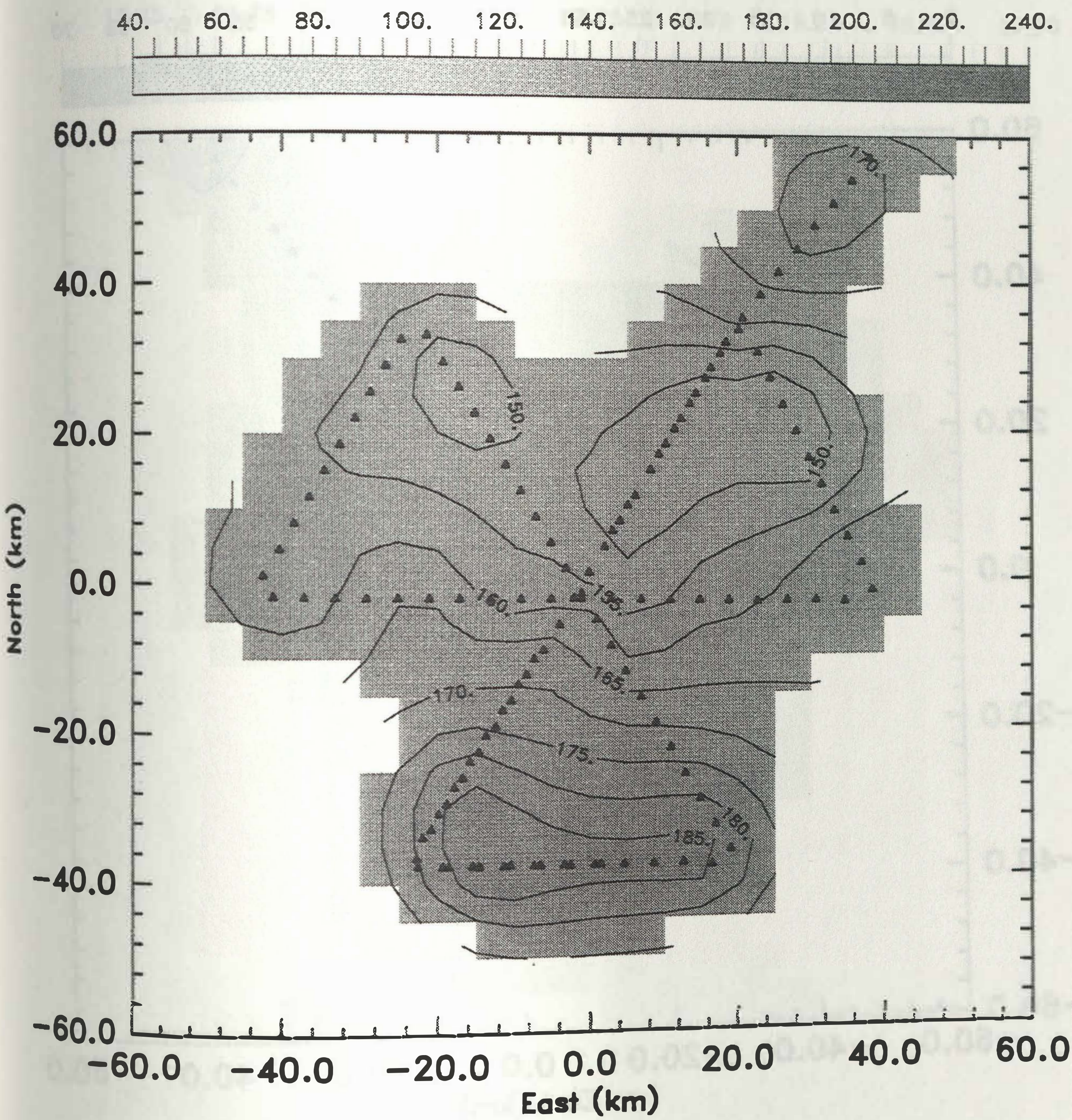
Figure D-8



Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: −29.6893 E
Mean: 17.6773
Std: 0.1868

Figure D-9

Pressure on Sigma-Theta 26.5 - Sub 3, Star 1



Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E

Mean: 163.4997
Std: 10.8143

Figure D-10

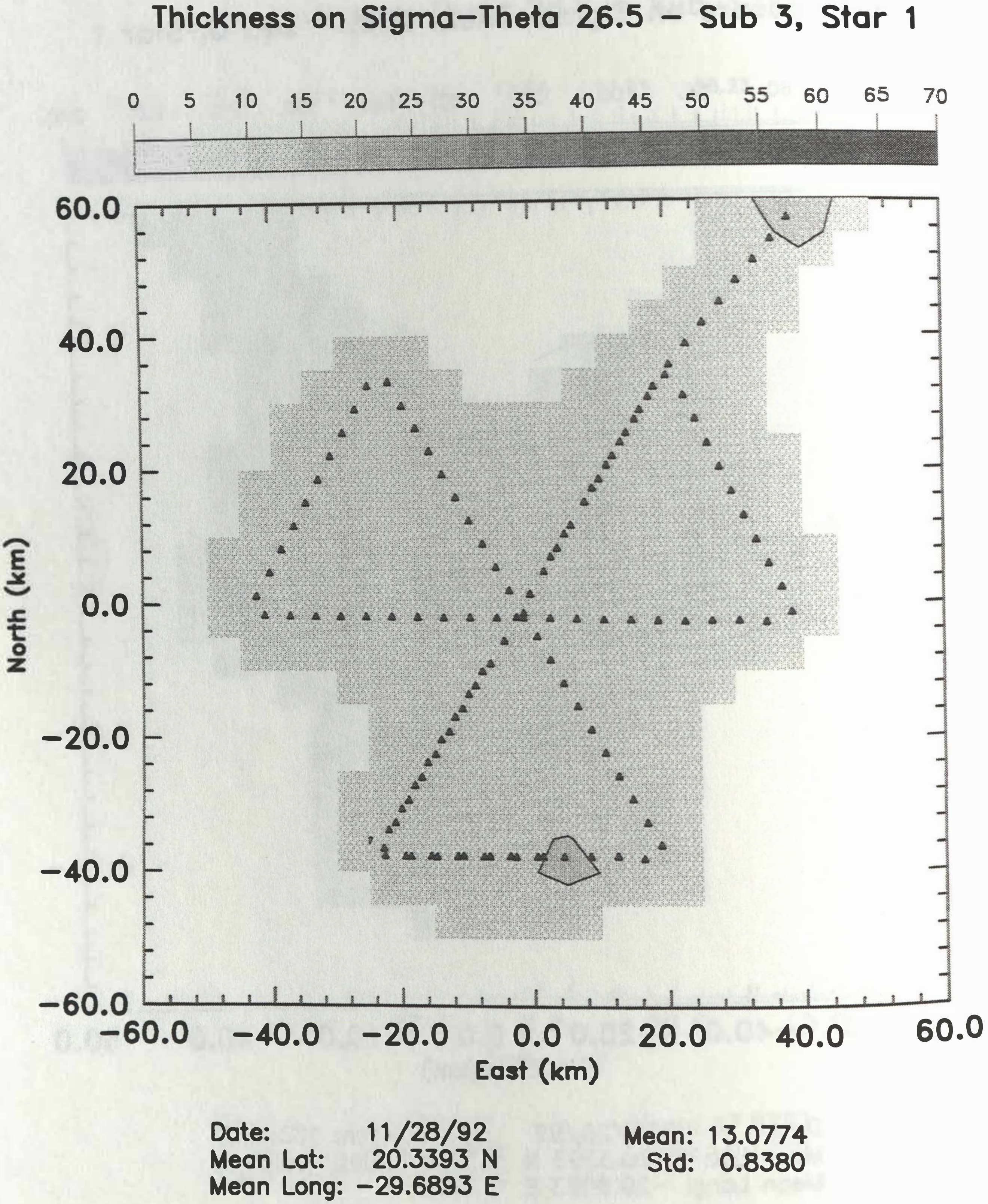
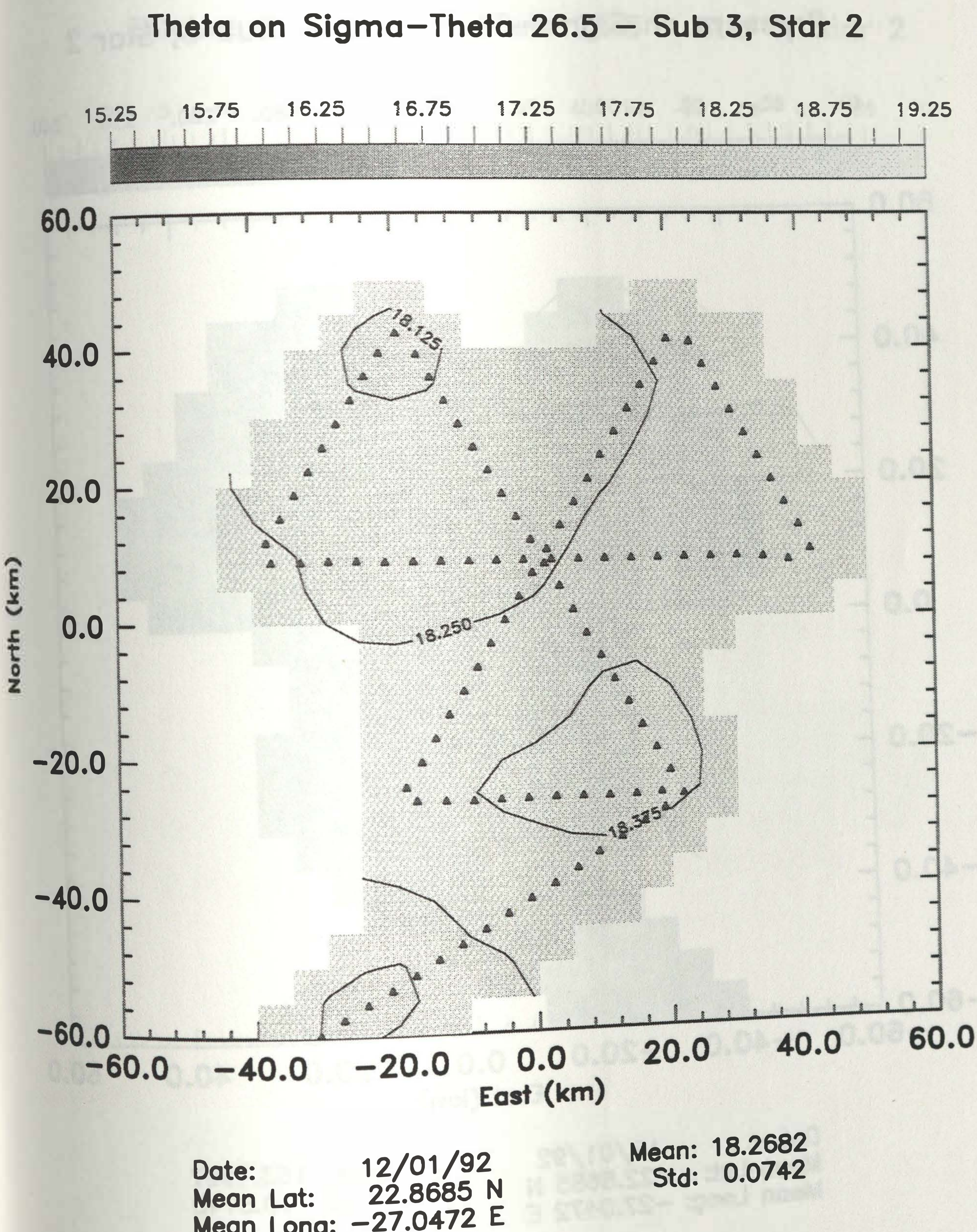
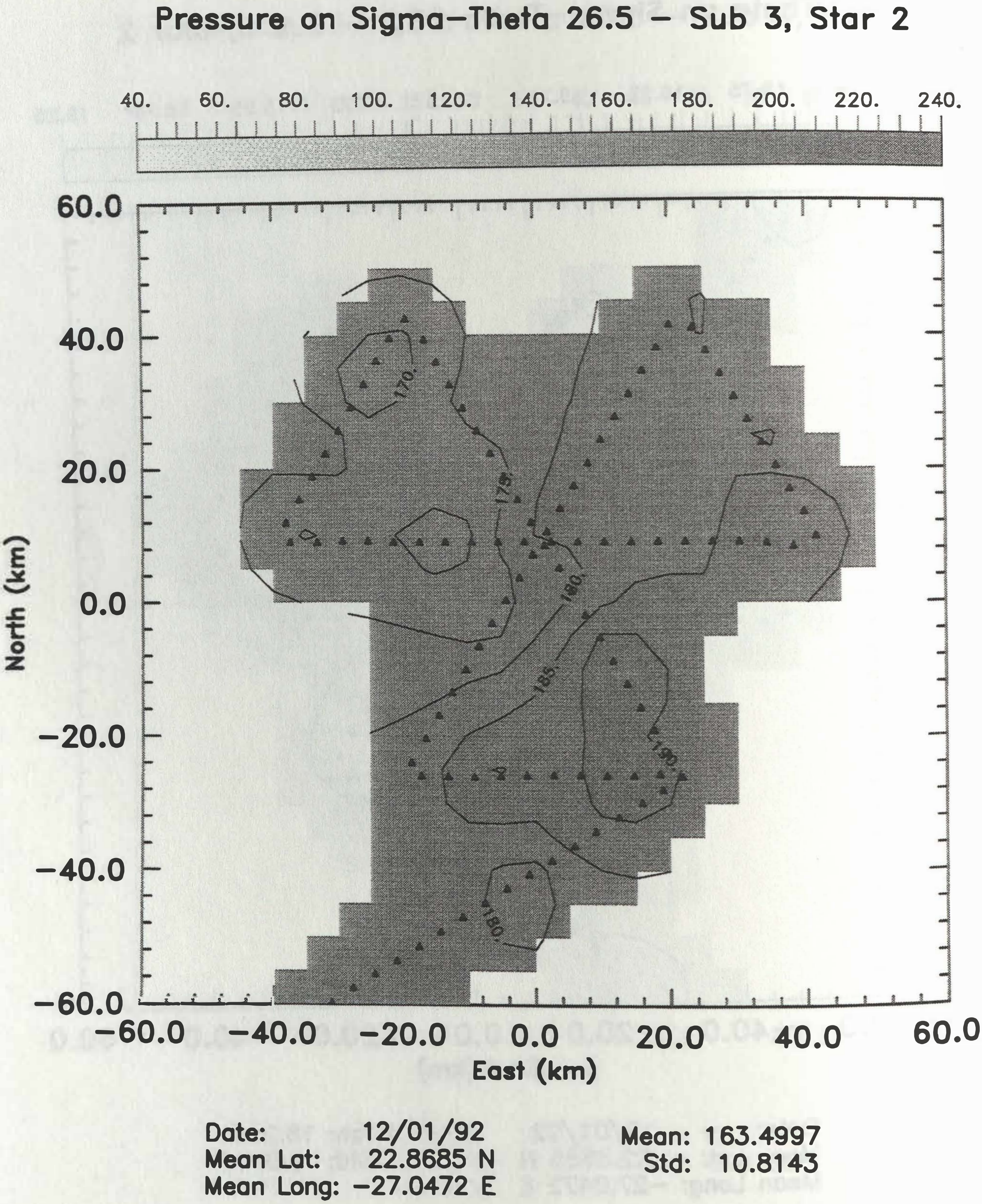

Thickness on Sigma-Theta 26.5 - Sub 3, Star 1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E
Mean: 13.0774
Std: 0.8380

Figure D-11



Theta on Sigma-Theta 26.5 - Sub 3, Star 2
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
18.125
18.250
18.375
Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 18.2682
Std: 0.0742

Figure D-12



Pressure on Sigma-Theta 26.5 - Sub 3, Star 2
40. 60. 80. 100. 120. 140. 160. 180. 200. 220. 240.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
170.
175.
180.
185.
190.
180.
Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 163.4997
Std: 10.8143

Figure D-13

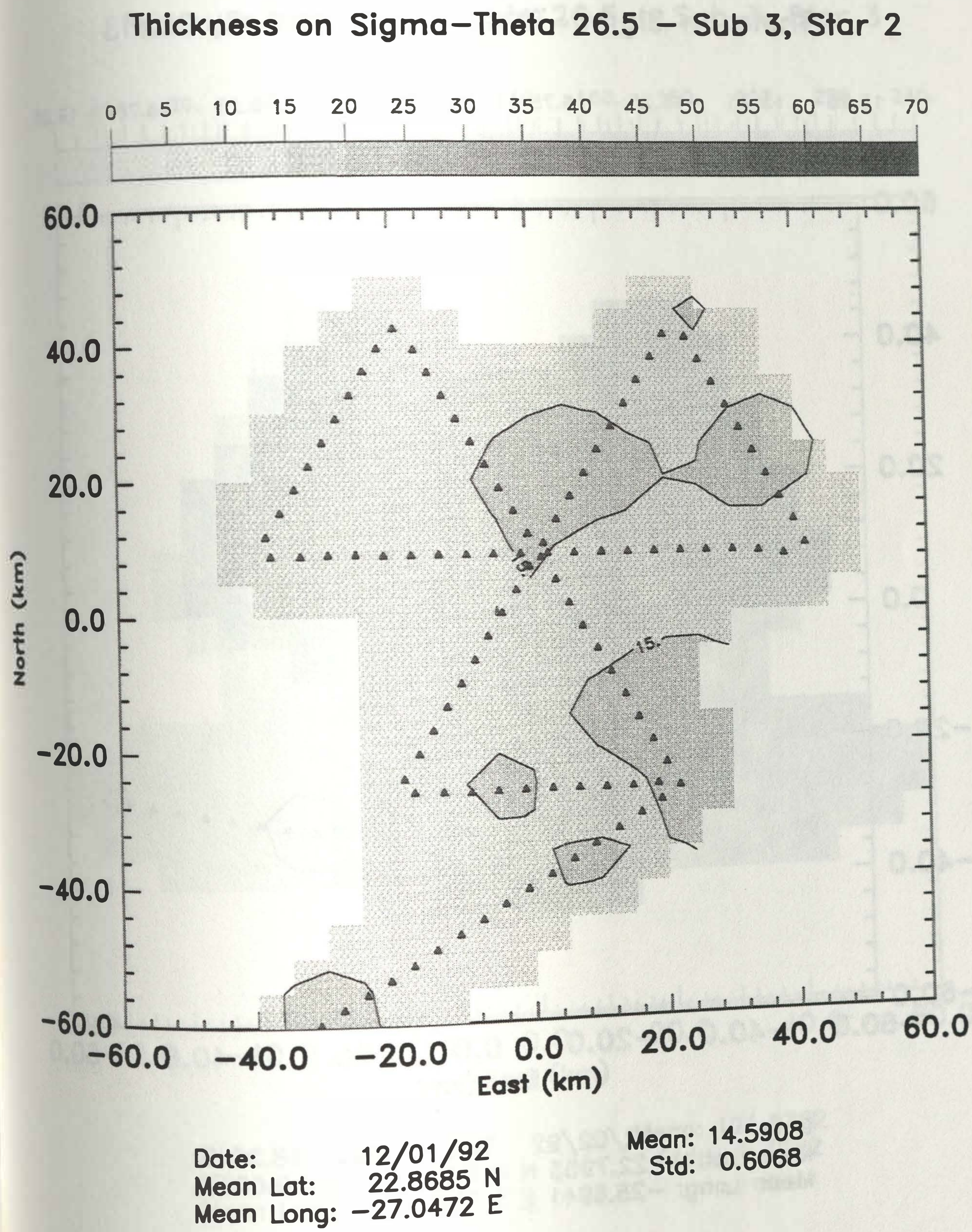
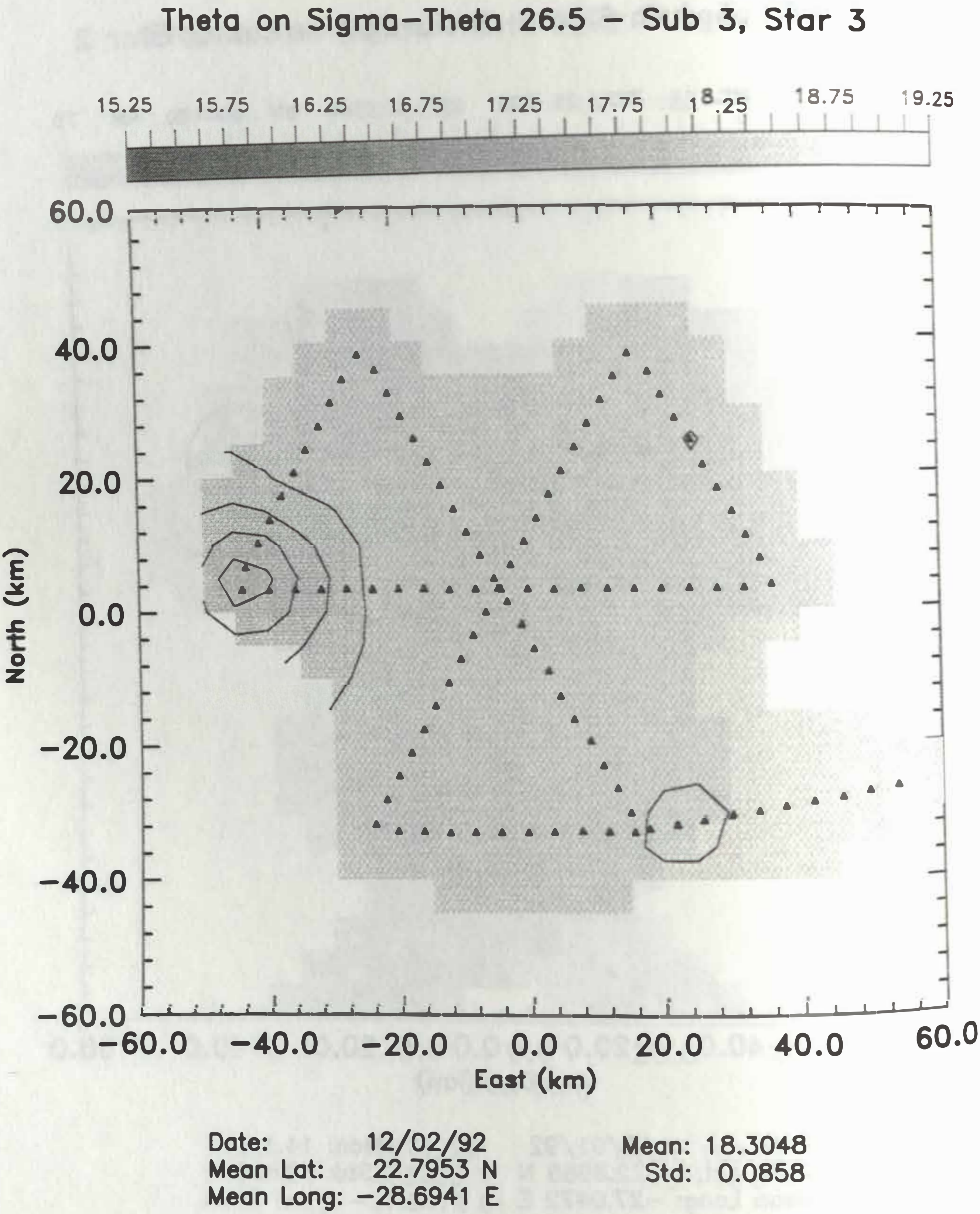
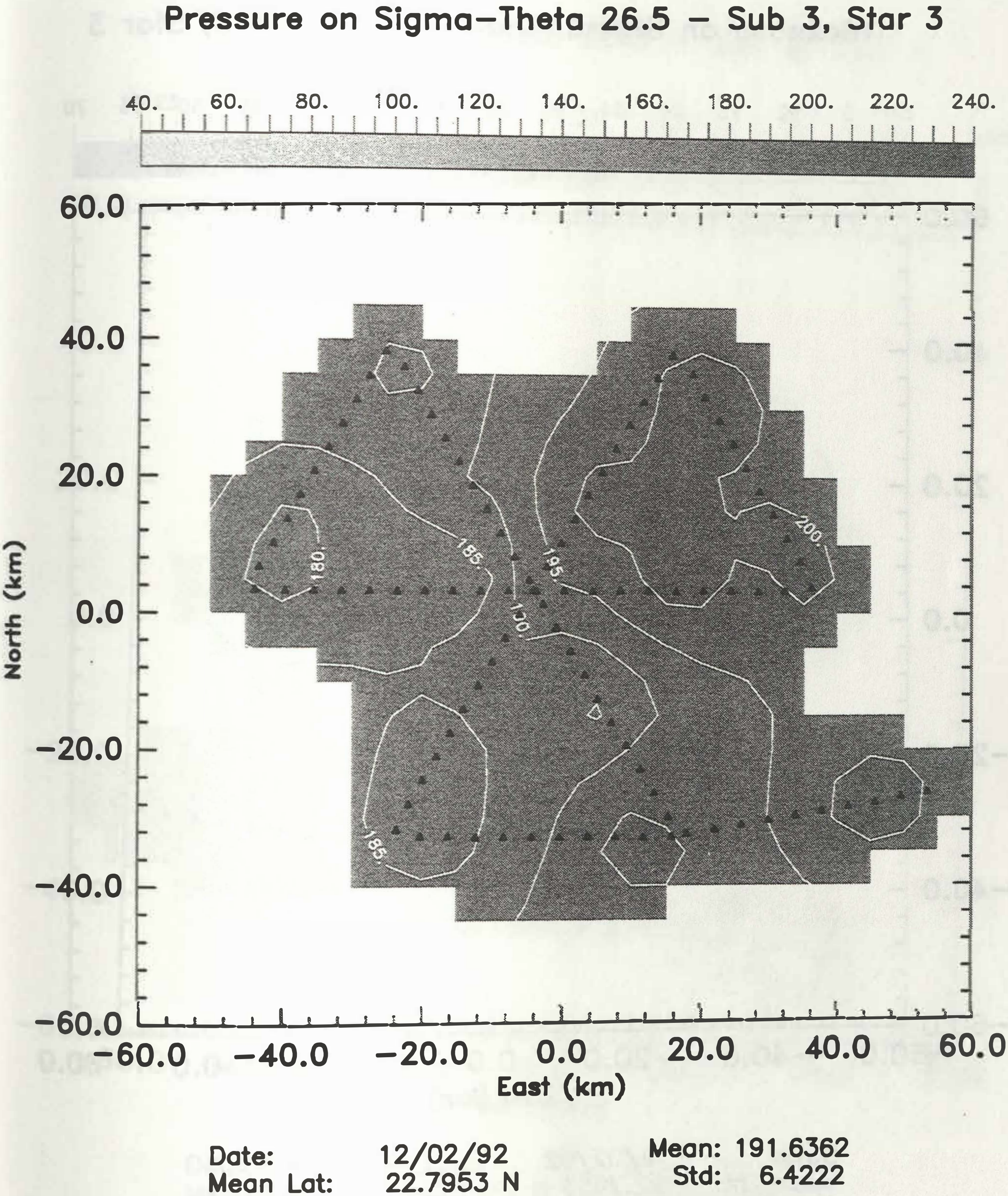

Thickness on Sigma-Theta 26.5 - Sub 3, Star 2
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
15.
15.
Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 14.5908
Std: 0.6068

Figure D-14



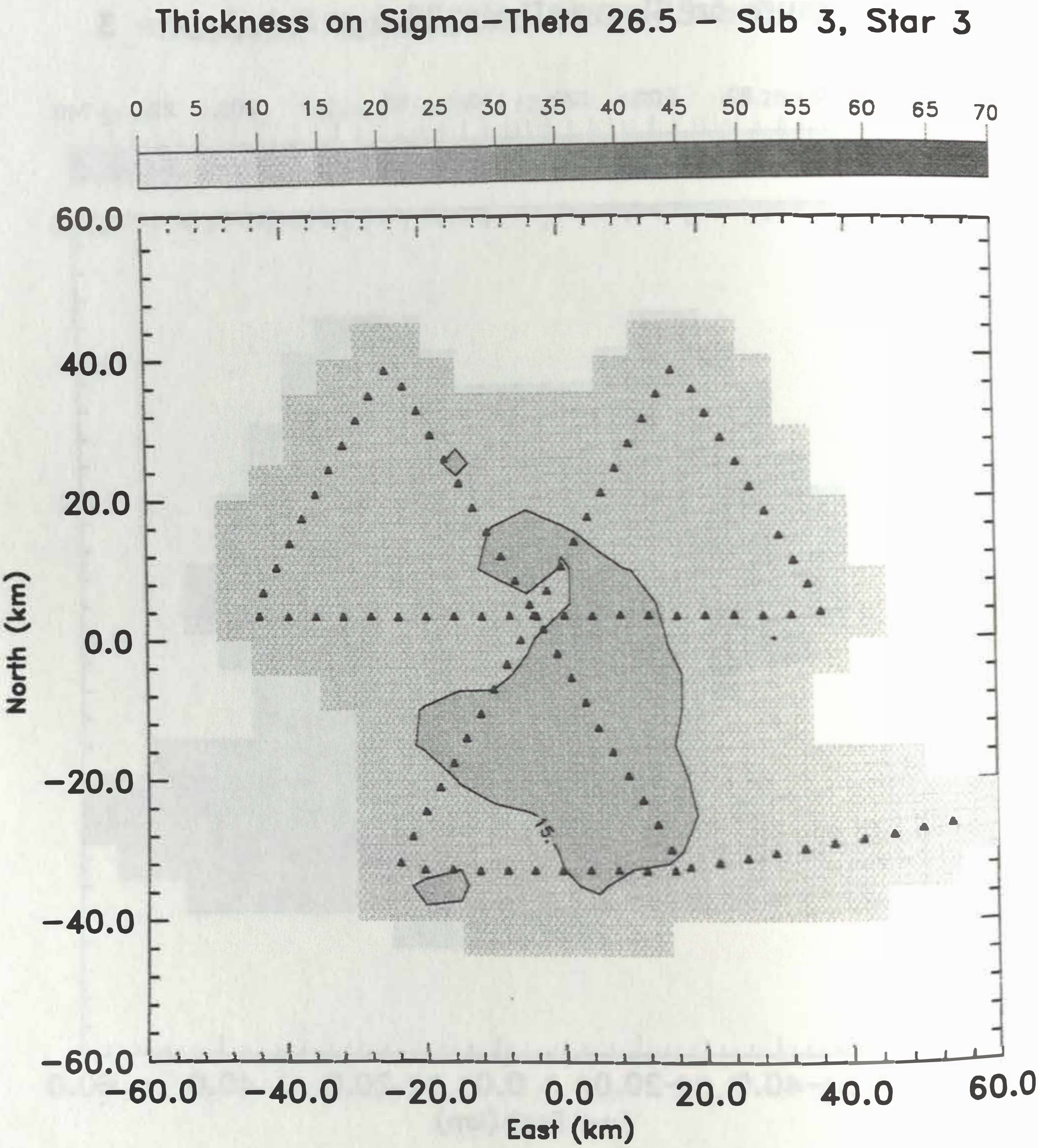
Theta on Sigma-Theta 26.5 - Sub 3, Star 3
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 18.3048
Std: 0.0858

Figure D-15



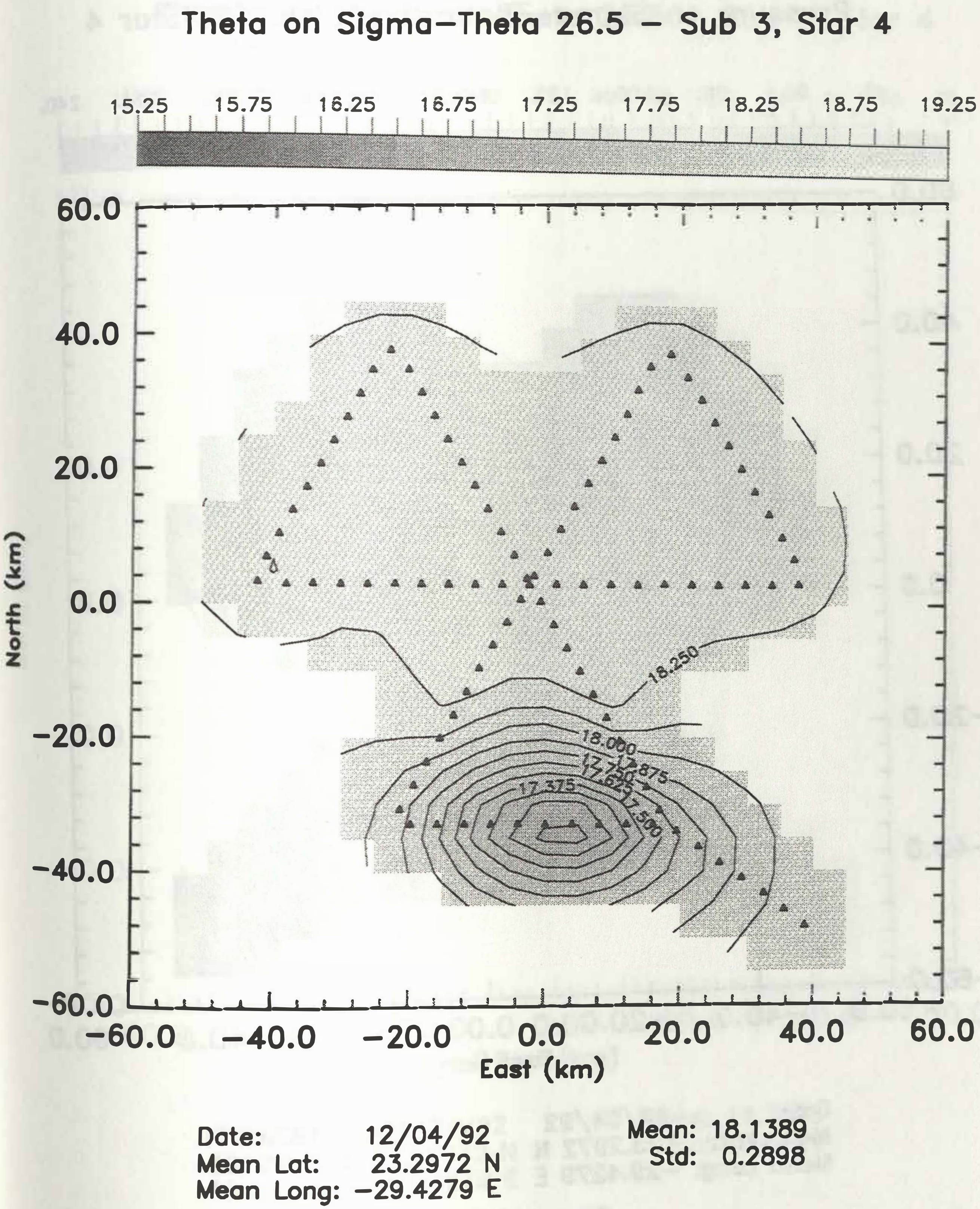
Pressure on Sigma-Theta 26.5 - Sub 3, Star 3
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
180.
185.
190.
195.
200.
185.
Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 191.6362
Std: 6.4222

Figure D-16



Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 14.3554
Std: 0.7220

Figure D-17



Theta on Sigma-Theta 26.5 - Sub 3, Star 4
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
North (km)
East (km)
18.250
18.000
17.875
17.750
17.625
17.500
17.375
Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 18.1389
Std: 0.2898

Figure D-18

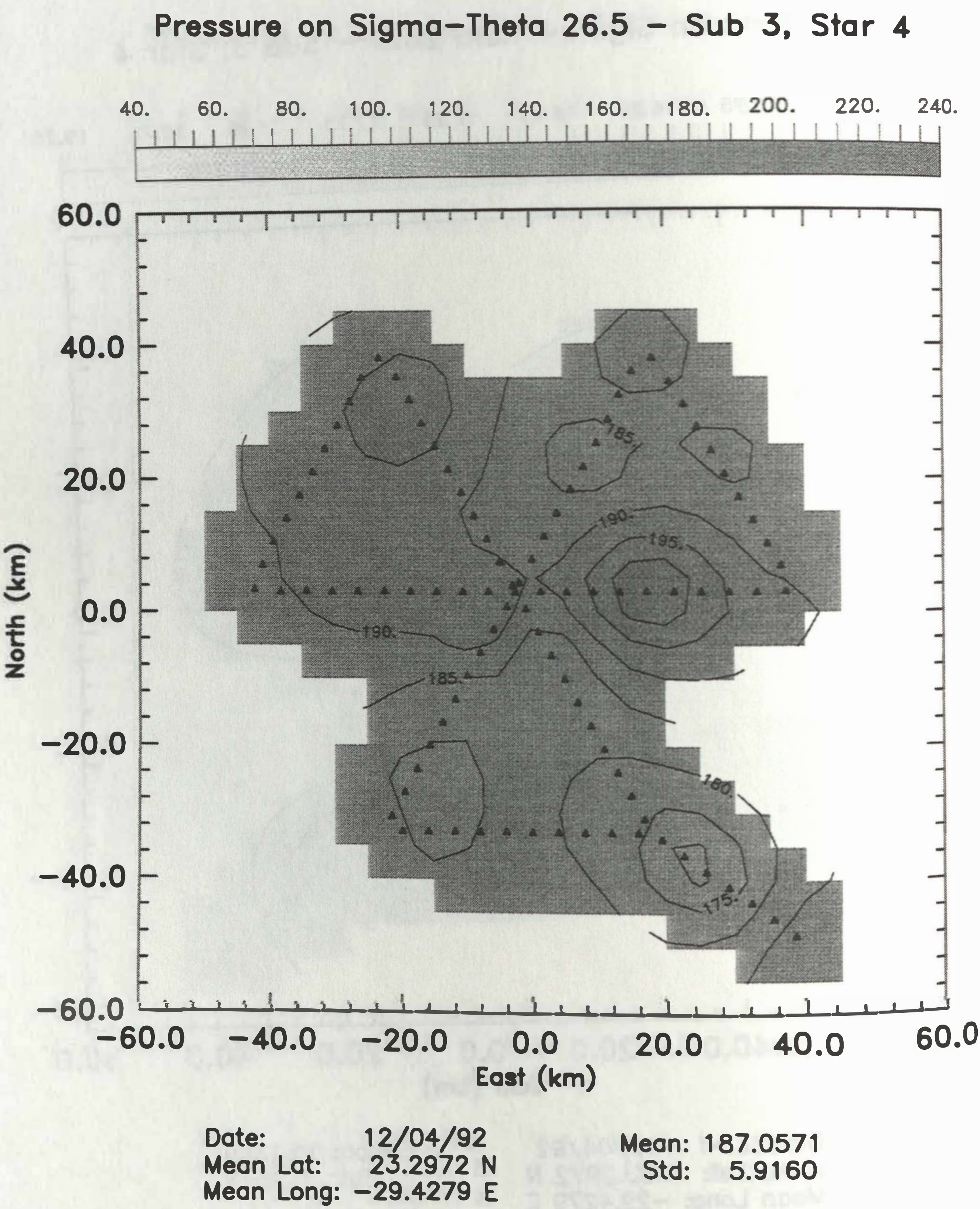
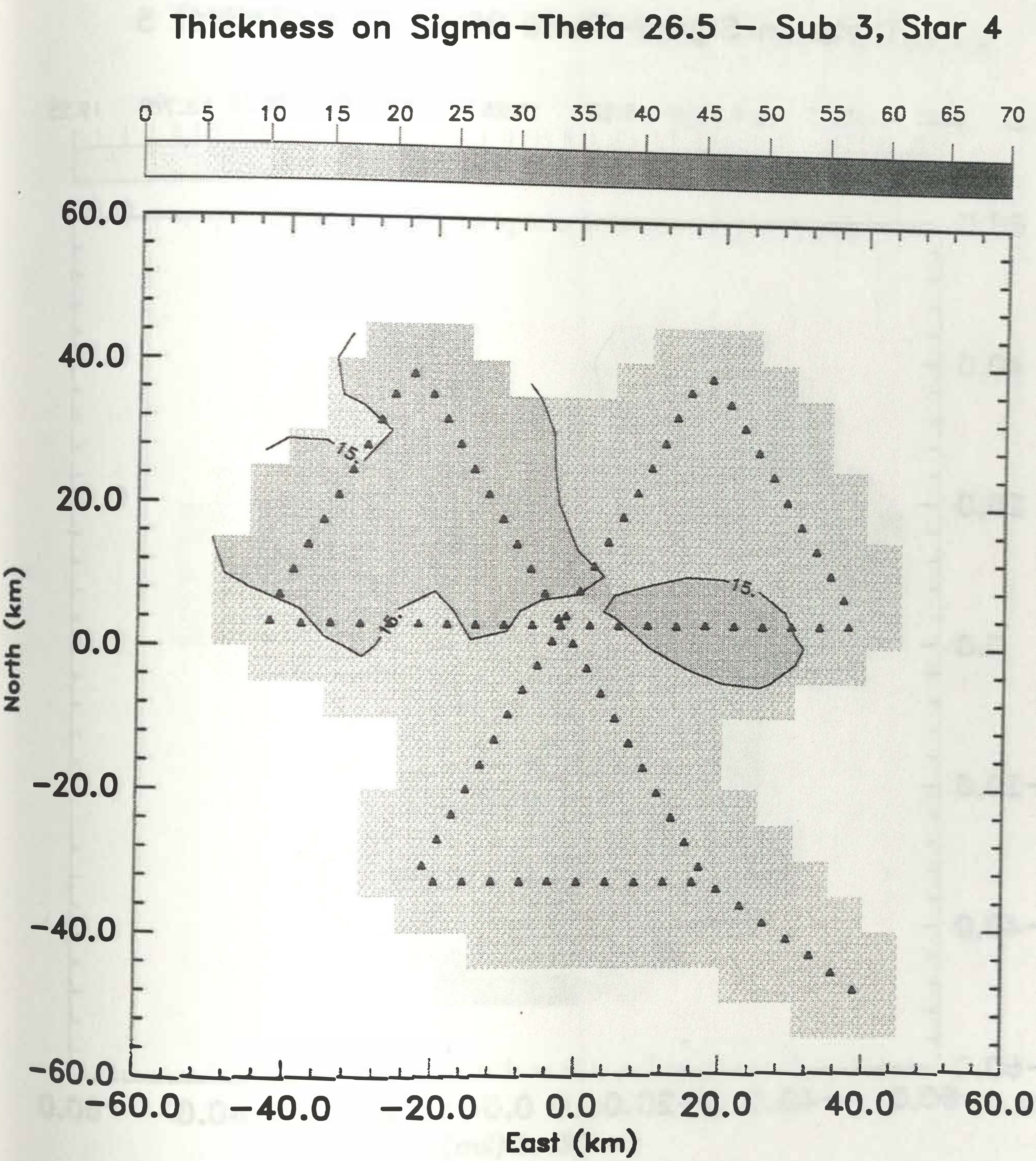

Pressure on Sigma-Theta 26.5 - Sub 3, Star 4
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
185.
190.
195.
190.
185.
180.
175.
Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 187.0571
Std: 5.9160

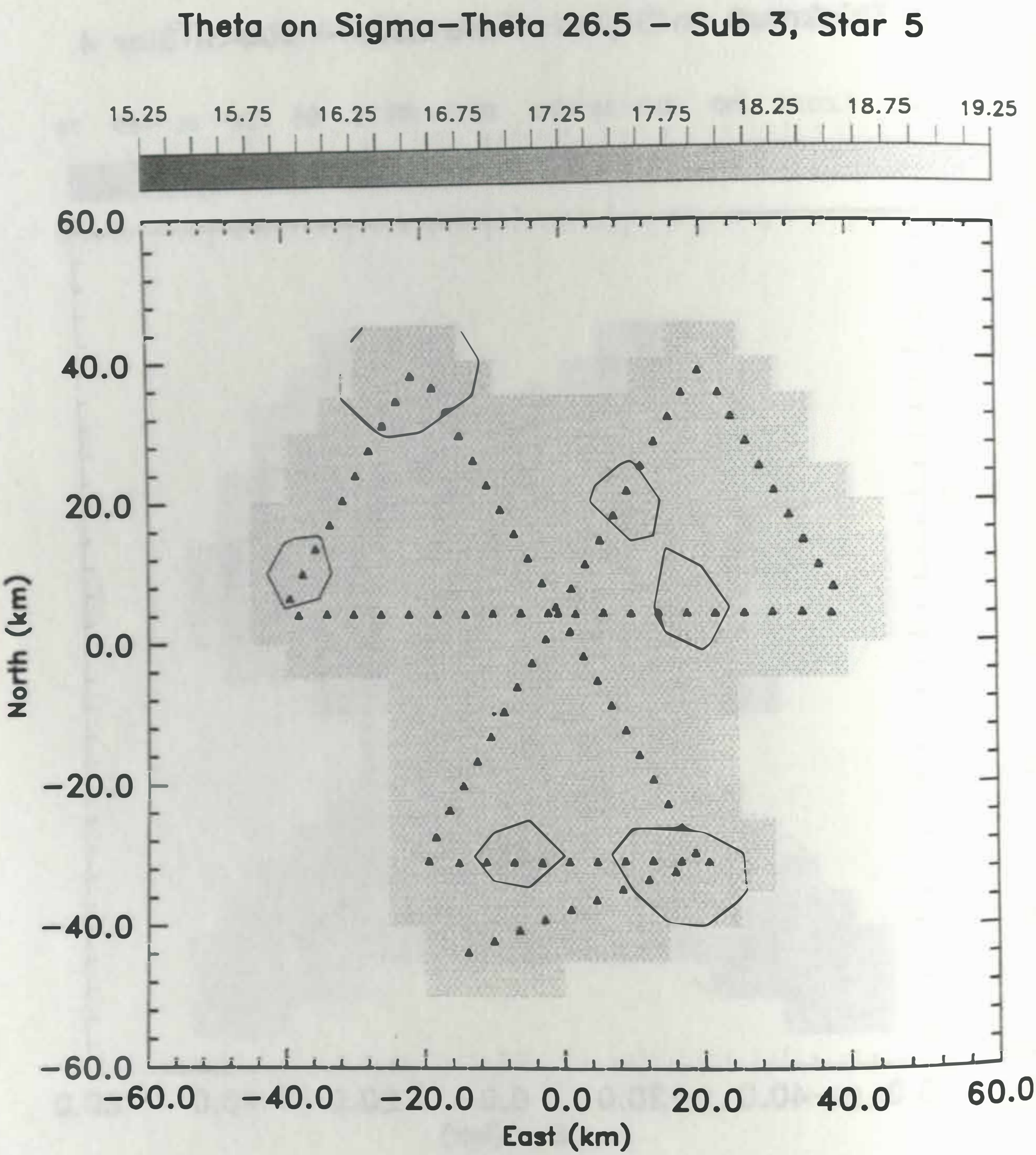
Figure D-19



Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E

Mean: 14.3723
Std: 0.8294

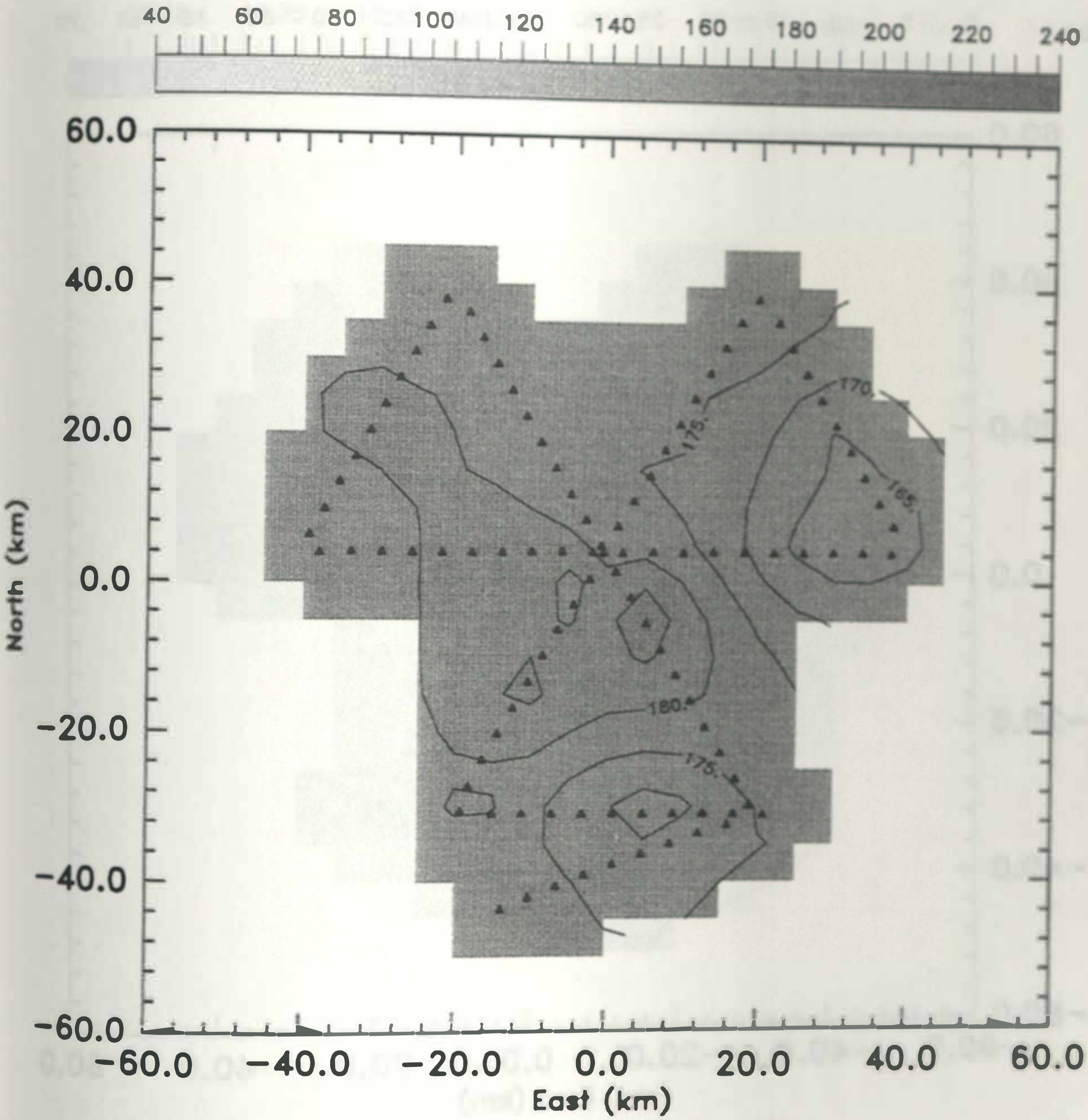
Figure D-20



Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: –24.4478 E
Mean: 18.5389
Std: 1.3784

Figure D-21

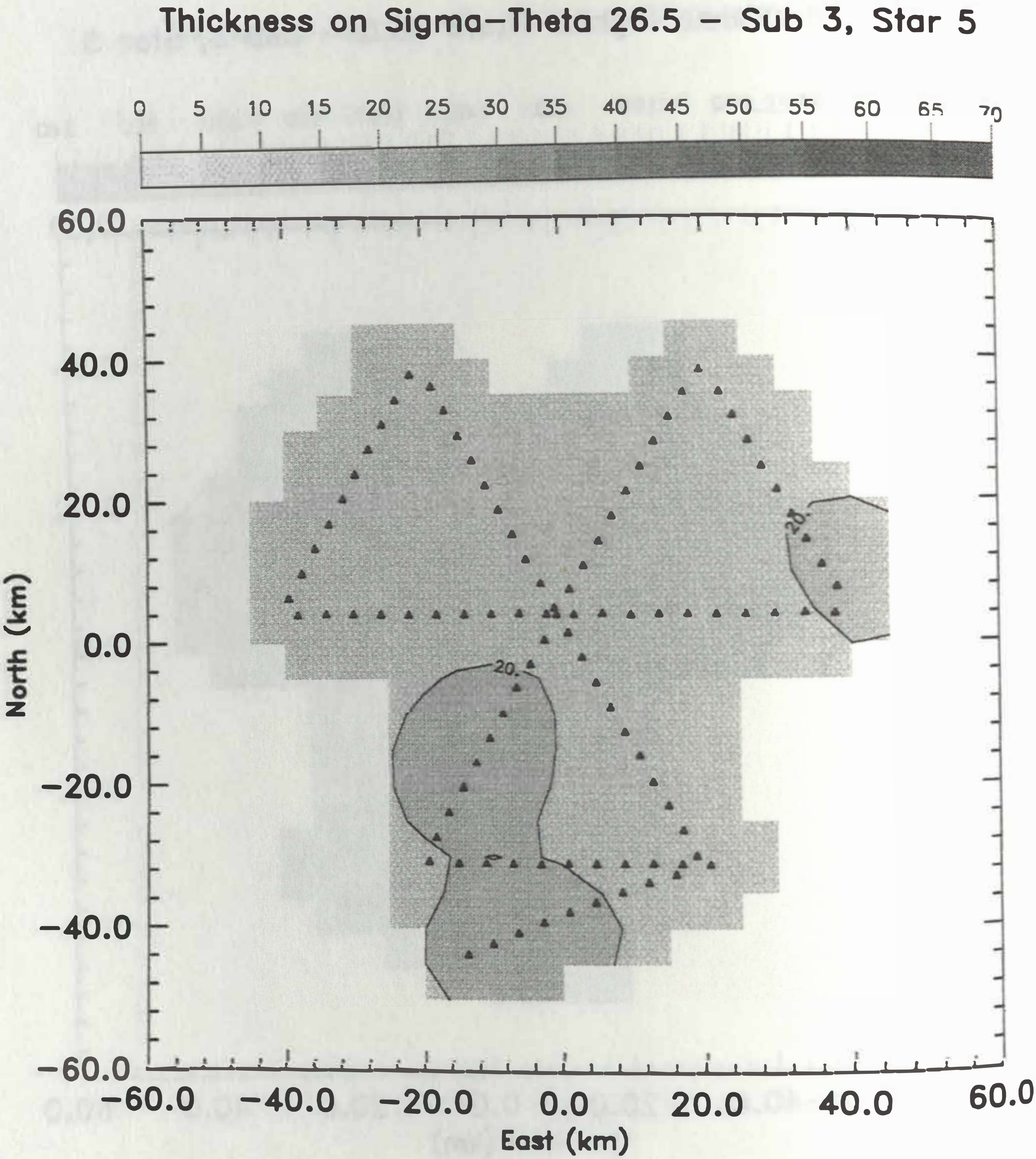
Pressure on Sigma-Theta 26.5 – Sub 3, Star 5



Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E

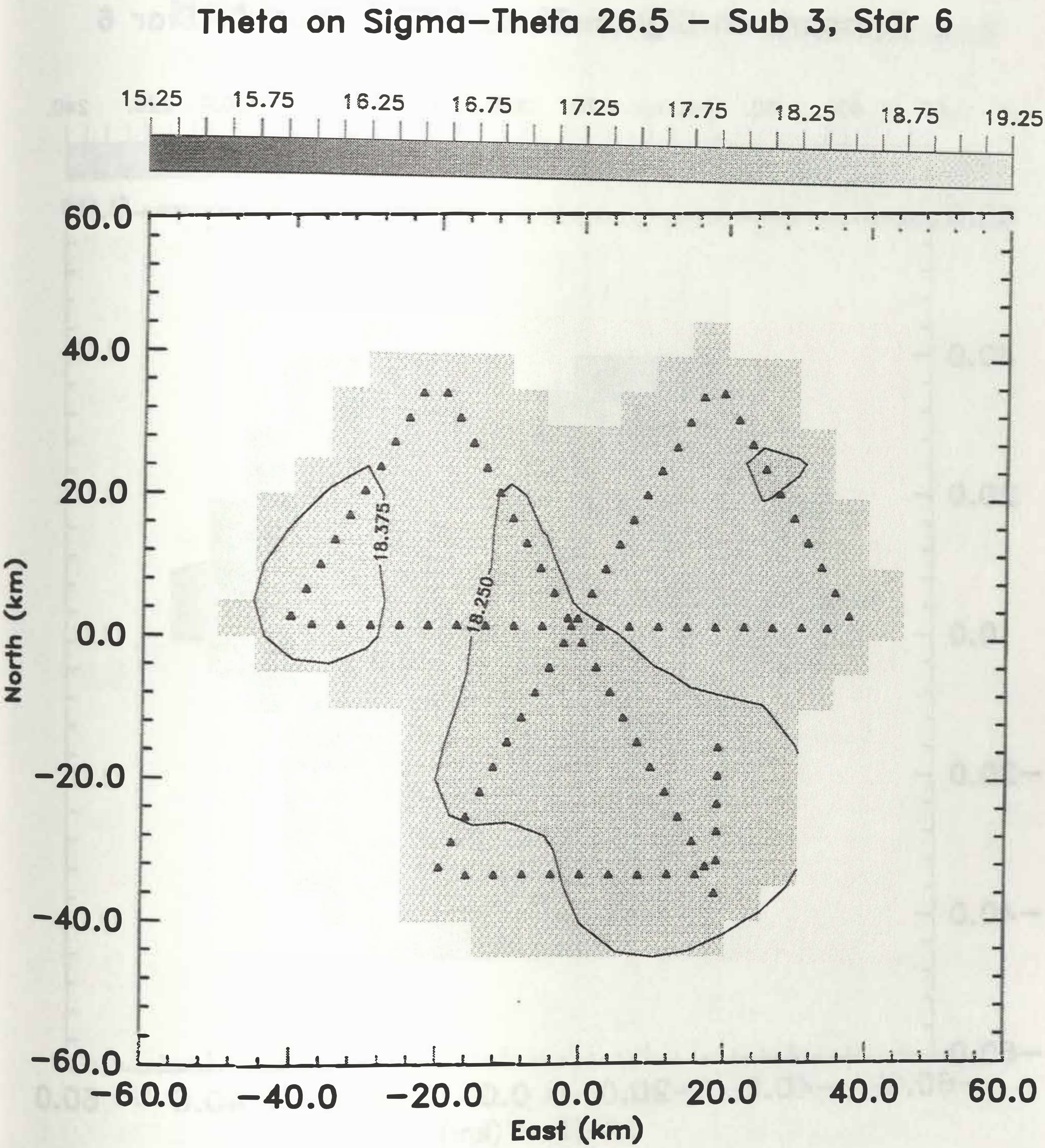
Mean: 176.1963
Std: 4.8472

Figure D-22



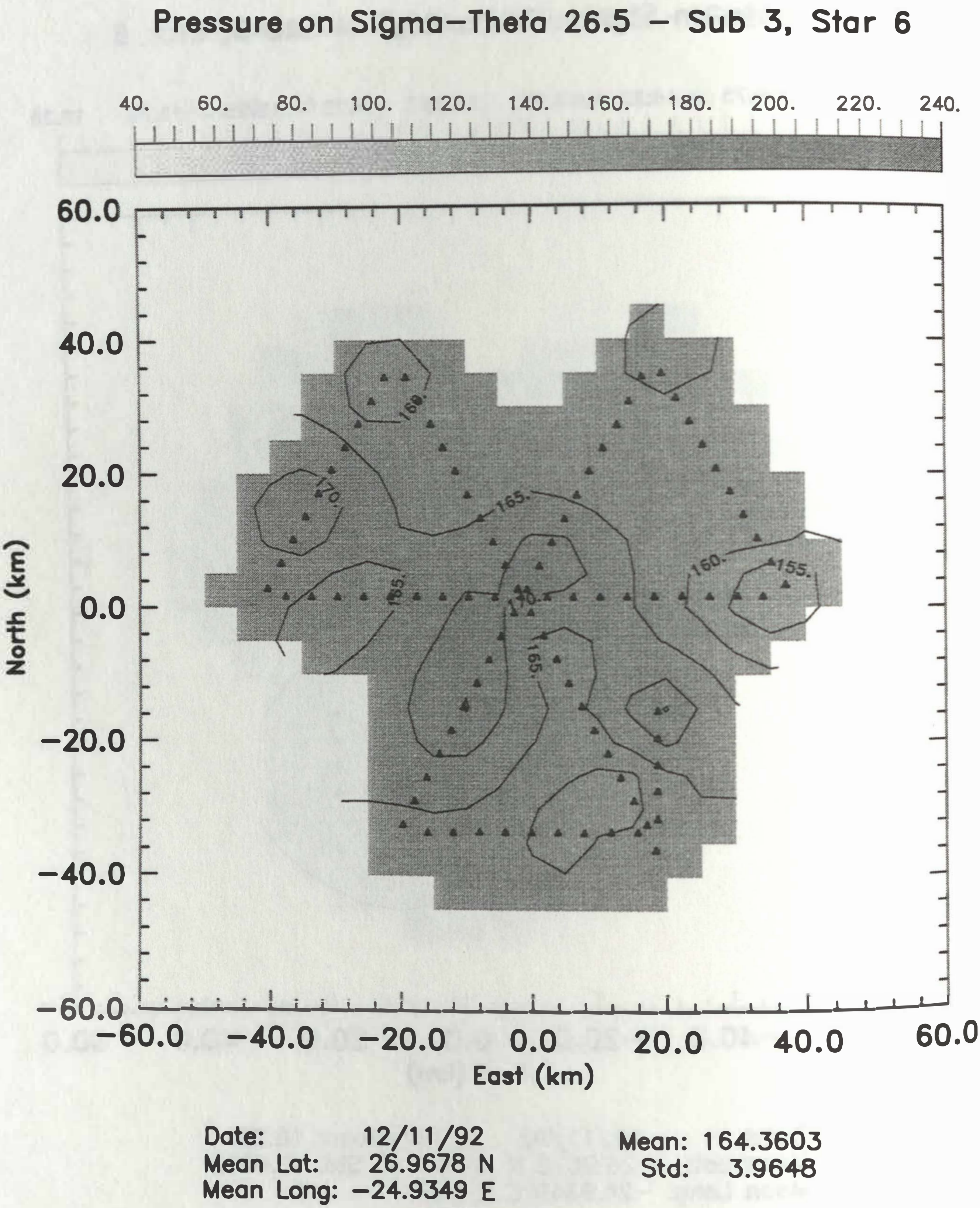
Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E
Mean: 18.6155
Std: 1.3784

Figure D-23



Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E
Mean: 18.2821
Std: 0.0512

Figure D-24



Pressure on Sigma-Theta 26.5 - Sub 3, Star 6
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
160.
170.
165.
165.
170.
165.
160.
155.
Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E
Mean: 164.3603
Std: 3.9648

Figure D-25

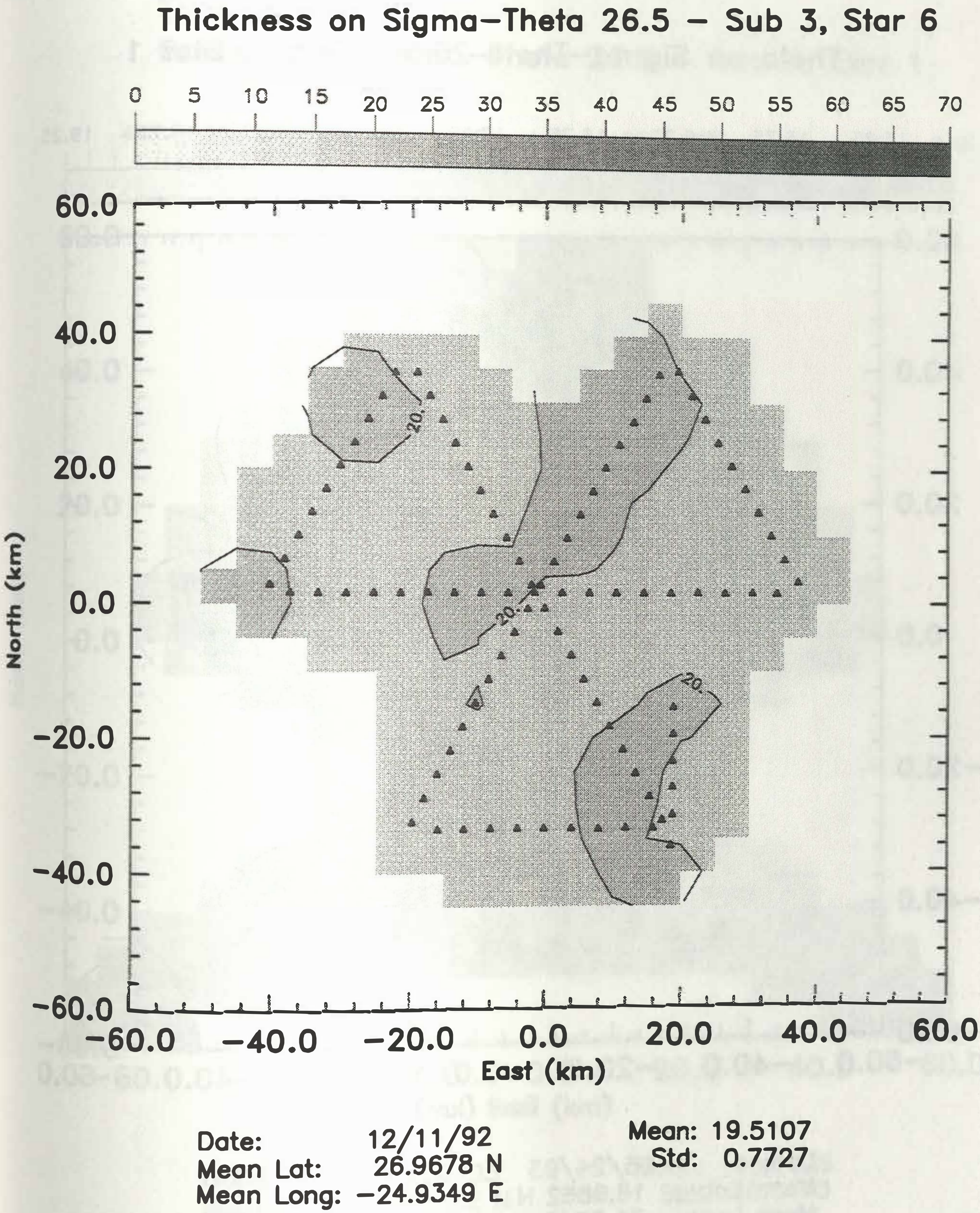

Thickness on Sigma-Theta 26.5 - Sub 3, Star 6
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
20.
Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E
Mean: 19.5107
Std: 0.7727

Figure D-26

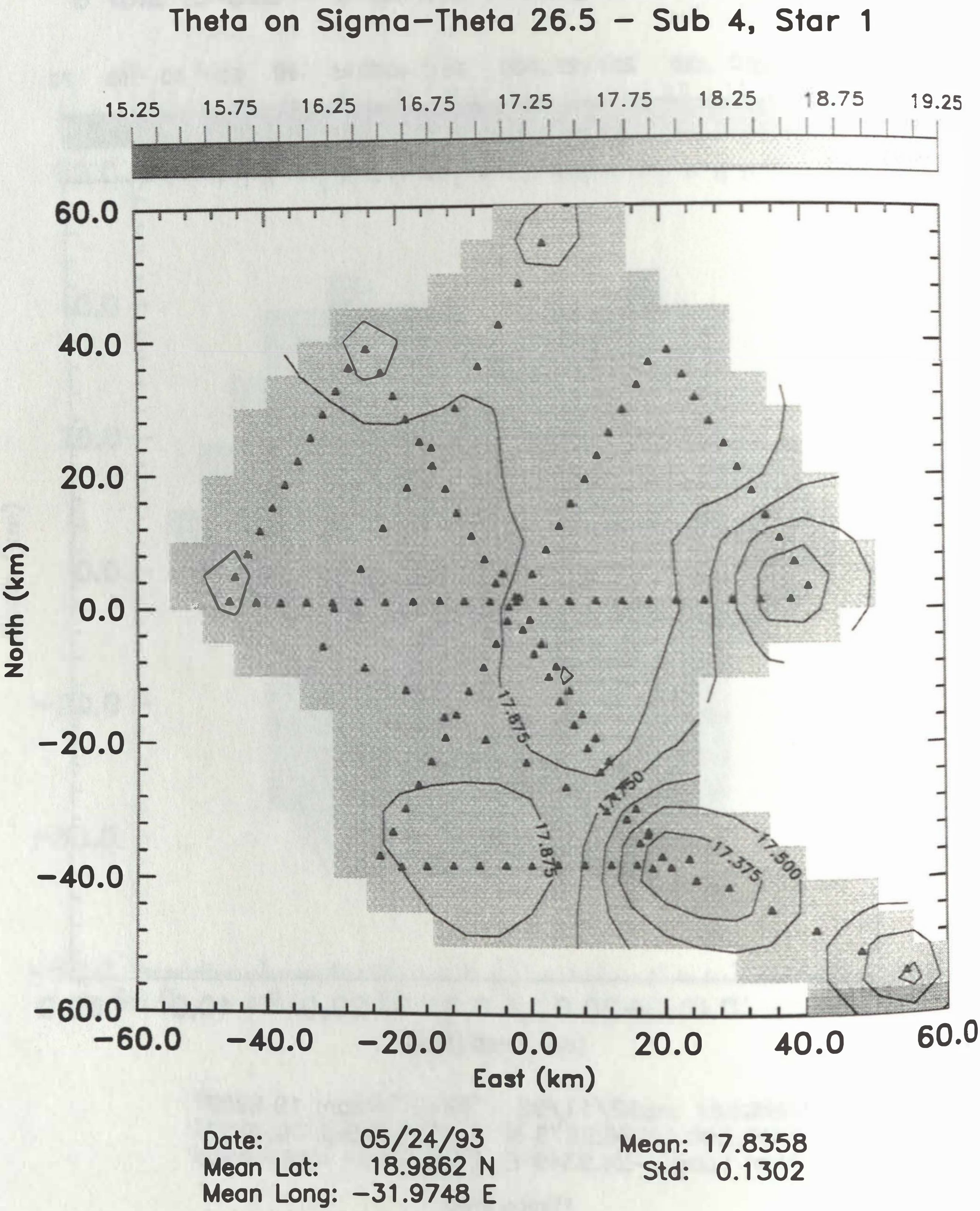
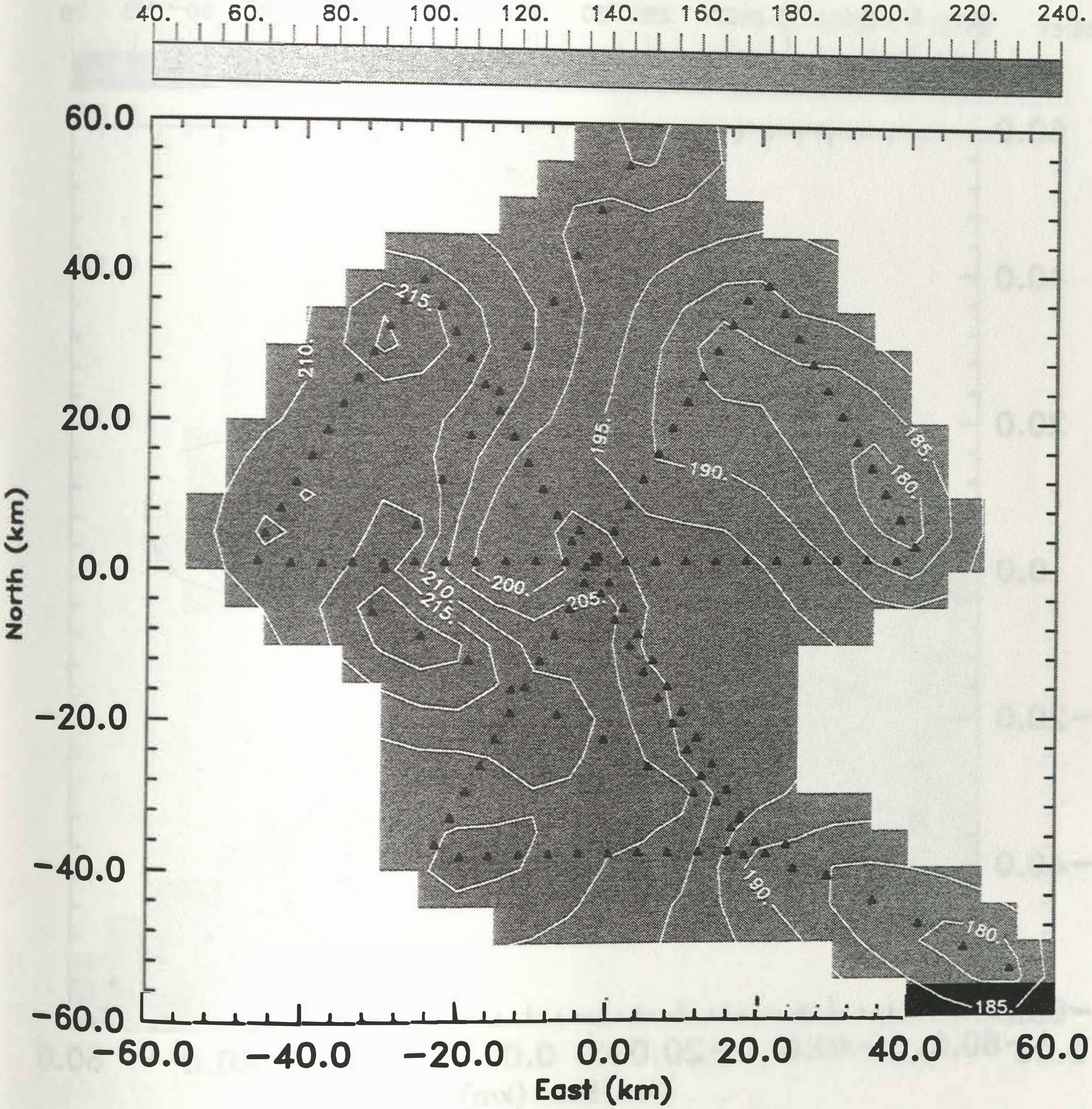

Theta on Sigma-Theta 26.5 - Sub 4, Star 1
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
17.875
17.750
17.875
17.375
17.500
Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E
Mean: 17.8358
Std: 0.1302

Figure D-27

Pressure on Sigma-Theta 26.5 – Sub 4, Star 1



Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E

Mean: 199.7486
Std: 10.6113

Figure D-28

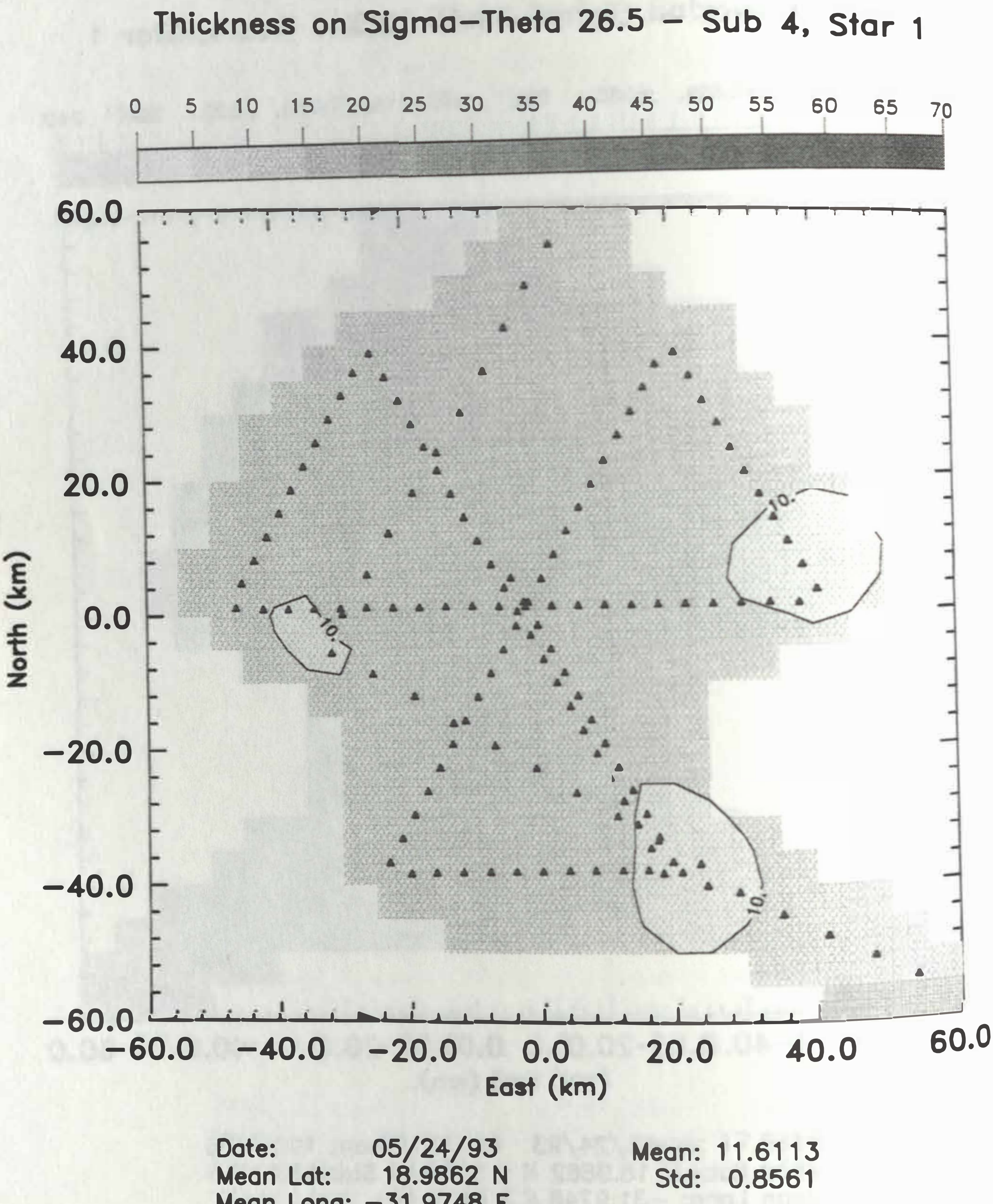
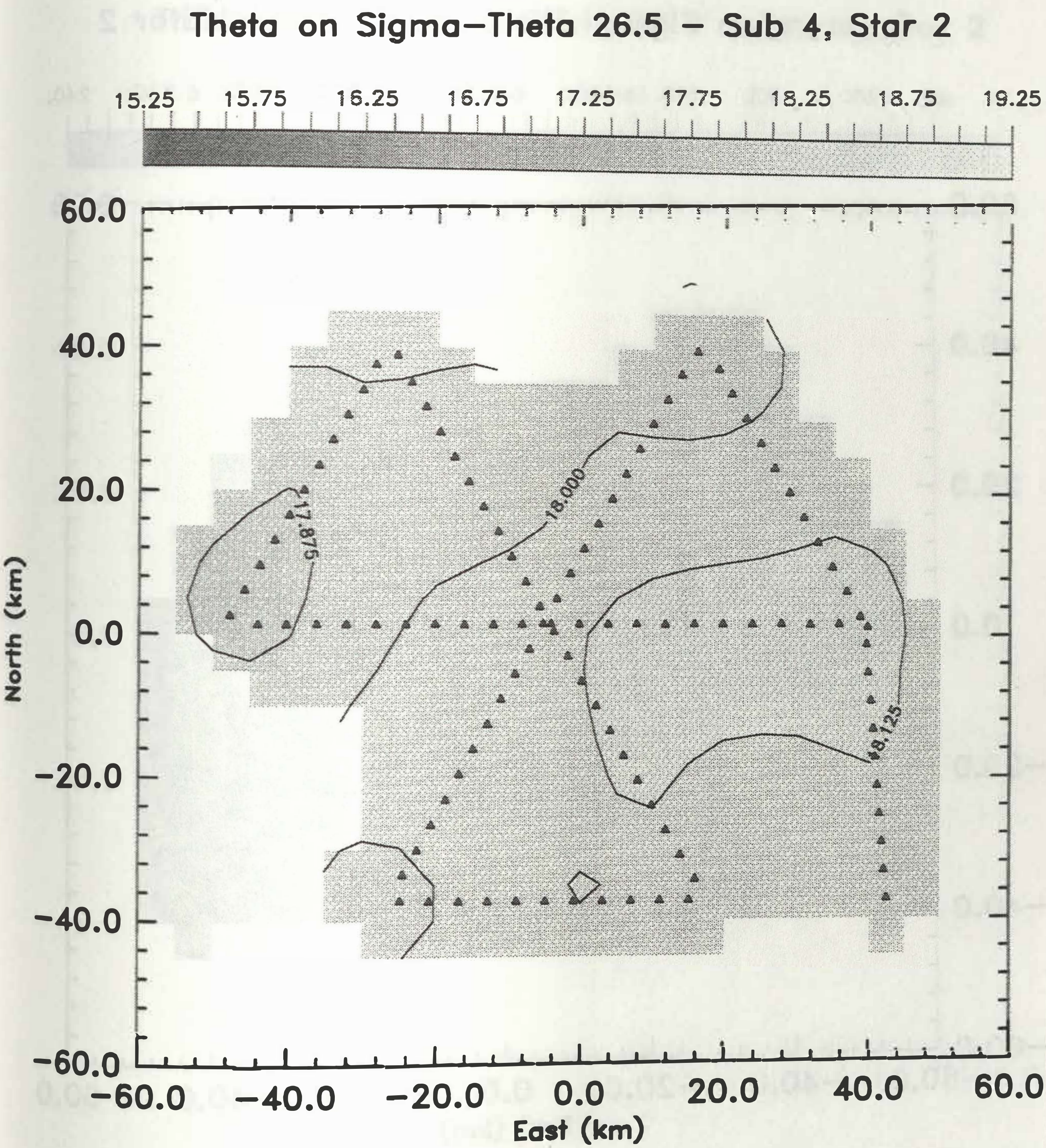

Thickness on Sigma-Theta 26.5 - Sub 4, Star 1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
10.
10.
10.
Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E
Mean: 11.6113
Std: 0.8561

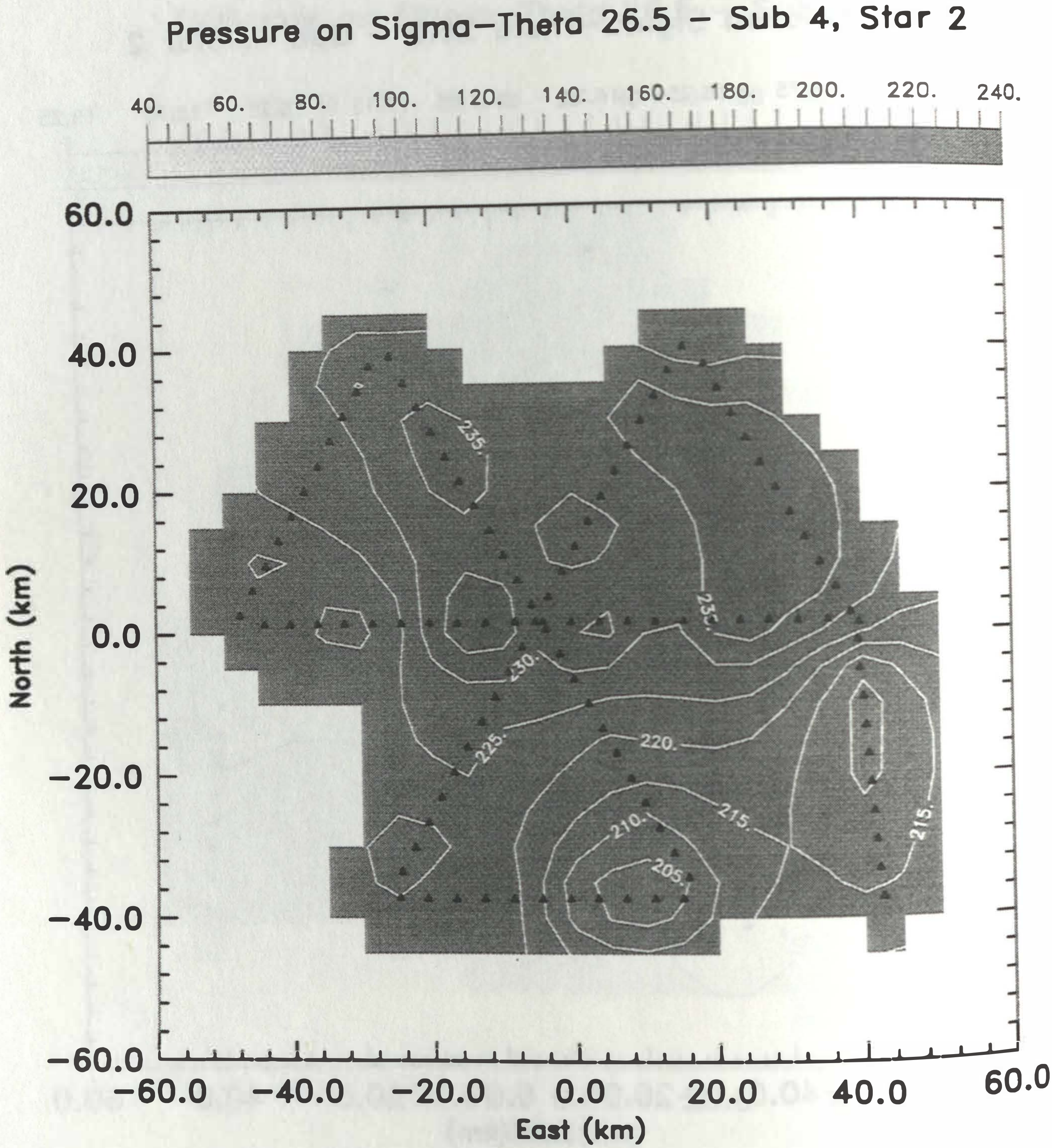
Figure D-29



Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E

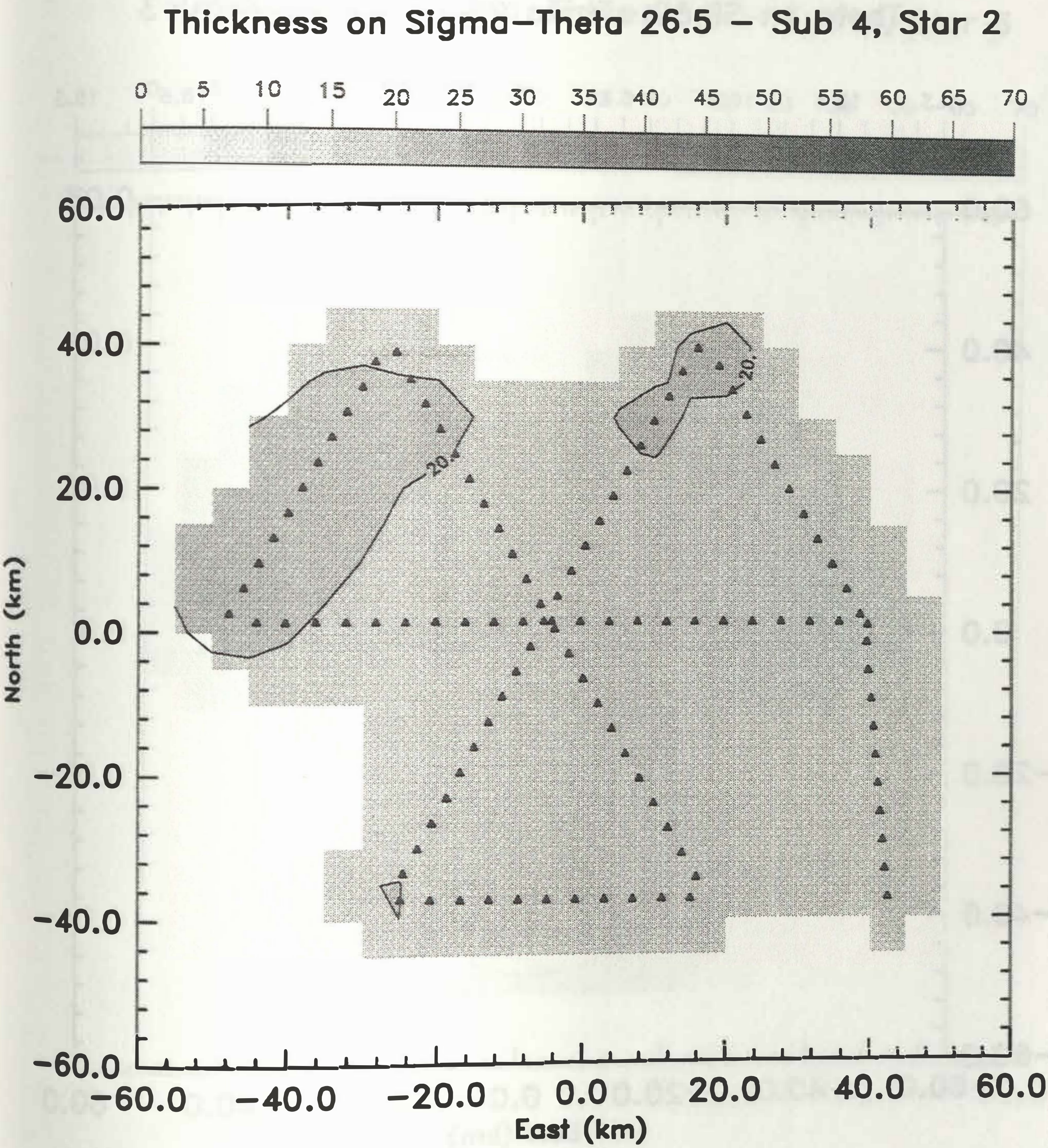
Mean: 18.0407
Std: 0.0810

Figure D-30



Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E
Mean: 224.9581
Std: 8.3322

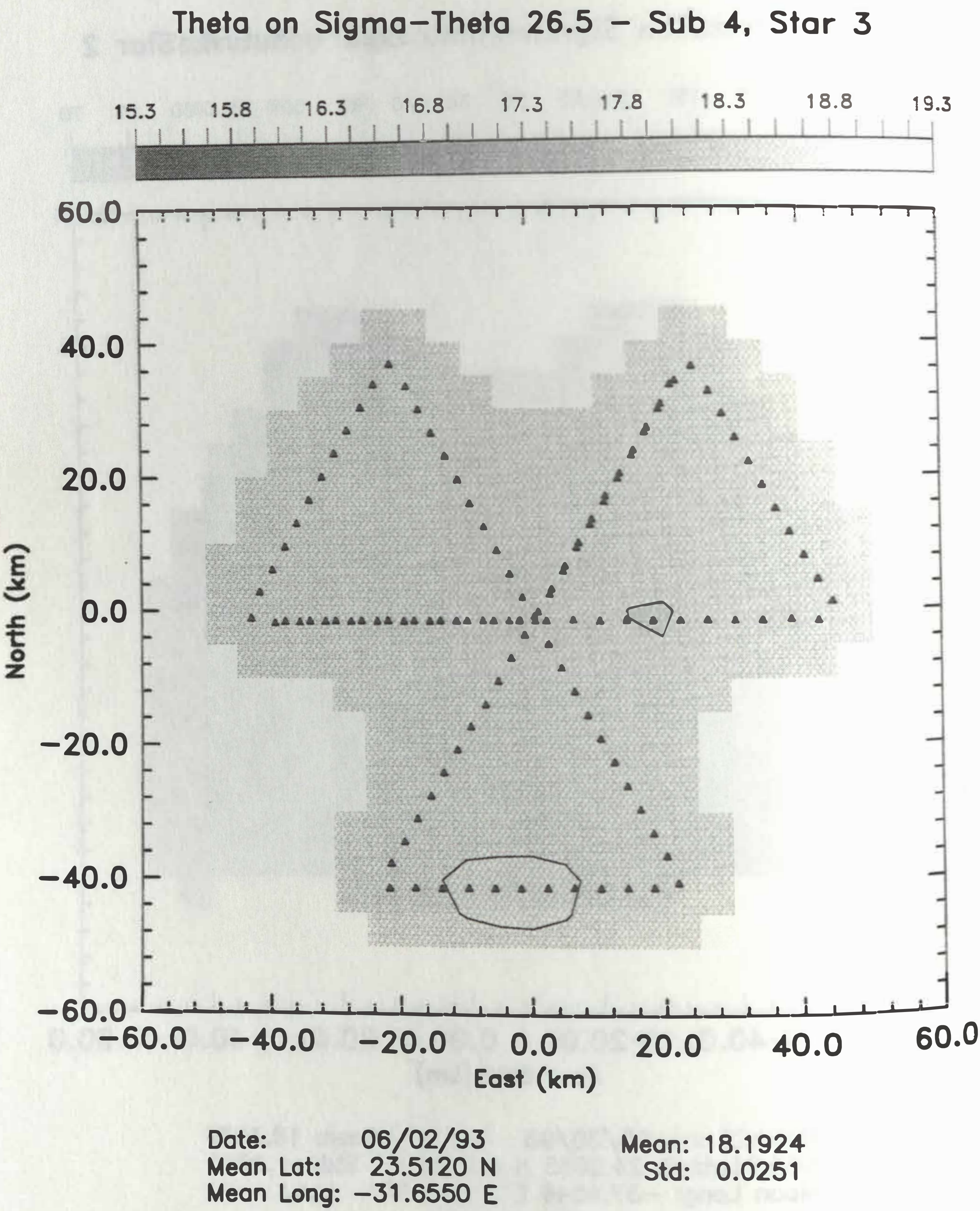
Figure D-31



Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E

Mean: 18.3139
Std: 1.4372

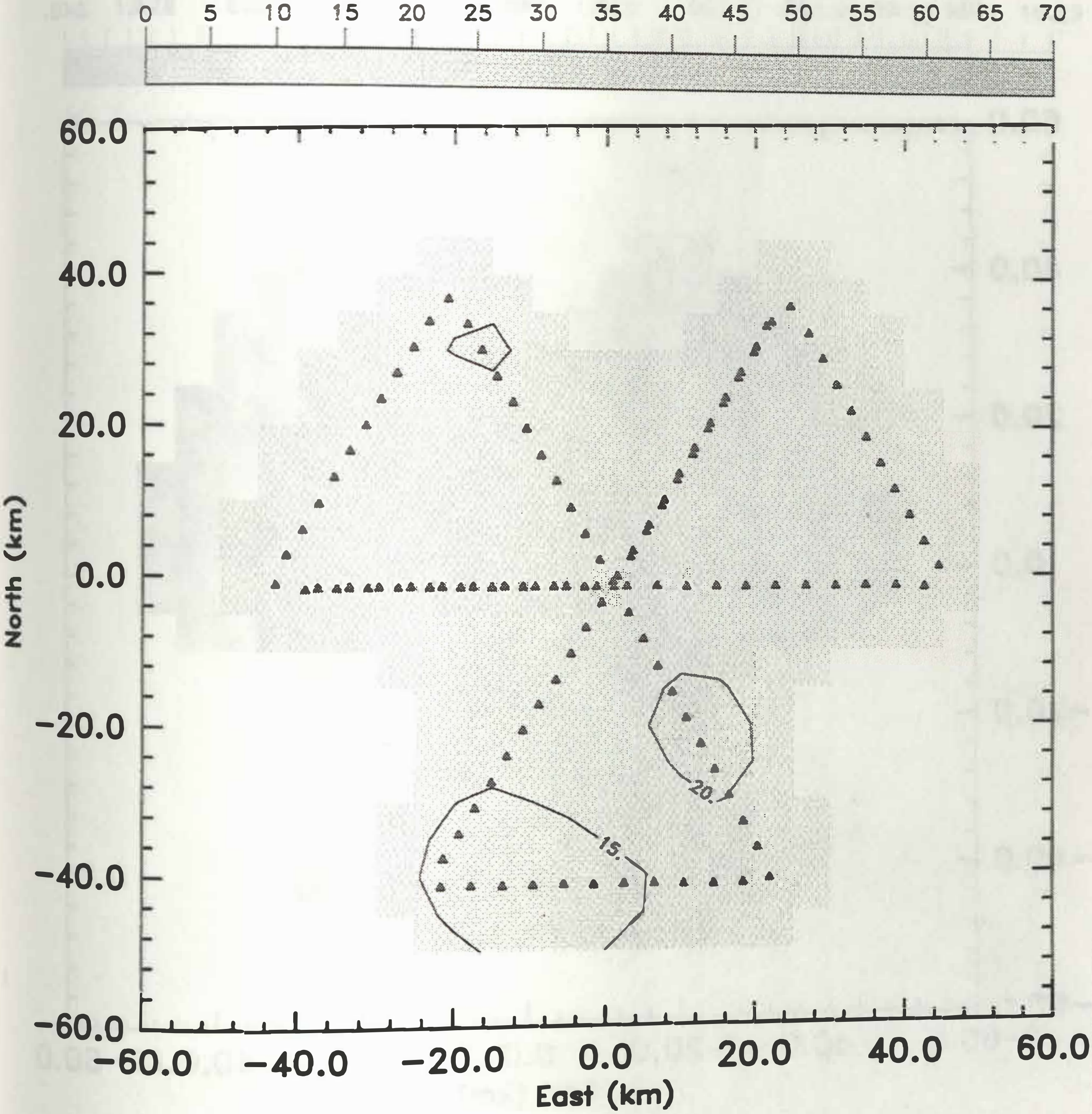
Figure D-32



Theta on Sigma-Theta 26.5 - Sub 4, Star 3
15.3
15.8
16.3
16.8
17.3
17.8
18.3
18.8
19.3
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: -31.6550 E
Mean: 18.1924
Std: 0.0251

Figure D-33

Thickness on Sigma–Theta 26.5 – Sub 4, Star 3



Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: –31.6550 E

Mean: 17.1146
Std: 1.3808

Figure D-34

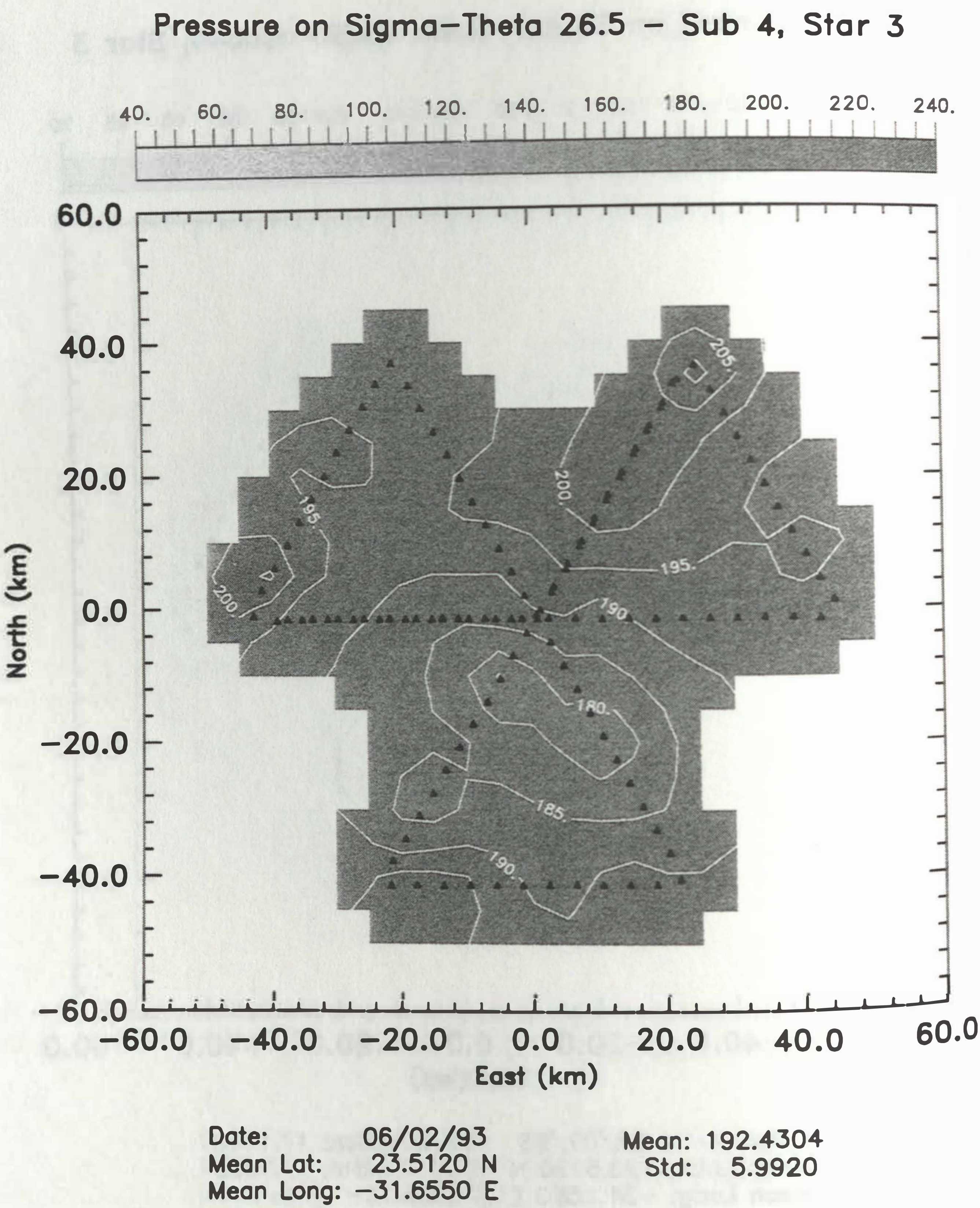
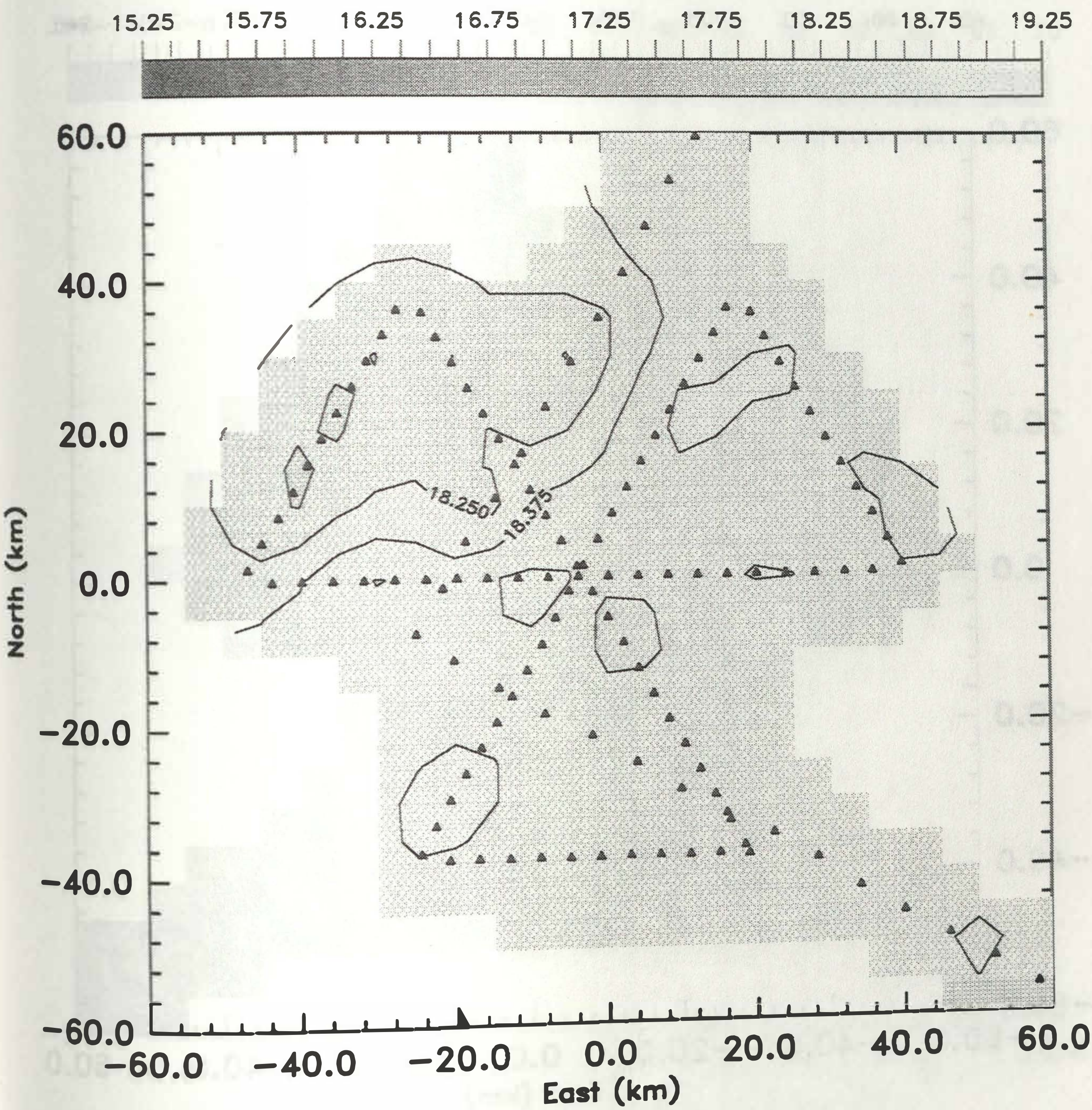

Pressure on Sigma-Theta 26.5 - Sub 4, Star 3
40. 60. 80. 100. 120. 140. 160. 180. 200. 220. 240.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
205.
200.
195.
190
180.
185.
190.
Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: -31.6550 E
Mean: 192.4304
Std: 5.9920

Figure D-35

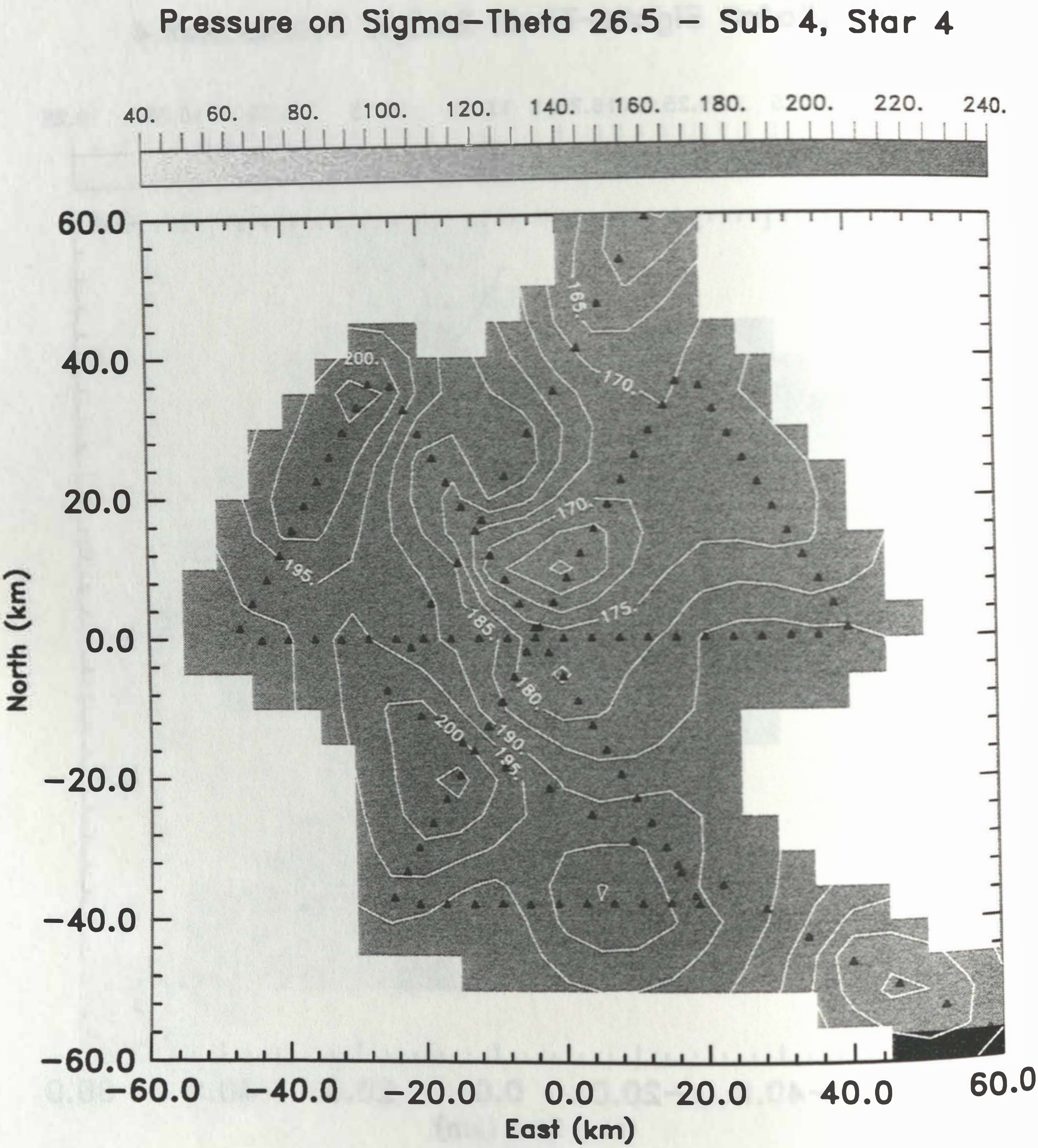
Theta on Sigma-Theta 26.5 - Sub 4, Star 4



Date: 06/05/93
Mean Lat: 28.1707 N
Mean Long: -26.3902 E

Mean: 18.4098
Std: 0.0979

Figure D-36



Date: 06/05/93
Mean Lat: 28.1707 N
Mean Long: -26.3902 E
Mean: 183.4098
Std: 11.0004

Figure D-37

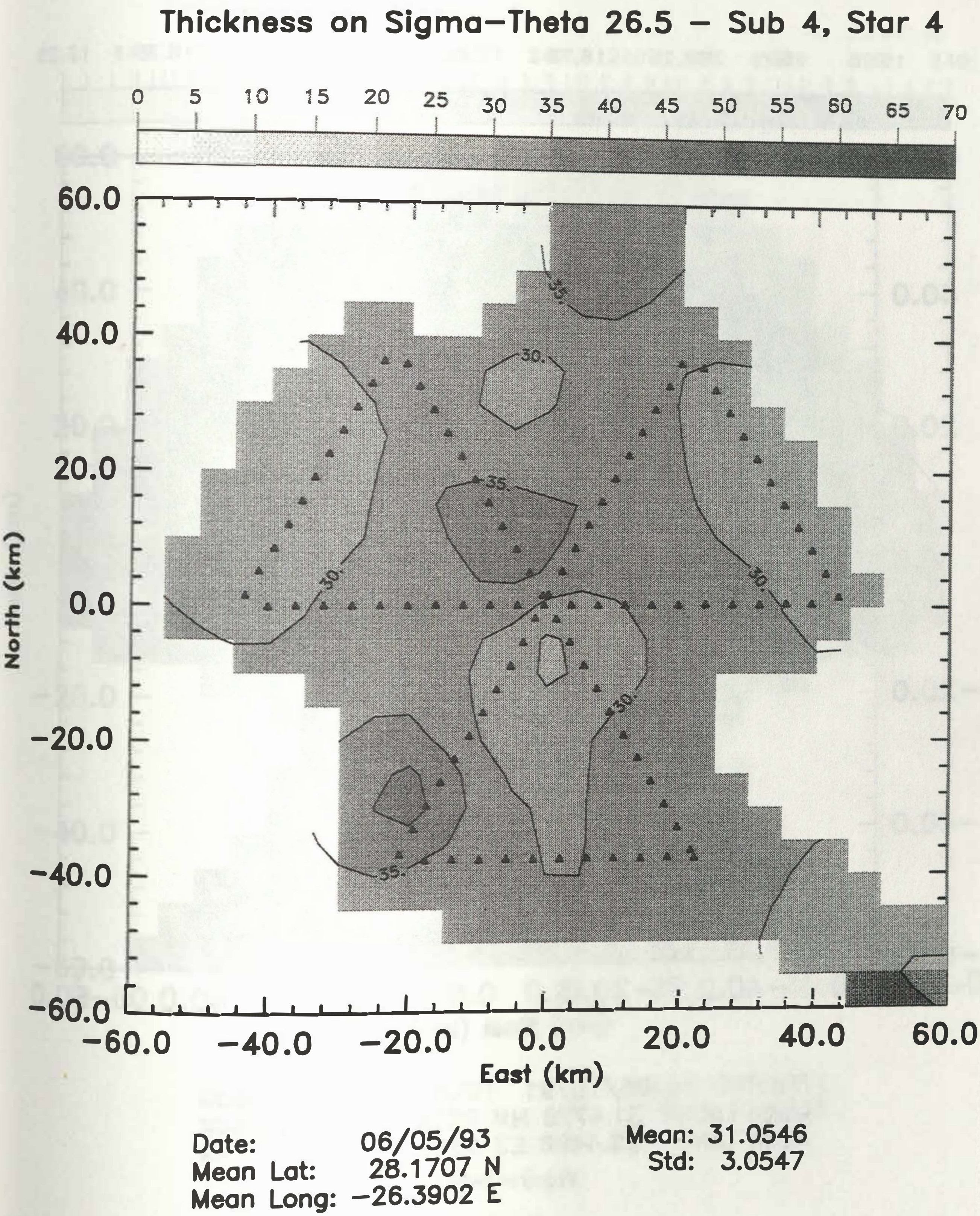
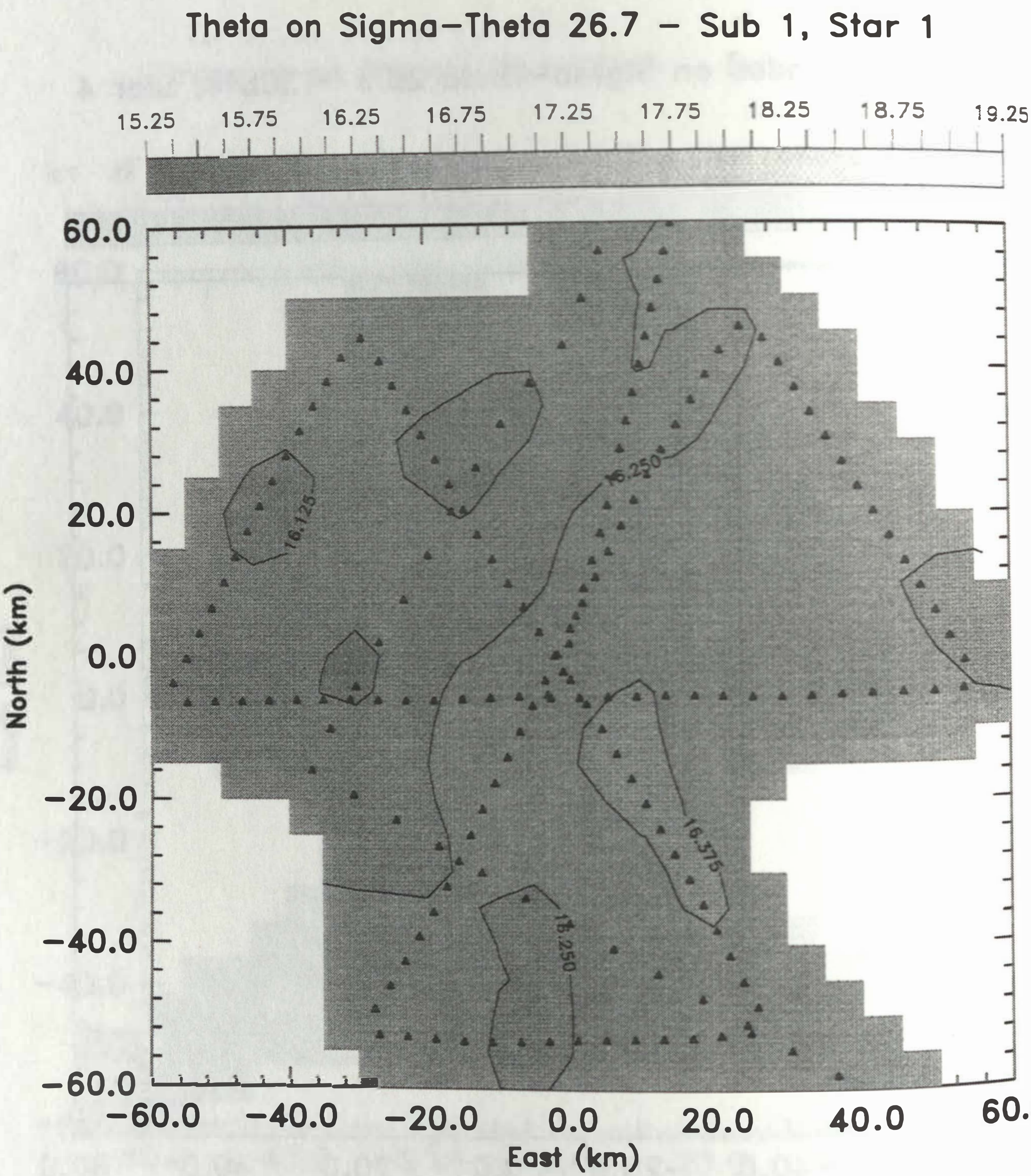

Thickness on Sigma-Theta 26.5 - Sub 4, Star 4
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
35.
30.
35.
30.
30.
30.
35.
Date: 06/05/93
Mean Lat: 28.1707 N
Mean Long: -26.3902 E
Mean: 31.0546
Std: 3.0547

Figure D-38



Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E

Mean: 16.2514
Std: 0.0680

Figure D-39

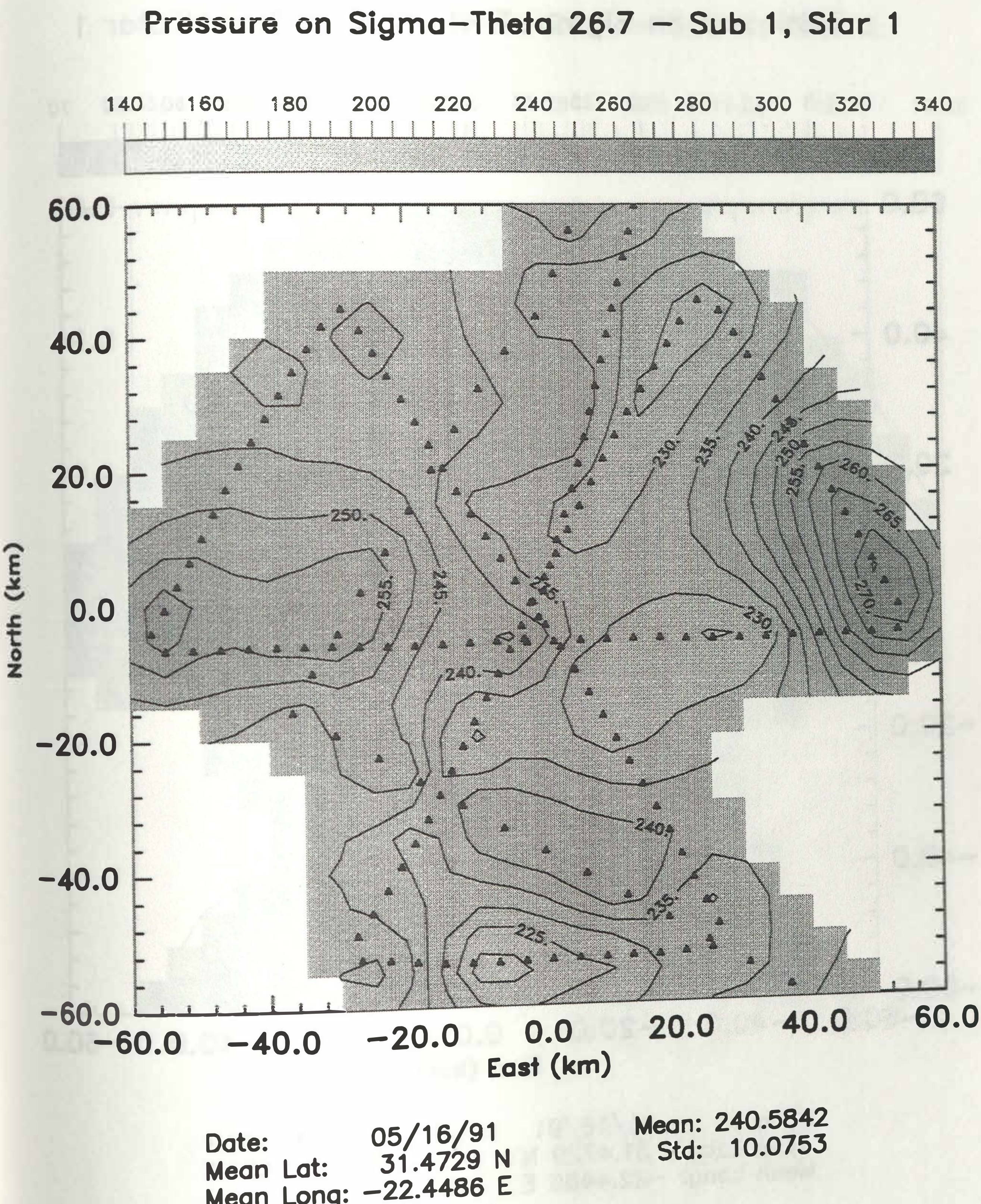
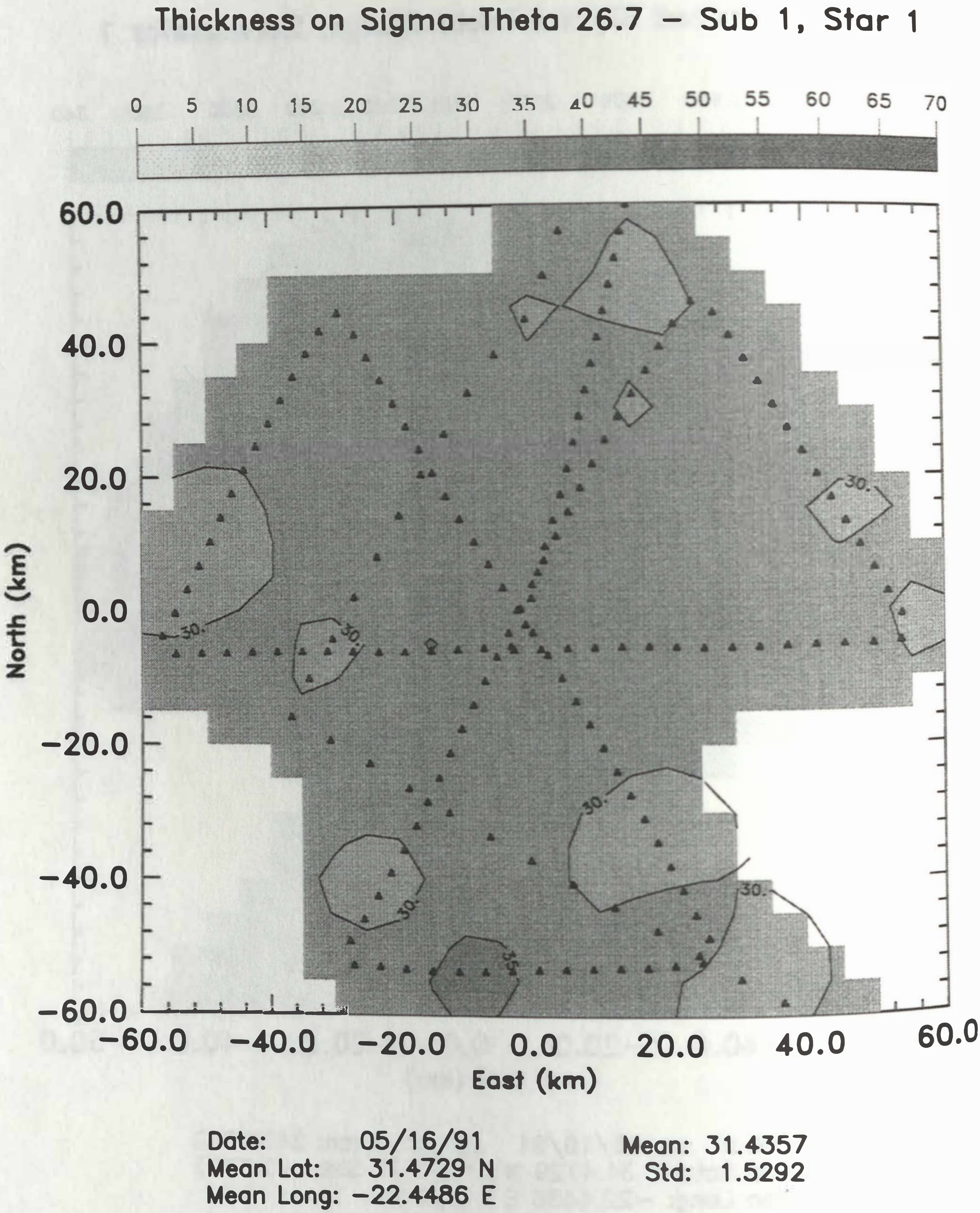
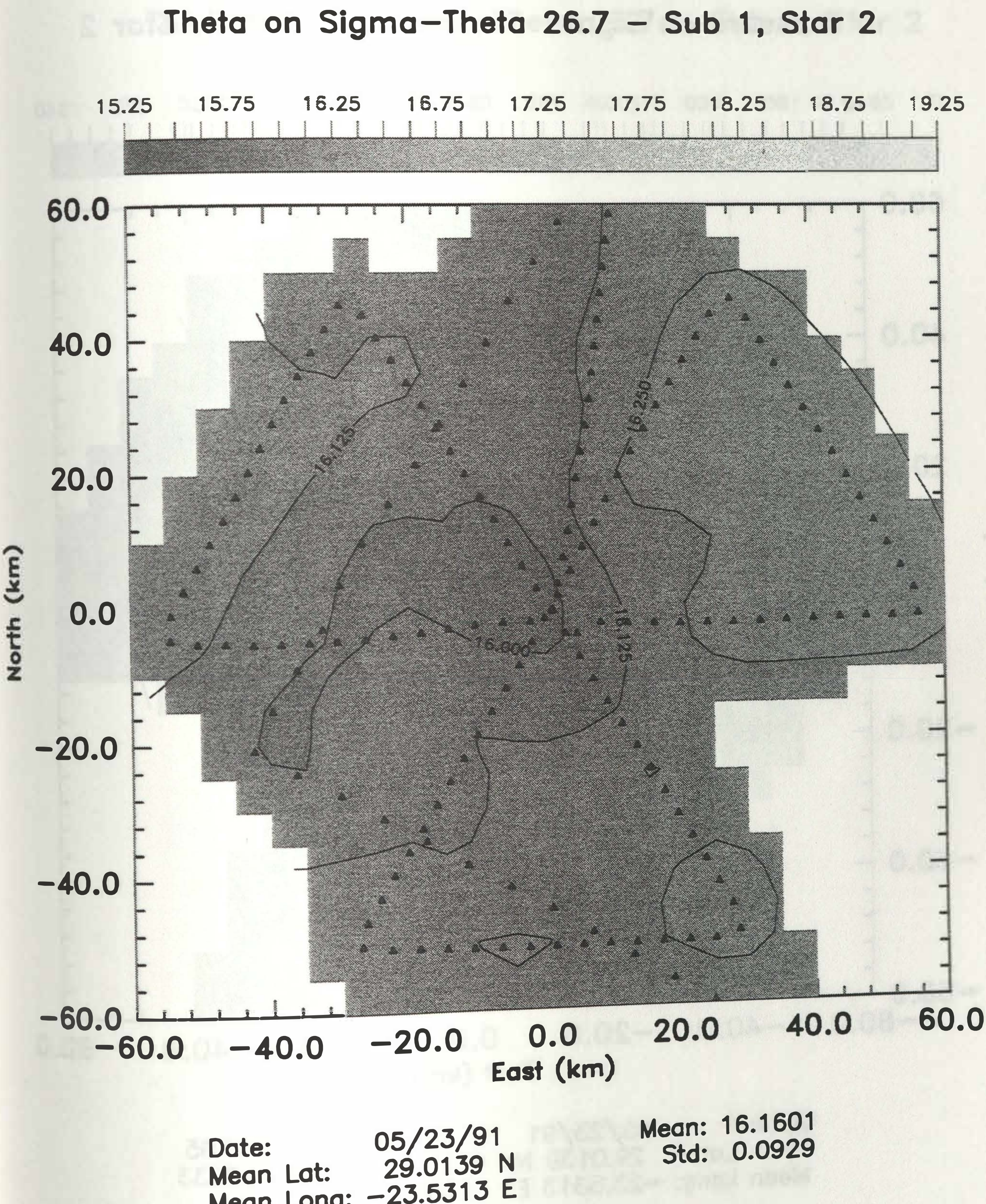

Pressure on Sigma-Theta 26.7 - Sub 1, Star 1
140 160 180 200 220 240 260 280 300 320 340
North (km)
East (km)
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E
Mean: 240.5842
Std: 10.0753

Figure D-40



Thickness on Sigma-Theta 26.7 - Sub 1, Star 1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
30.
35
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E
Mean: 31.4357
Std: 1.5292

Figure D-41



Theta on Sigma-Theta 26.7 - Sub 1, Star 2
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
16.125
16.250
16.000
16.125
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 16.1601
Std: 0.0929

Figure D-42

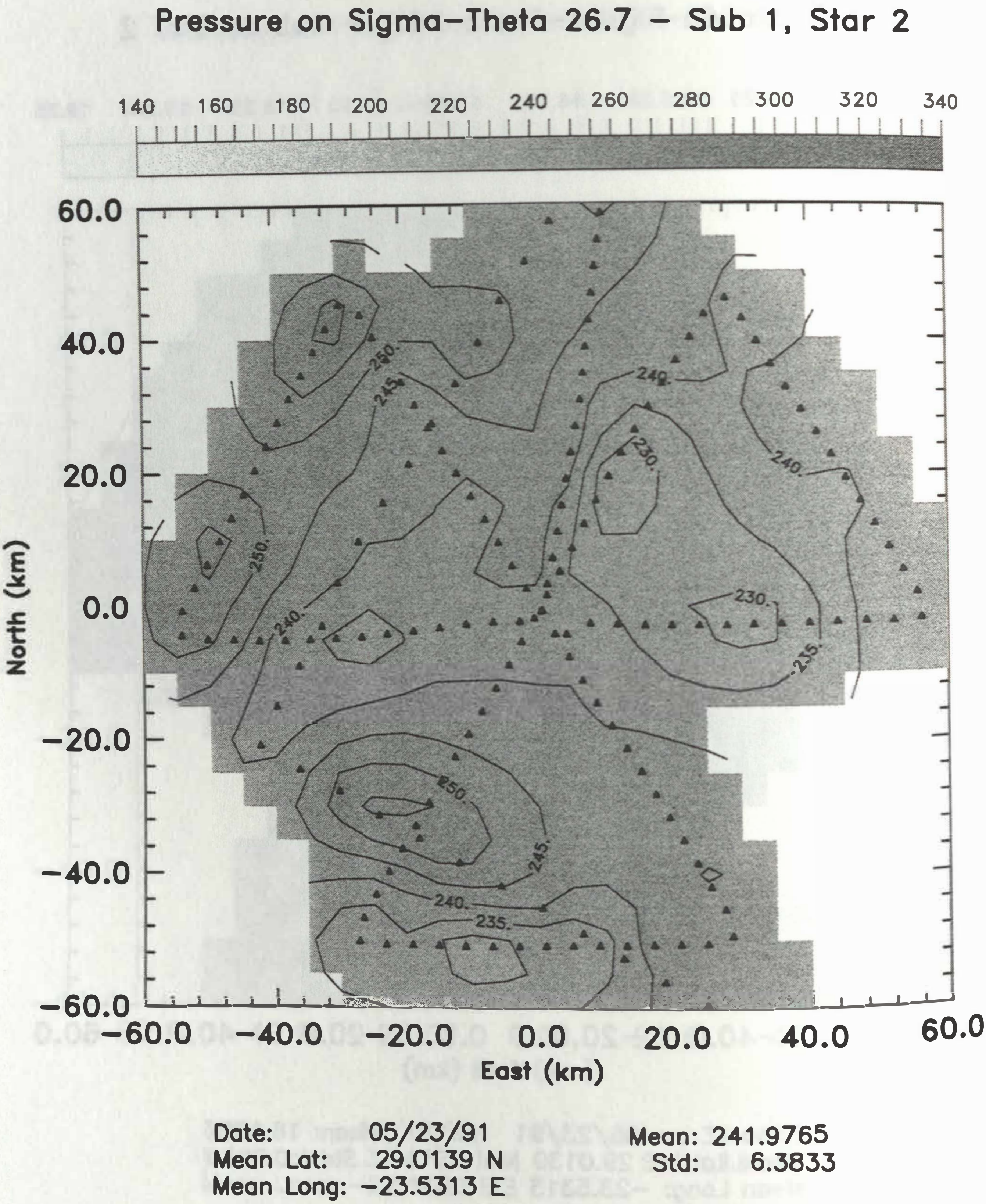
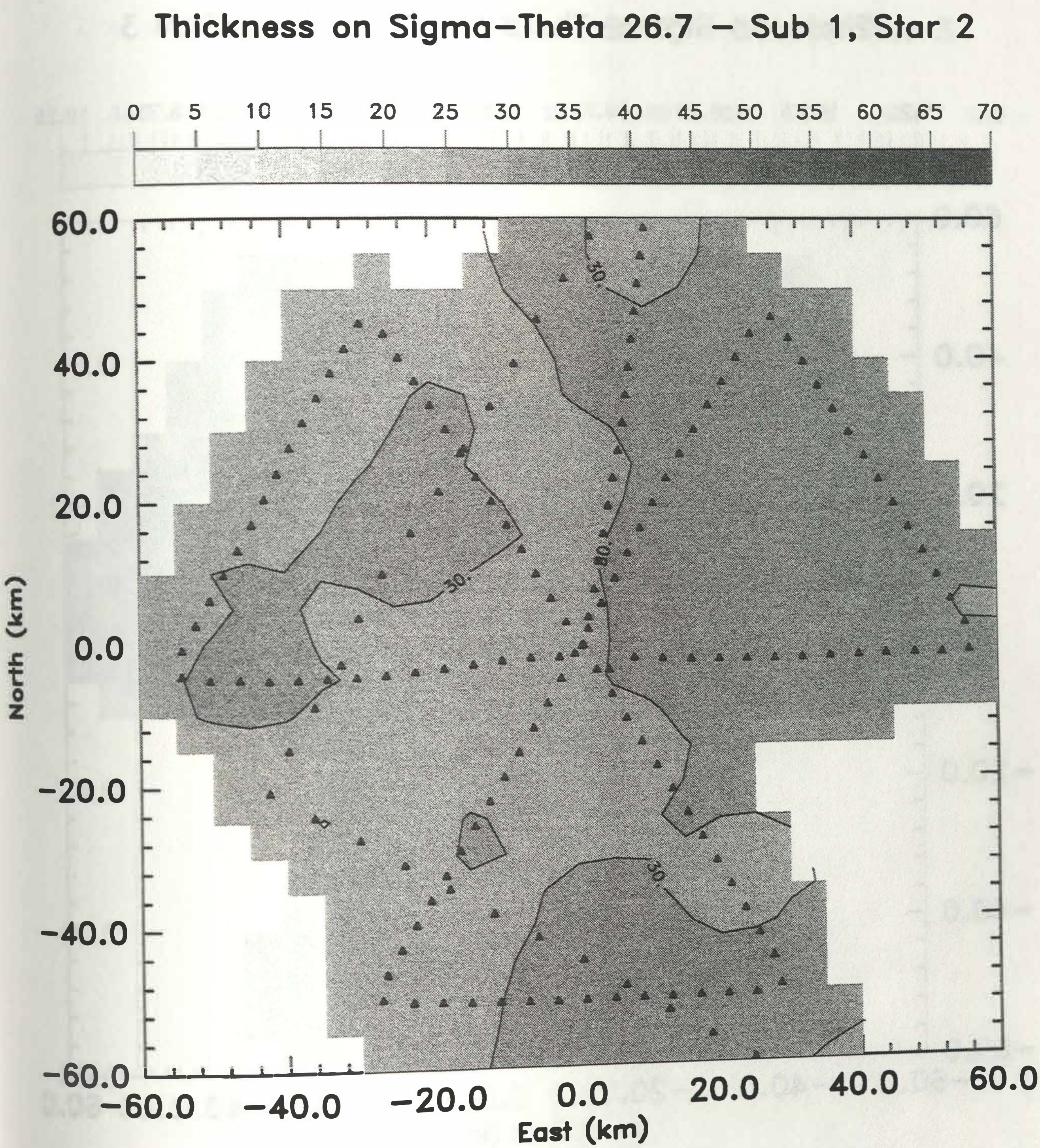

Pressure on Sigma-Theta 26.7 - Sub 1, Star 2
140
160
180
200
220
240
260
280
300
320
340
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
250.
245.
240.
230.
235.
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 241.9765
Std: 6.3833

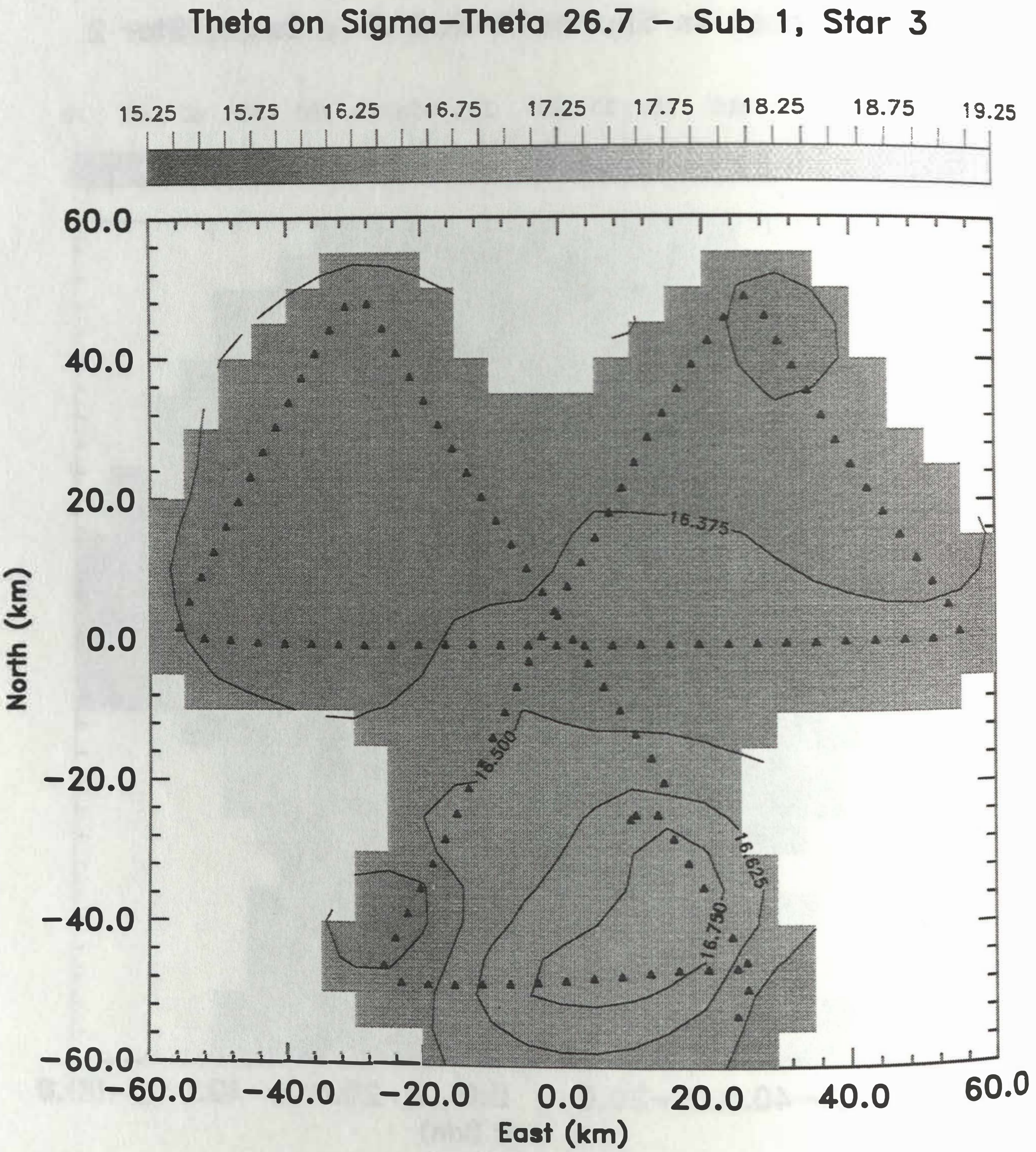
Figure D-43



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E

Mean: 30.1820
Std: 1.6768

Figure D-44

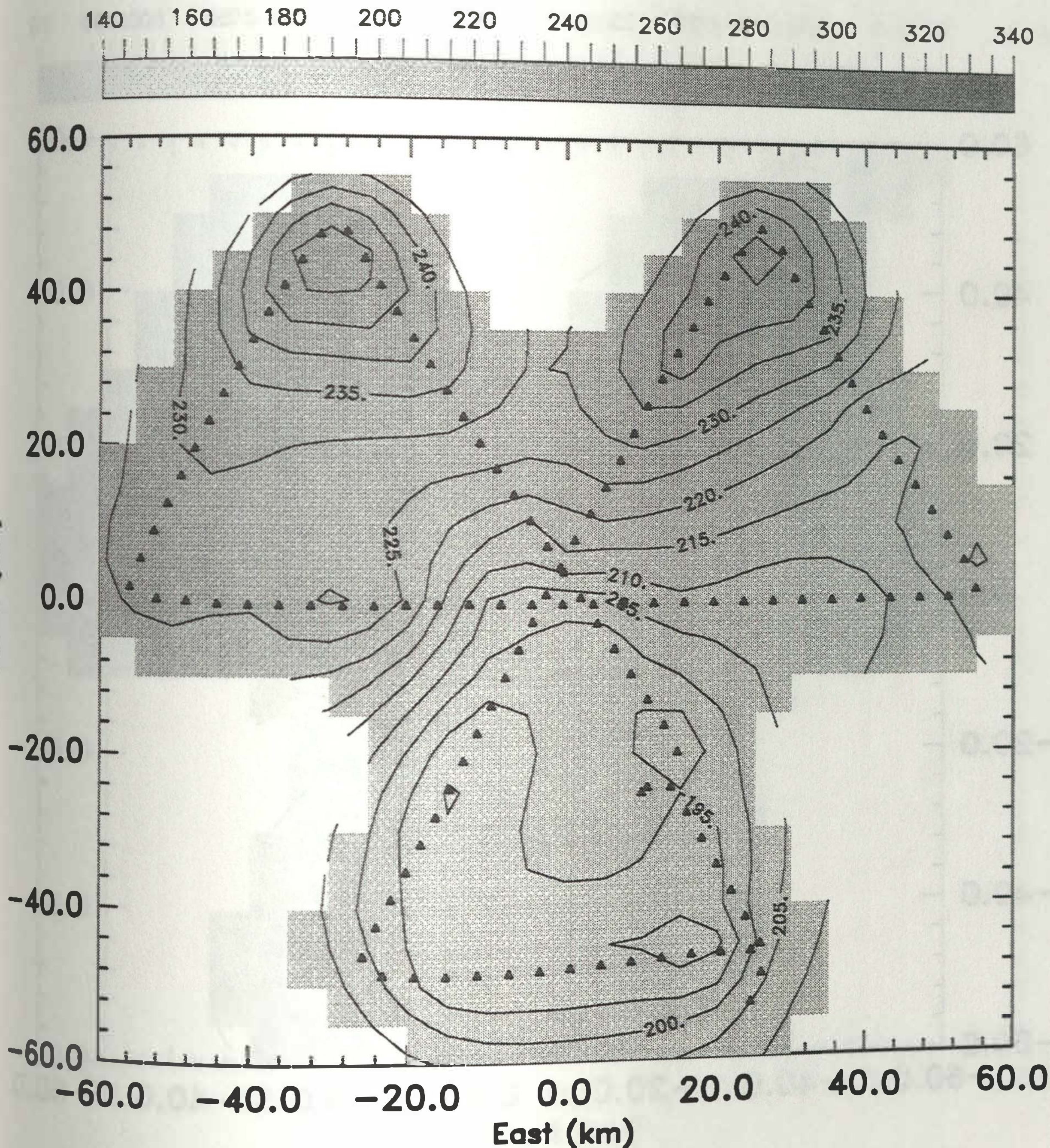


Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E

Mean: 16.4236
Std: 0.1287

Figure D-45

Pressure on Sigma–Theta 26.7 – Sub 1, Star 3

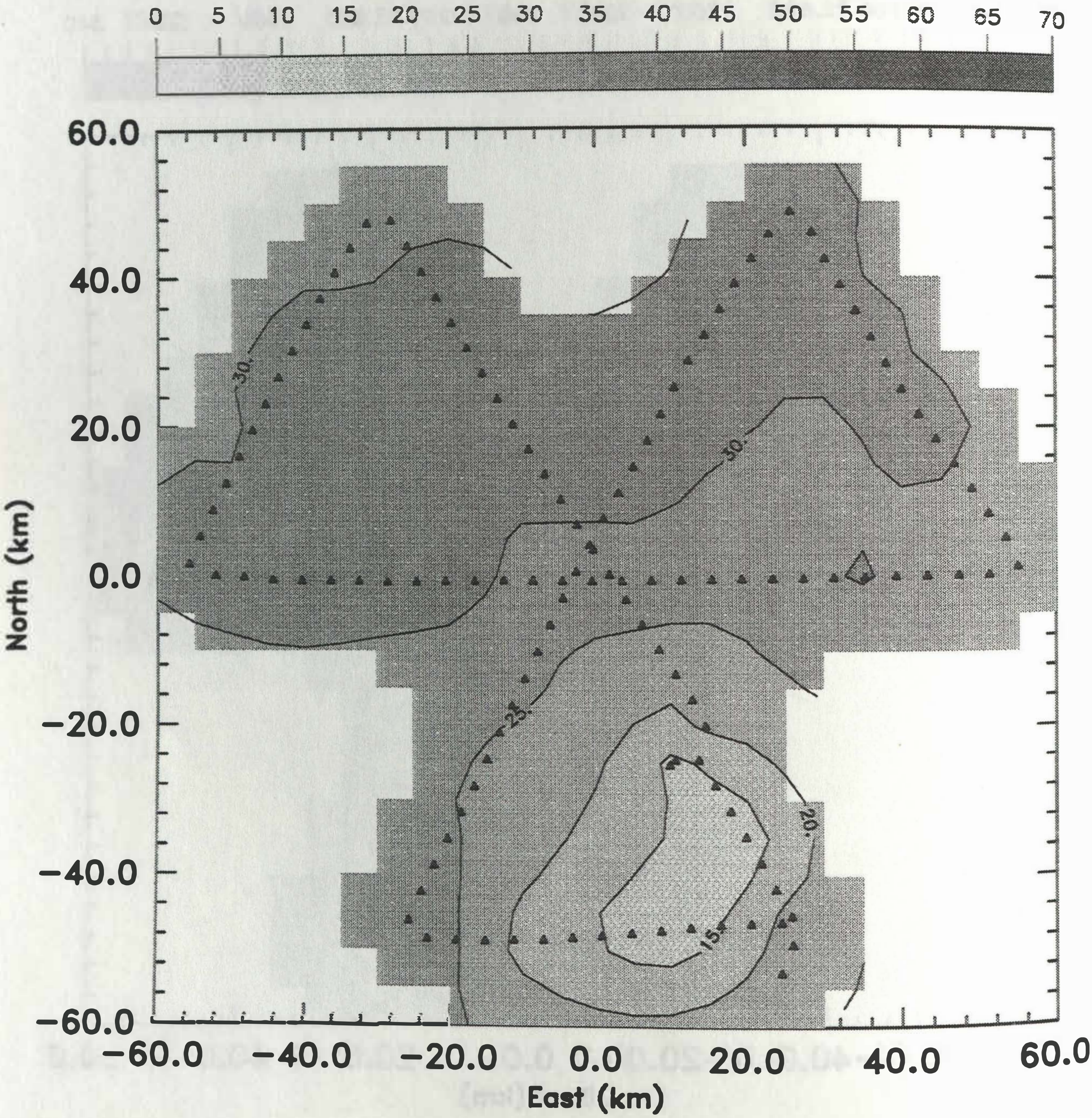


Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E

Mean: 216.5273
Std: 15.9862

Figure D-46

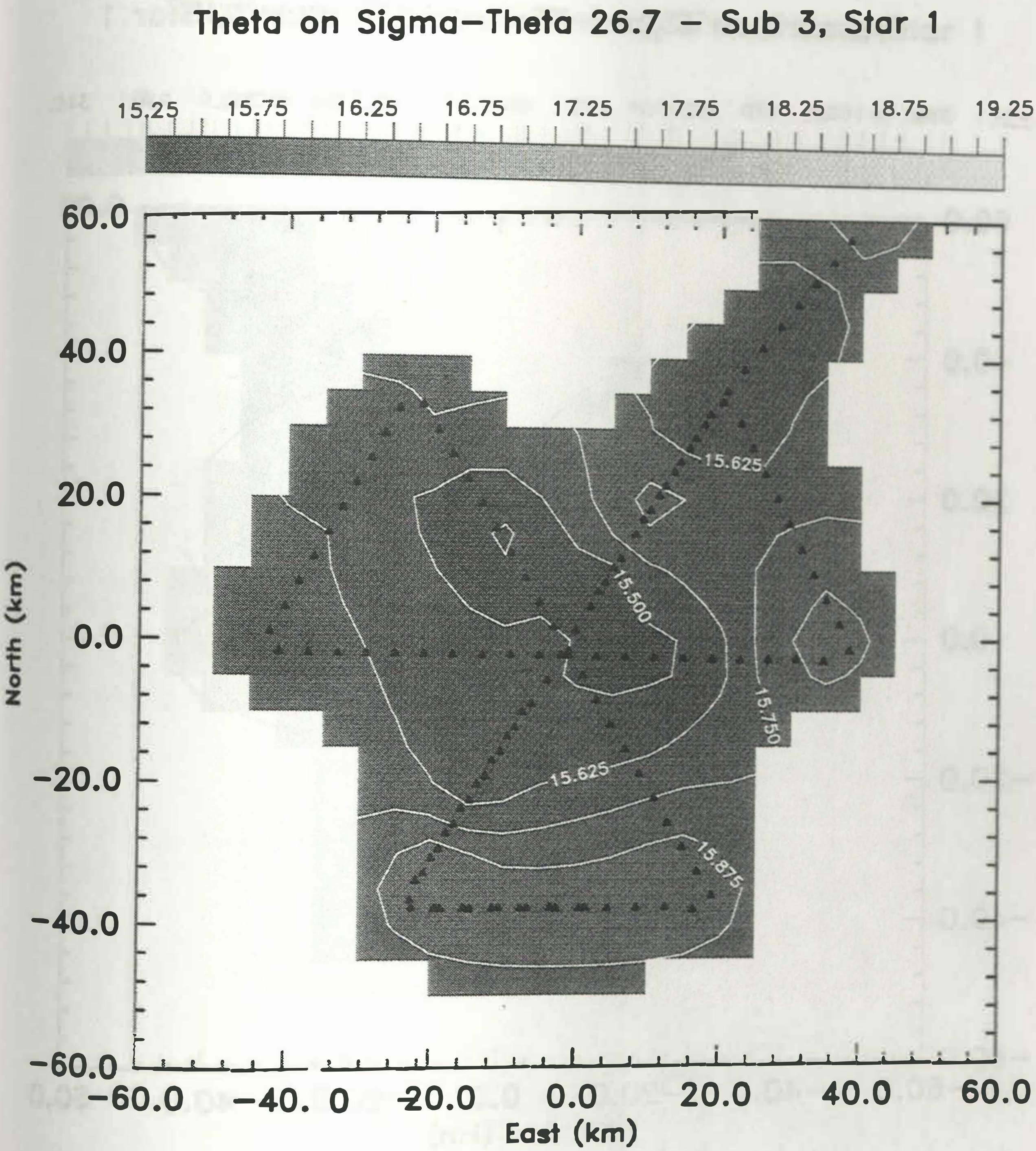
Thickness on Sigma-Theta 26.7 – Sub 1, Star 3



Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E

Mean: 27.1940
Std: 4.7615

Figure D-47



Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: –29.6893 E

Mean: 15.6800
Std: 0.1361

Figure D-48

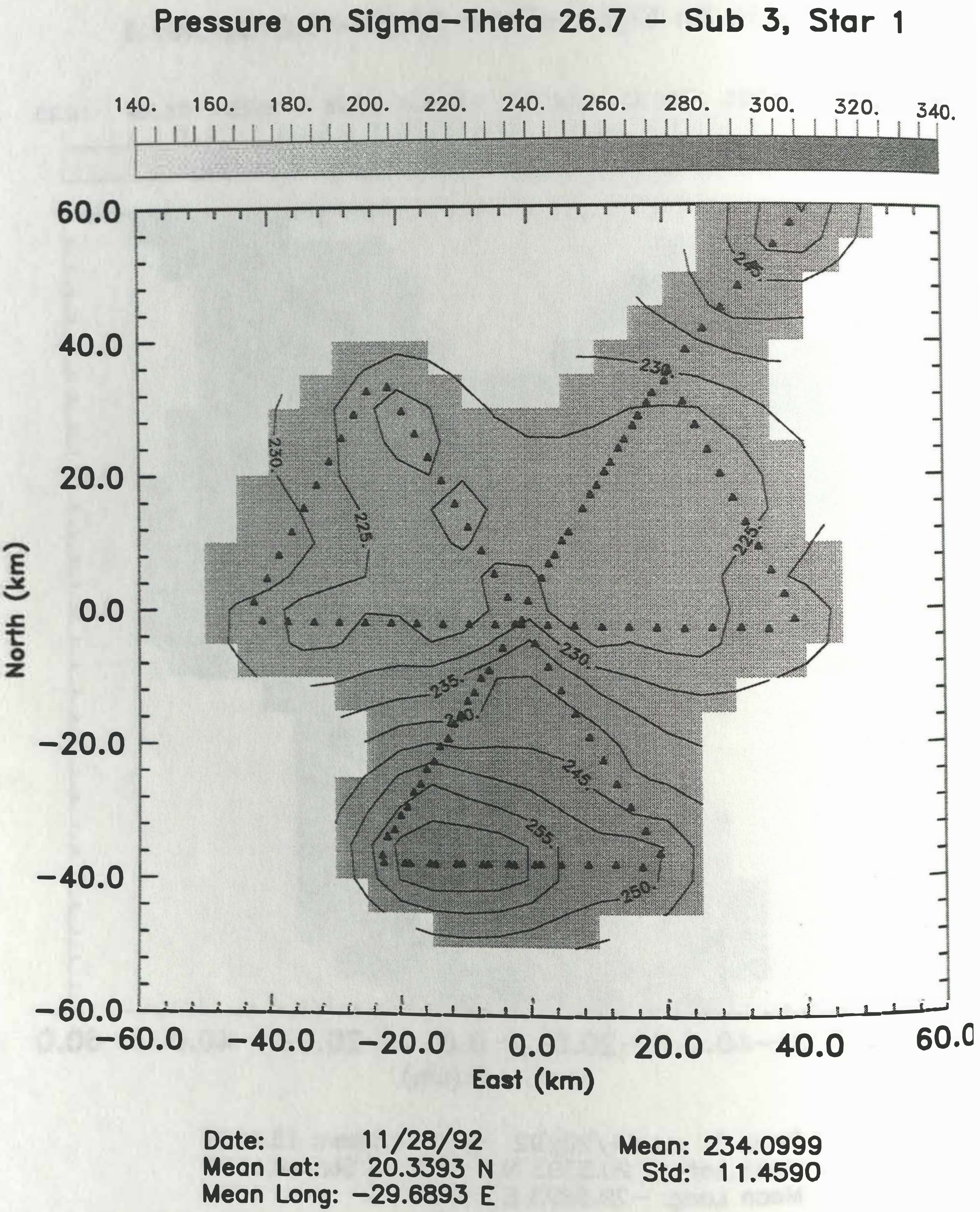
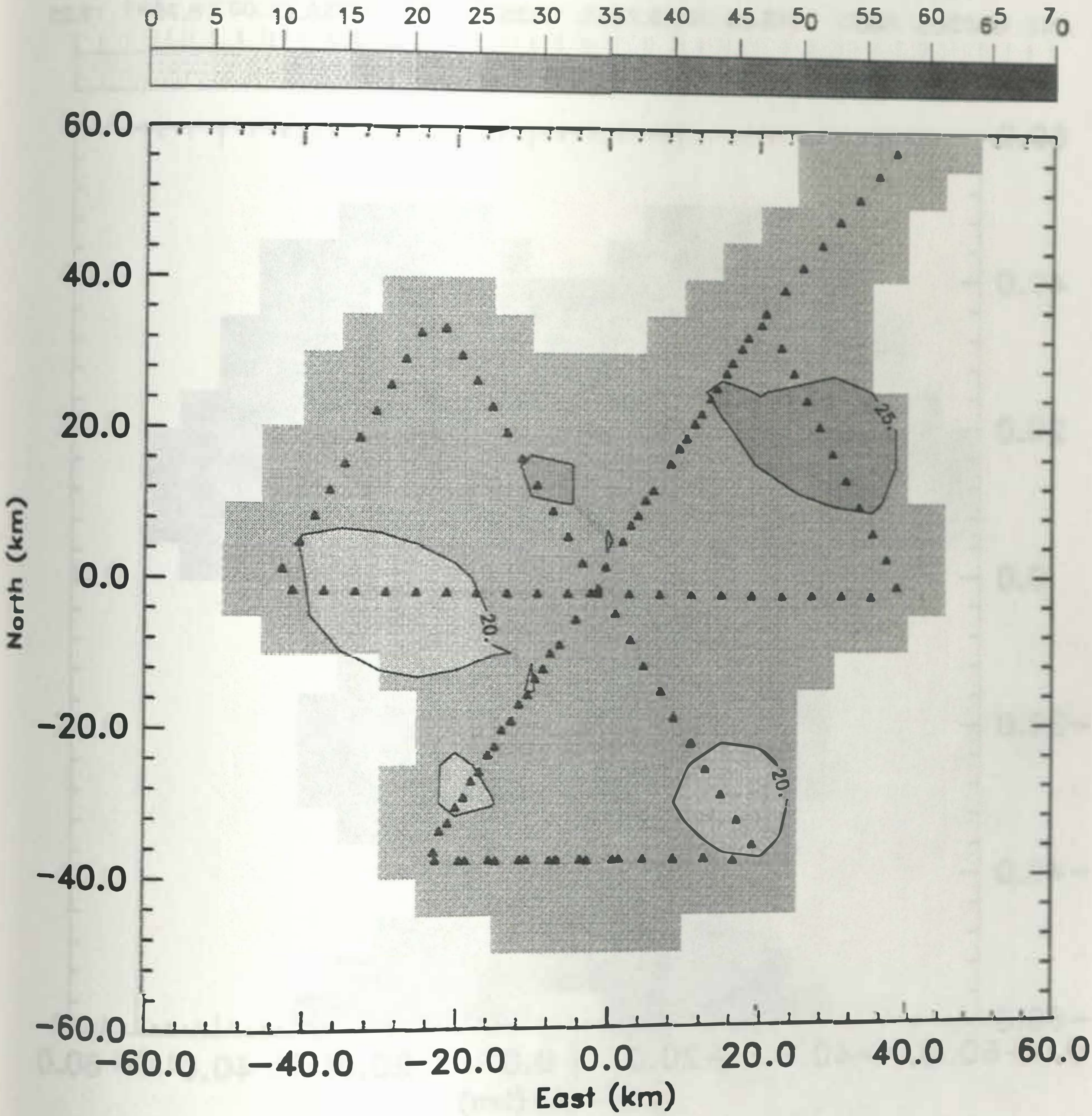

Pressure on Sigma-Theta 26.7 - Sub 3, Star 1
140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
245.
230.
225.
230.
225.
230.
235.
240.
245.
255.
250.
Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E
Mean: 234.0999
Std: 11.4590

Figure D-49

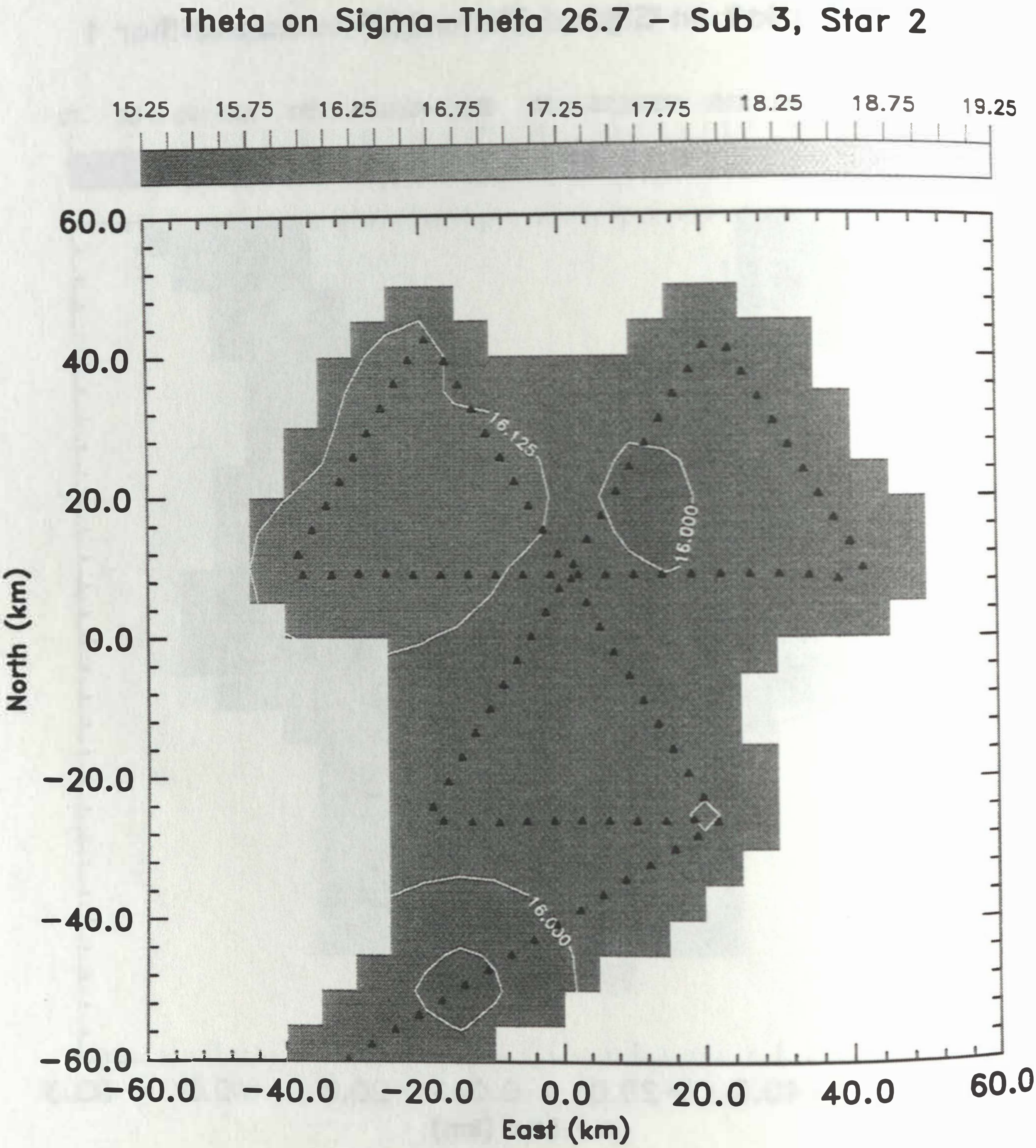
Thickness on Sigma–Theta 26.7 – Sub 3, Star 1



Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E

Mean: 22.1654
Std: 1.6846

Figure D-50



Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 16.0629
Std: 0.0673

Figure D-51

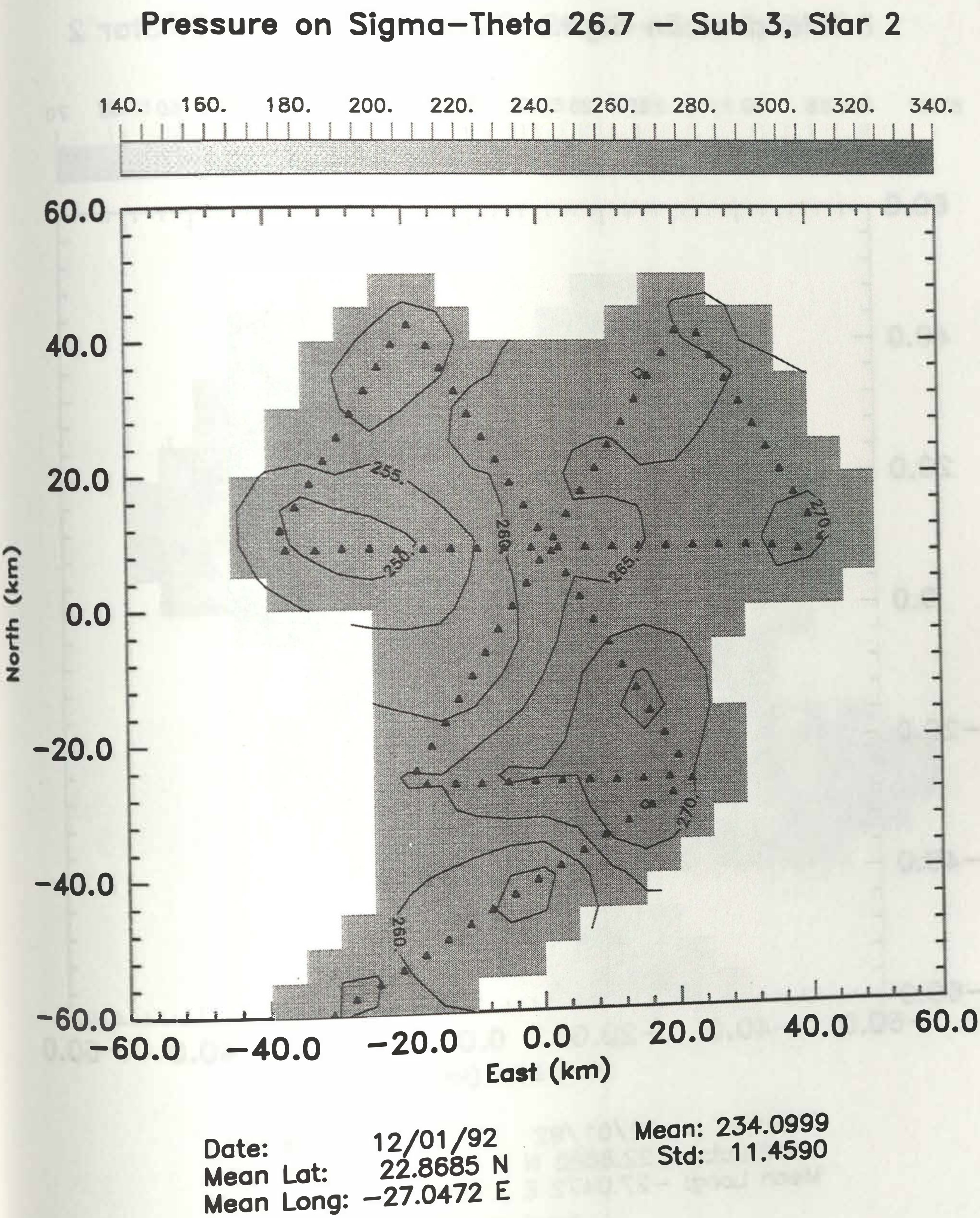
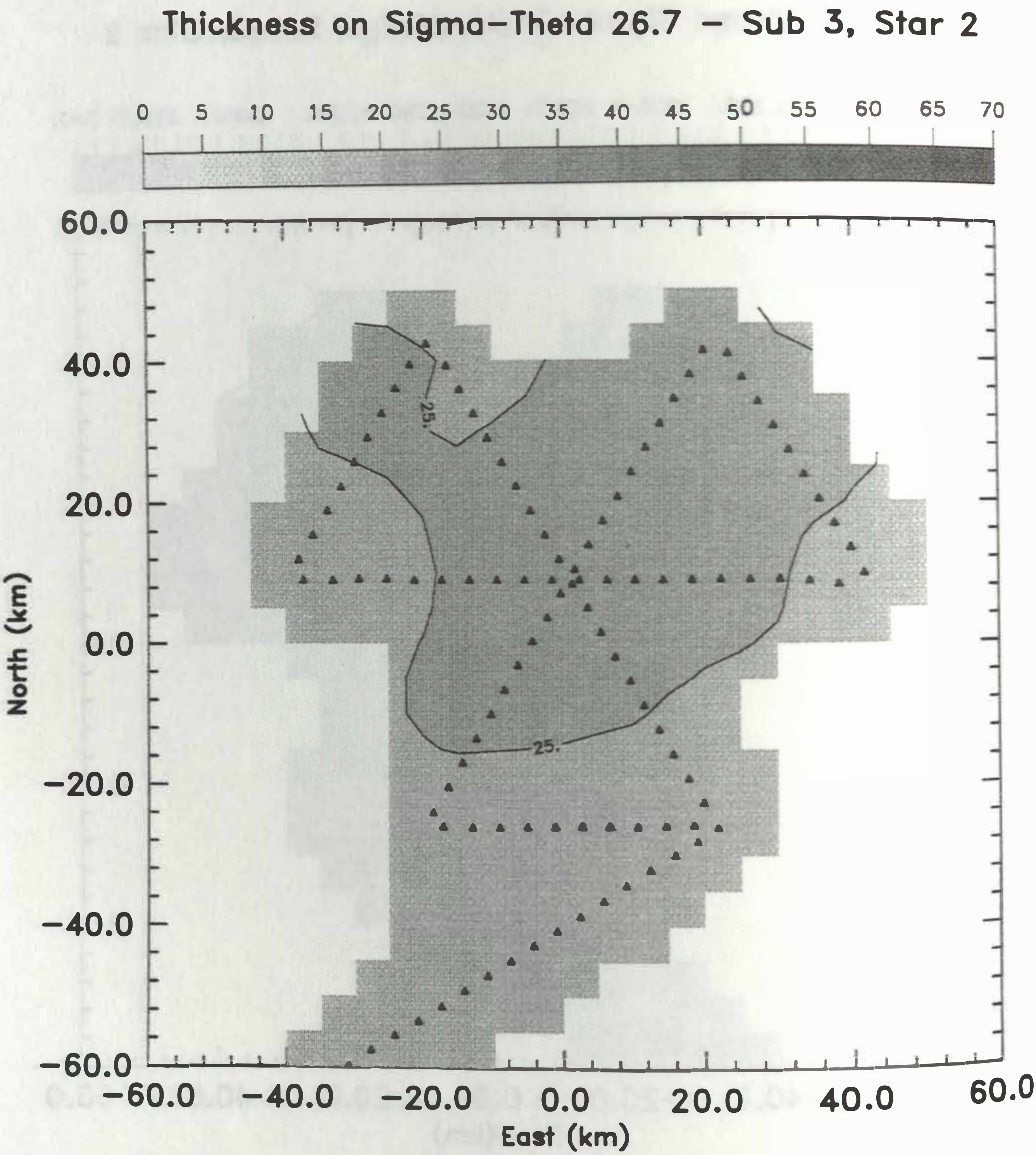

Pressure on Sigma-Theta 26.7 - Sub 3, Star 2
140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
255.
250.
260.
265.
270.
Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 234.0999
Std: 11.4590

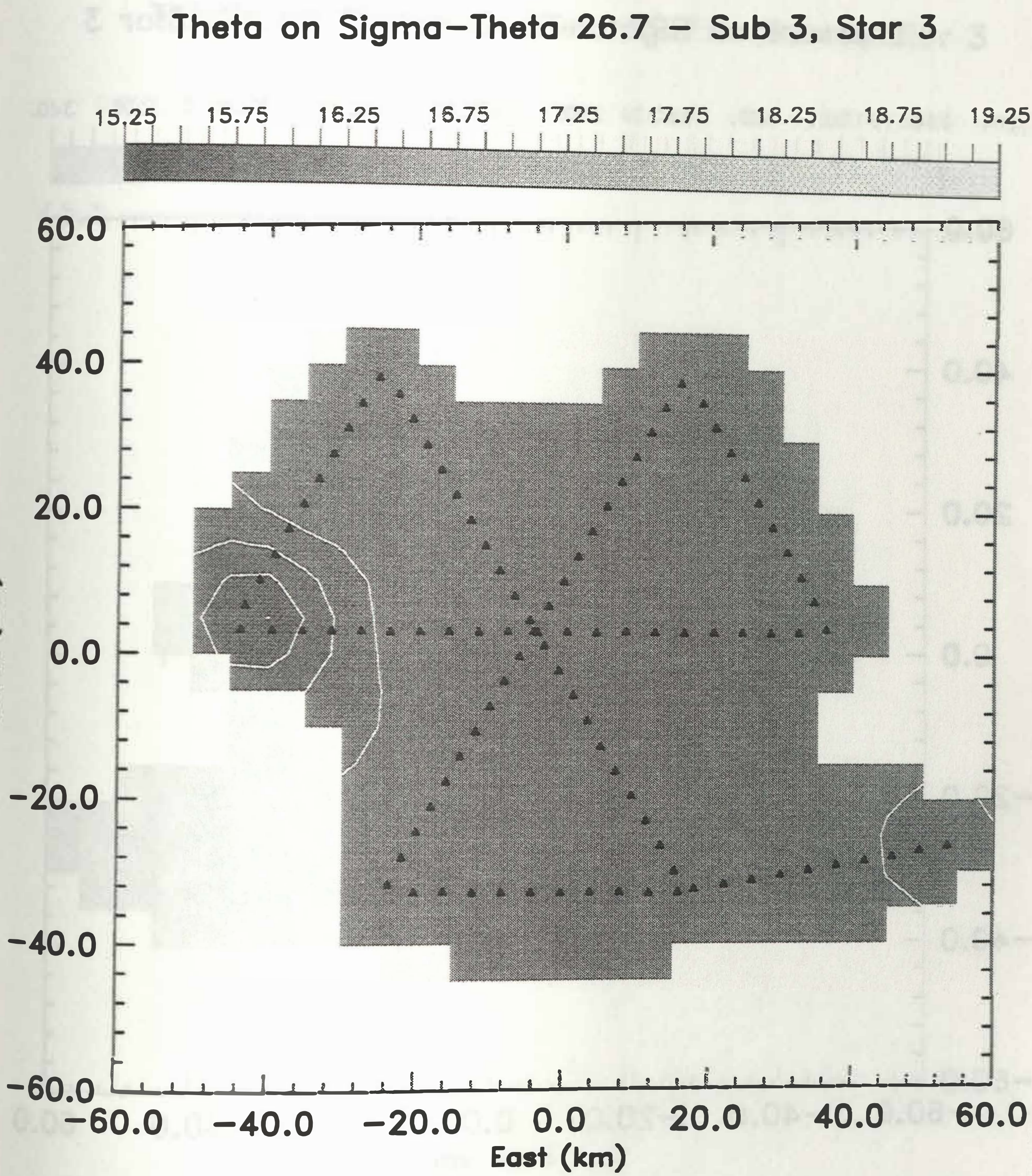
Figure D-52



Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E

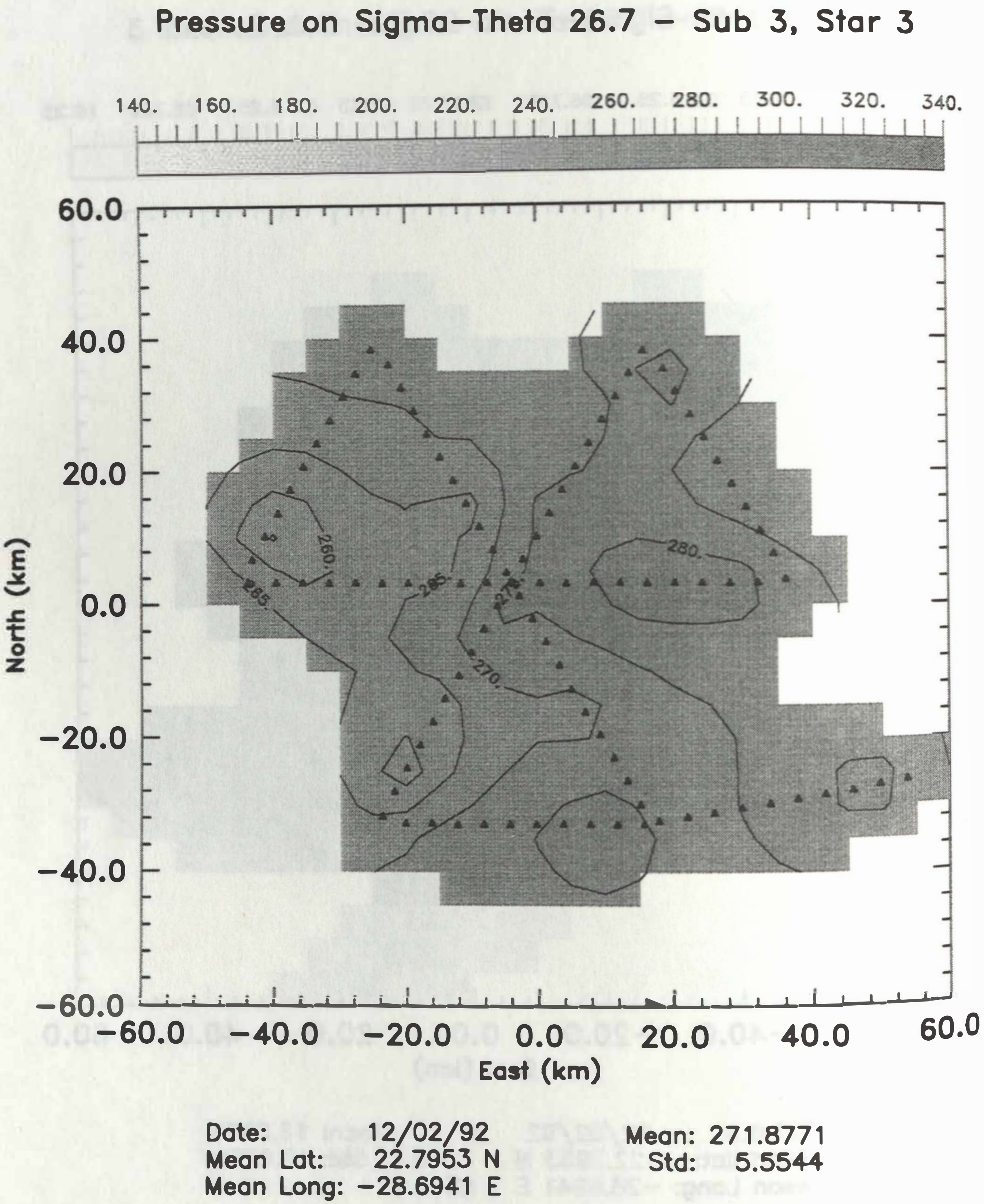
Mean: 24.6175
Std: 1.1954

Figure D-53



Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 16.0337
Std: 0.0732

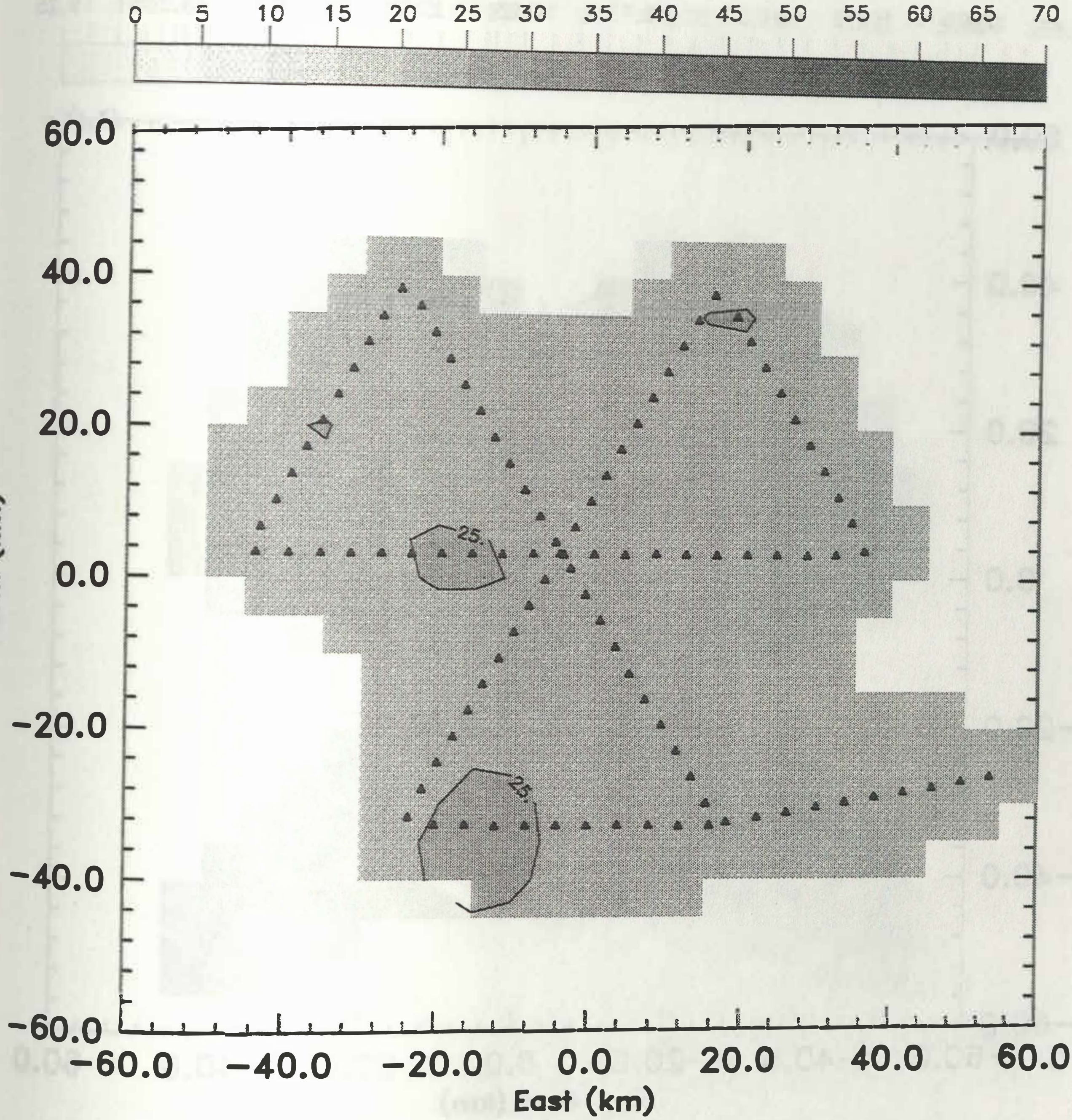
Figure D-54



Pressure on Sigma-Theta 26.7 - Sub 3, Star 3
140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
260.
265.
265.
270.
270.
280.
Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 271.8771
Std: 5.5544

Figure D-55

Thickness on Sigma-Theta 26.7 - Sub 3, Star 3

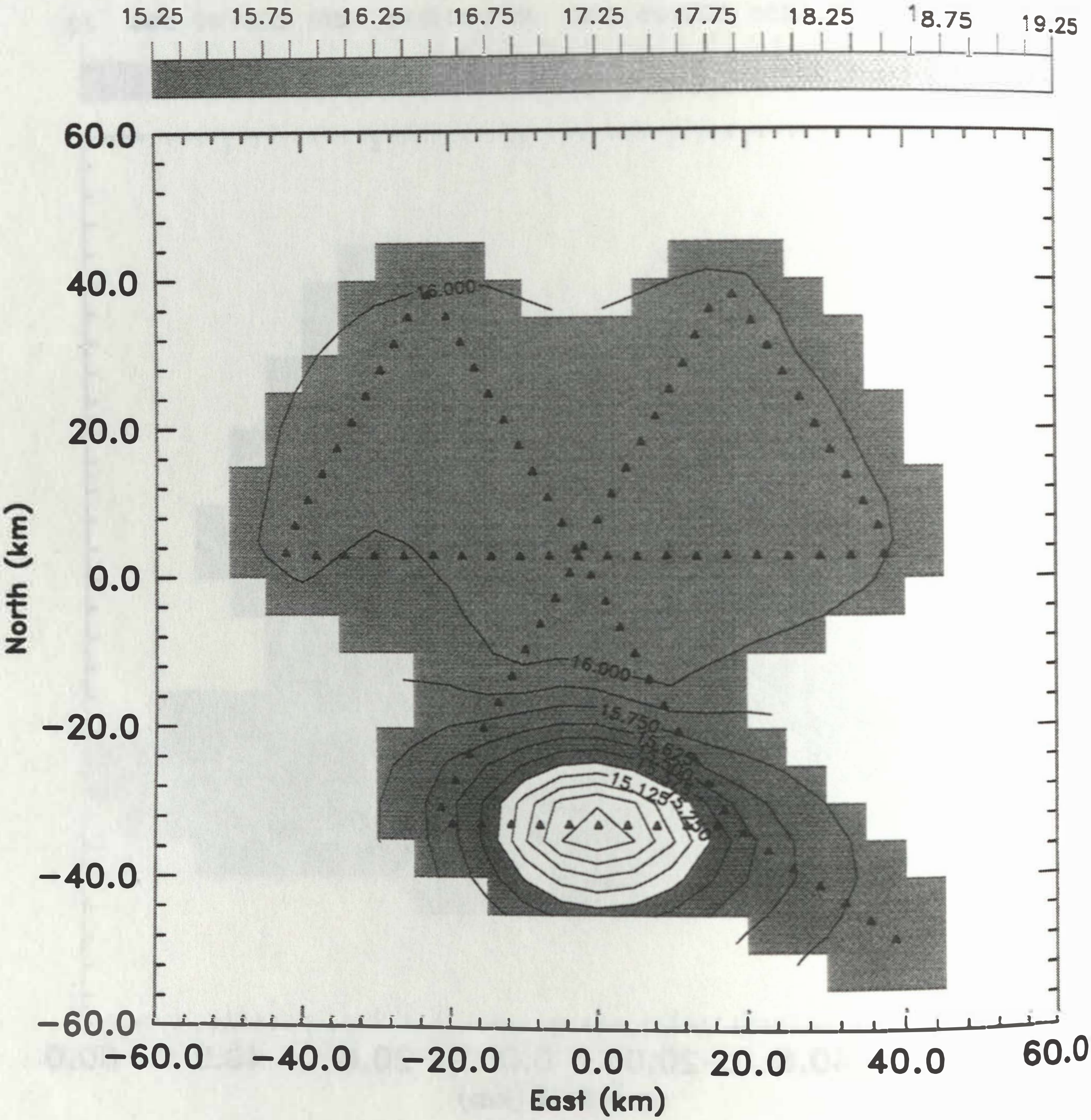


Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E

Mean: 23.5976
Std: 0.8780

Figure D-56

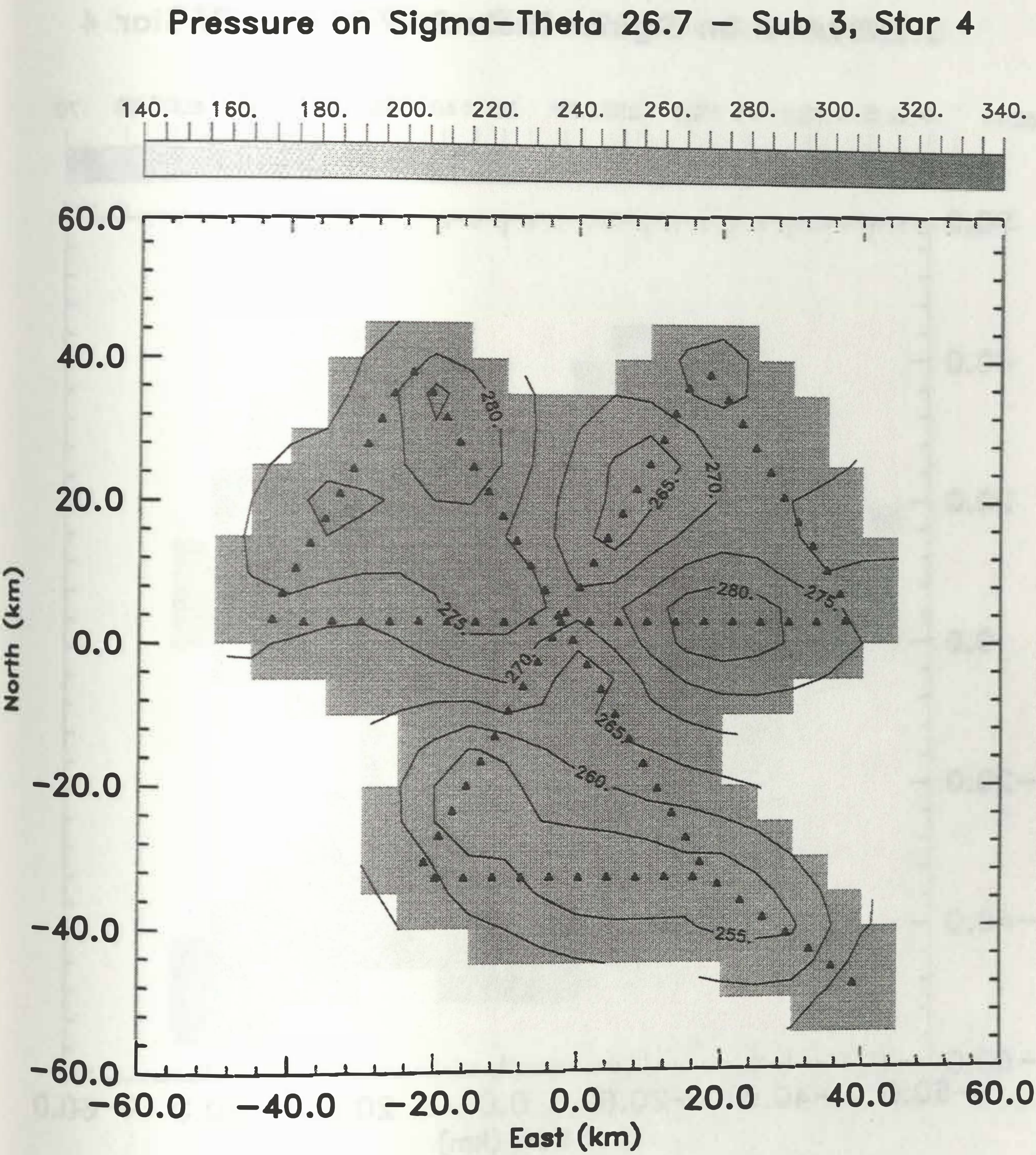
Theta on Sigma-Theta 26.7 - Sub 3, Star 4



Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E

Mean: 15.8712
Std: 0.2891

Figure D-57



Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E

Mean: 268.6239
Std: 8.1597

Figure D-58

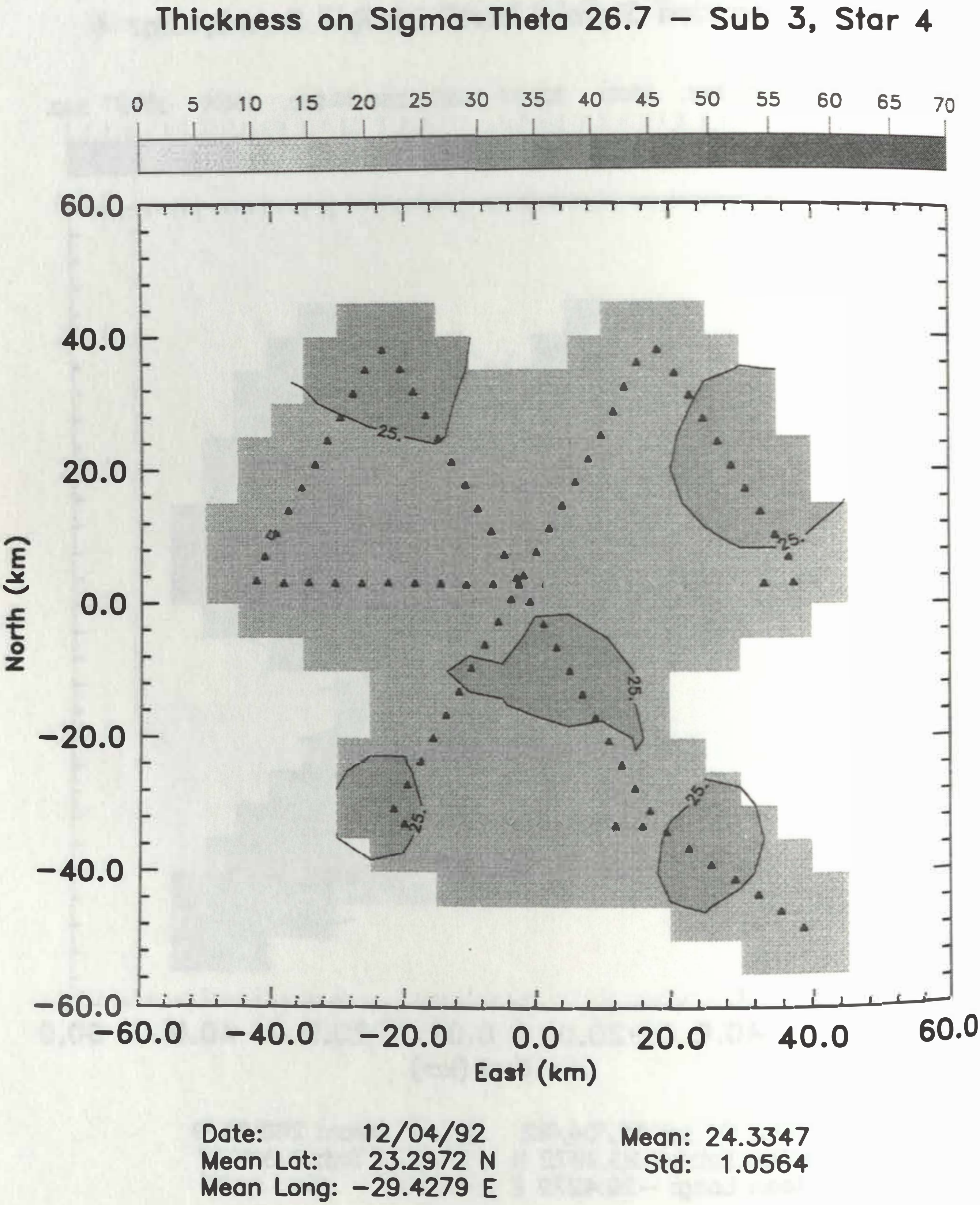
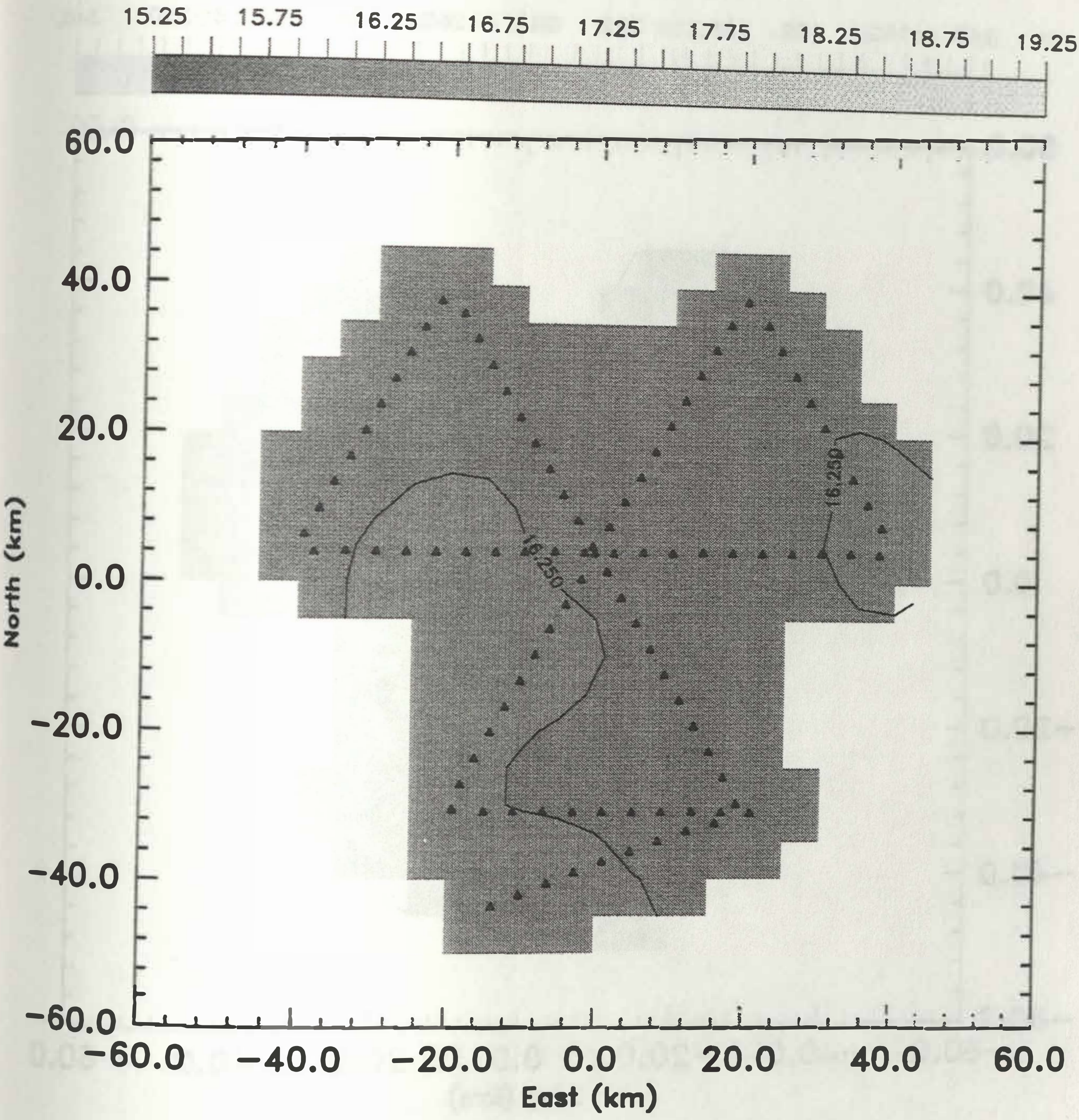

Thickness on Sigma-Theta 26.7 - Sub 3, Star 4
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
25.
Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 24.3347
Std: 1.0564

Figure D-59

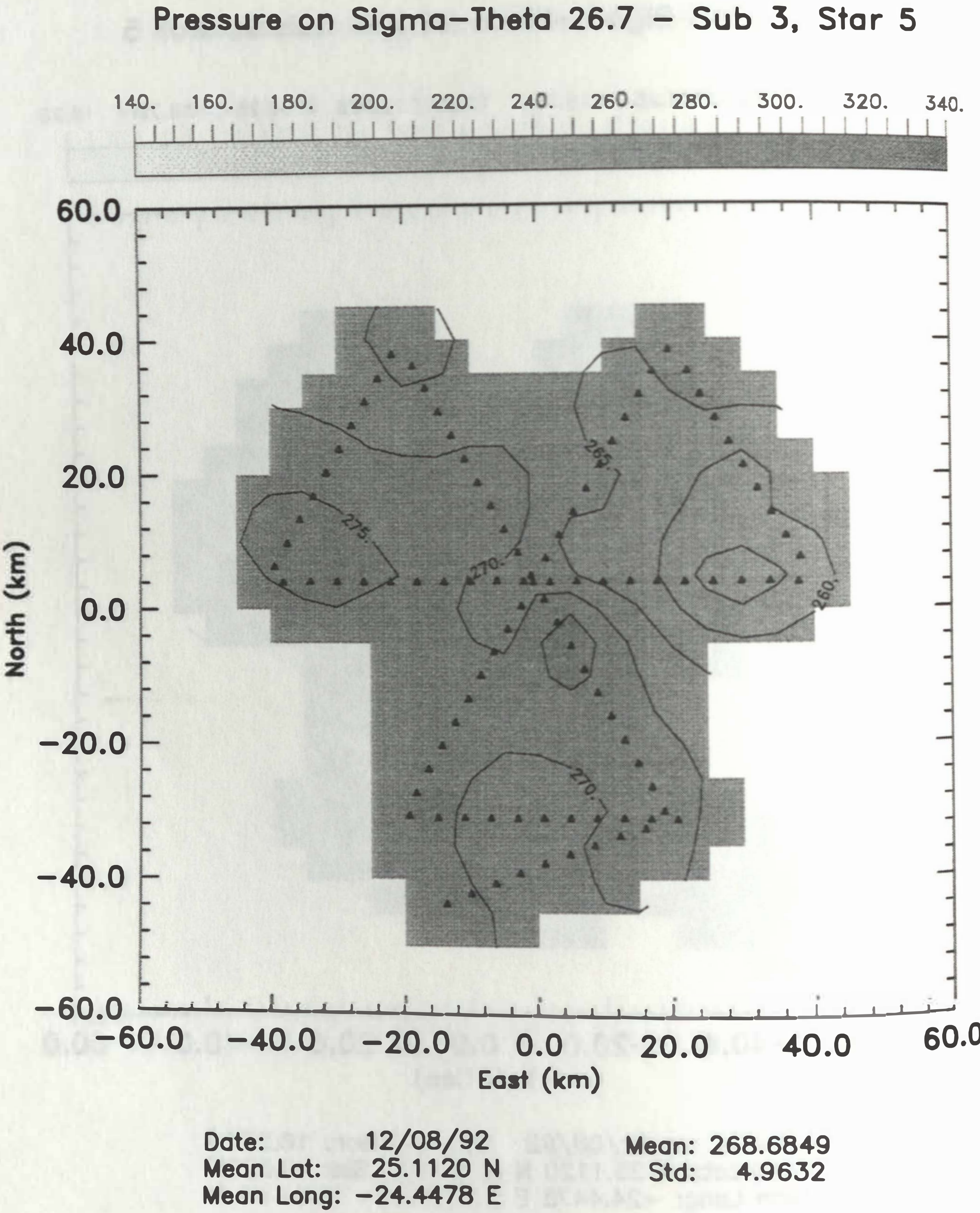
Theta on Sigma–Theta 26.7 – Sub 3, Star 5



Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E

Mean: 16.2373
Std: 0.0267

Figure D-60



Pressure on Sigma-Theta 26.7 - Sub 3, Star 5
140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
275.
270.
265.
260.
270.
Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E
Mean: 268.6849
Std: 4.9632

Figure D-61

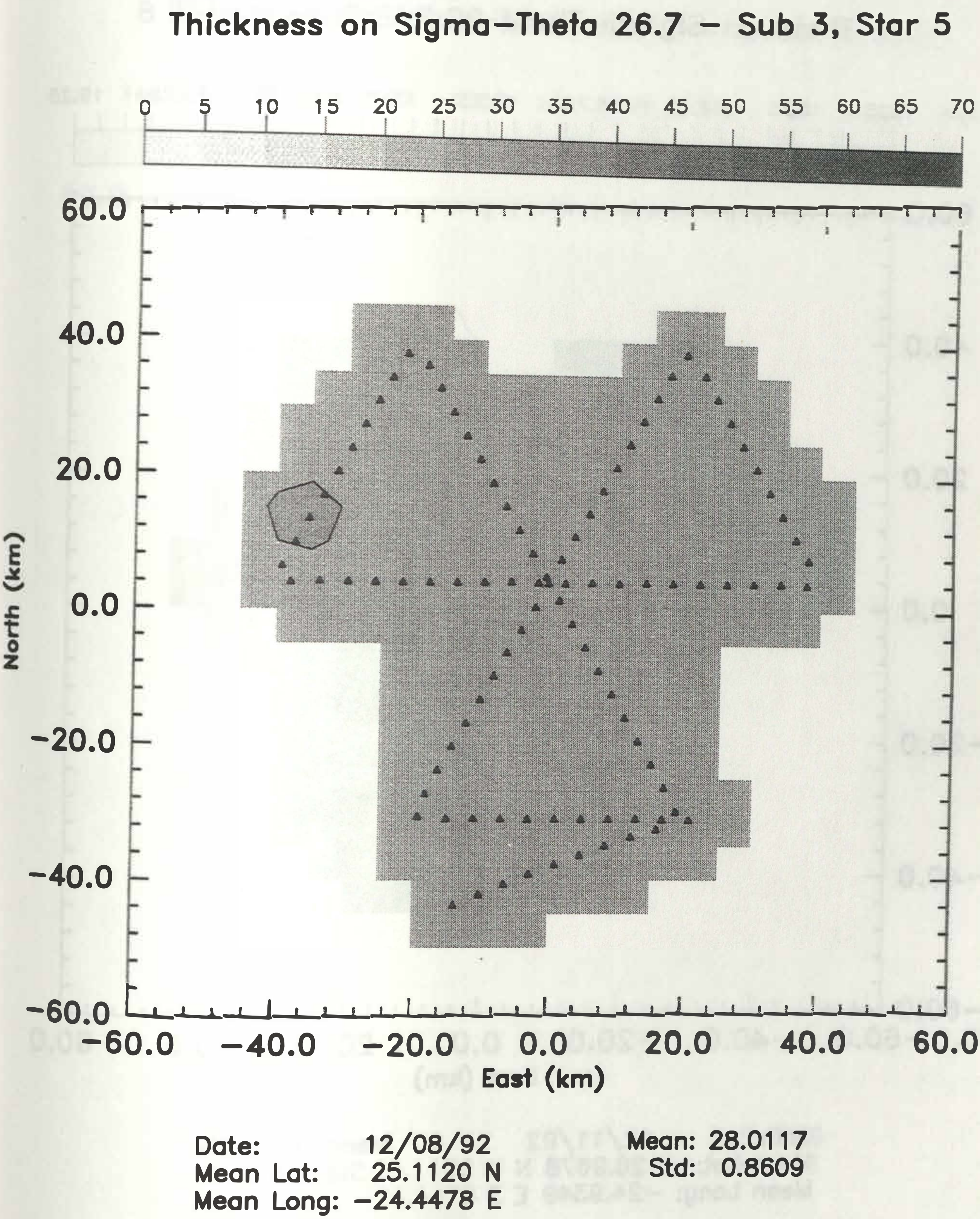
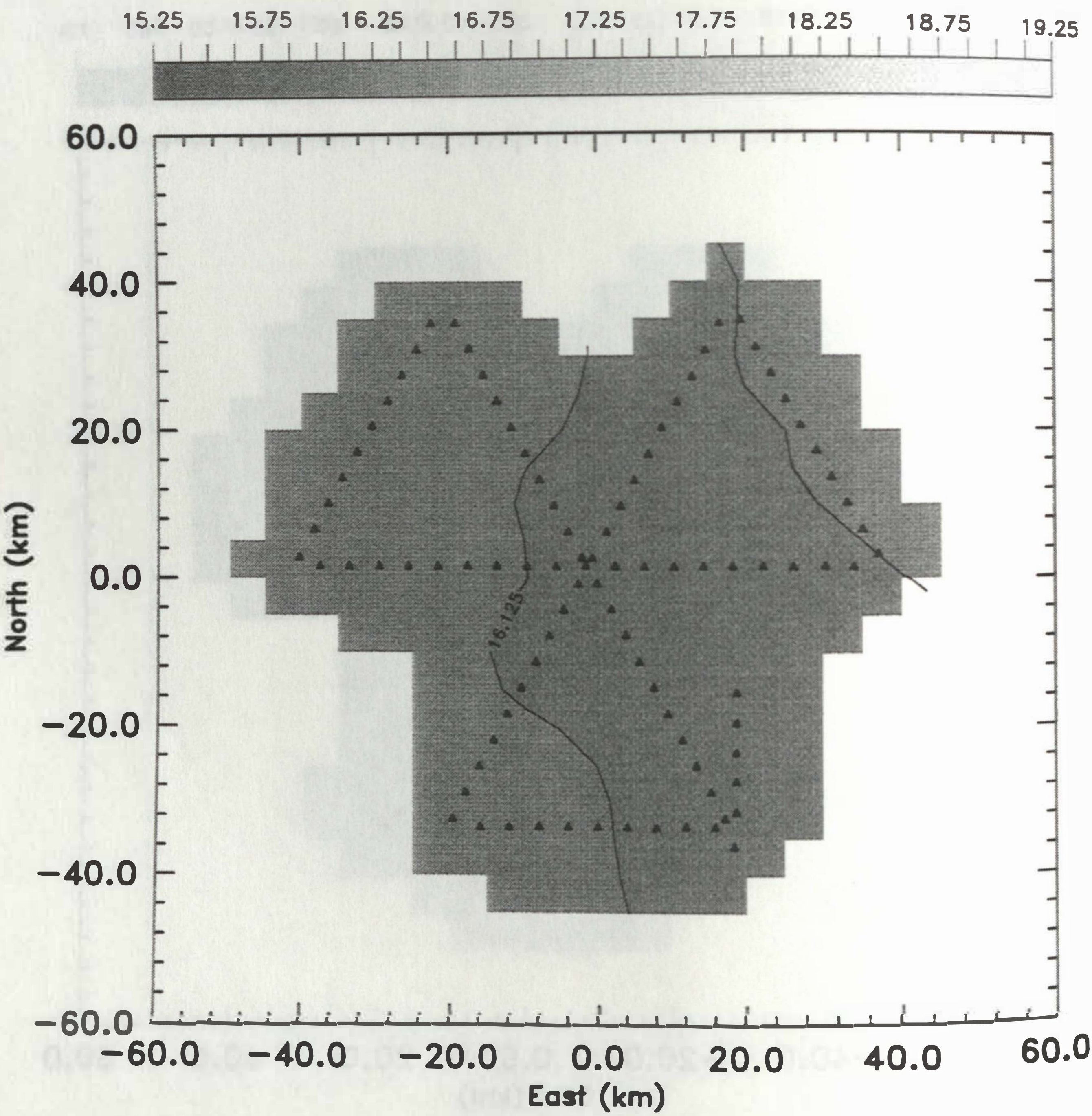

Thickness on Sigma-Theta 26.7 - Sub 3, Star 5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E
Mean: 28.0117
Std: 0.8609

Figure D-62

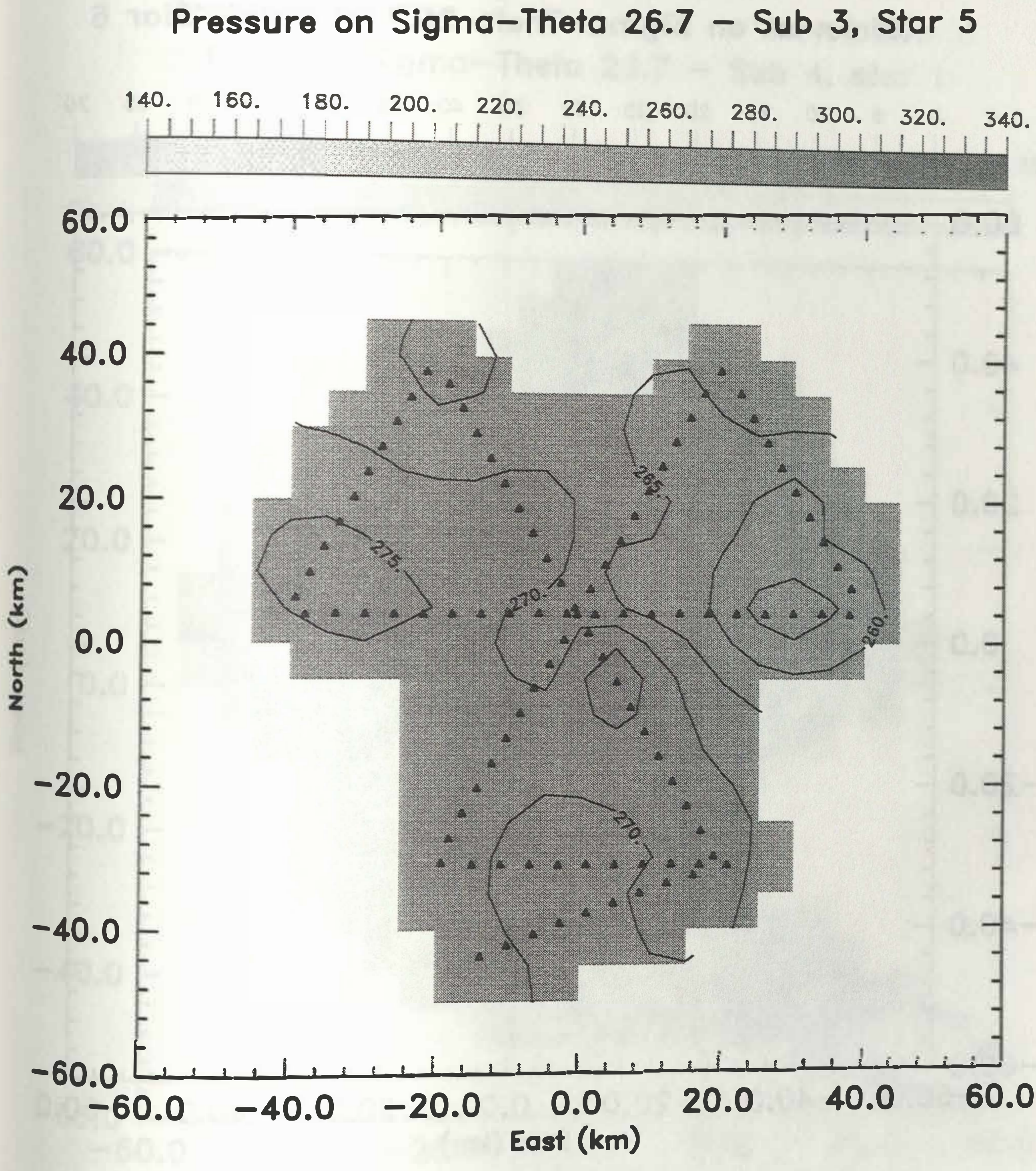
Theta on Sigma-Theta 26.7 - Sub 3, Star 6



Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E

Mean: 16.1338
Std: 0.0342

Figure D-63



Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E

Mean: 268.6849
Std: 4.9632

Figure D-64

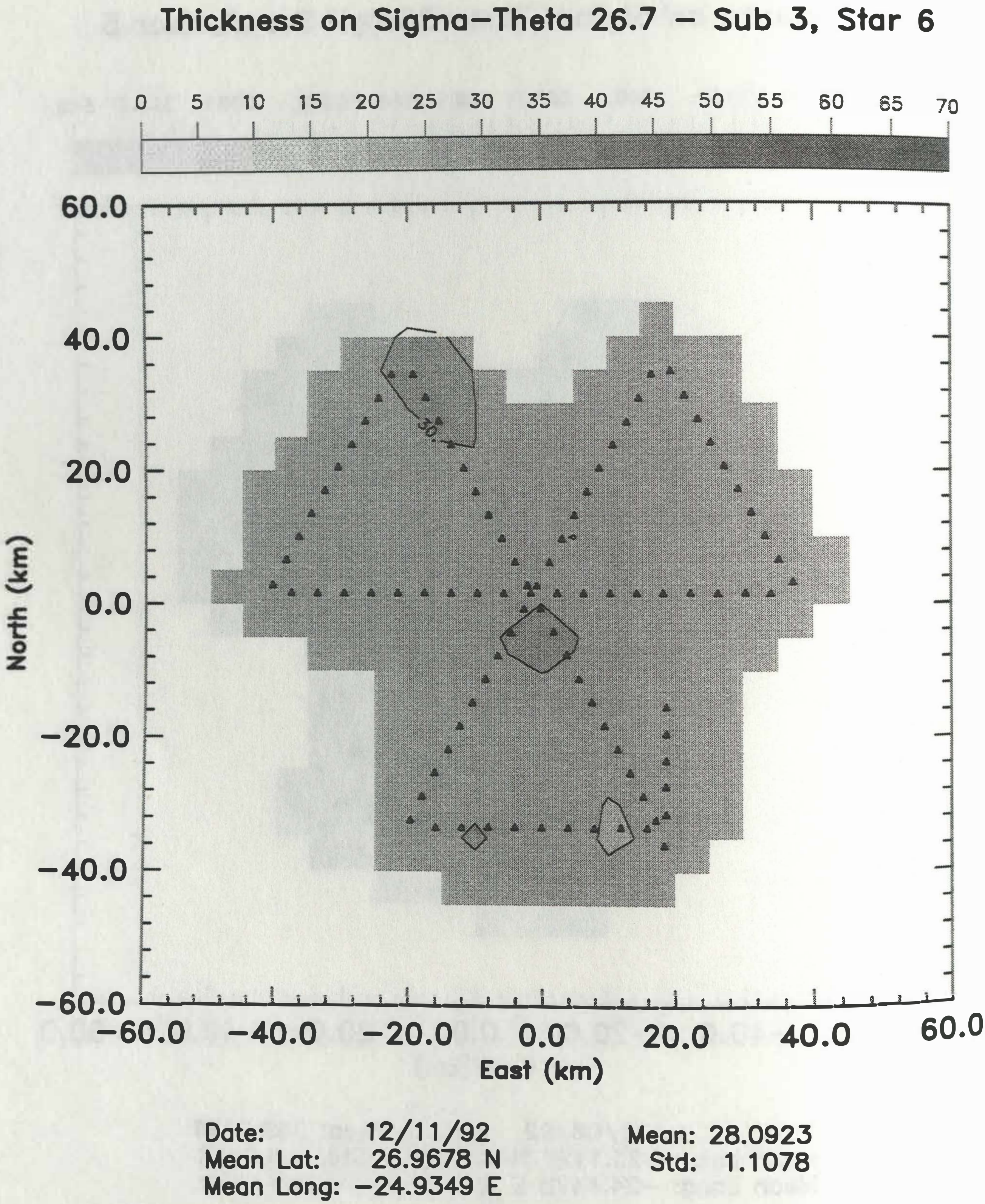
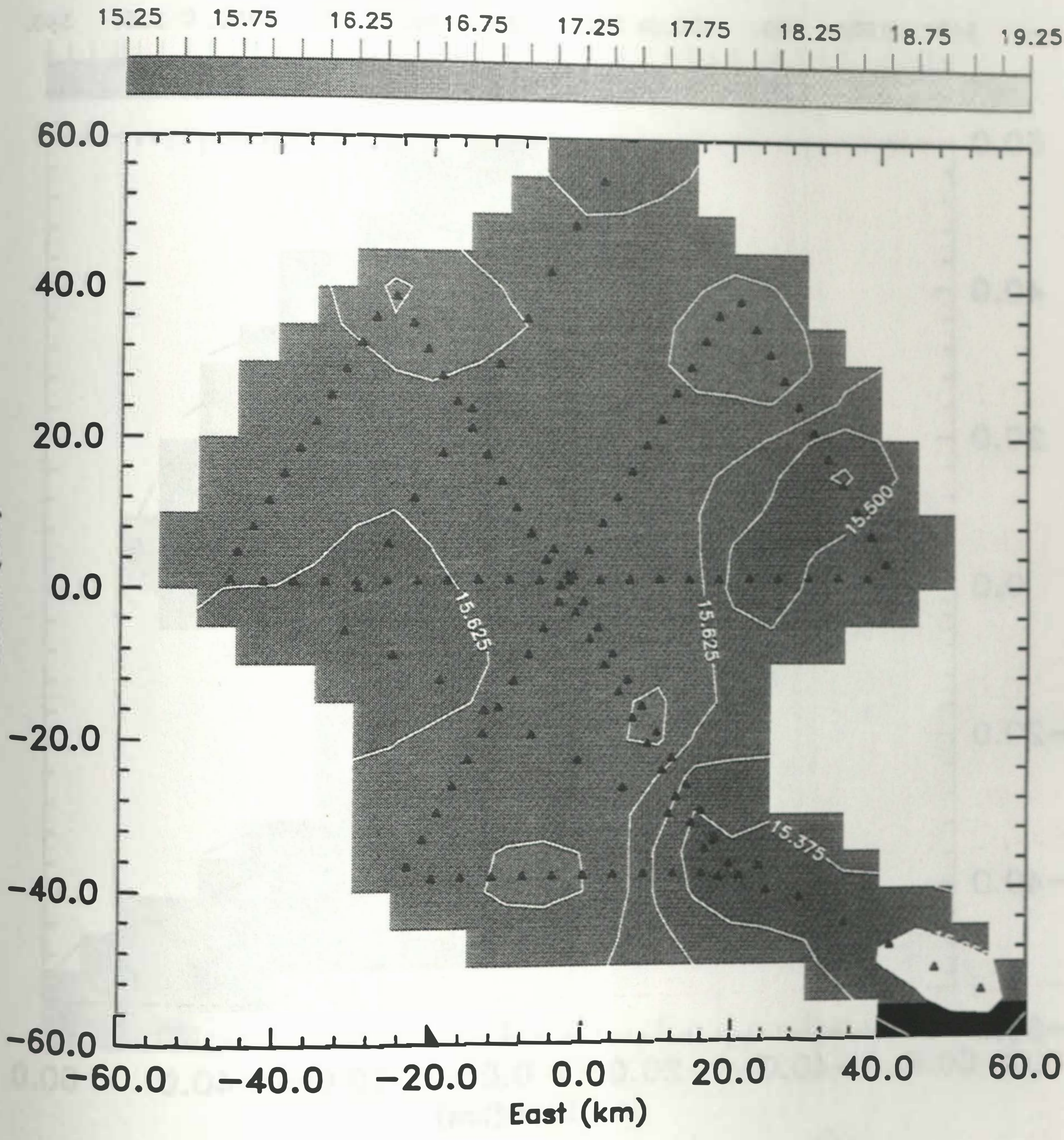

Thickness on Sigma-Theta 26.7 - Sub 3, Star 6
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
30.
Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E
Mean: 28.0923
Std: 1.1078

Figure D-65

Theta on Sigma-Theta 26.7 - Sub 4, star 1

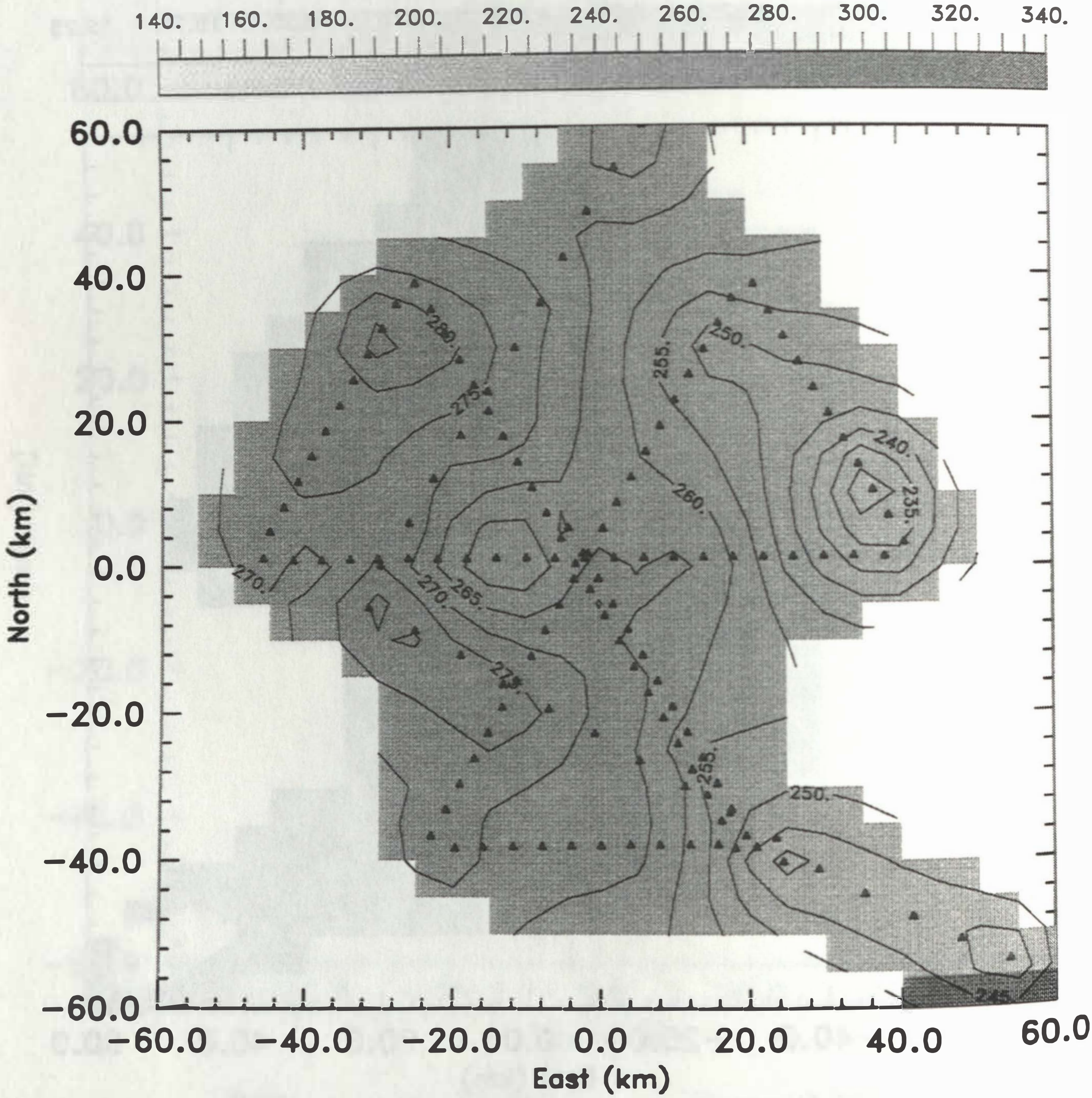


Date: 05/24/93
Mean Lat: 18.9862 E
Mean Long: -31.9748 N

Mean: 15.6538
Std: 0.0988

Figure D-66

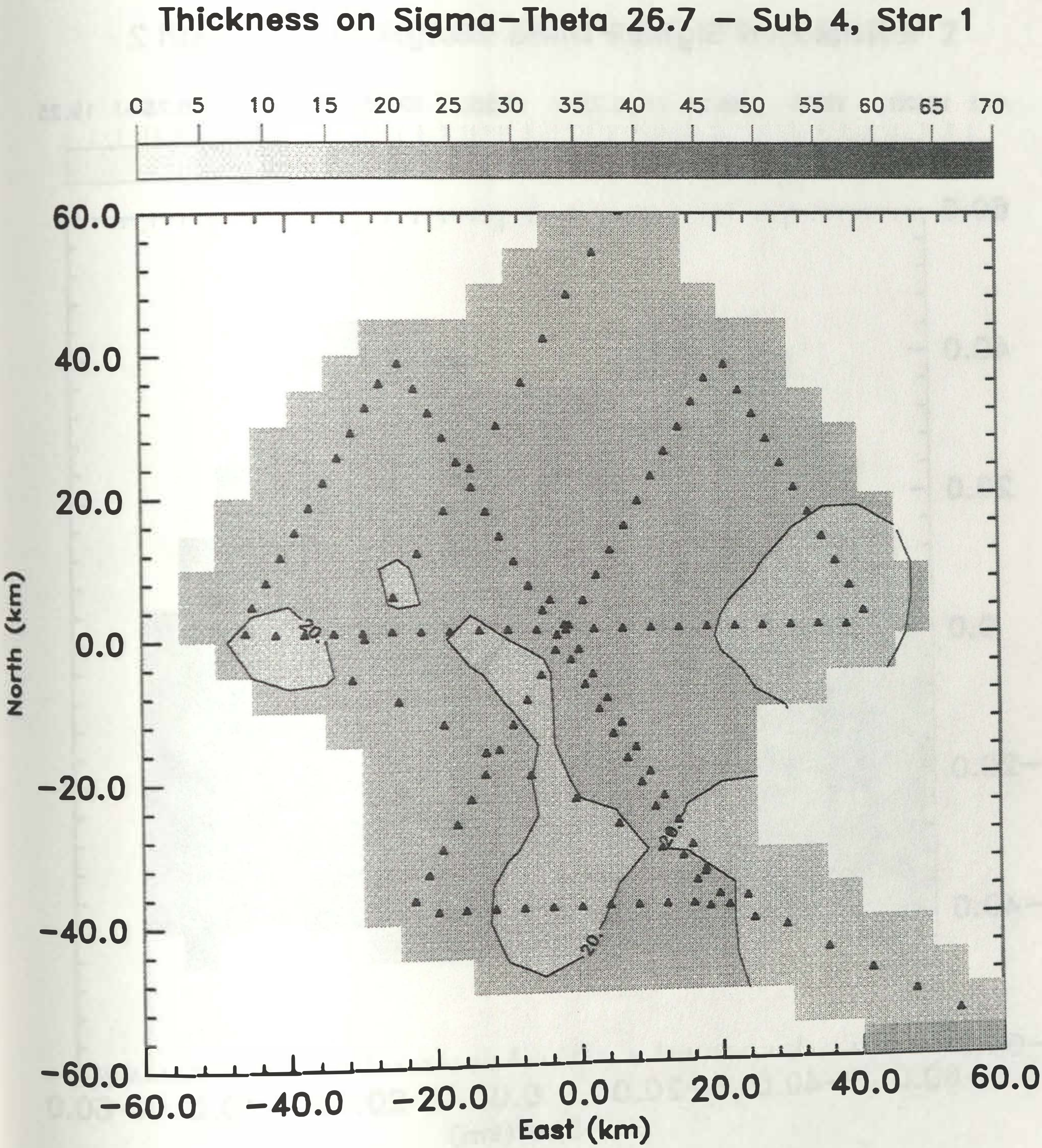
Pressure on Sigma-Theta 26.7 - Sub 4, Star 1



Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E

Mean: 261.7677
Std: 11.6073

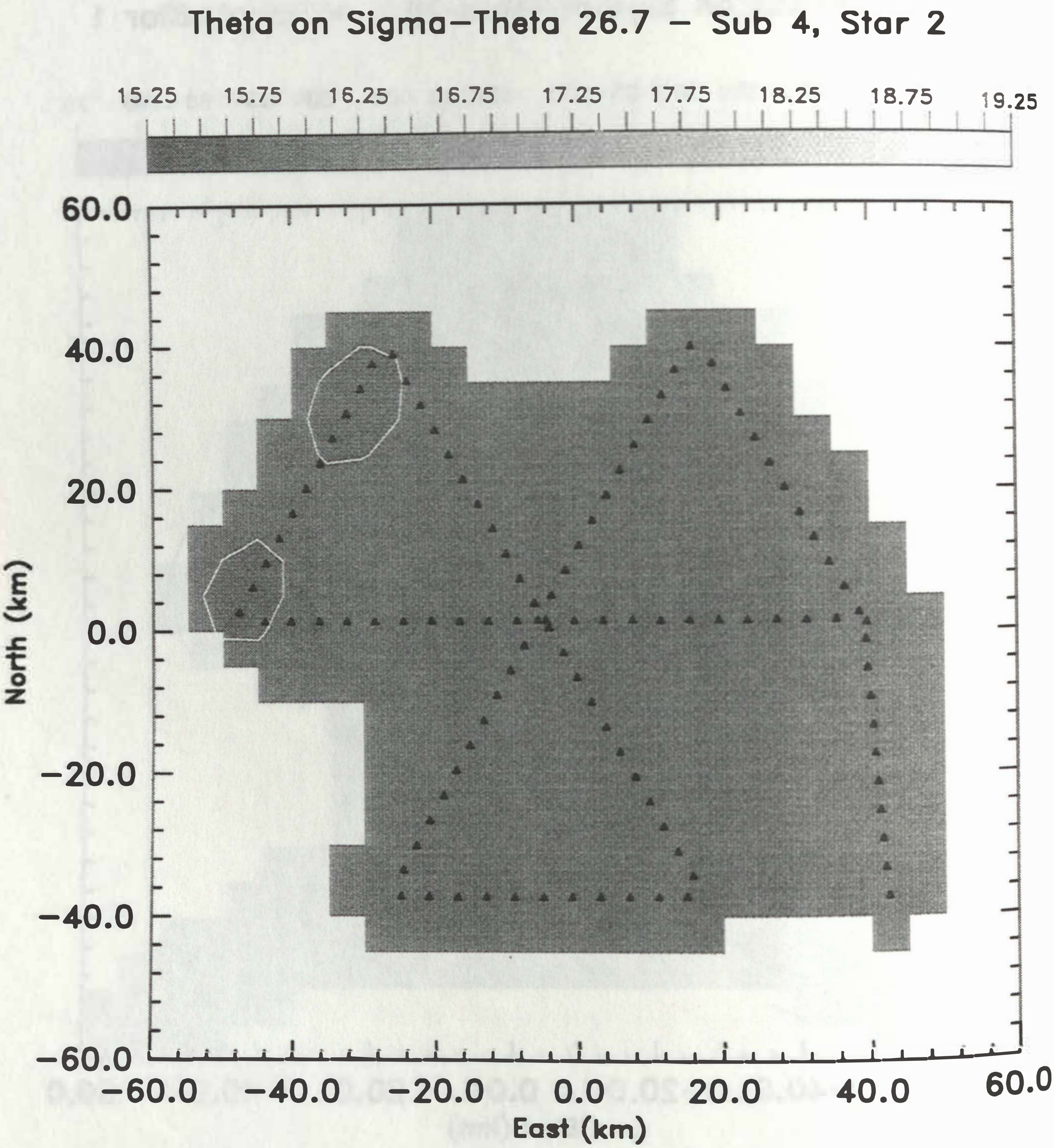
Figure D-67



Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: –31.9748 E

Mean: 20.6743
Std: 0.9830

Figure D-68



Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: −37.4544 E
Mean: 16.0338
Std: 0.0271

Figure D-69

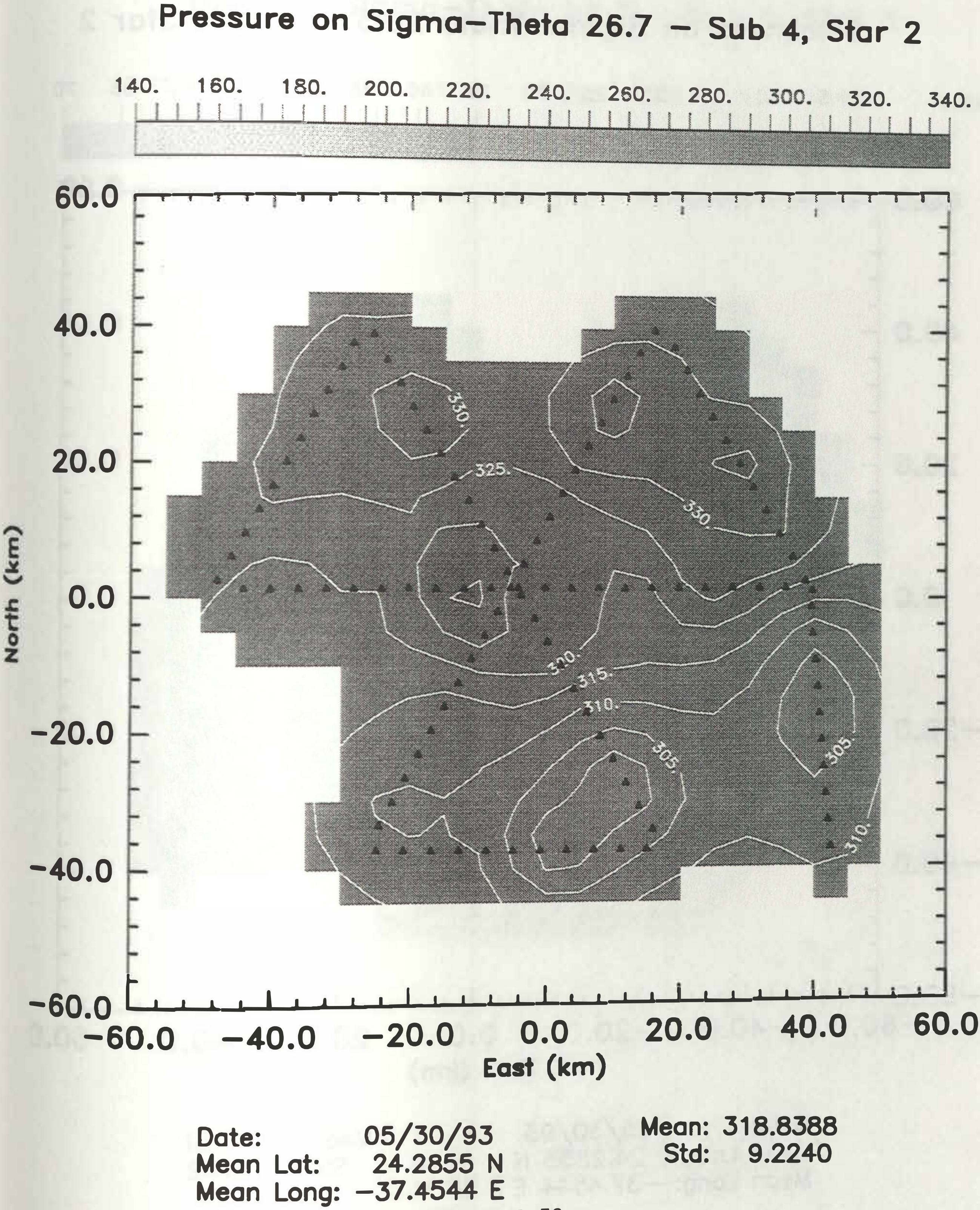

Pressure on Sigma-Theta 26.7 - Sub 4, Star 2
140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
330.
325.
330.
320.
315.
310.
305.
305.
310.
Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E
Mean: 318.8388
Std: 9.2240

Figure D-70

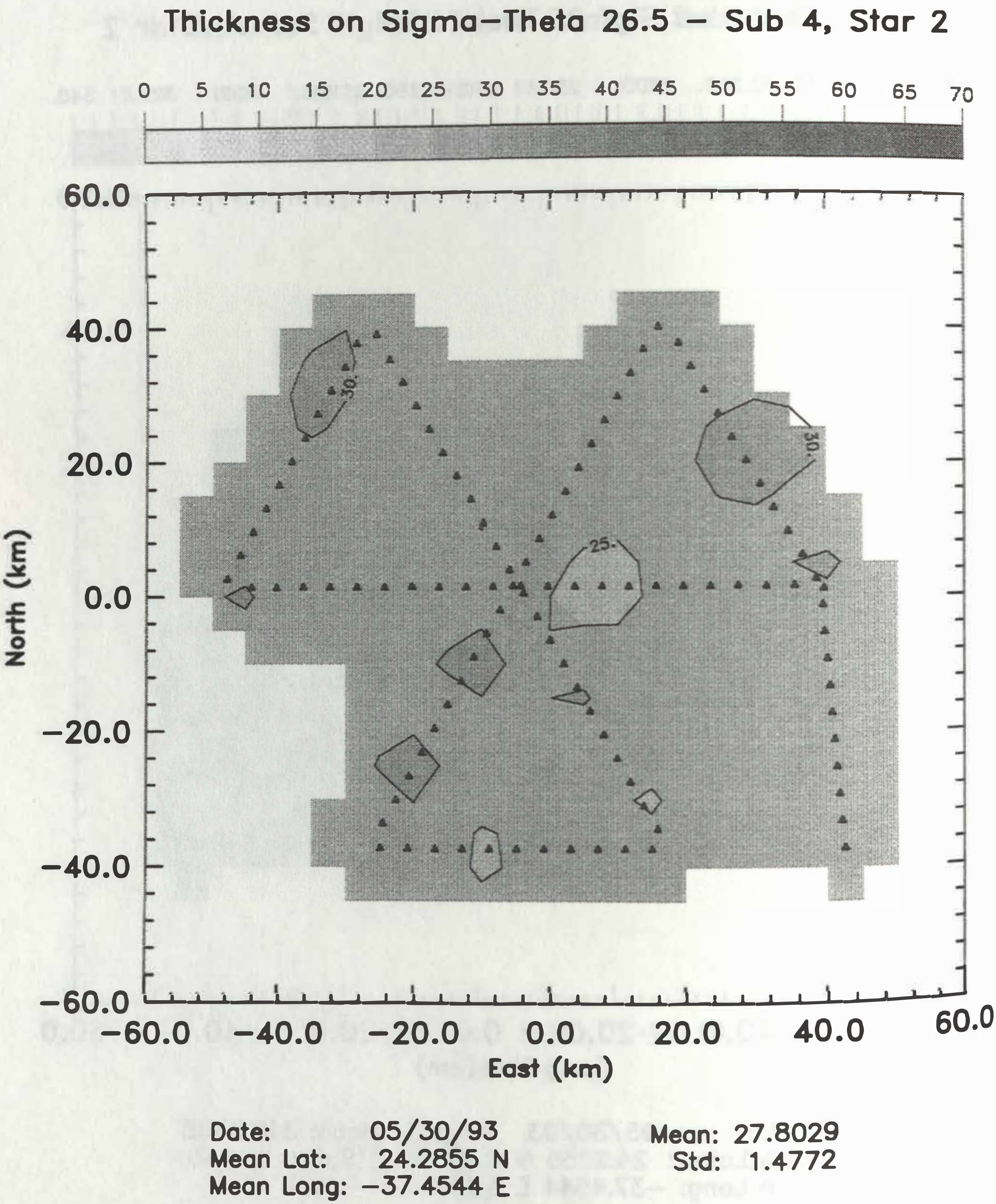
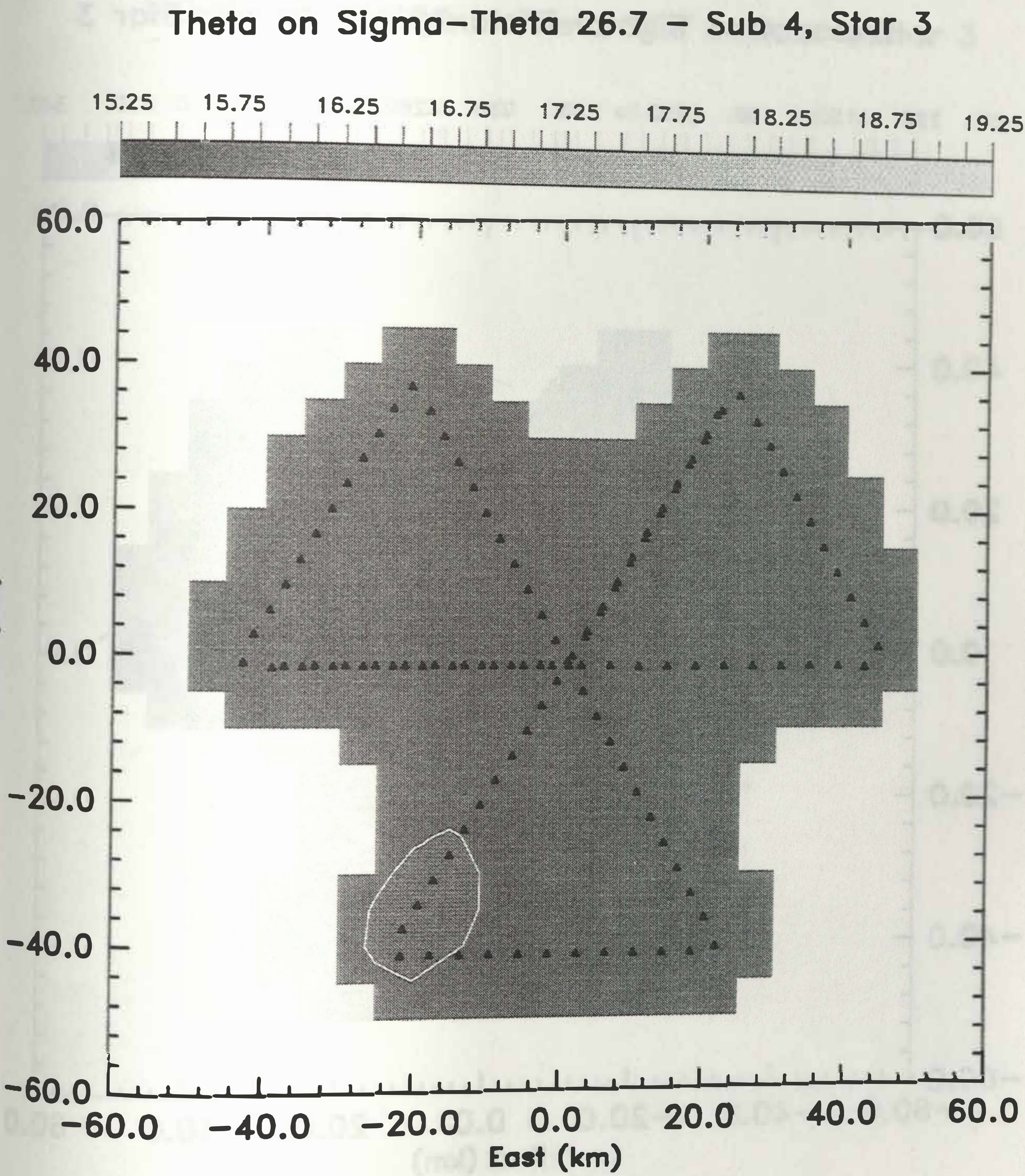

Thickness on Sigma–Theta 26.5 – Sub 4, Star 2
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
–20.0
–40.0
–60.0
North (km)
–60.0 –40.0 –20.0 0.0 20.0 40.0 60.0
East (km)
30.
30.
25.
Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: –37.4544 E
Mean: 27.8029
Std: 1.4772

Figure D-71

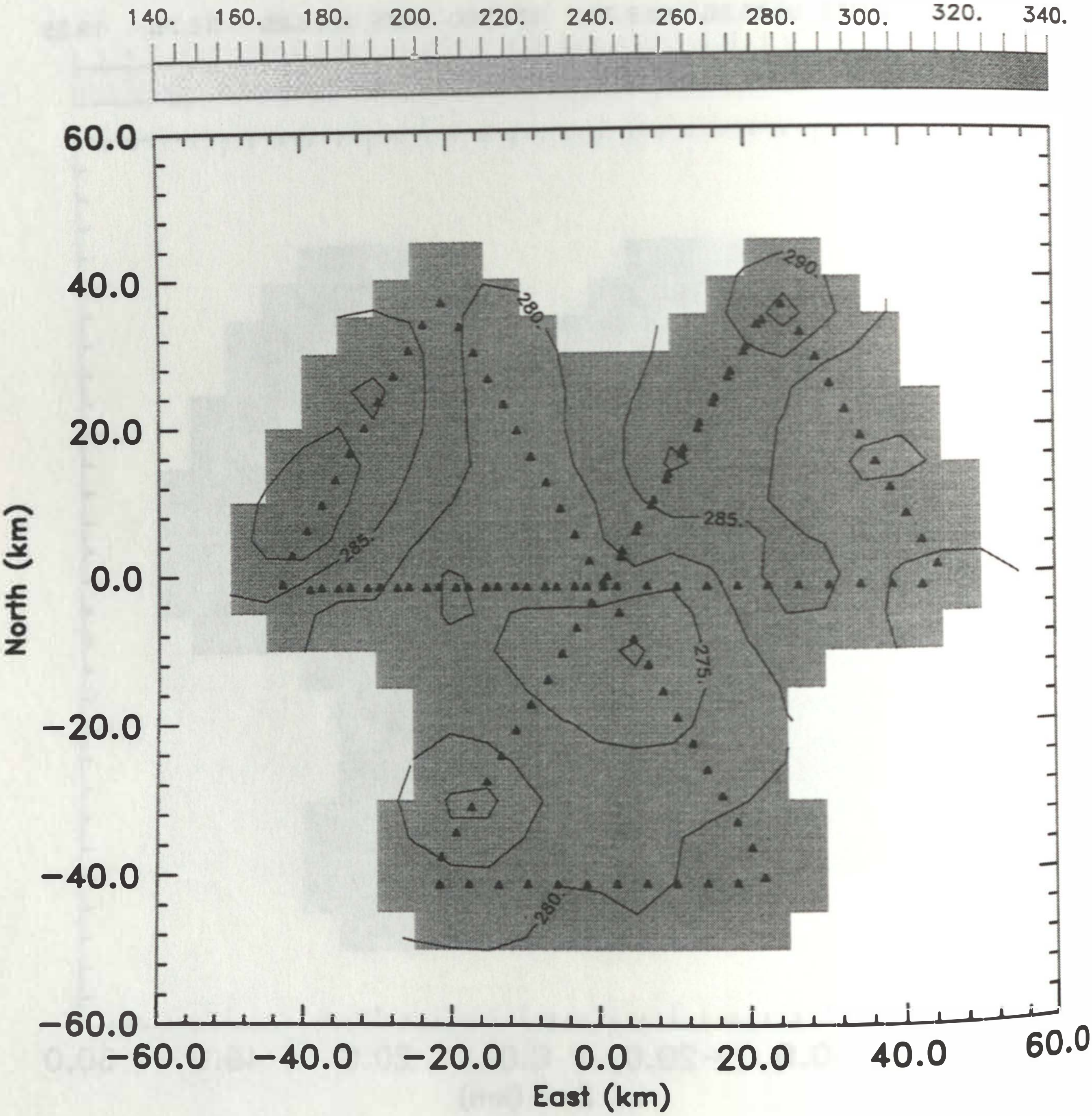


Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: -31.6550 E

Mean: 16.0873
Std: 0.0184

Figure D-72

Pressure on Sigma-Theta 26.7 - Sub 4, Star 3



Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: -31.6550 E

Mean: 281.1632
Std: 5.0778

Figure D-73

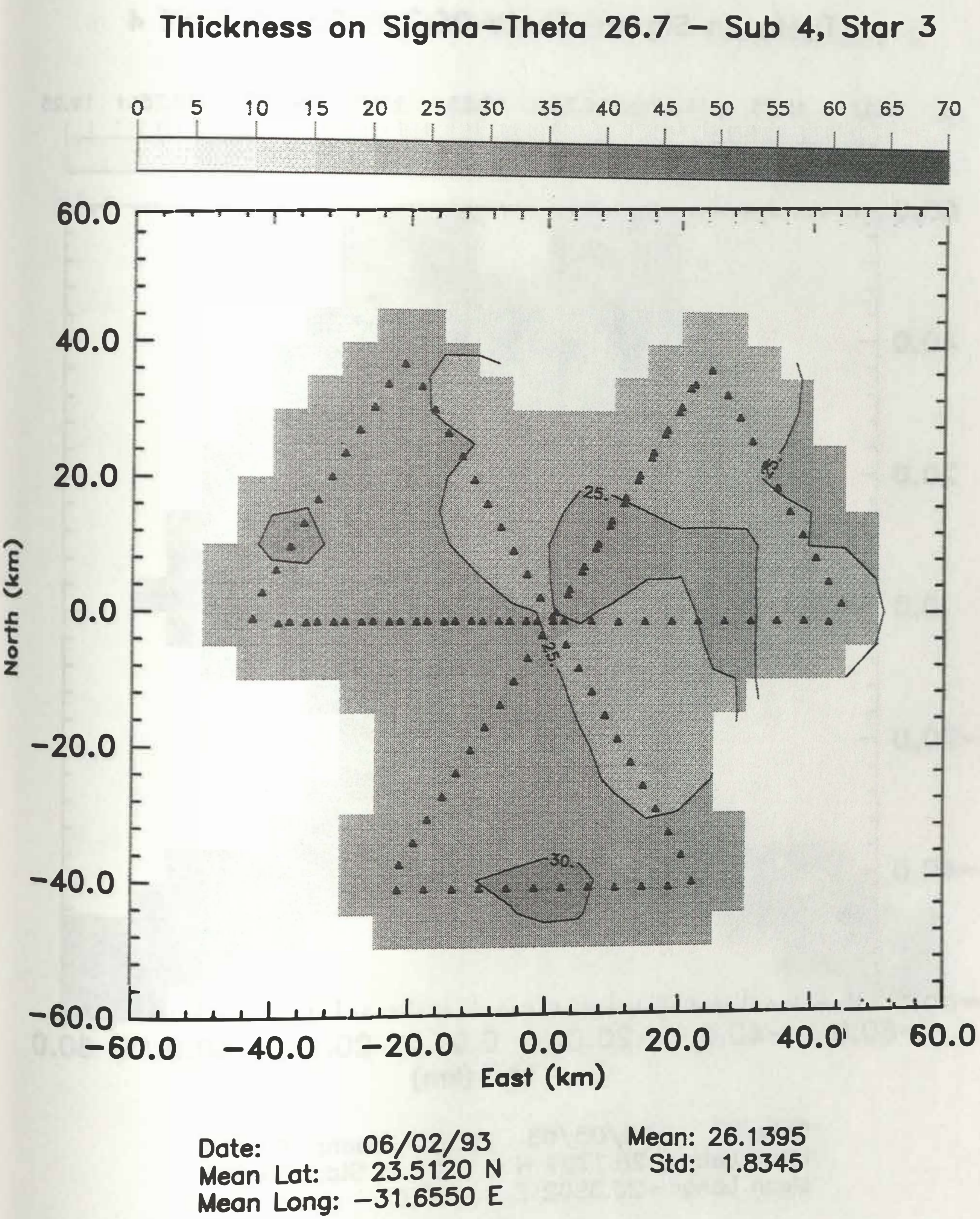

Thickness on Sigma-Theta 26.7 - Sub 4, Star 3
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
25.
30.
Date: 06/02/93
Mean Lat: 23.5120 N
Mean Long: -31.6550 E
Mean: 26.1395
Std: 1.8345

Figure D-74

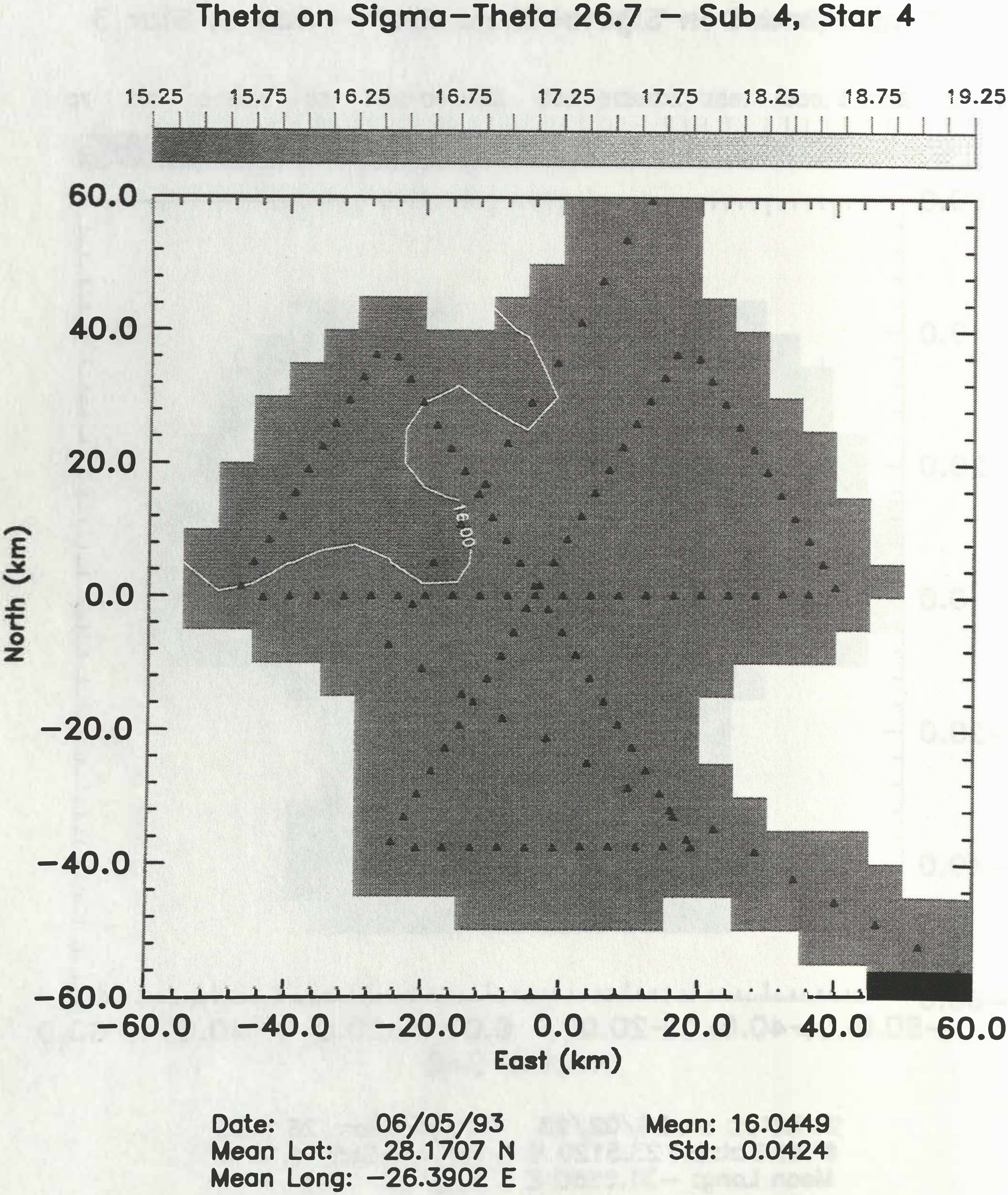

Theta on Sigma–Theta 26.7 – Sub 4, Star 4
15.25
15.75
16.25
16.75
17.25
17.75
18.25
18.75
19.25
60.0
40.0
20.0
0.0
–20.0
–40.0
–60.0
North (km)
16.00
–60.0
–40.0
–20.0
0.0
20.0
40.0
60.0
East (km)
Date: 06/05/93
Mean Lat: 28.1707 N
Mean Long: –26.3902 E
Mean: 16.0449
Std: 0.0424

Figure D-75

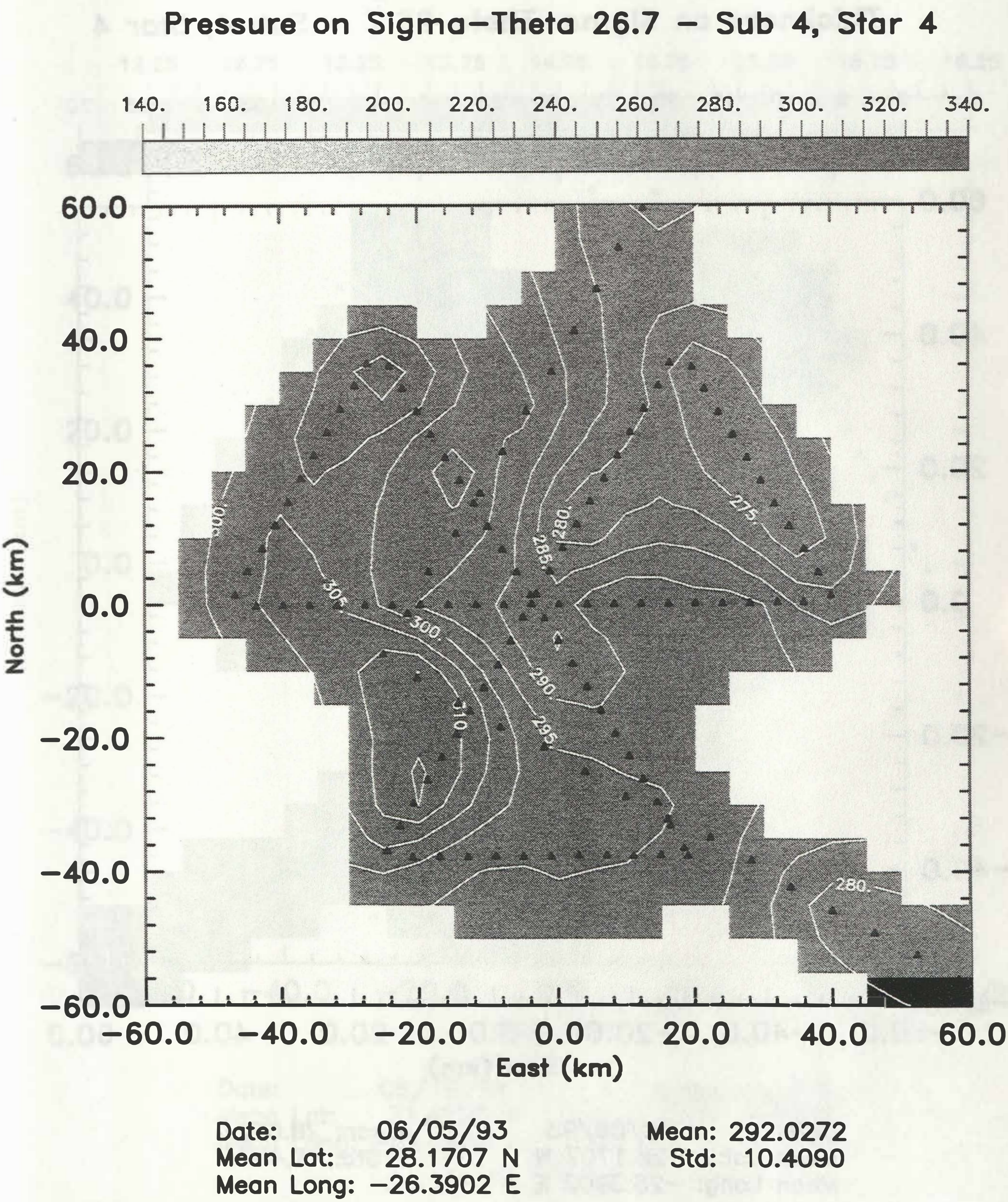
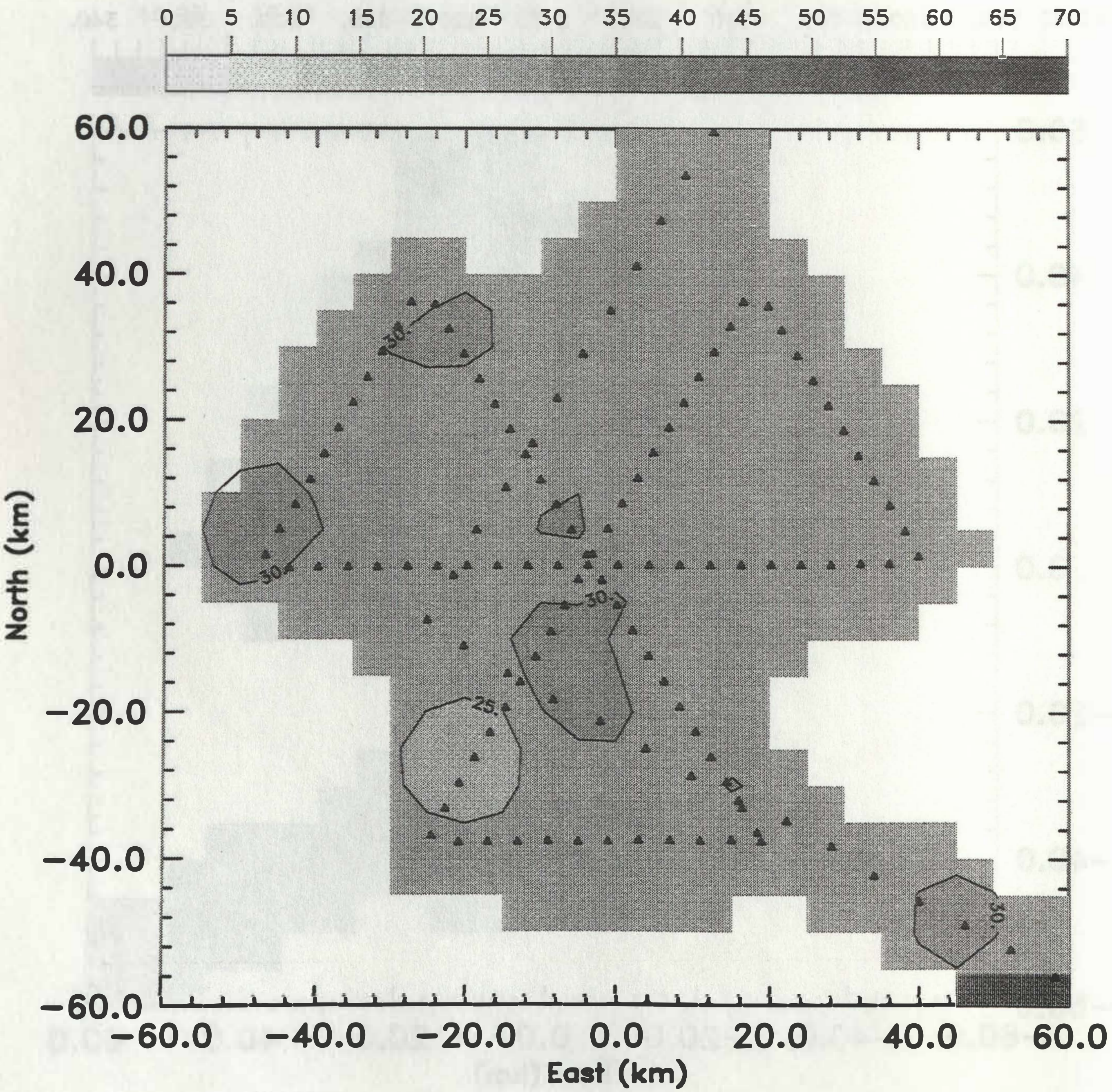

Pressure on Sigma–Theta 26.7 – Sub 4, Star 4
140.
160.
180.
200.
220.
240.
260.
280.
300.
320.
340.
60.0
40.0
20.0
0.0
–20.0
–40.0
–60.0
North (km)
–60.0
–40.0
–20.0
0.0
20.0
40.0
60.0
East (km)
300.
305.
300.
310.
290.
295.
285.
280.
275.
280.
Date: 06/05/93
Mean Lat: 28.1707 N
Mean Long: –26.3902 E
Mean: 292.0272
Std: 10.4090

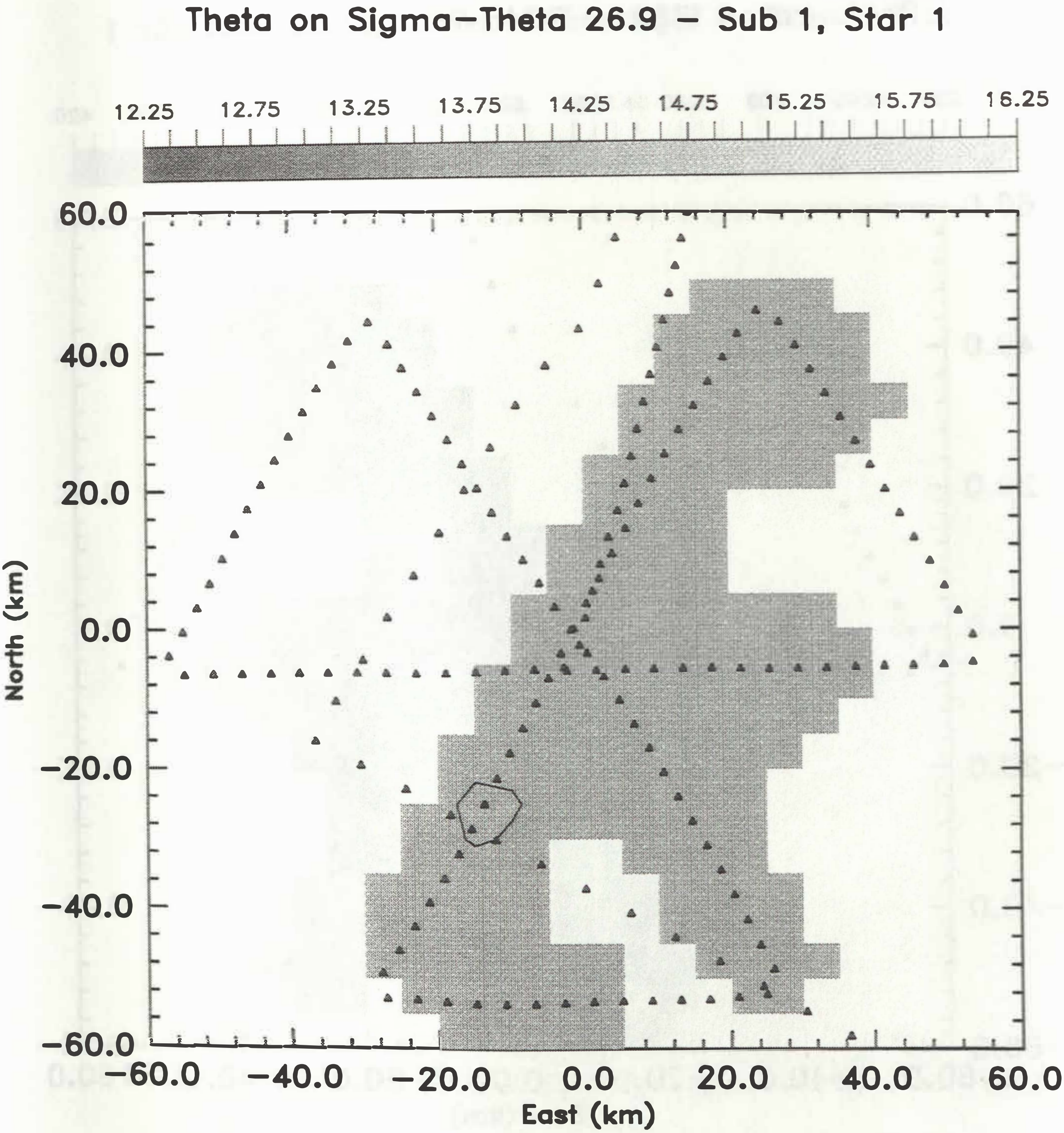
Figure D-76

Thickness on Sigma–Theta 26.7 – Sub 4, Star 4



Date: 06/05/93 Mean: 28.0224
Mean Lat: 28.1707 N Std: 1.4874
Mean Long: −26.3902 E

Figure D-77



Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E
Mean: 13.9505
Std: 0.0206

Figure D-78

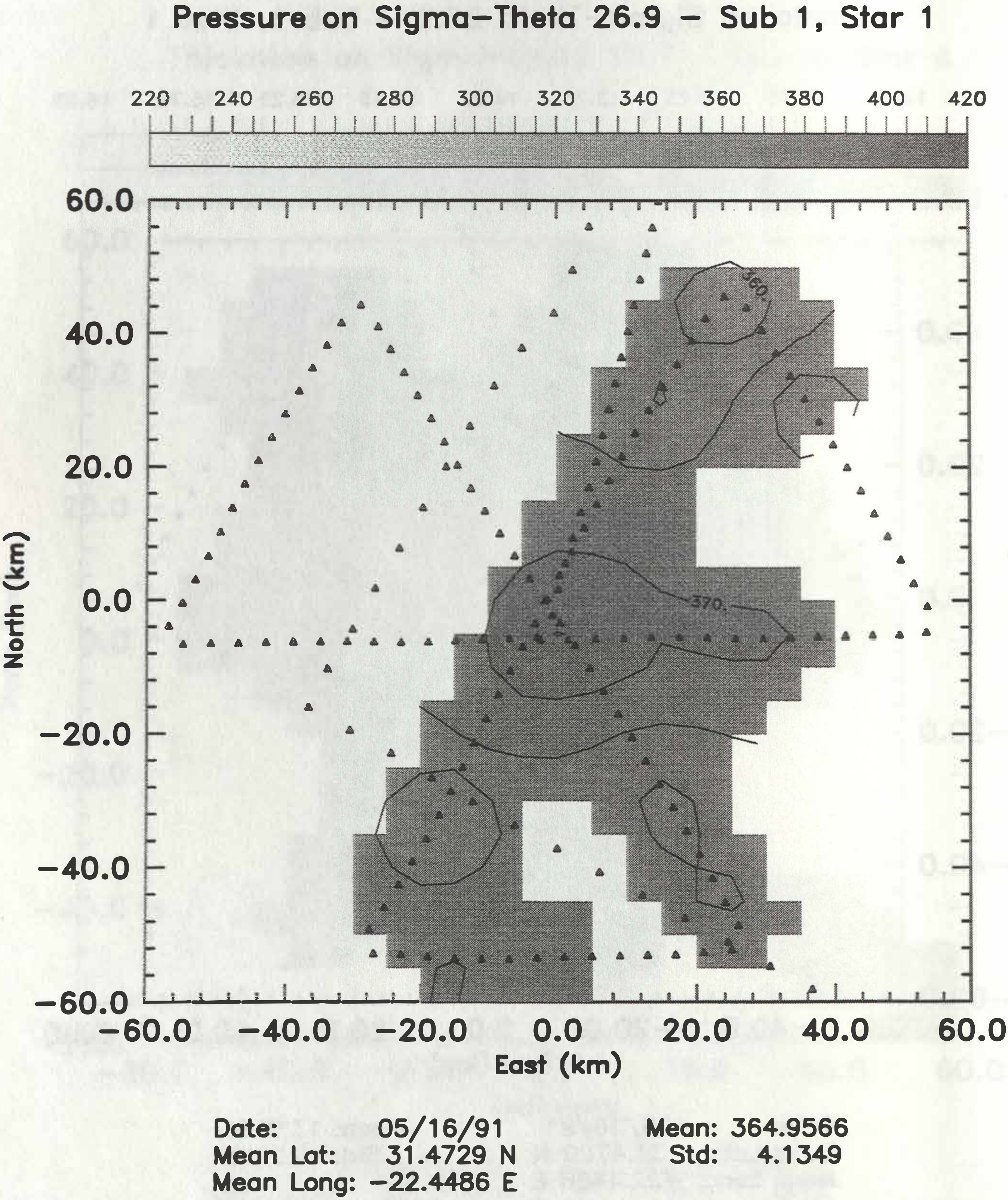

Pressure on Sigma-Theta 26.9 - Sub 1, Star 1
220 240 260 280 300 320 340 360 380 400 420
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
360.
370.
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: -22.4486 E
Mean: 364.9566
Std: 4.1349

Figure D-79

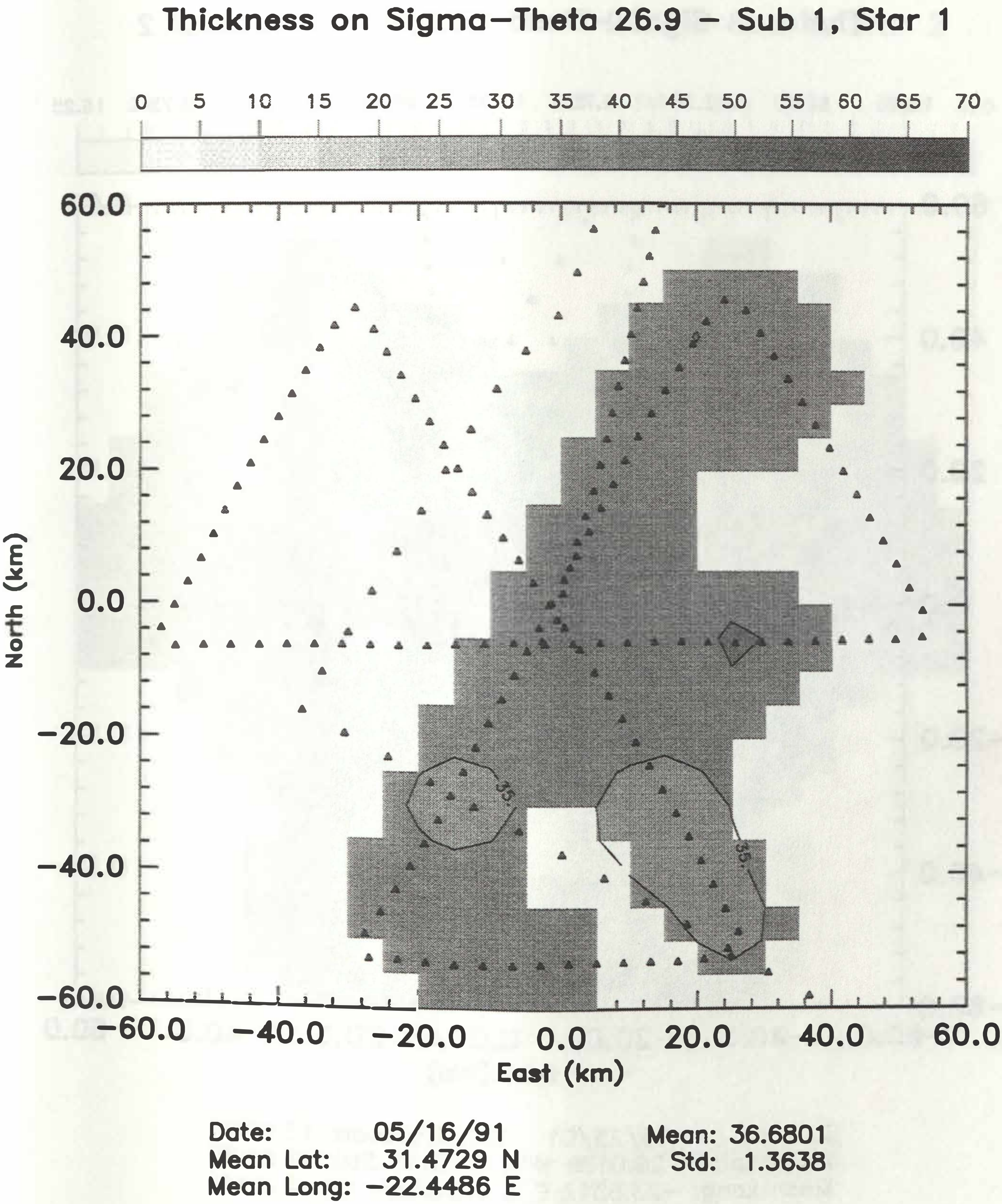

Thickness on Sigma–Theta 26.9 – Sub 1, Star 1
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
–20.0
–40.0
–60.0
North (km)
–60.0
–40.0
–20.0
0.0
20.0
40.0
60.0
East (km)
35.
35.
Date: 05/16/91
Mean Lat: 31.4729 N
Mean Long: –22.4486 E
Mean: 36.6801
Std: 1.3638

Figure D-80

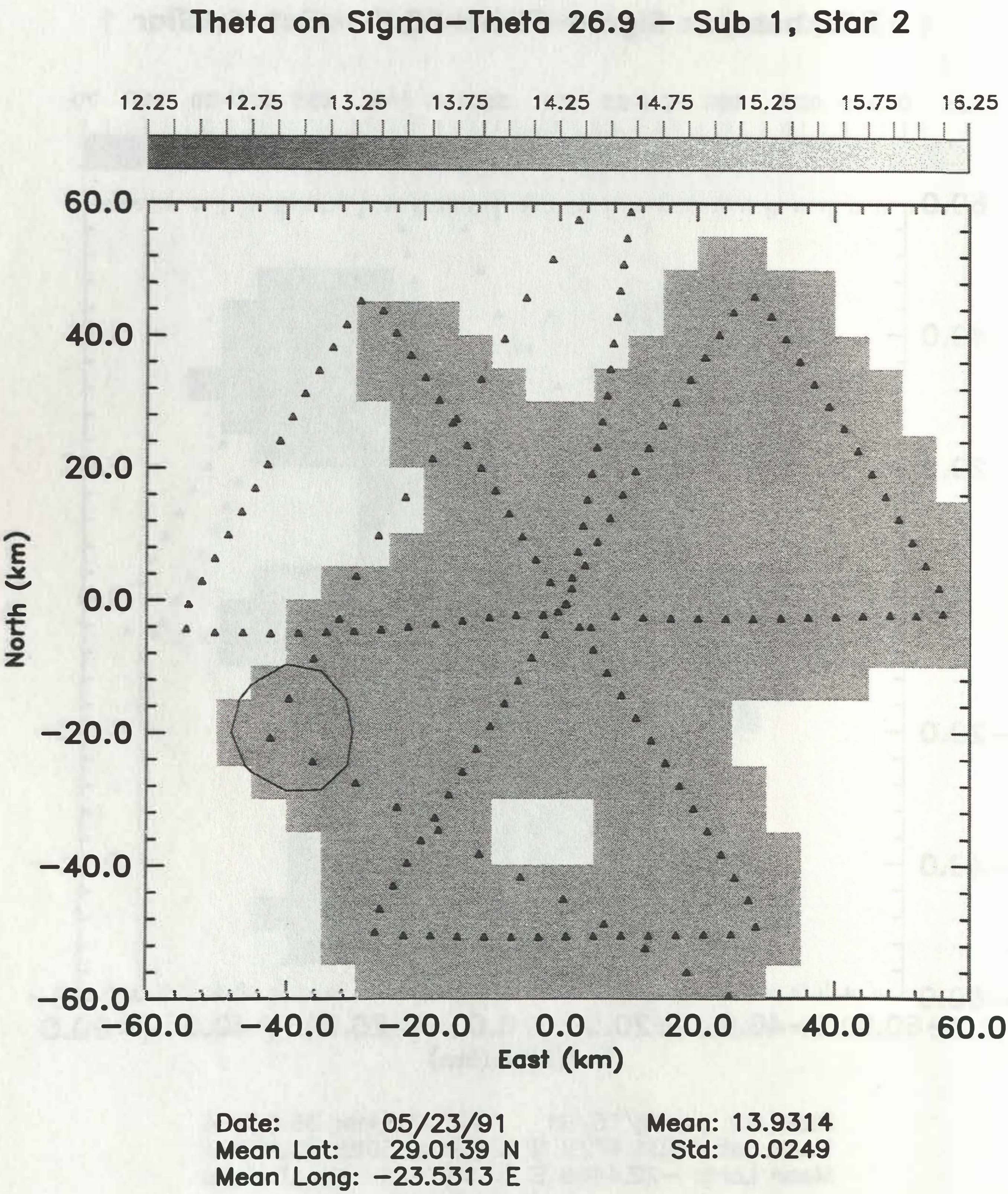
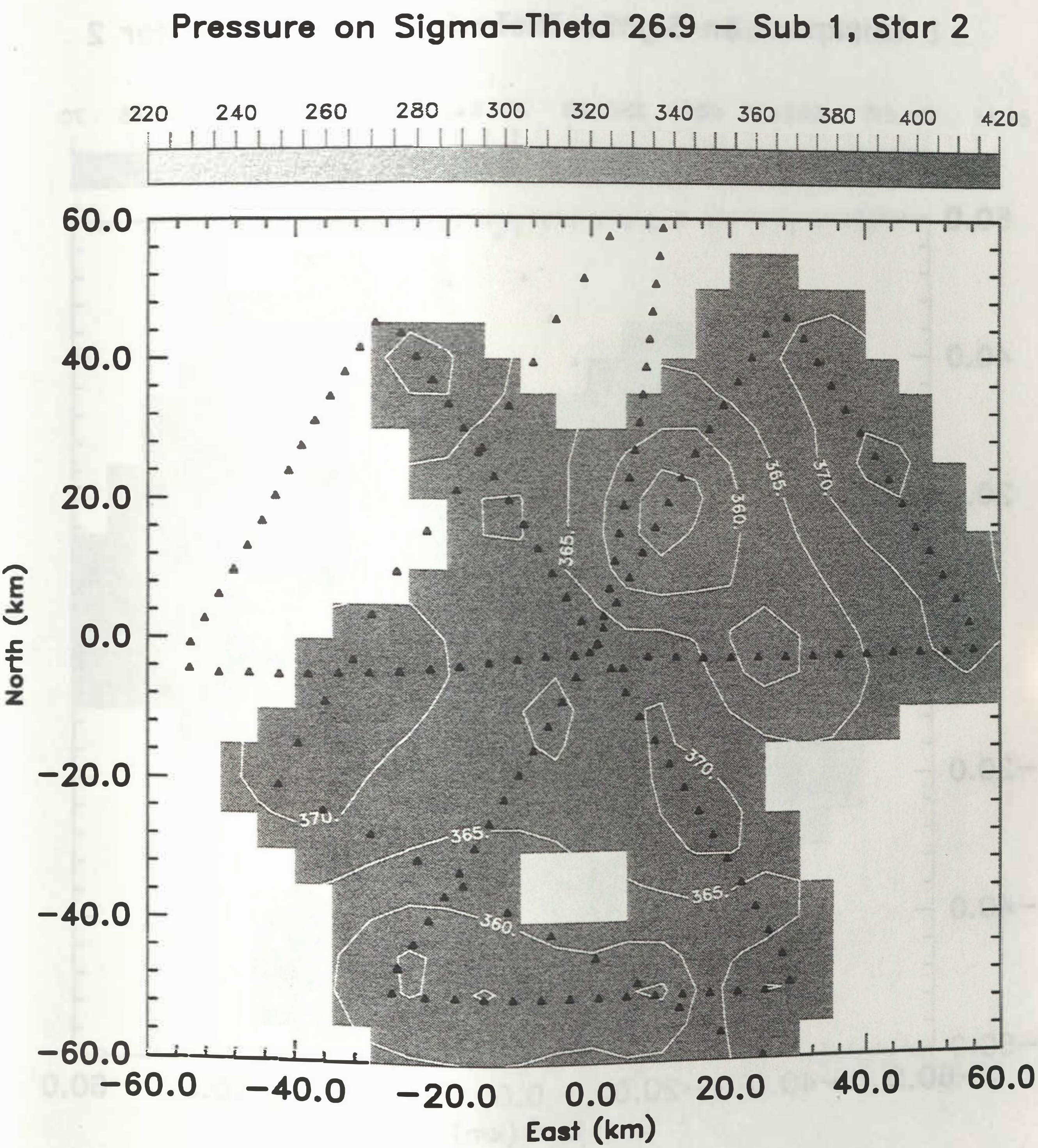

Theta on Sigma-Theta 26.9 - Sub 1, Star 2
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 13.9314
Std: 0.0249

Figure D-81



Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E

Mean: 366.1262
Std: 4.9197

Figure D-82

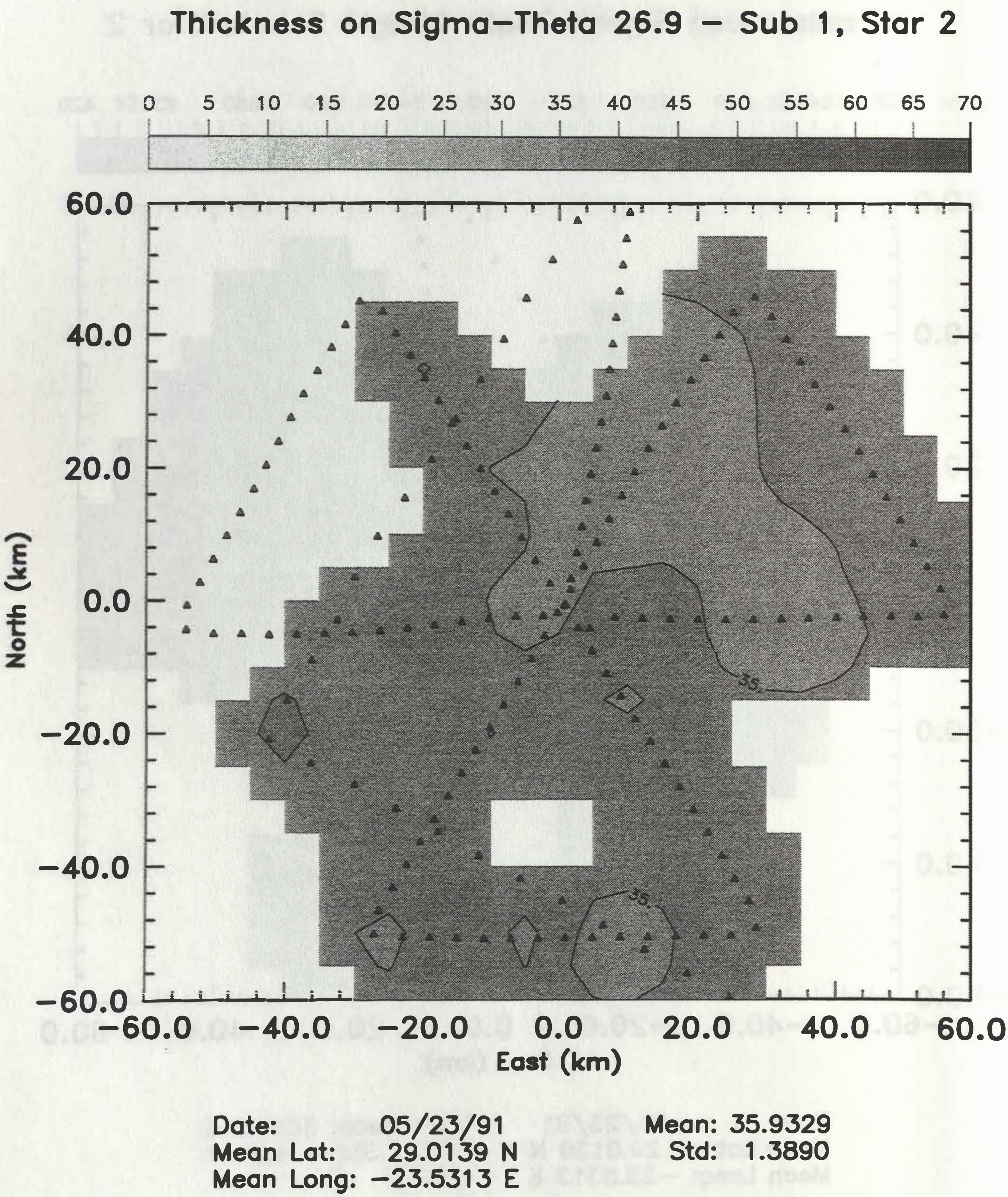
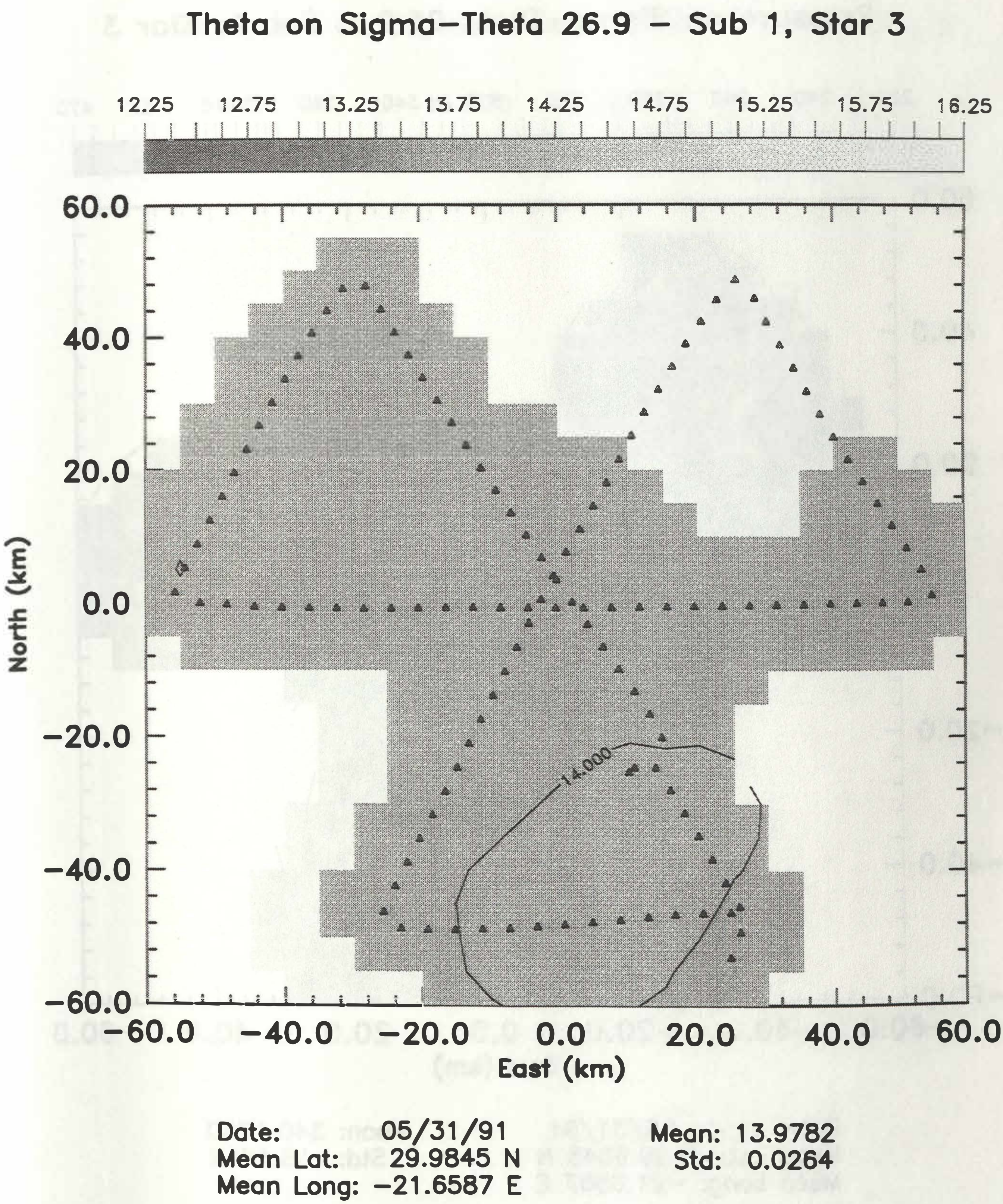

Thickness on Sigma-Theta 26.9 - Sub 1, Star 2
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
35.
Date: 05/23/91
Mean Lat: 29.0139 N
Mean Long: -23.5313 E
Mean: 35.9329
Std: 1.3890

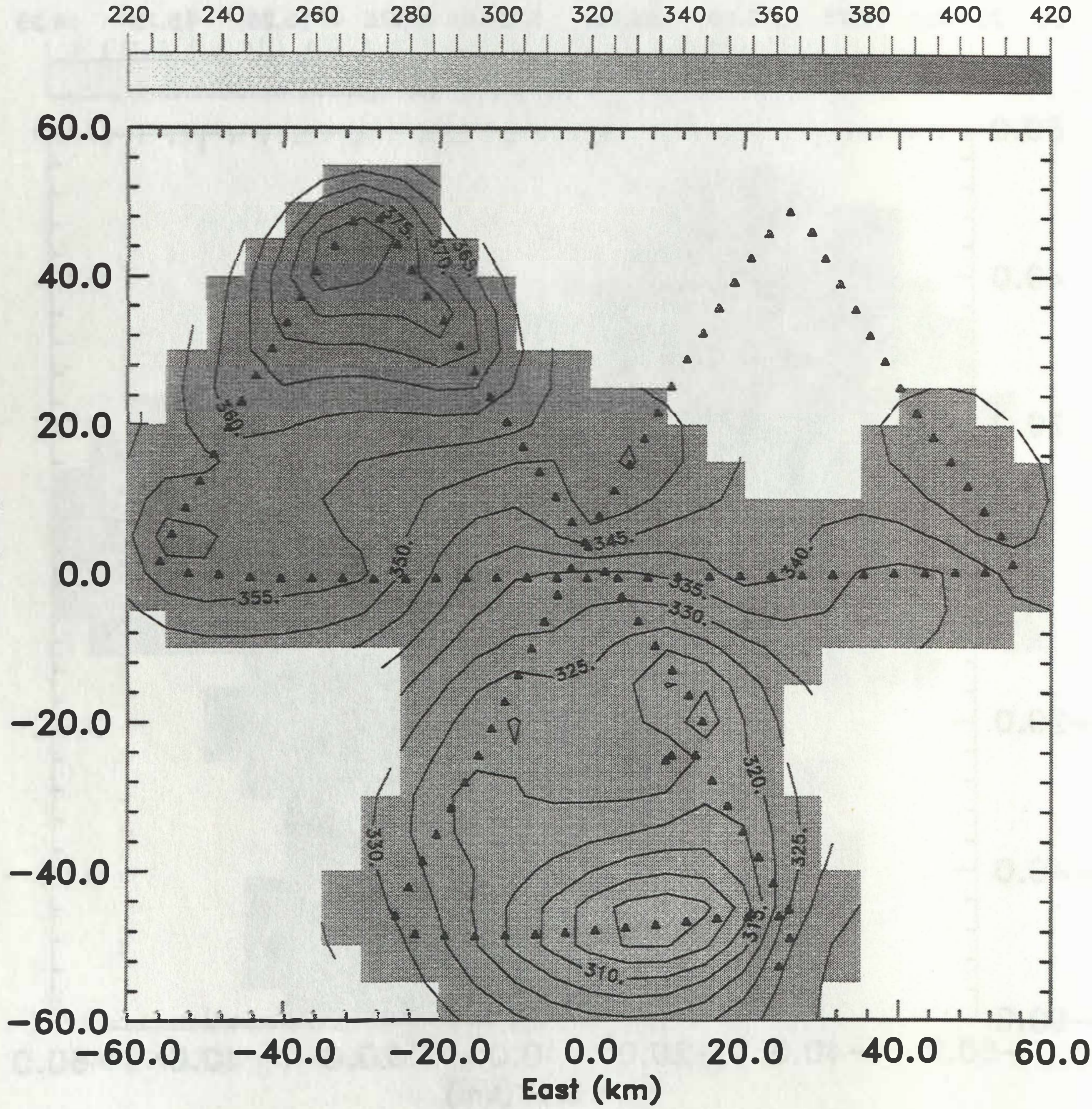
Figure D-83



Theta on Sigma-Theta 26.9 - Sub 1, Star 3
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
14.000
Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E
Mean: 13.9782
Std: 0.0264

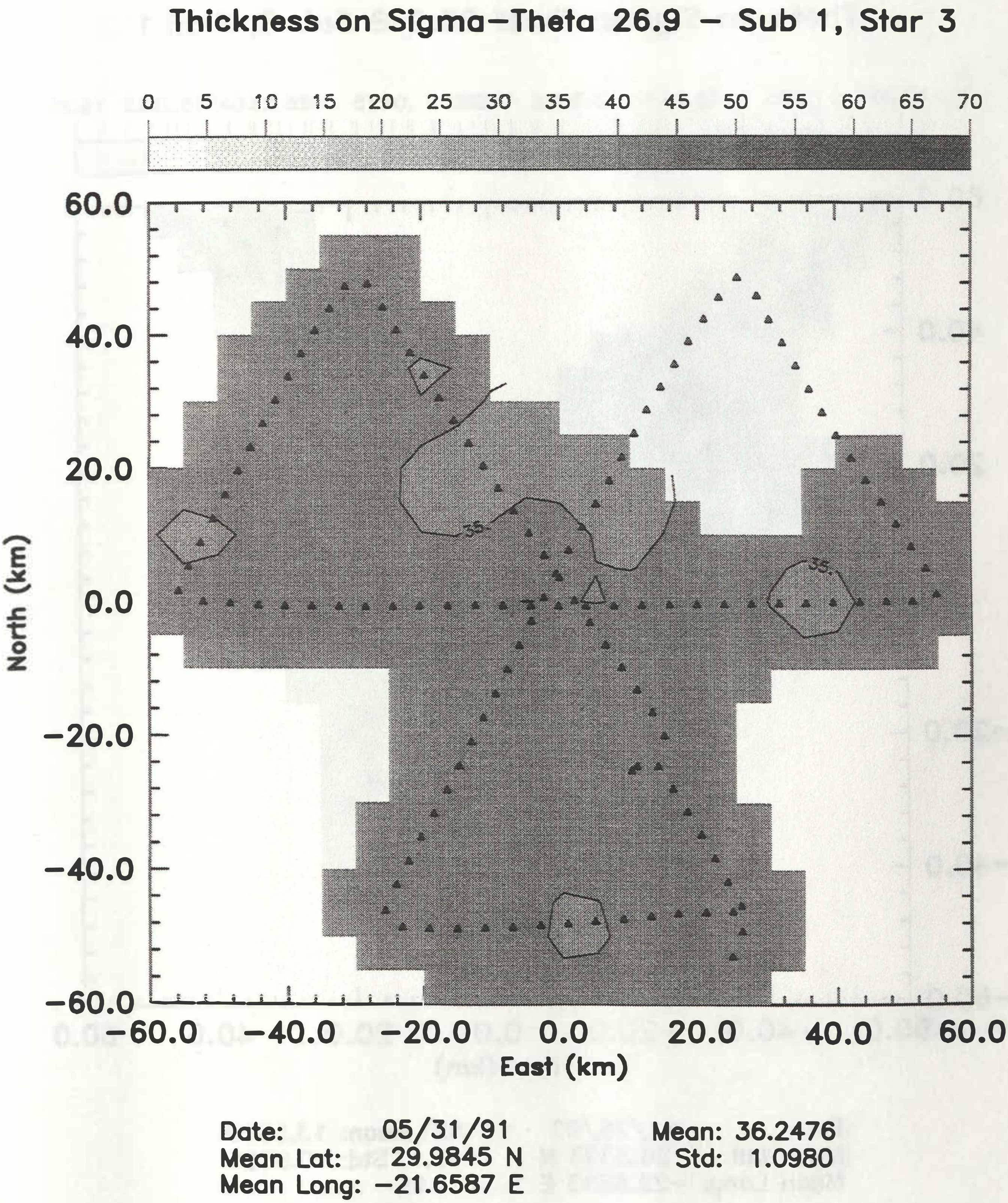
Figure D-84

Pressure on Sigma-Theta 26.9 - Sub 1, Star 3



Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E
Mean: 340.1730
Std: 18.1612

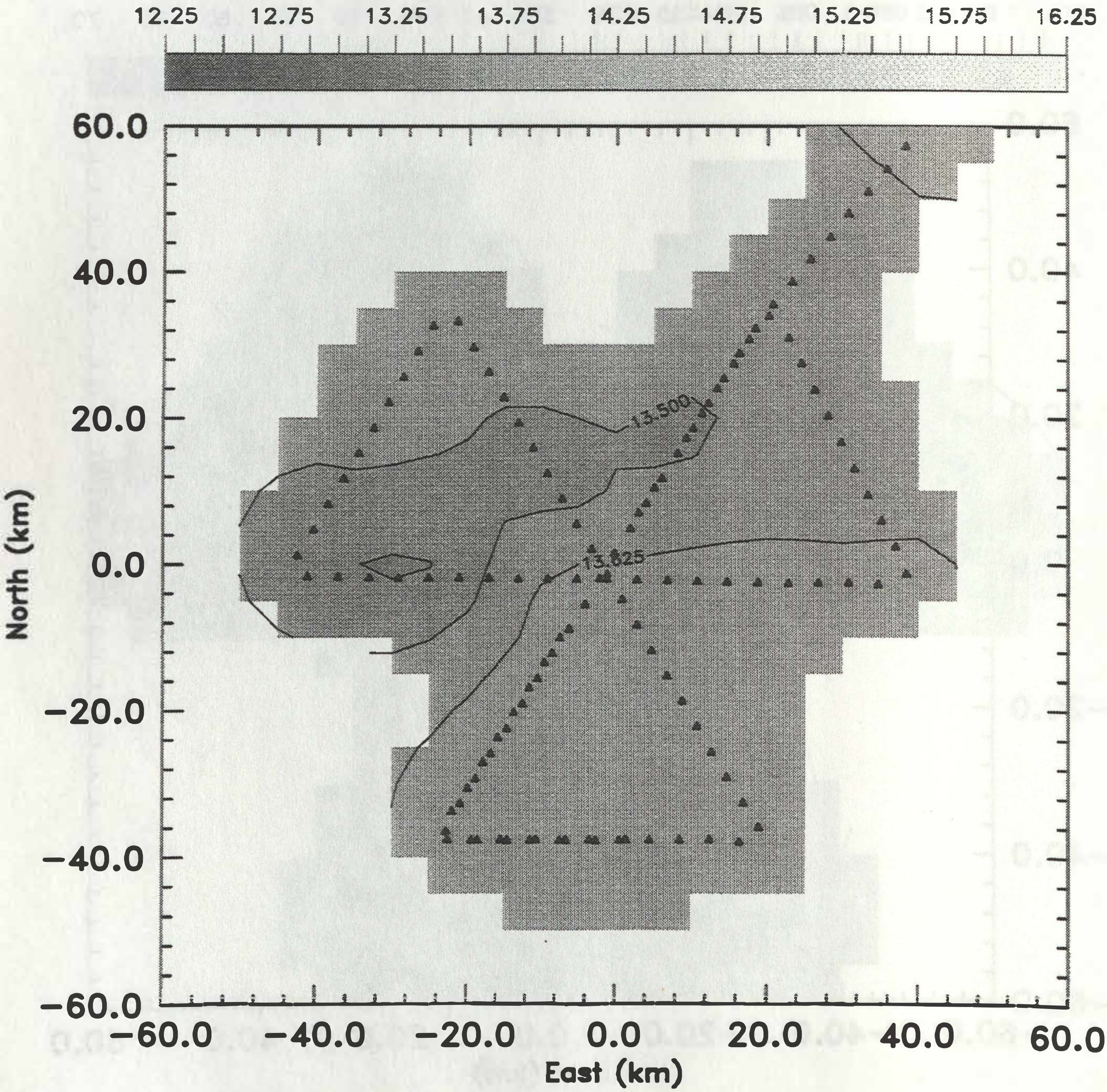
Figure D-85



Thickness on Sigma-Theta 26.9 - Sub 1, Star 3
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
35
35
Date: 05/31/91
Mean Lat: 29.9845 N
Mean Long: -21.6587 E
Mean: 36.2476
Std: 1.0980

Figure D-86

Theta on Sigma-Theta 26.9 - Sub 3, Star 1



Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E
Mean: 13.5893
Std: 0.0823

Figure D-87

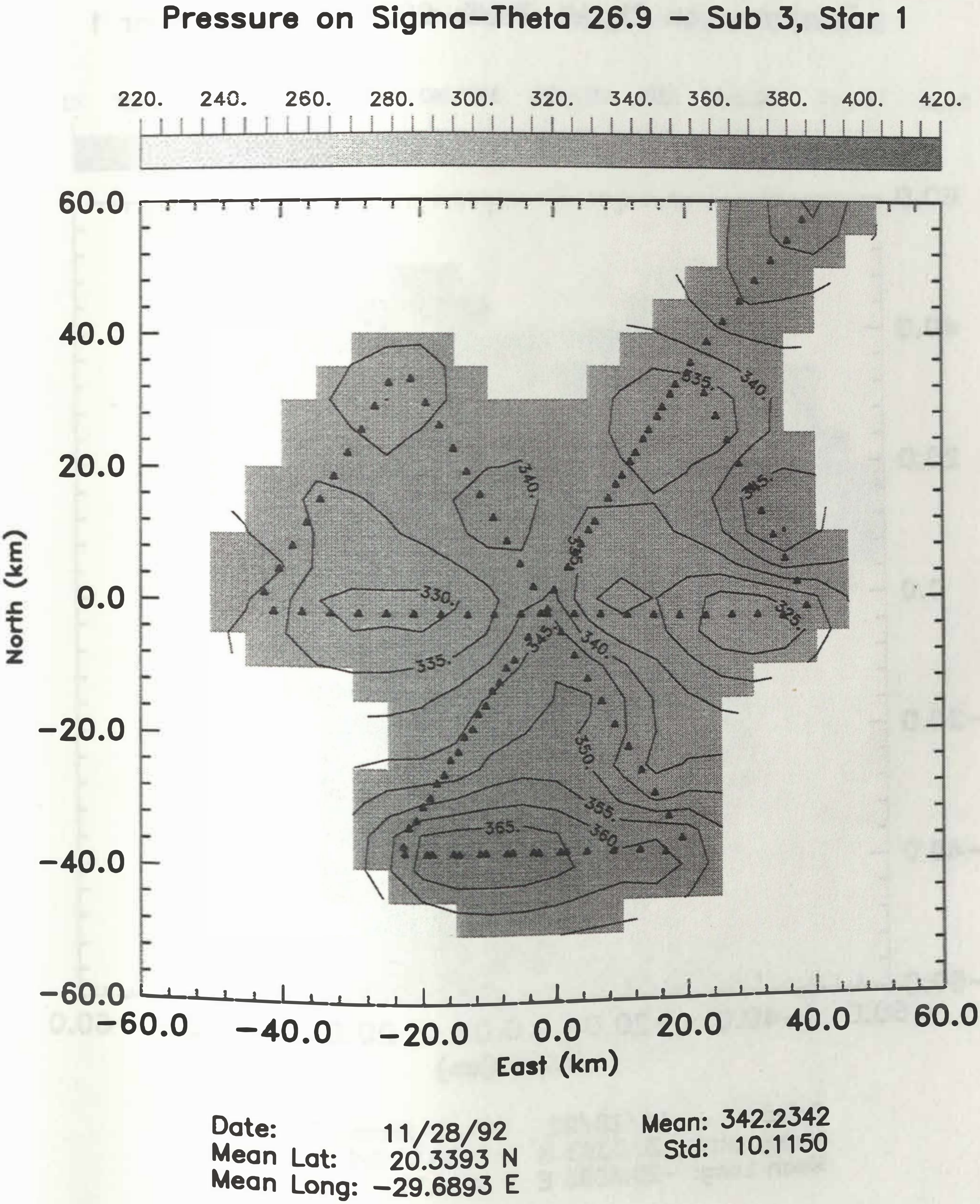
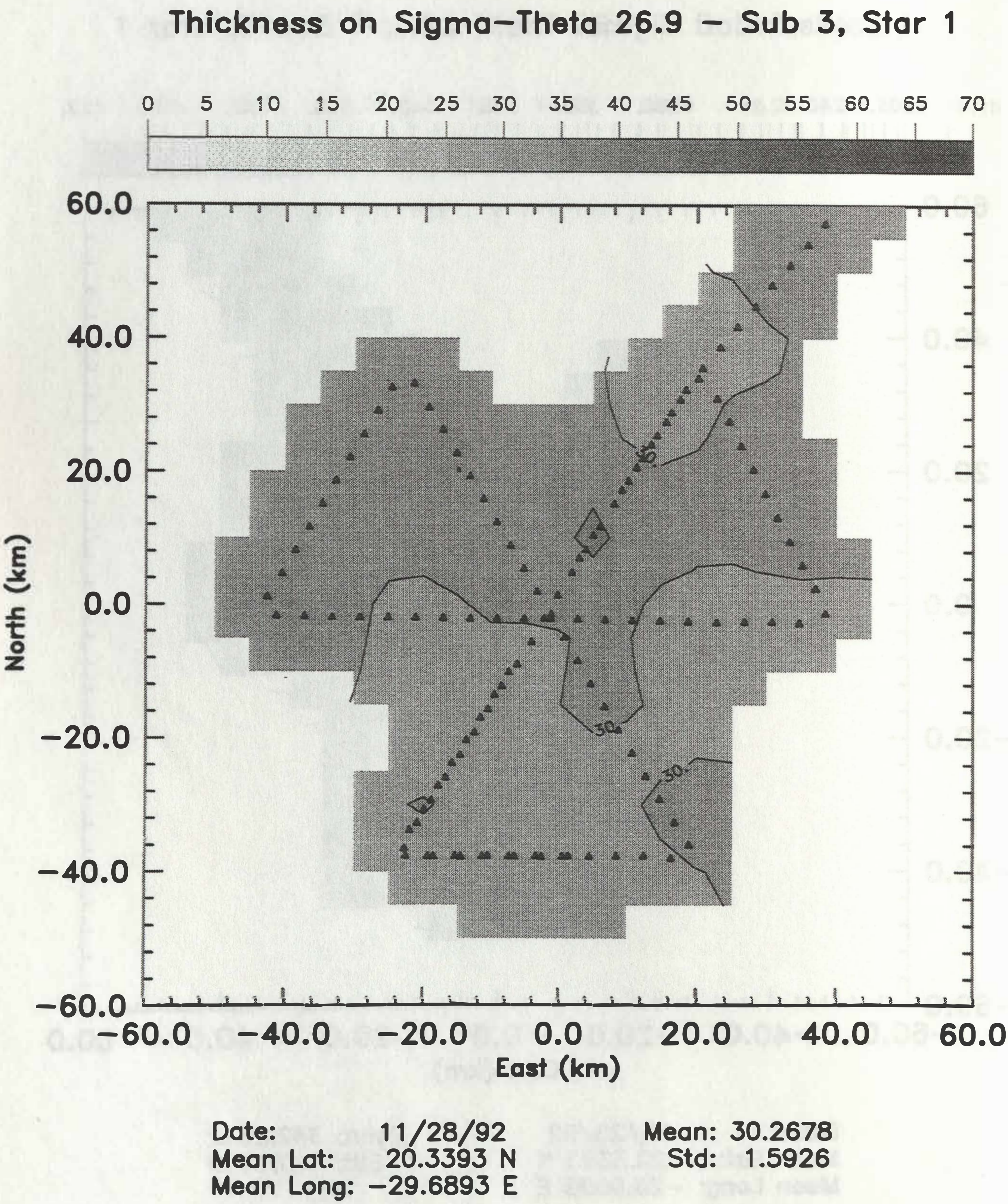
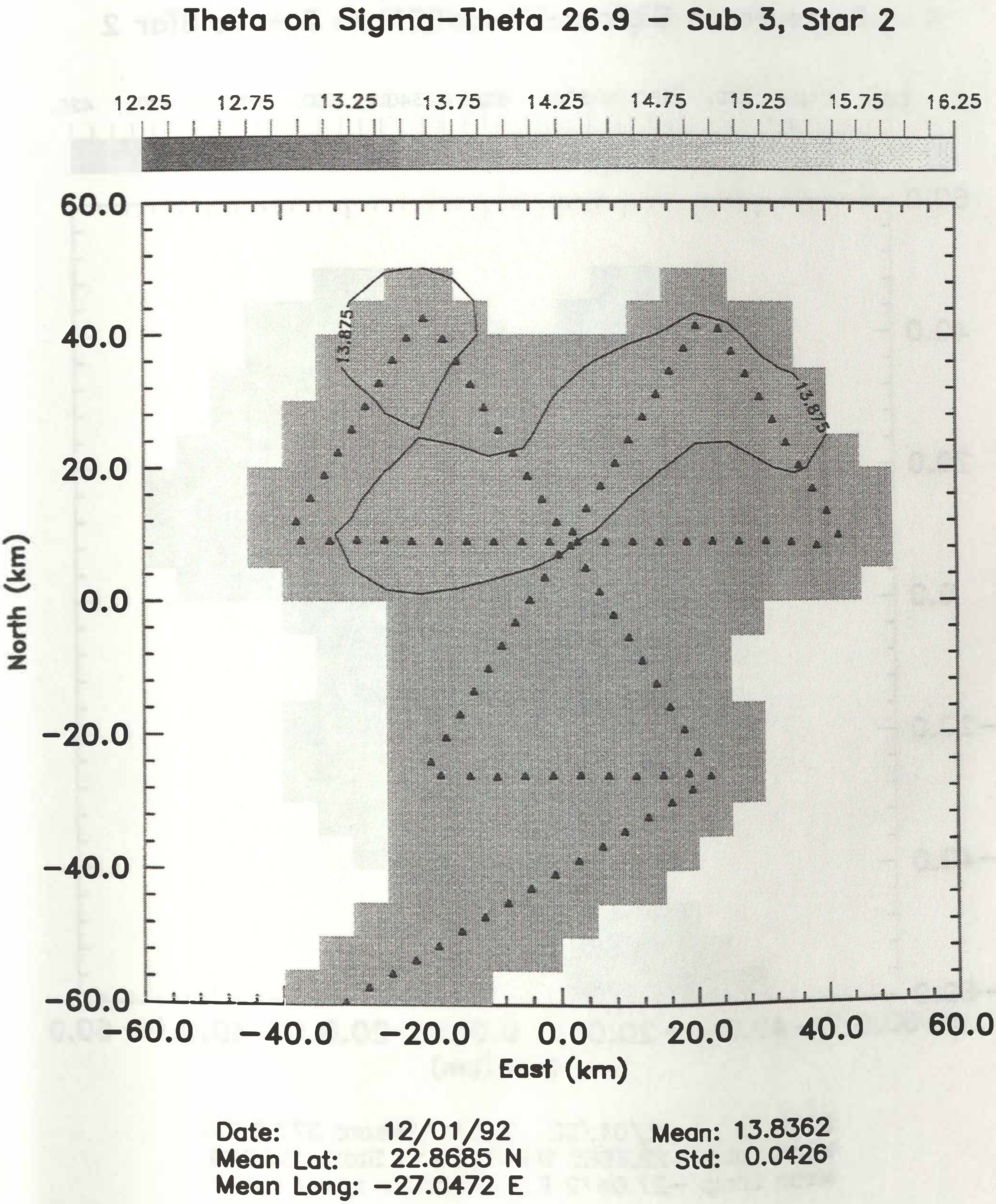

Pressure on Sigma-Theta 26.9 - Sub 3, Star 1
220.
240.
260.
280.
300.
320.
340.
360.
380.
400.
420.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
335.
340.
345.
340.
335
330.
325.
335.
345.
340.
350.
355.
360.
365.
Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E
Mean: 342.2342
Std: 10.1150

Figure D-88



Thickness on Sigma-Theta 26.9 - Sub 3, Star 1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
30
Date: 11/28/92
Mean Lat: 20.3393 N
Mean Long: -29.6893 E
Mean: 30.2678
Std: 1.5926

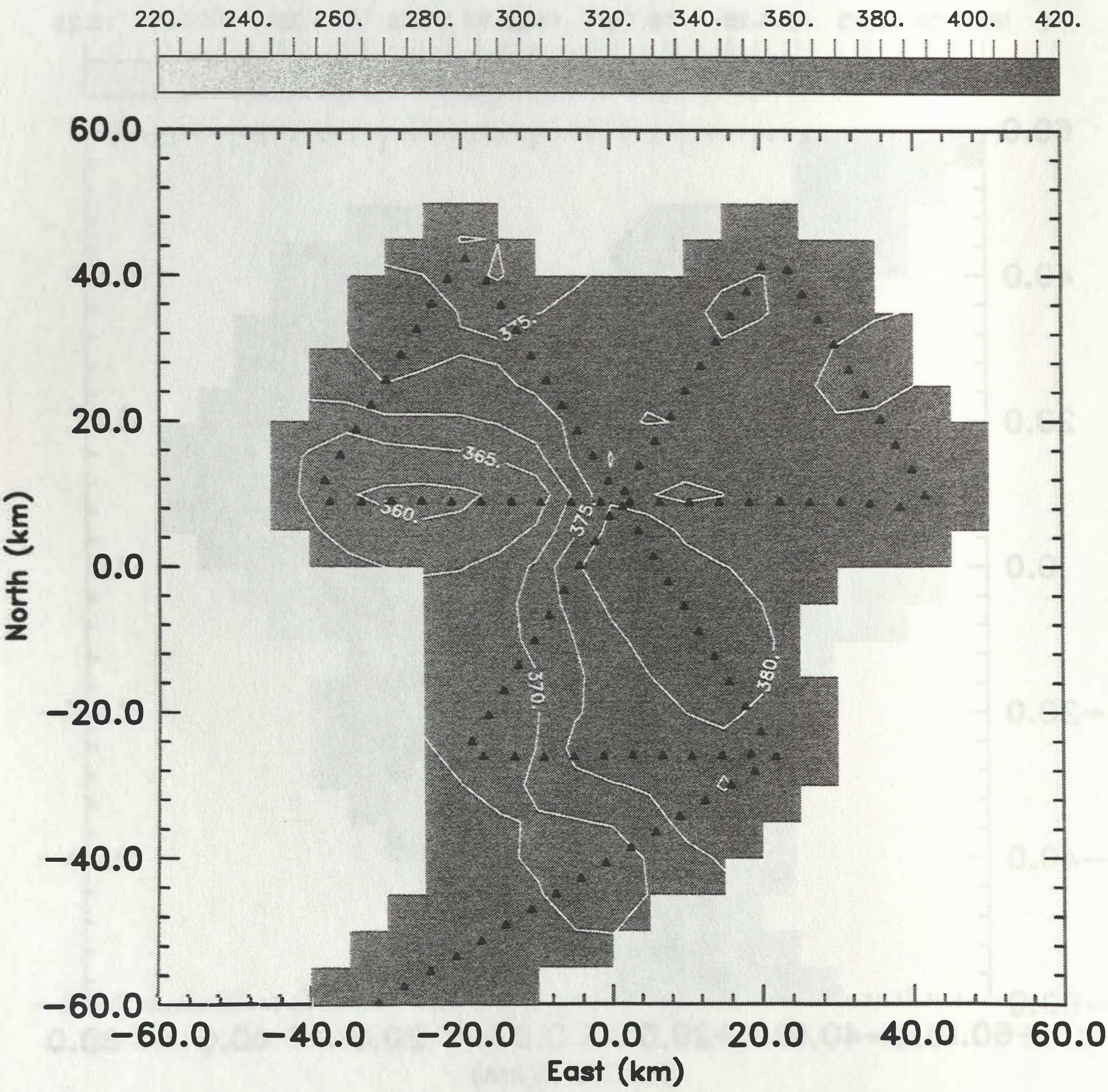
Figure D-89



Theta on Sigma—Theta 26.9 — Sub 3, Star 2
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
13.875
13.875
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 13.8362
Std: 0.0426

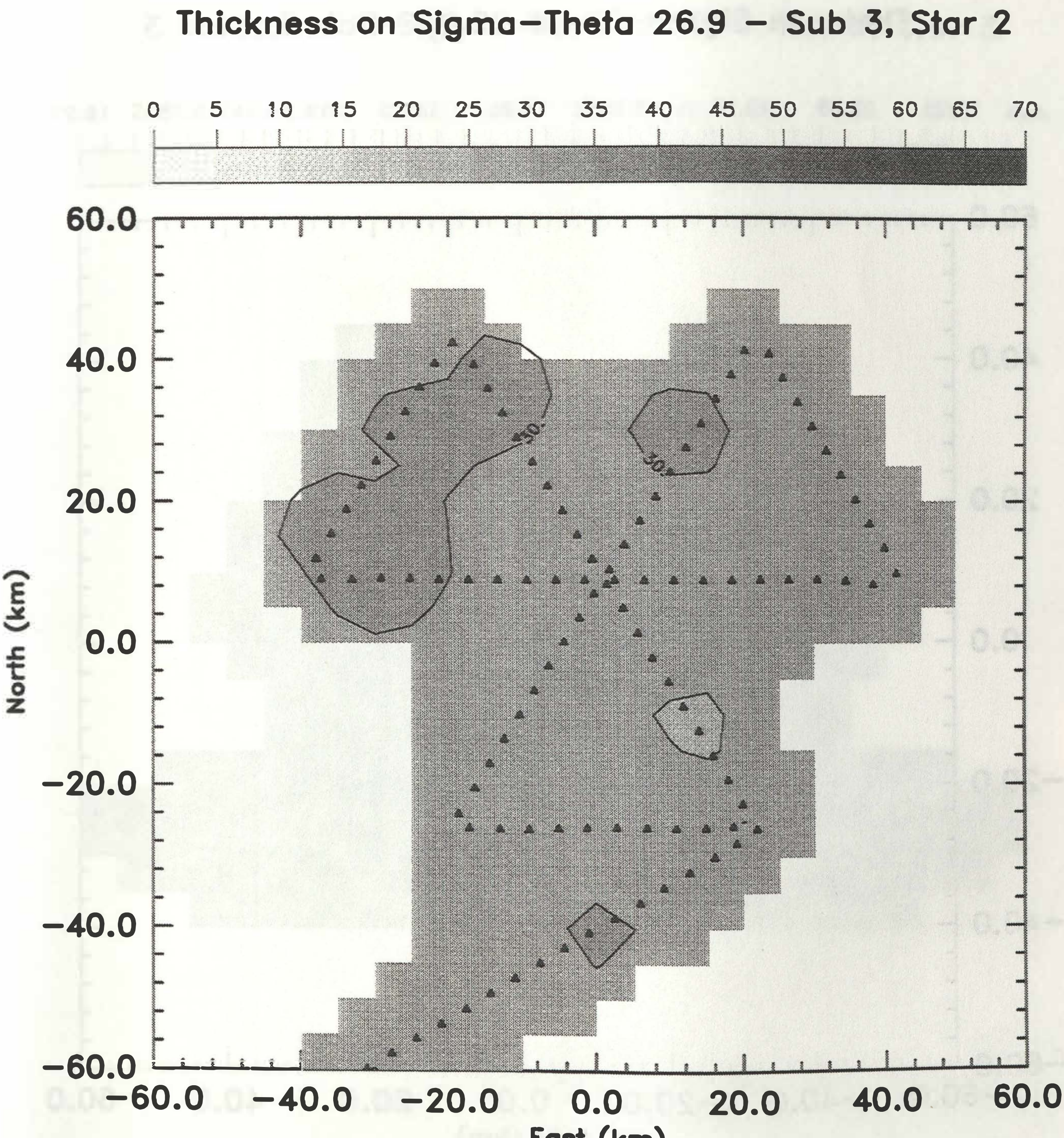
Figure D-90

Pressure on Sigma-Theta 26.9 - Sub 3, Star 2



Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E
Mean: 373.9740
Std: 5.1209

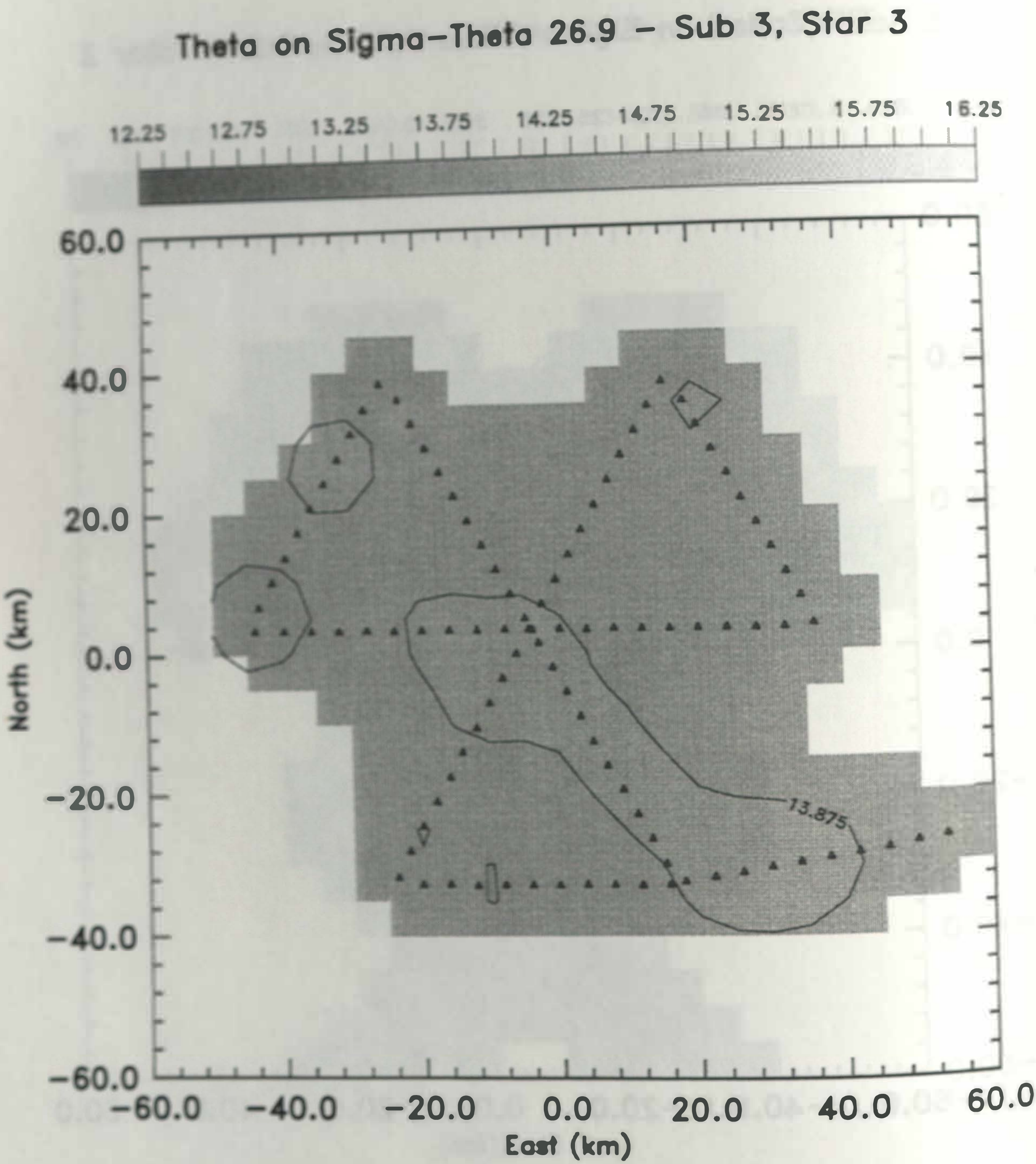
Figure D-91



Date: 12/01/92
Mean Lat: 22.8685 N
Mean Long: -27.0472 E

Mean: 28.2718
Std: 1.4681

Figure D-92



Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 13.8438
Std: 0.0426

Figure D-93

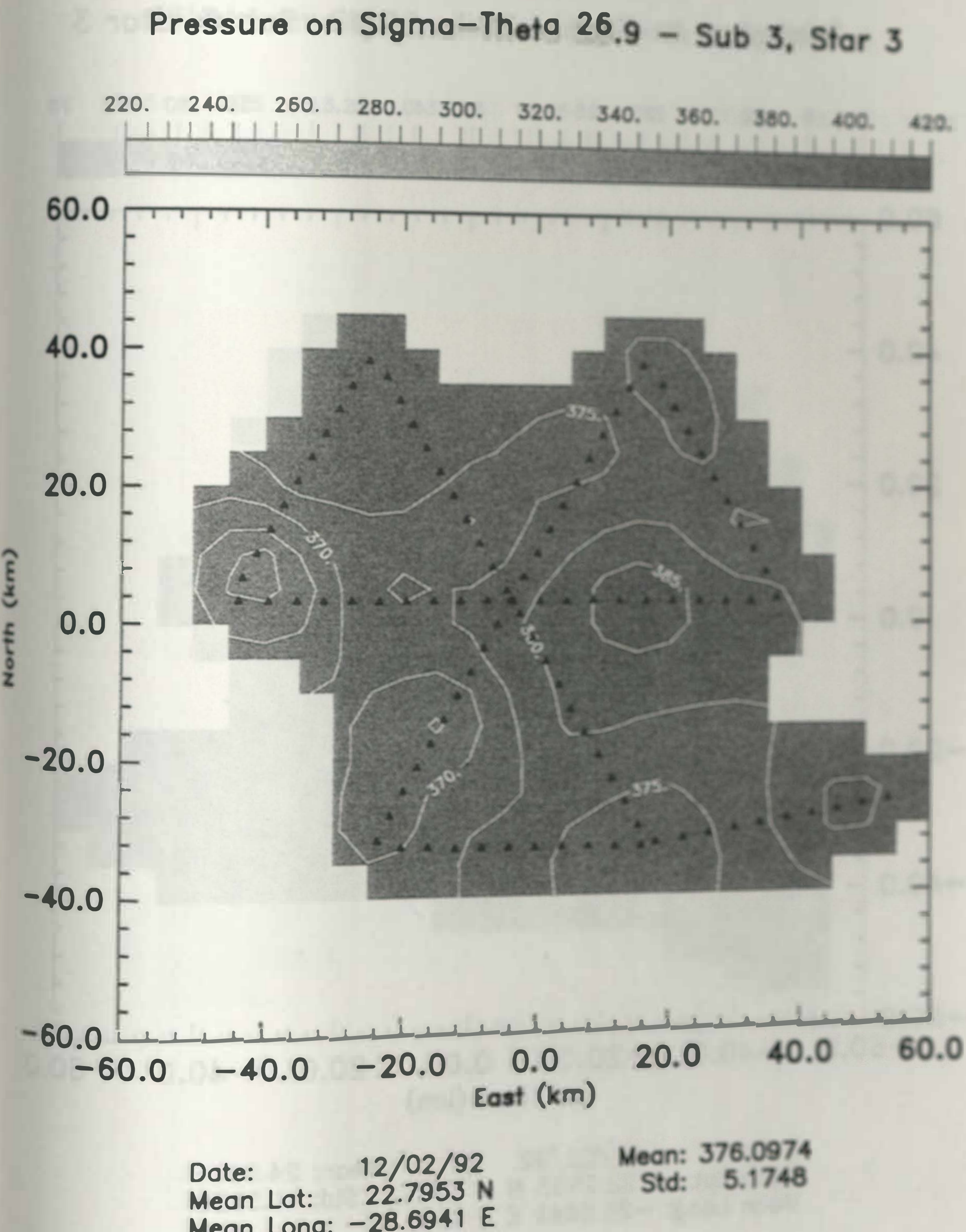
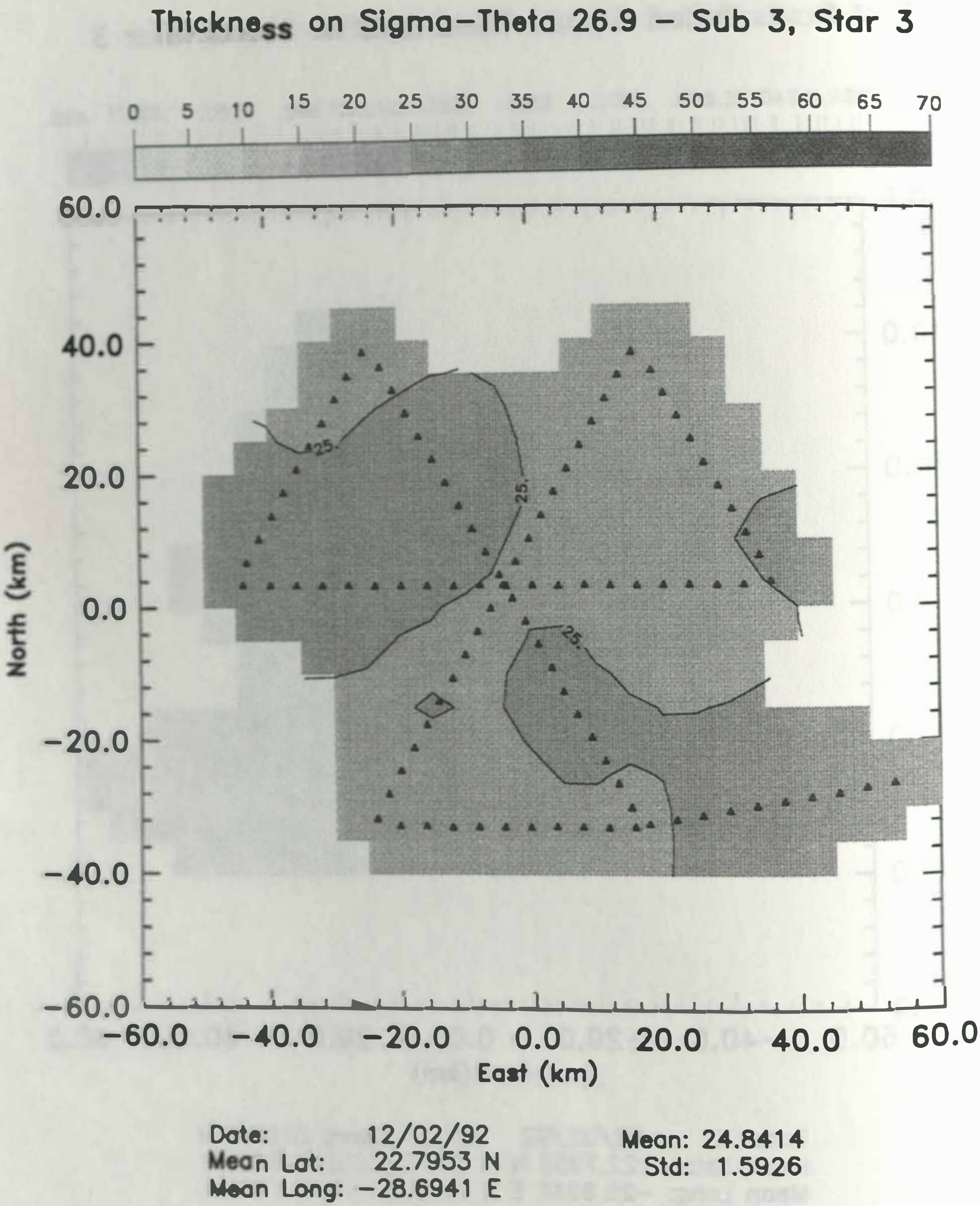
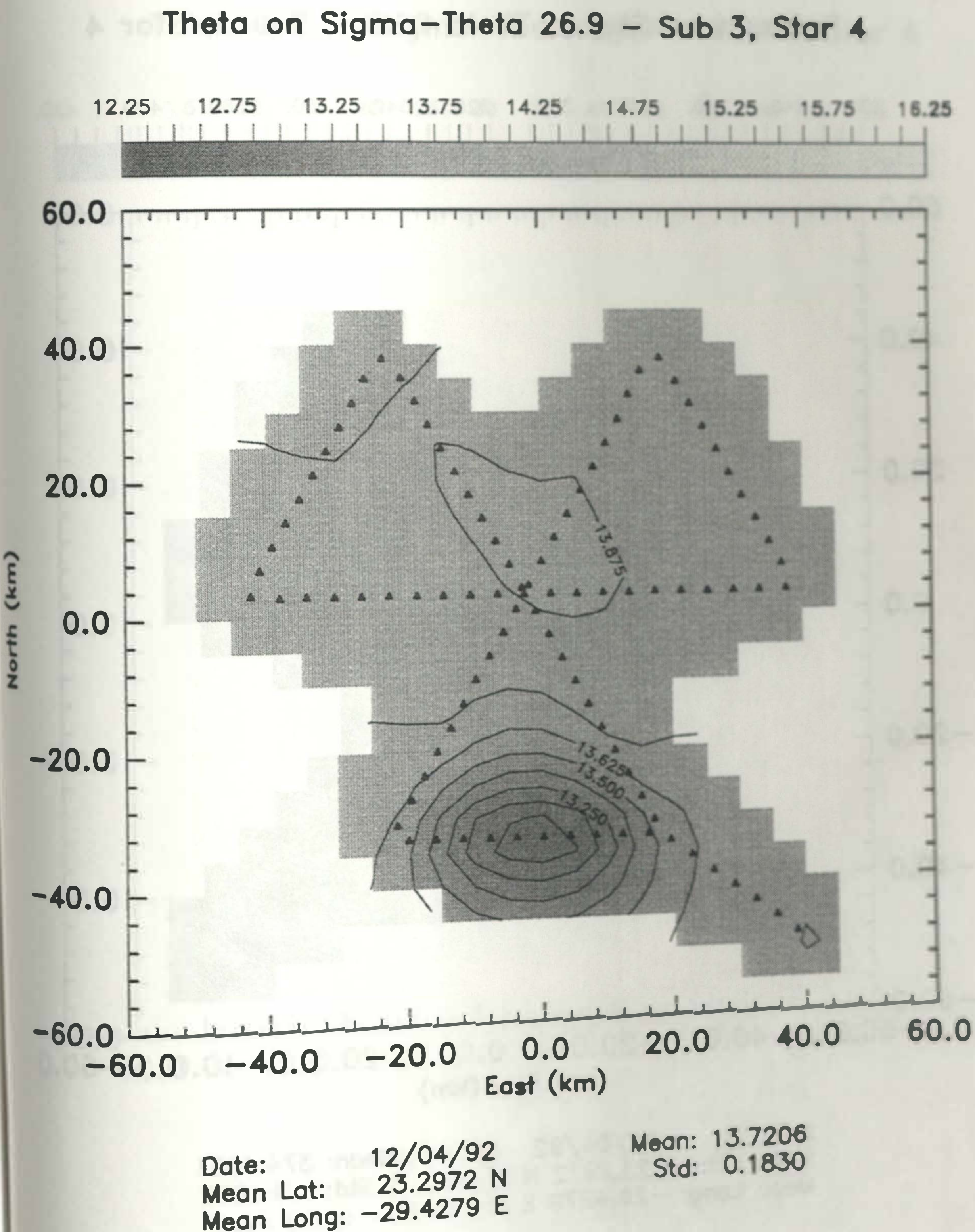

Pressure on Sigma-Theta 26.9 - Sub 3, Star 3
220.
240.
260.
280.
300.
320.
340.
360.
380.
400.
420.
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
375.
370.
385.
370.
375.
Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 376.0974
Std: 5.1748

Figure D-94



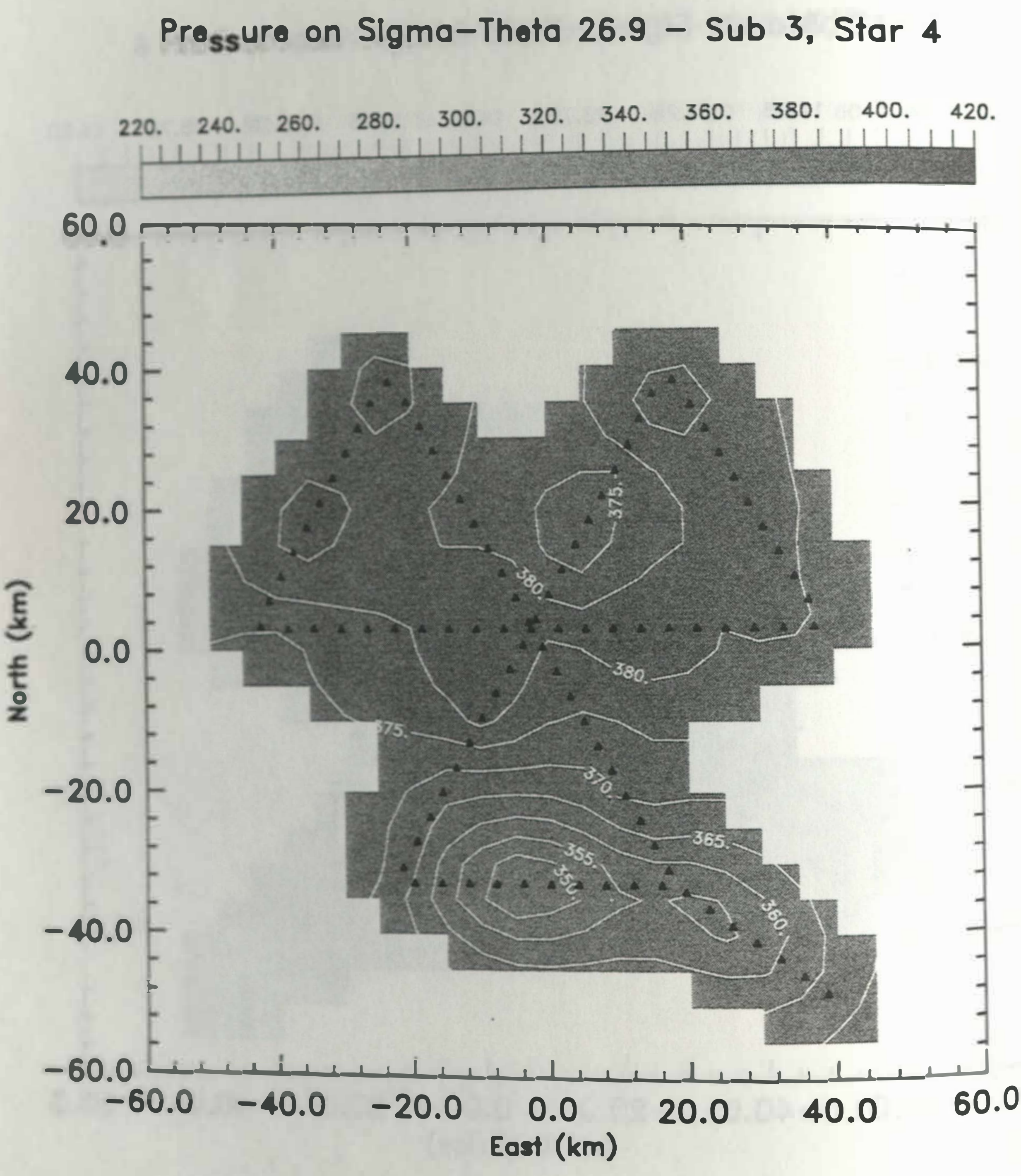
Thickness on Sigma-Theta 26.9 - Sub 3, Star 3
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
25.
25.
25.
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
Date: 12/02/92
Mean Lat: 22.7953 N
Mean Long: -28.6941 E
Mean: 24.8414
Std: 1.5926

Figure D-95



Theta on Sigma-Theta 26.9 - Sub 3, Star 4
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
13.875
13.625
13.500
13.250
Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 13.7206
Std: 0.1830

Figure D-96



Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 374.4001
Std: 9.1982

Figure D-97

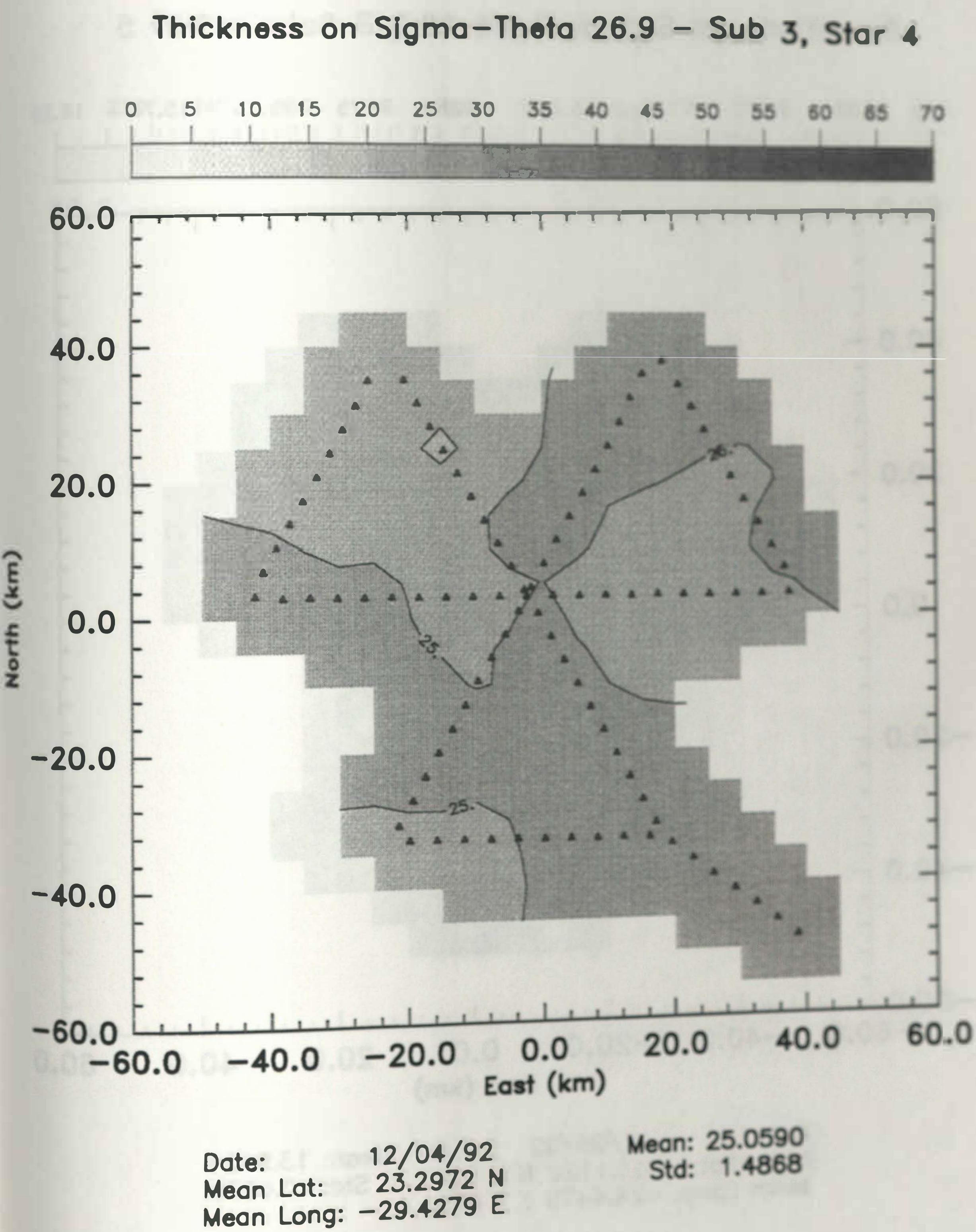
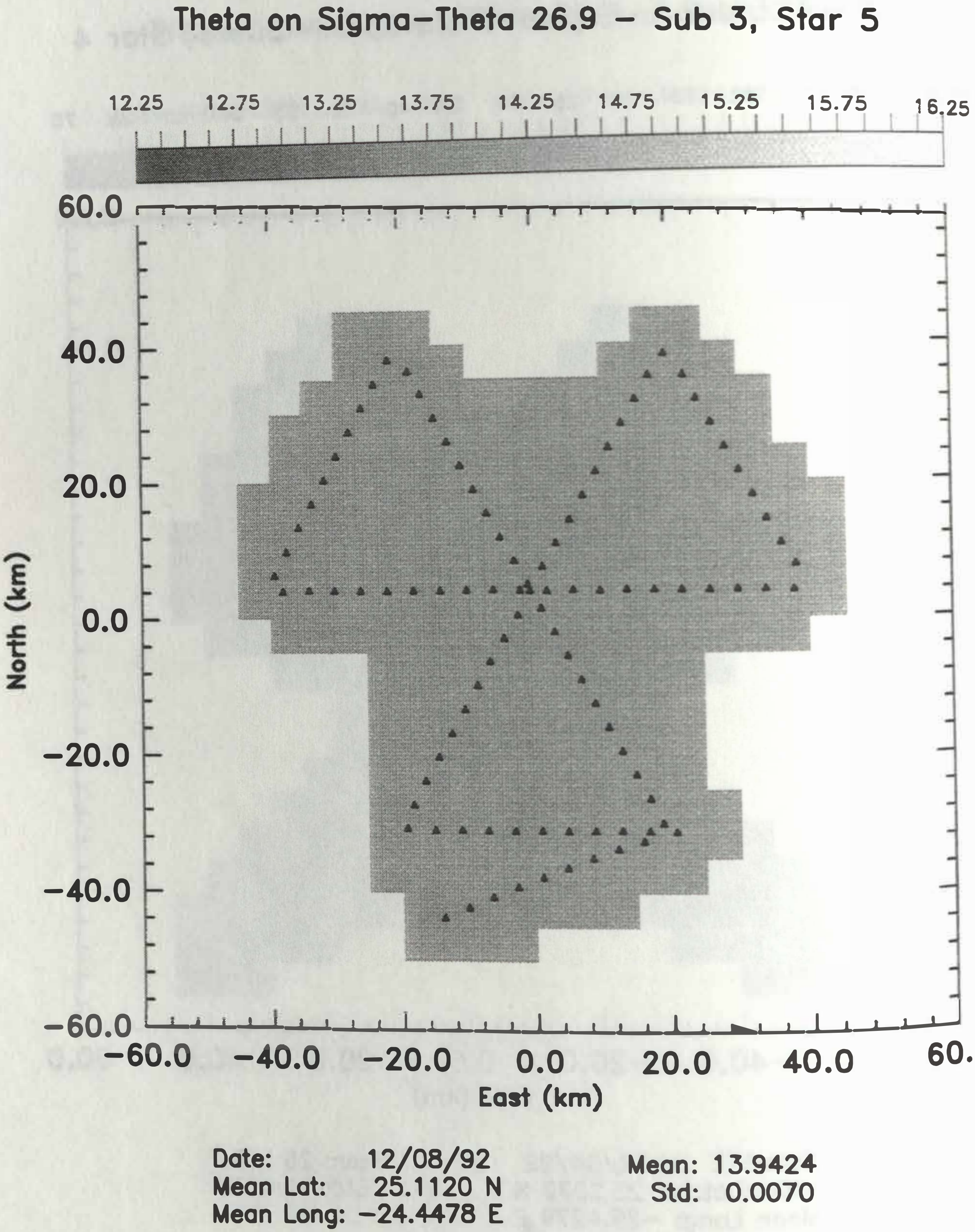
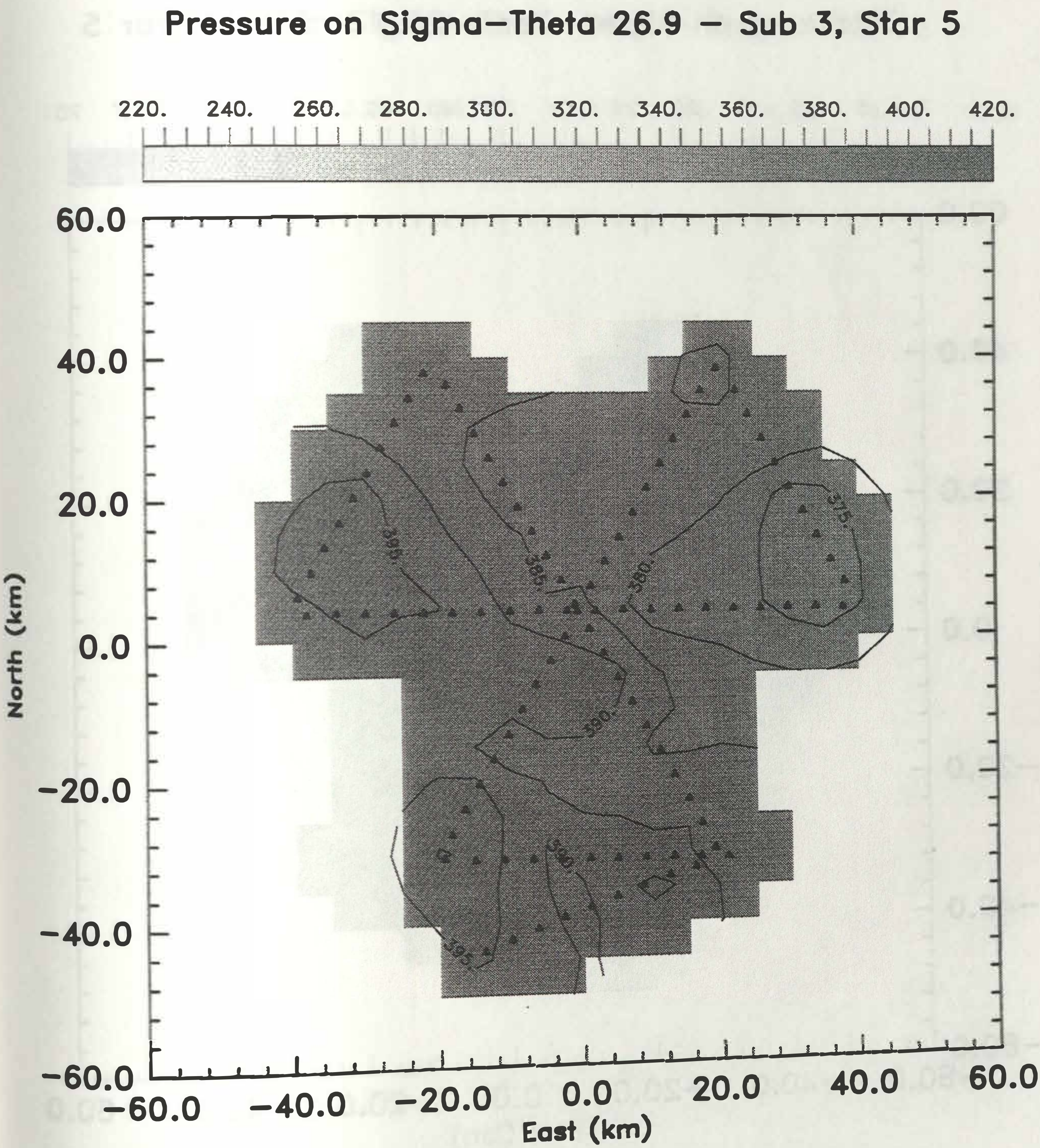

Thickness on Sigma-Theta 26.9 - Sub 3, Star 4
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0 -40.0 -20.0 0.0 20.0 40.0 60.0
East (km)
25.
25.
26.
Date: 12/04/92
Mean Lat: 23.2972 N
Mean Long: -29.4279 E
Mean: 25.0590
Std: 1.4868

Figure D-98



Theta on Sigma-Theta 26.9 - Sub 3, Star 5
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E
Mean: 13.9424
Std: 0.0070

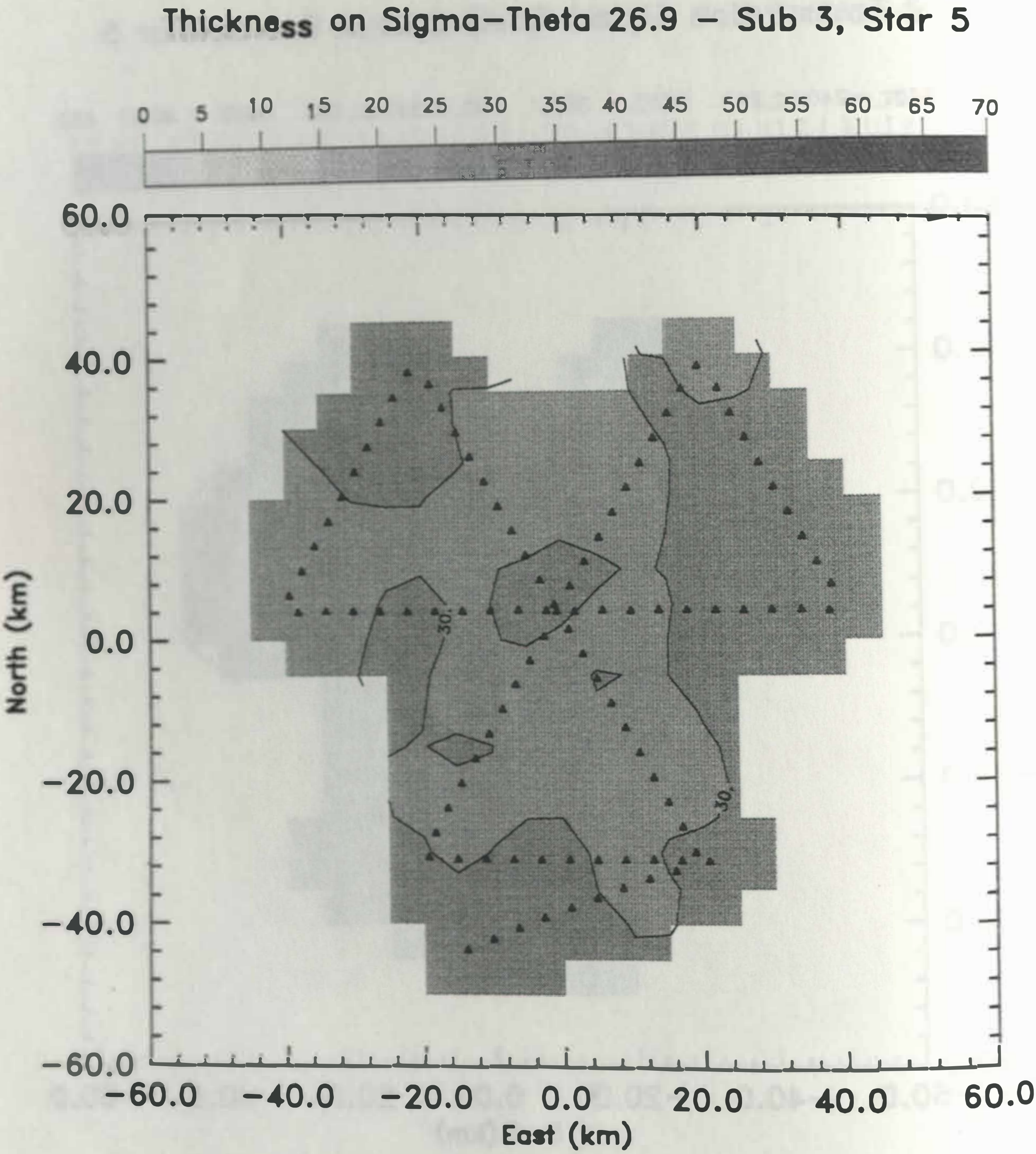
Figure D-99



Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E

Mean: 387.1770
Std: 6.2923

Figure D-100

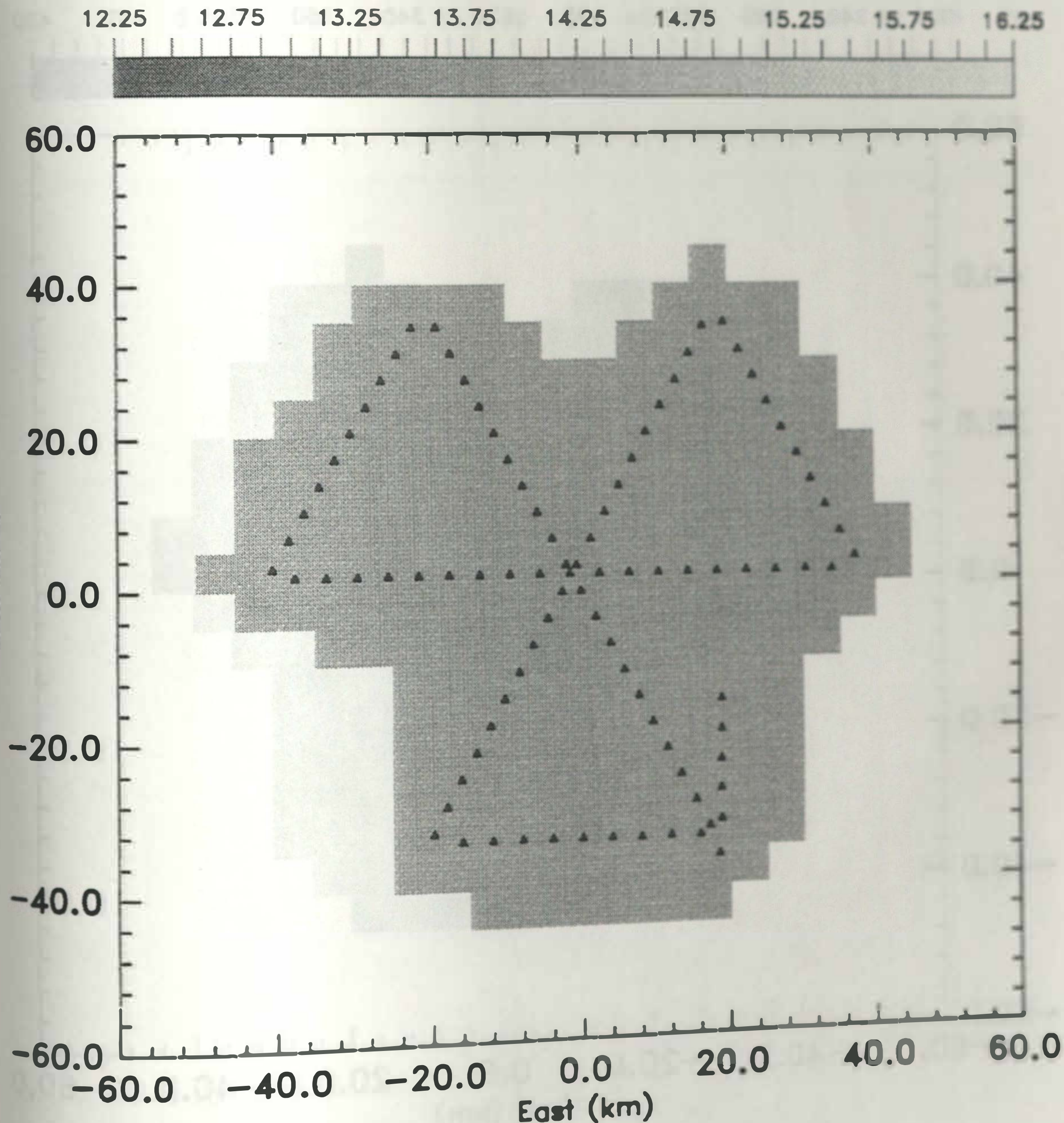


Date: 12/08/92
Mean Lat: 25.1120 N
Mean Long: -24.4478 E

Mean: 30.1917
Std: 1.1335

Figure D-101

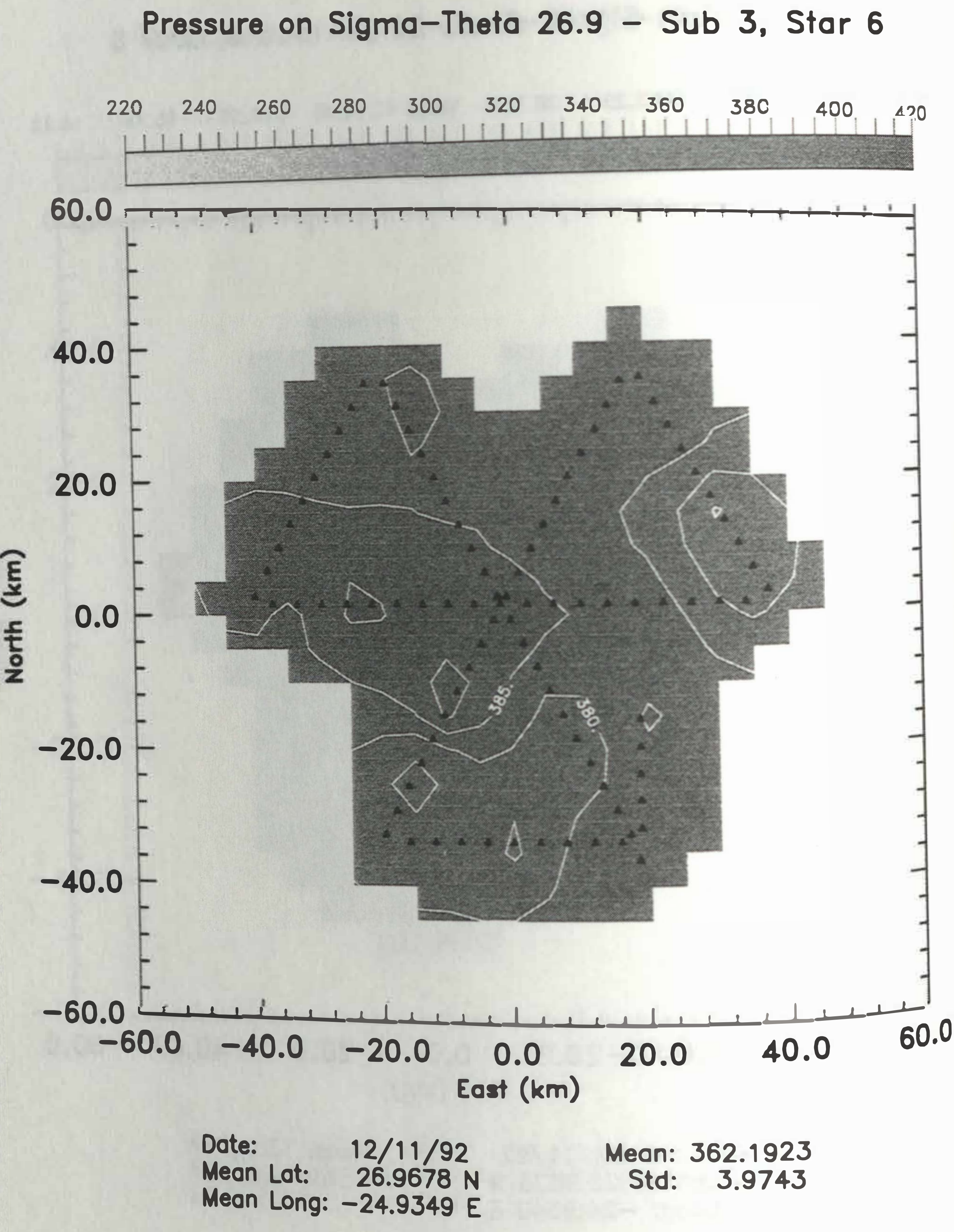
Theta on Sigma–Theta 26.9 – Sub 3, Star 6



Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E

Mean: 13.9678
Std: 0.0164

Figure D-102



Pressure on Sigma-Theta 26.9 - Sub 3, Star 6
220
240
260
280
300
320
340
360
380
400
420
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
385.
380.
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: -24.9349 E
Mean: 362.1923
Std: 3.9743

Figure D-103

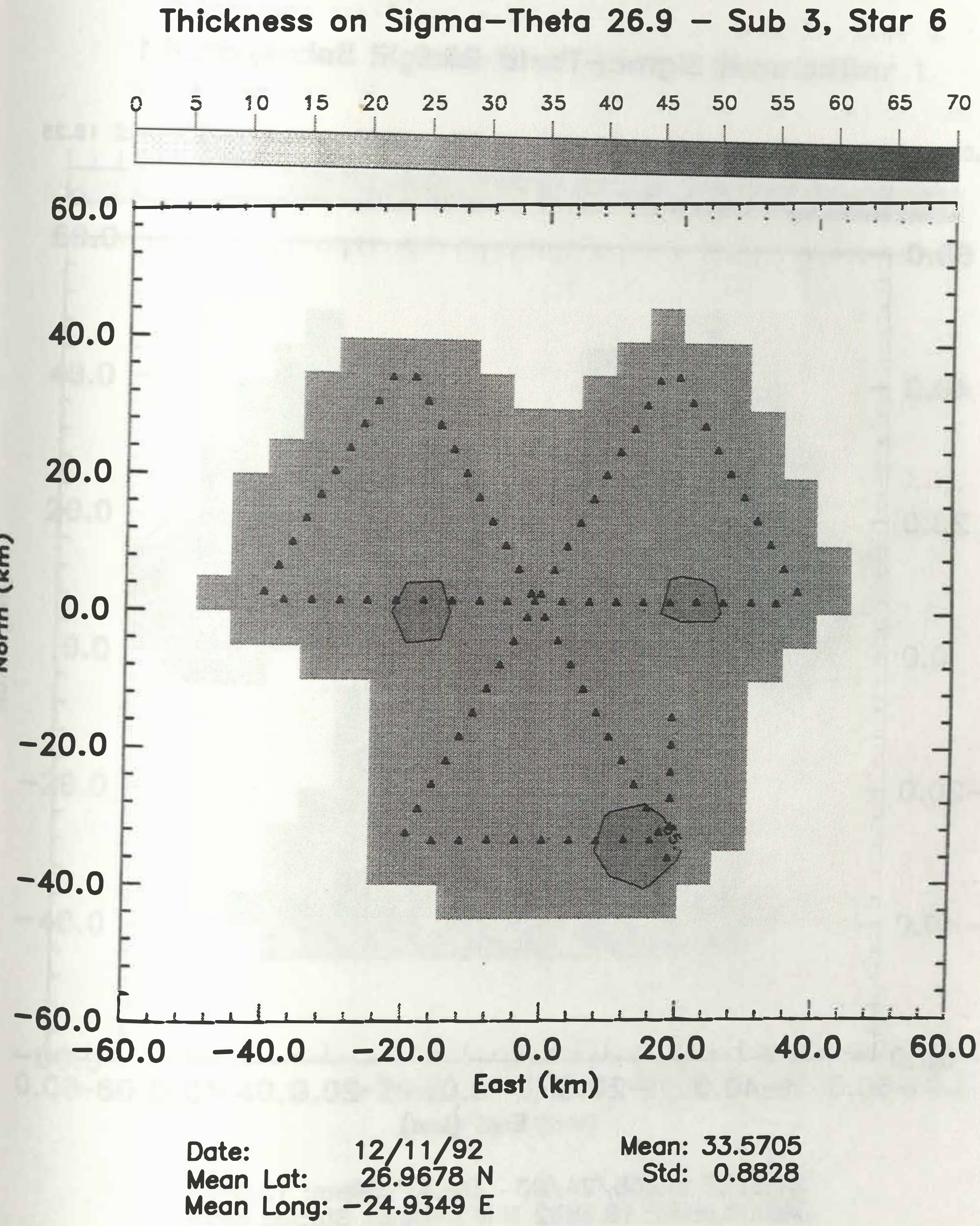
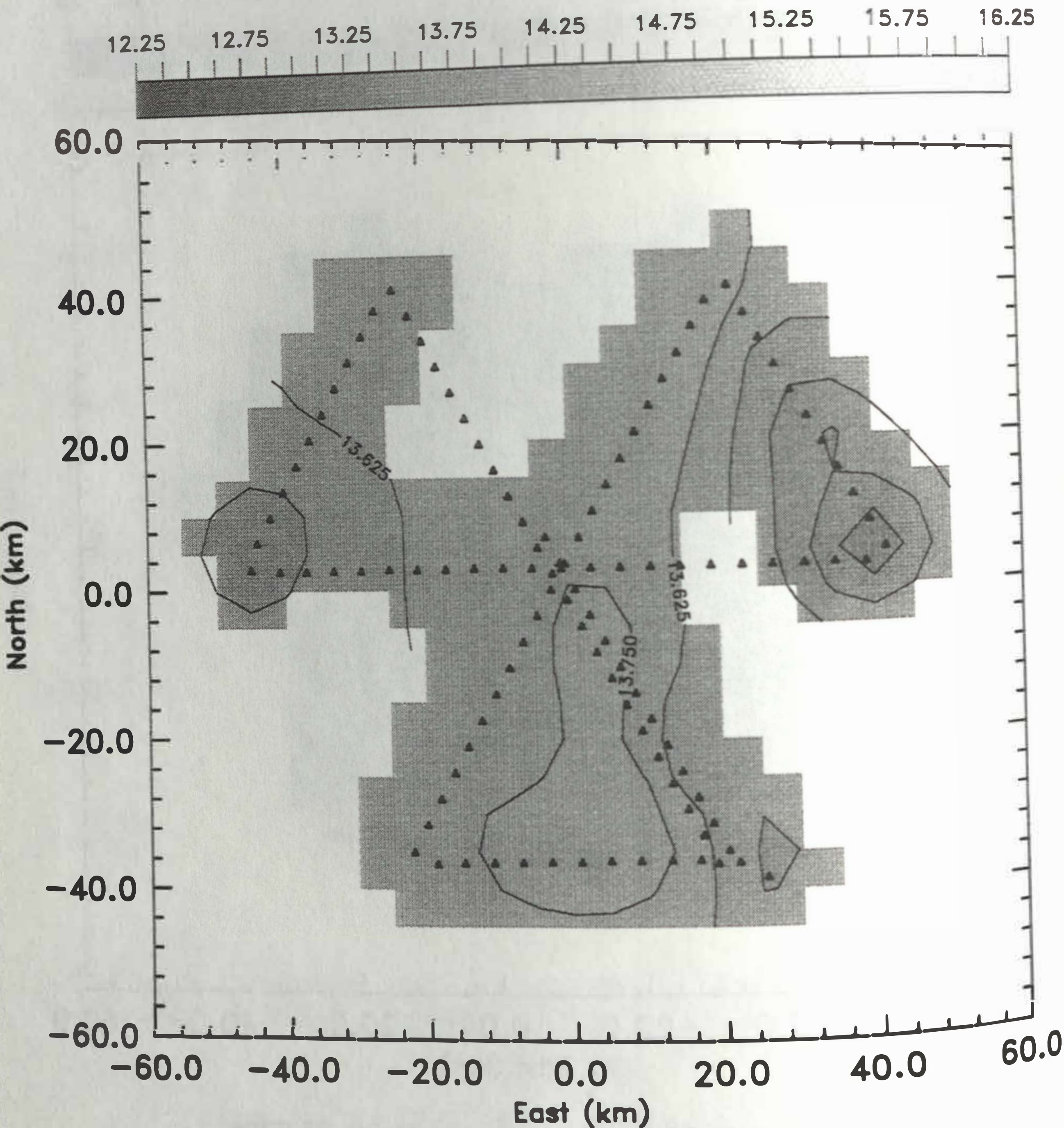

Thickness on Sigma–Theta 26.9 – Sub 3, Star 6
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
−20.0
−40.0
−60.0
North (km)
−60.0
−40.0
−20.0
0.0
20.0
40.0
60.0
East (km)
Date: 12/11/92
Mean Lat: 26.9678 N
Mean Long: −24.9349 E
Mean: 33.5705
Std: 0.8828

Figure D-104

Theta on Sigma-Theta 26.9 - Sub 4, Star 1

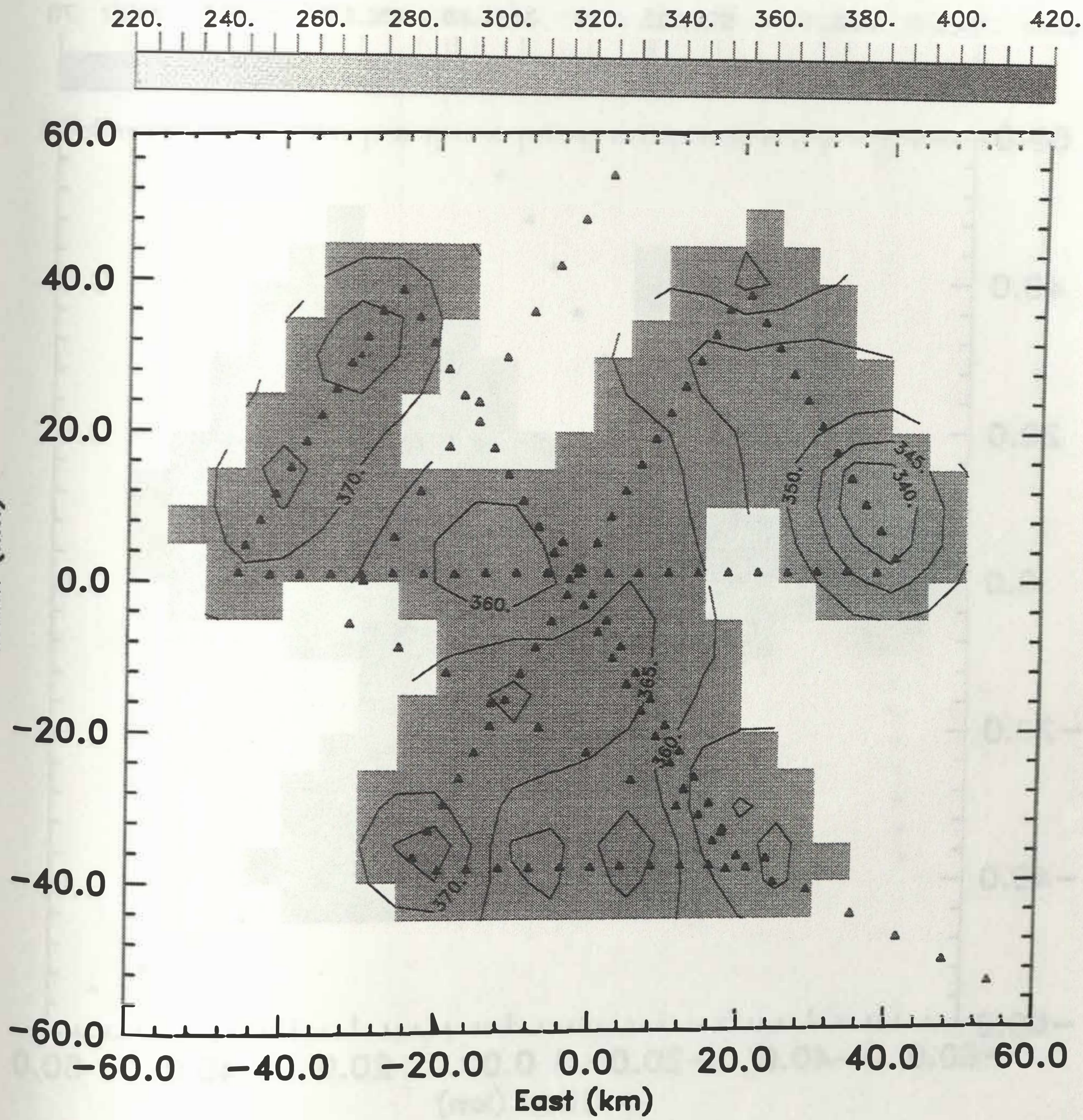


Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E

Mean: 13.5999
Std: 0.1453

Figure D-105

Pressure on Sigma-Theta 26.9 - Sub 4, Star 1



Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E

Mean: 361.5999
Std: 8.3183

Figure D-106

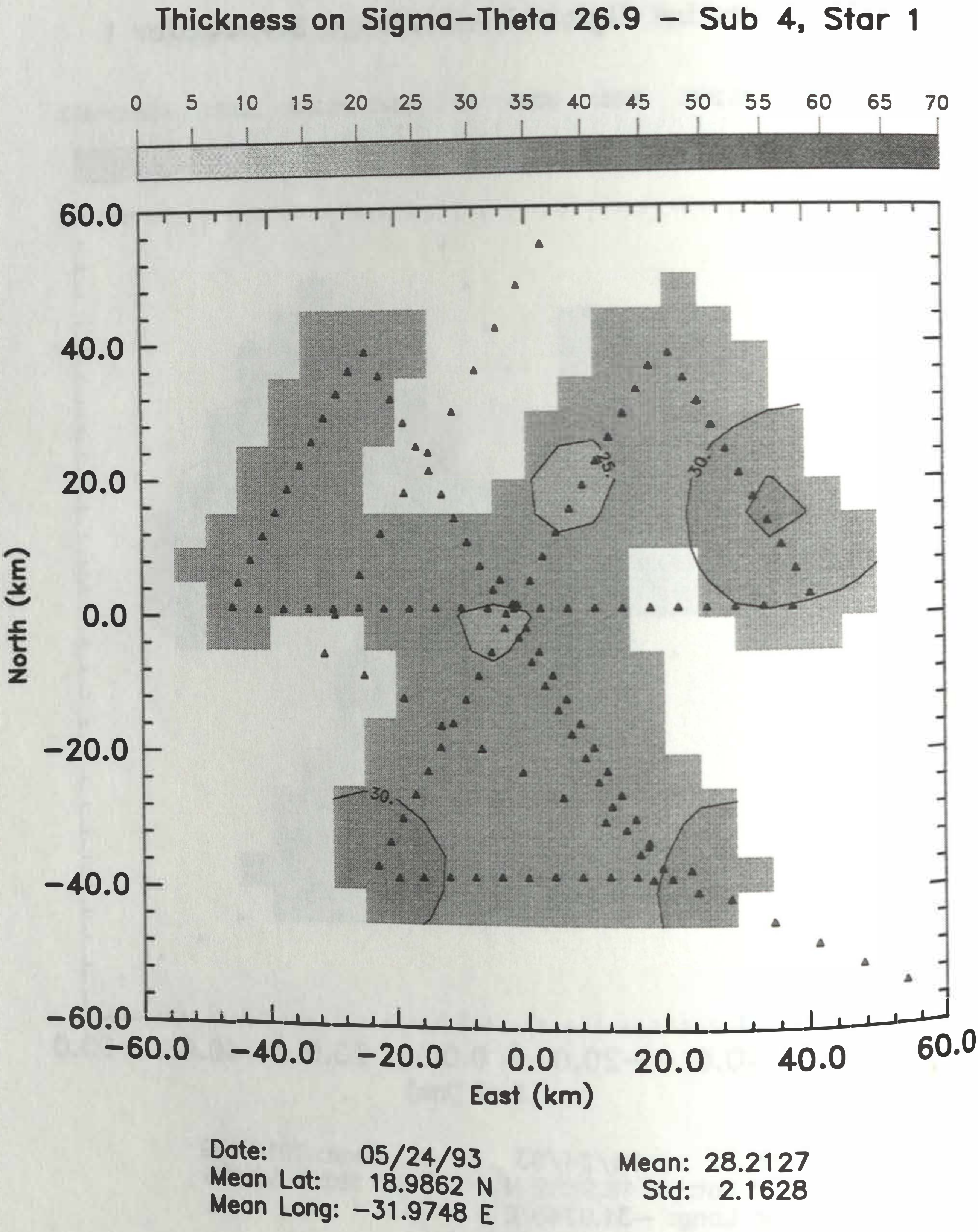

Thickness on Sigma-Theta 26.9 - Sub 4, Star 1
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
North (km)
East (km)
25.
30.
30.
Date: 05/24/93
Mean Lat: 18.9862 N
Mean Long: -31.9748 E
Mean: 28.2127
Std: 2.1628

Figure D-107

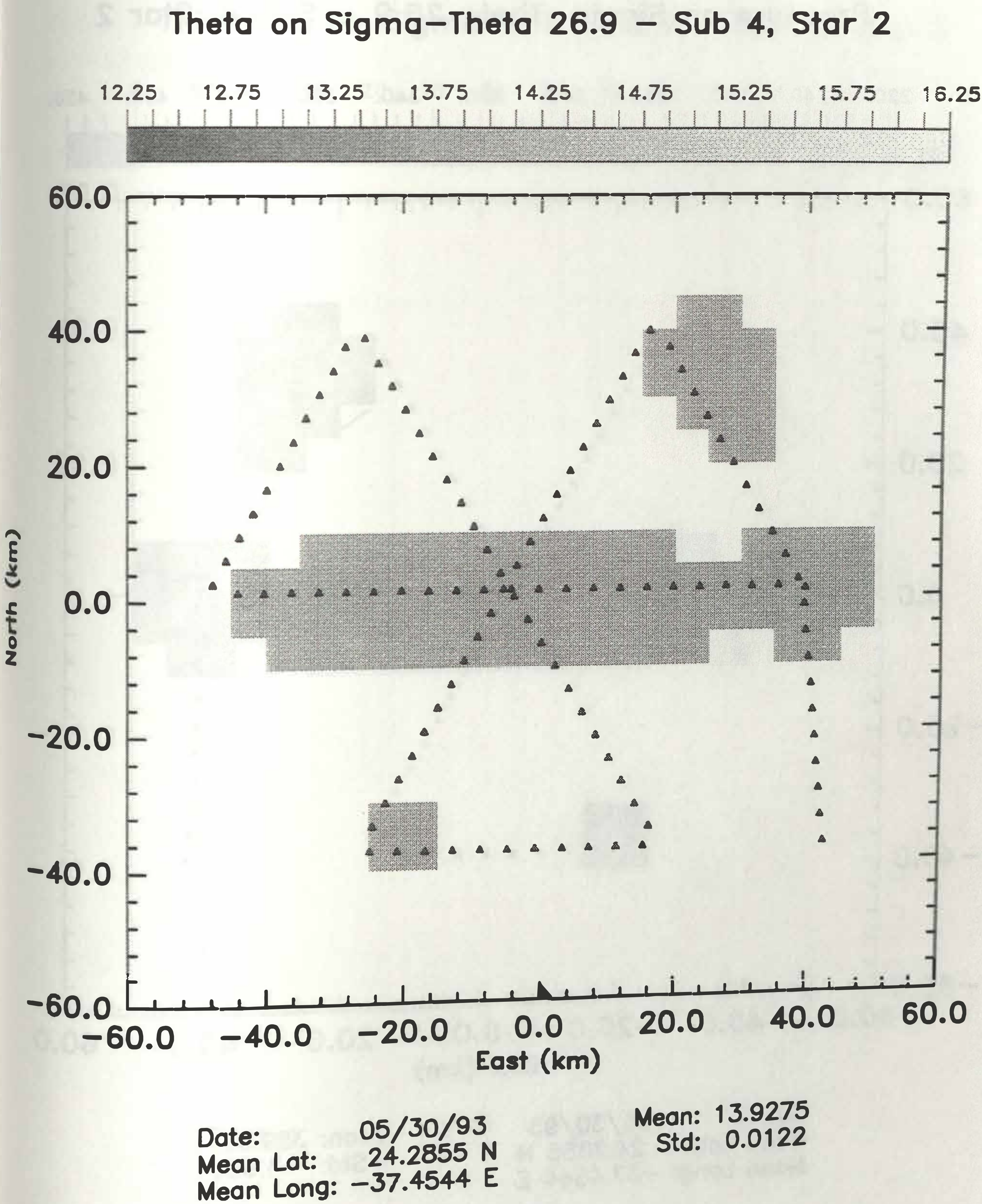
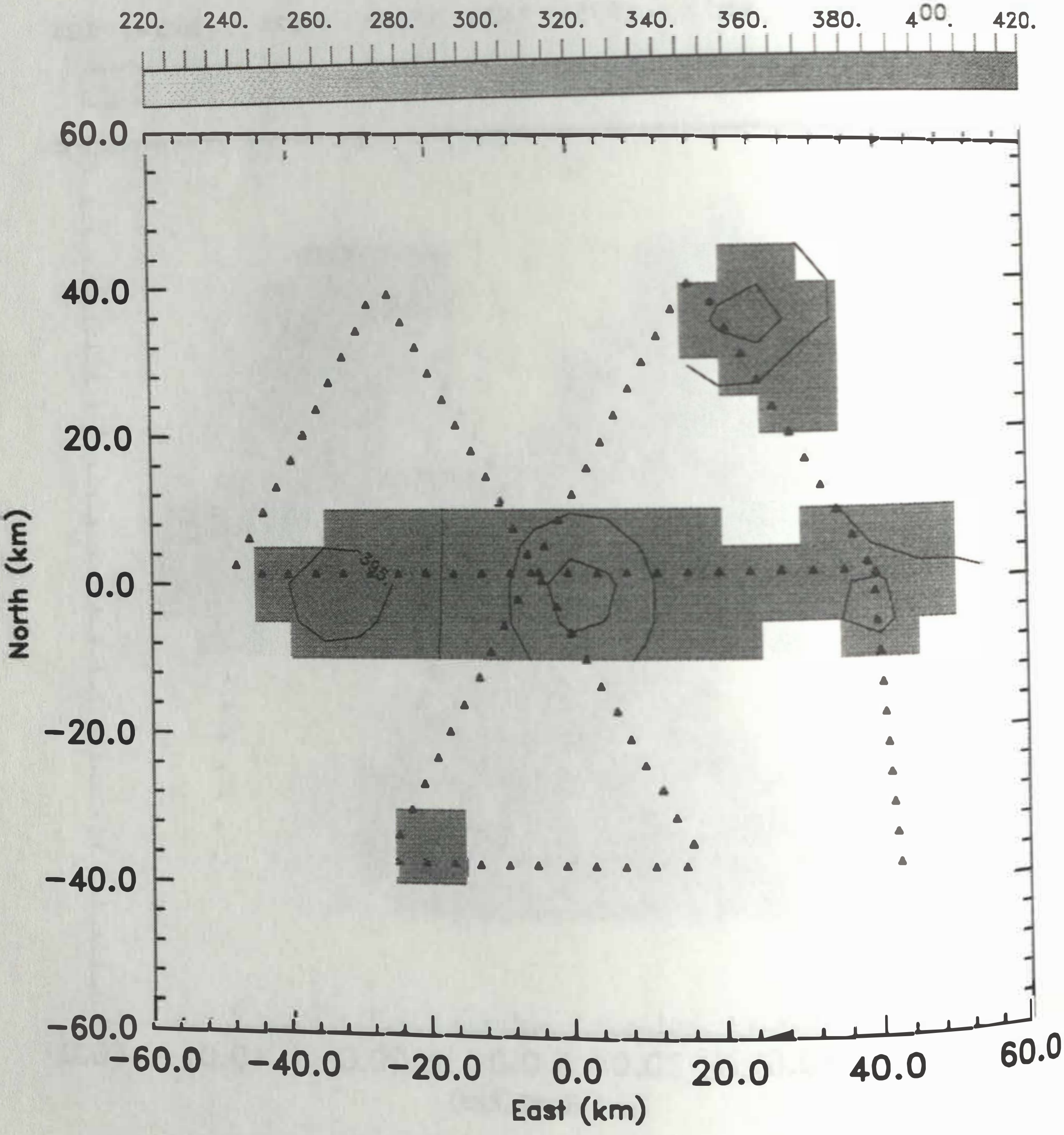

Theta on Sigma-Theta 26.9 - Sub 4, Star 2
12.25
12.75
13.25
13.75
14.25
14.75
15.25
15.75
16.25
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
North (km)
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
East (km)
Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E
Mean: 13.9275
Std: 0.0122

Figure D-108

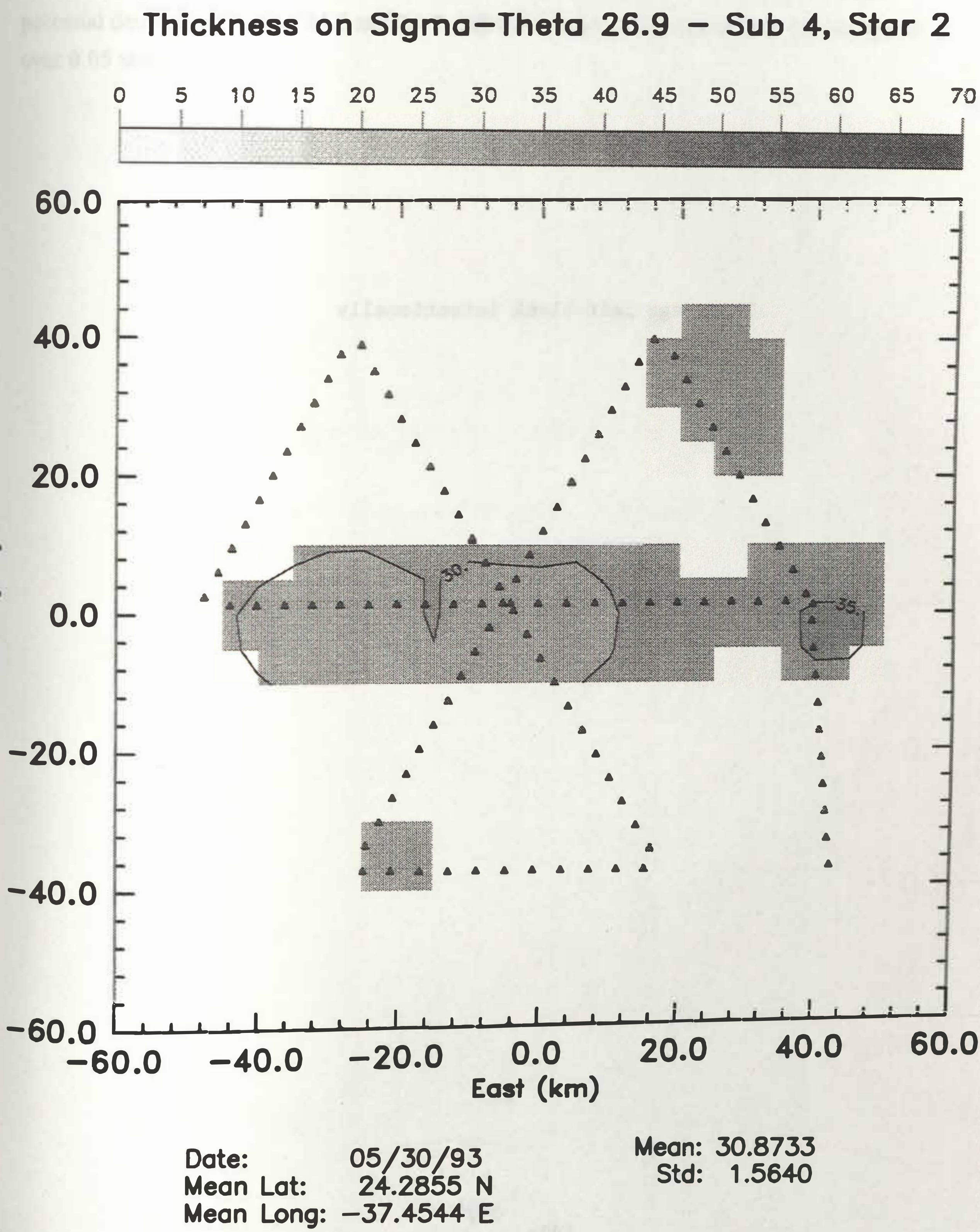
Pressure on Sigma-Theta 26.9 - Sub 4, Star 2



Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: -37.4544 E

Mean: 389.9275
Std: 4.6894

Figure D-109



Thickness on Sigma–Theta 26.9 – Sub 4, Star 2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
60.0
40.0
20.0
0.0
–20.0
–40.0
–60.0
North (km)
–60.0
–40.0
–20.0
0.0
20.0
40.0
60.0
East (km)
30.
35.
Date: 05/30/93
Mean Lat: 24.2855 N
Mean Long: –37.4544 E
Mean: 30.8733
Std: 1.5640

Figure D-110

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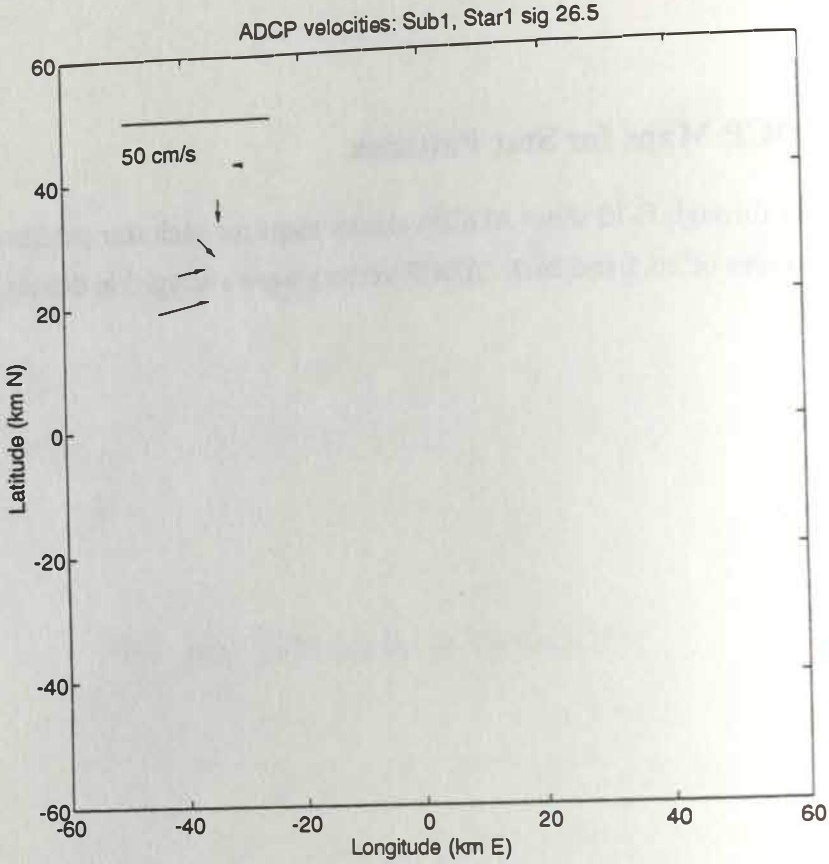
Appendix E: ADCP Maps for Star Patterns

Figures E-1 through E-12 show ADCP velocity maps for each star pattern on potential density surfaces of 26.5 and 26.7. ADCP vectors were averaged in density space over 0.05 sigma theta.


ADCP velocities: Sub1, Star1 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

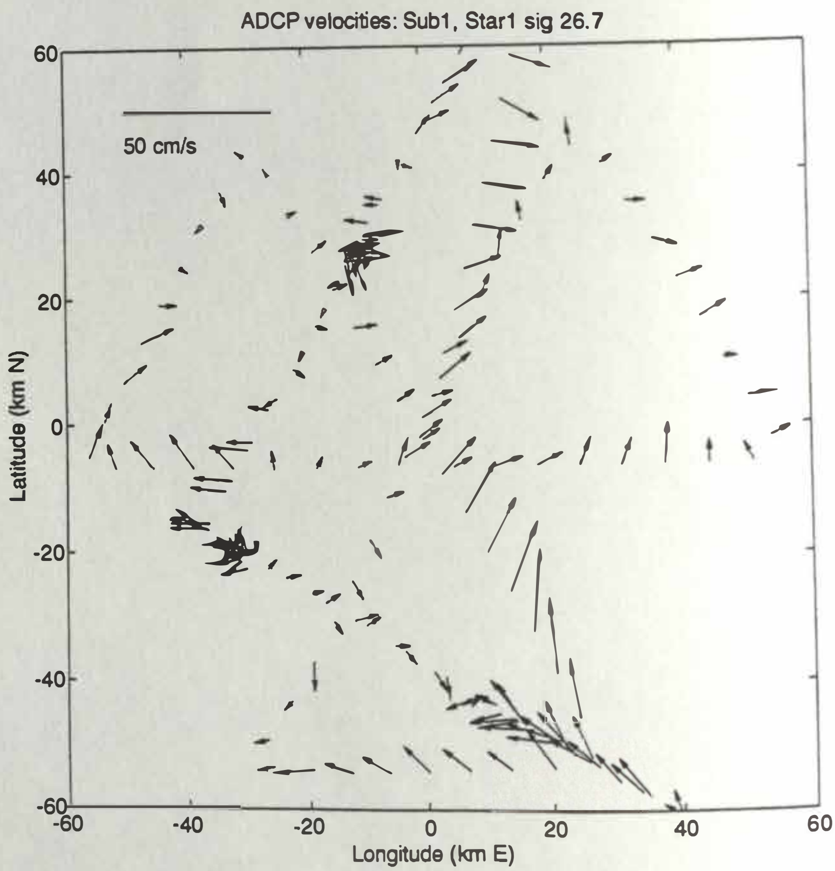
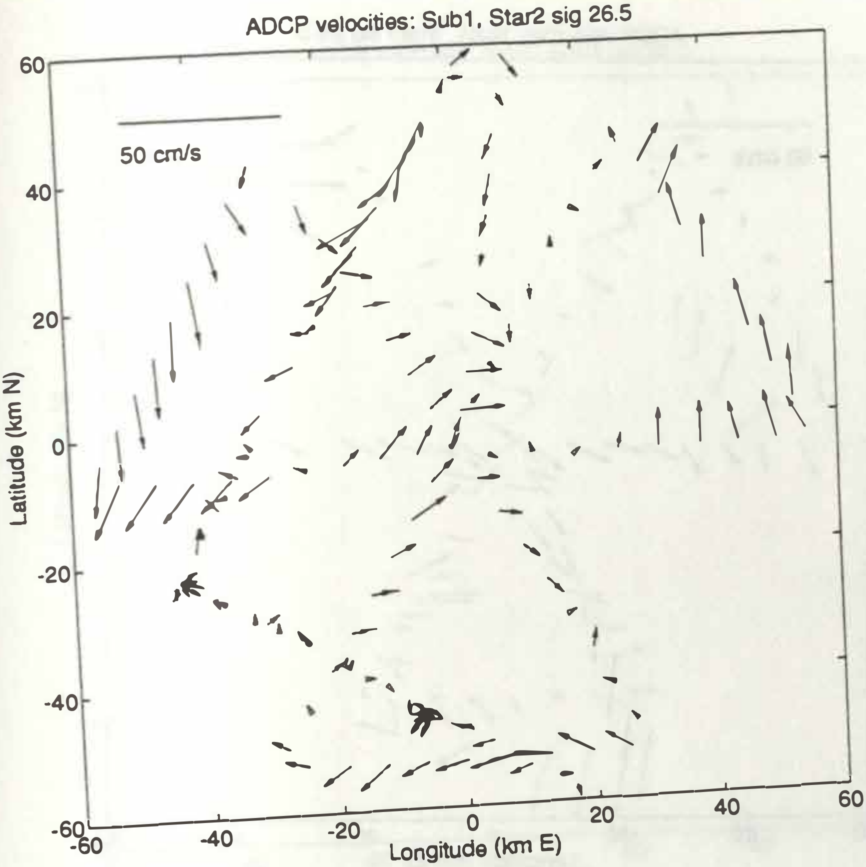

ADCP velocities: Sub1, Star1 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-1


ADCP velocities: Sub1, Star2 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

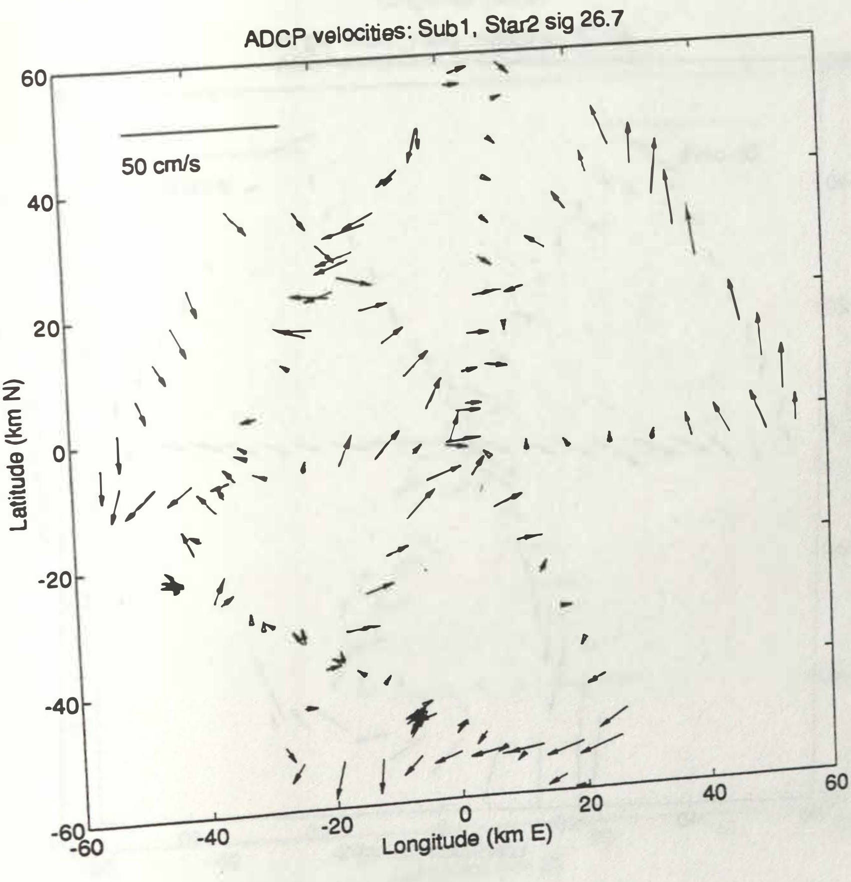
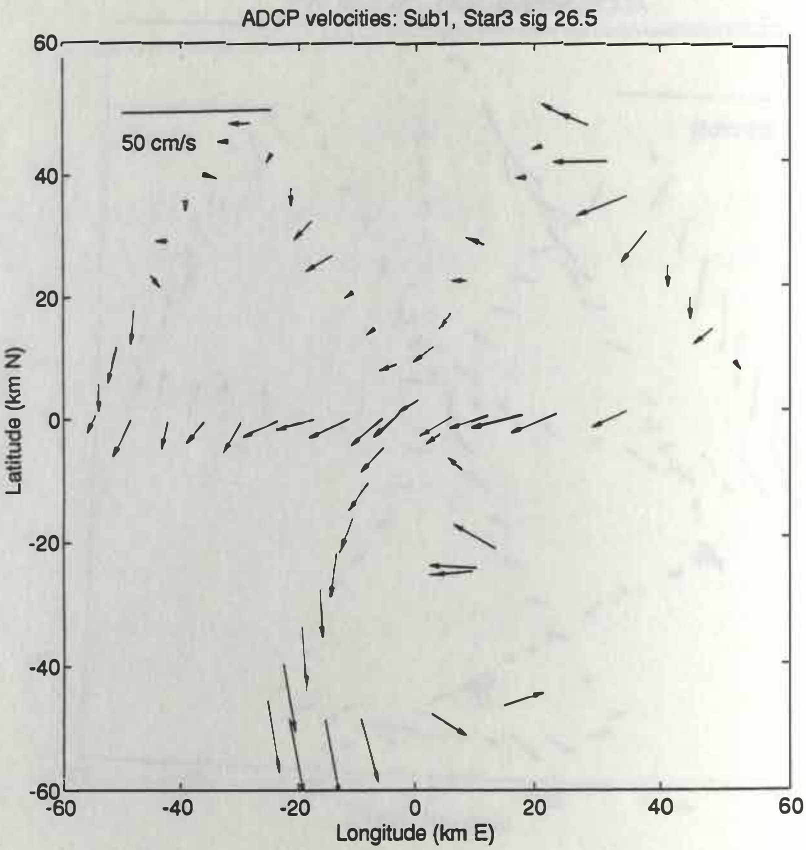

ADCP velocities: Sub1, Star2 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-2


ADCP velocities: Sub1, Star3 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

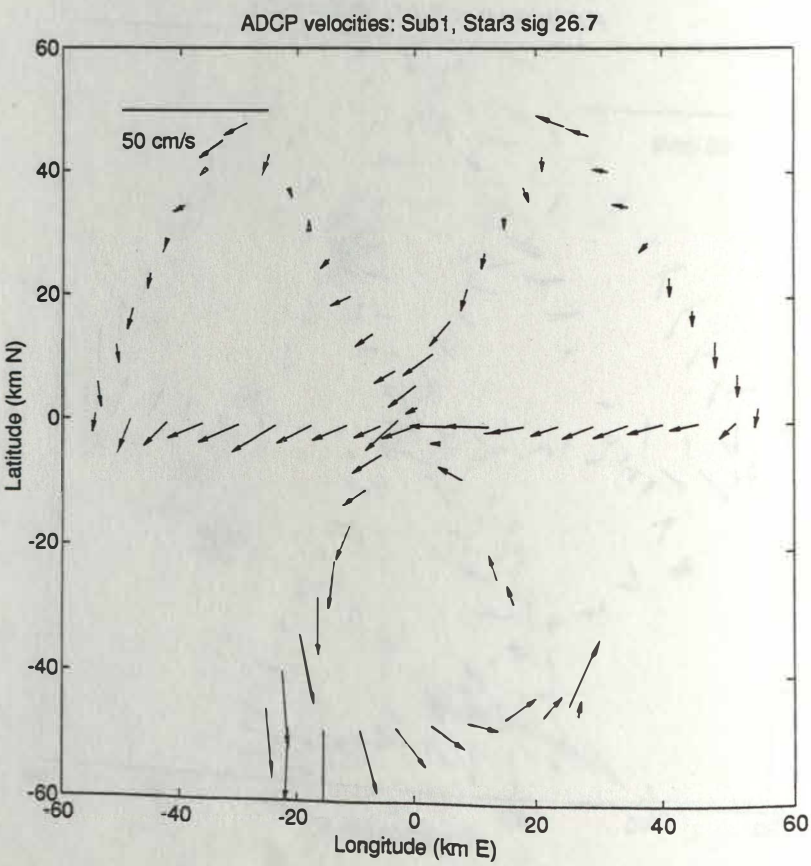
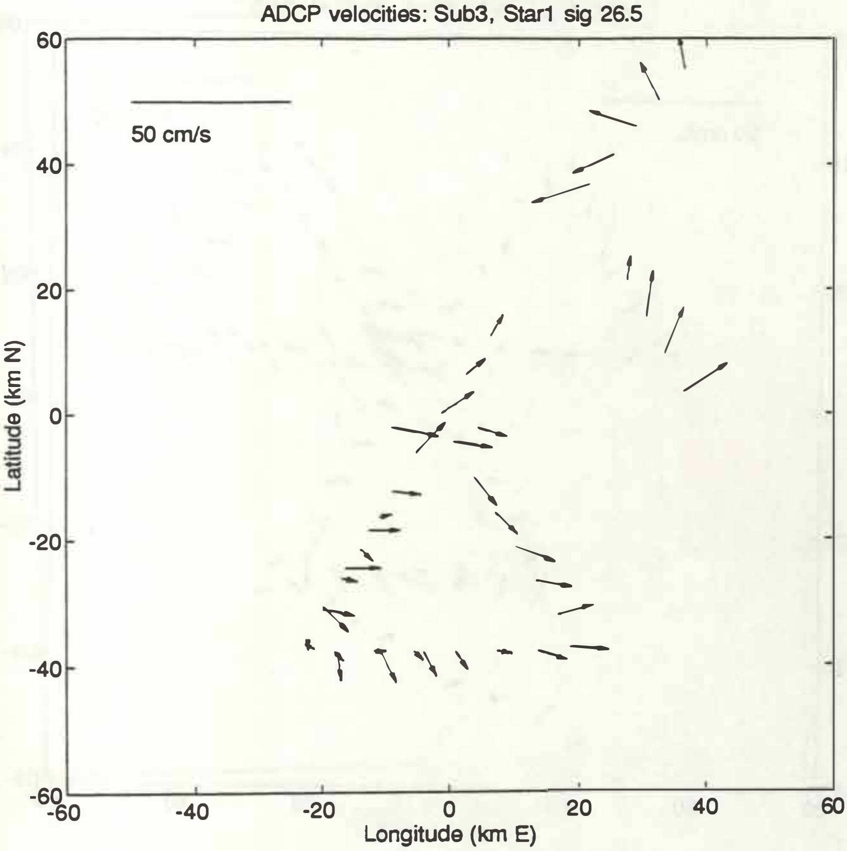

ADCP velocities: Sub1, Star3 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-3


ADCP velocities: Sub3, Star1 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

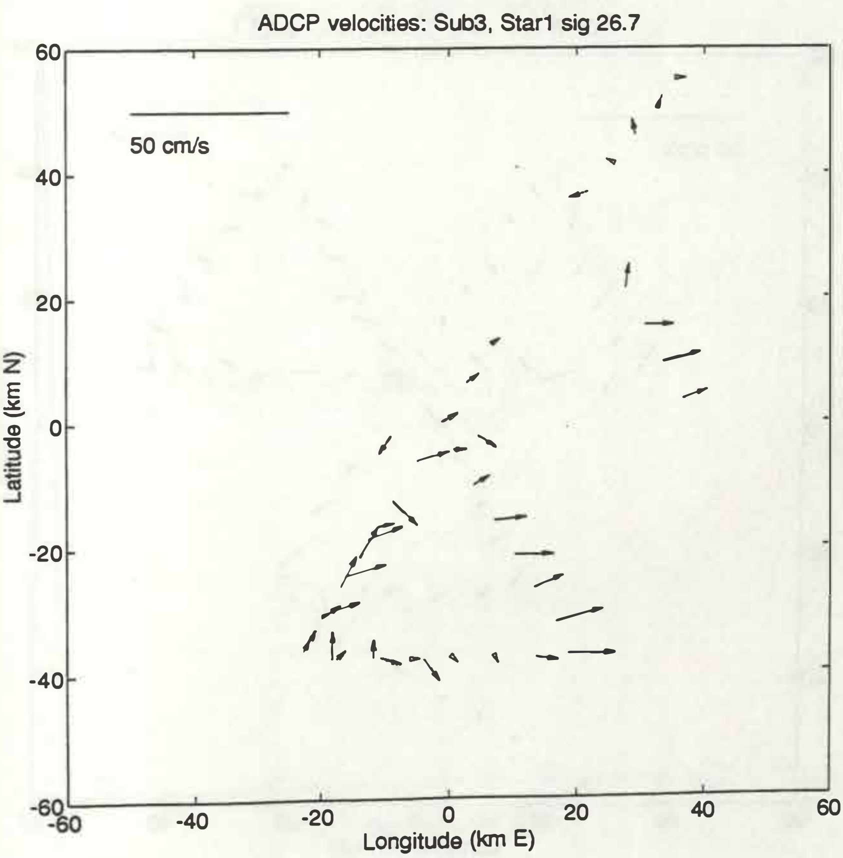
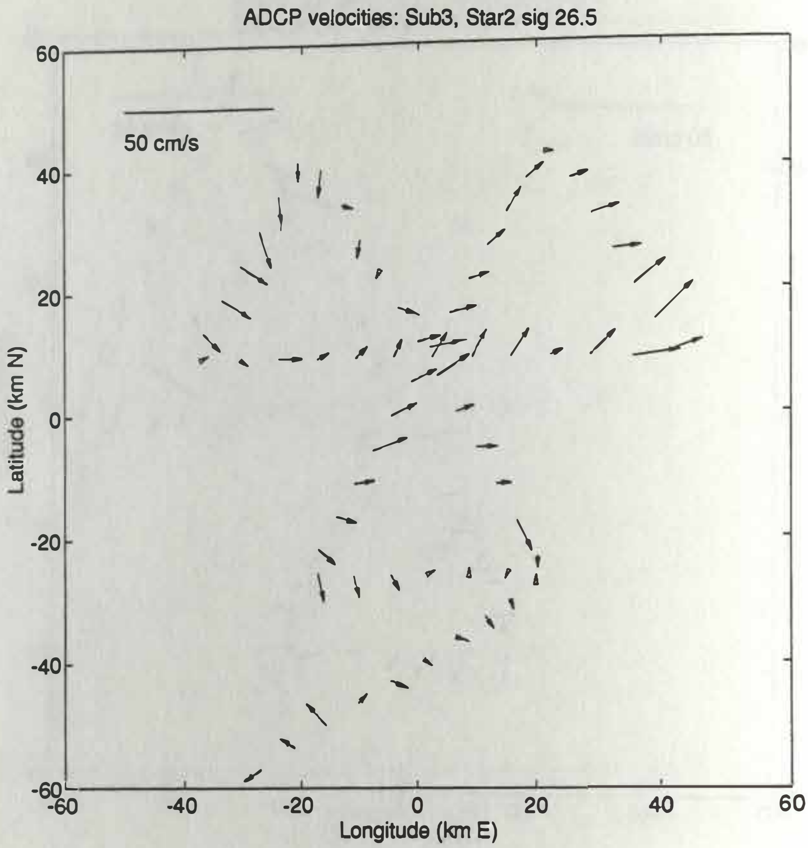
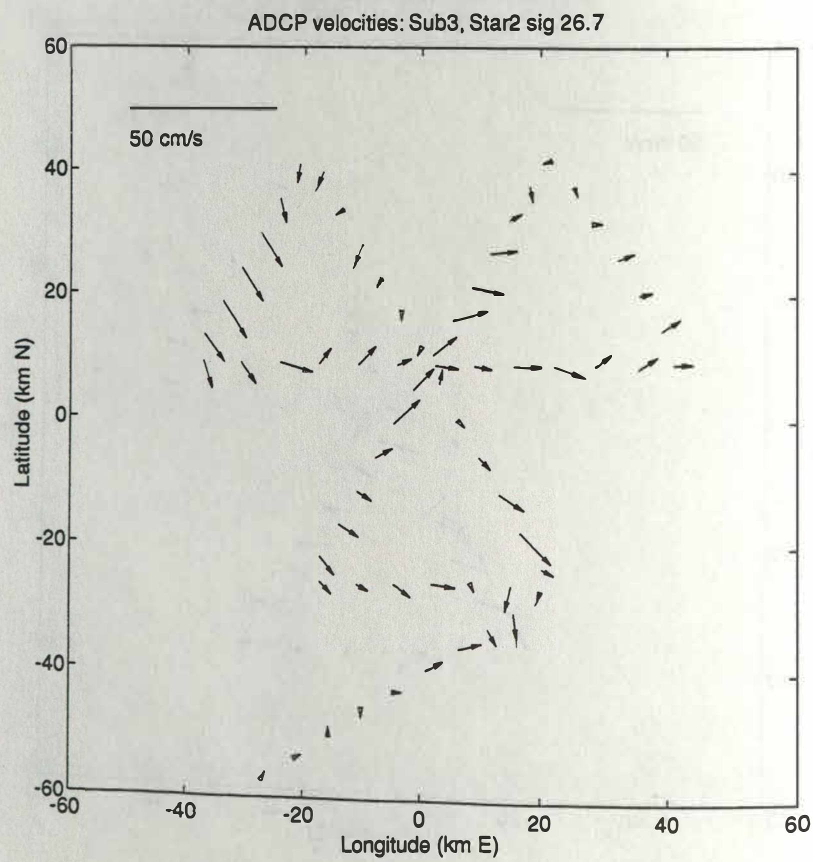

ADCP velocities: Sub3, Star1 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-4

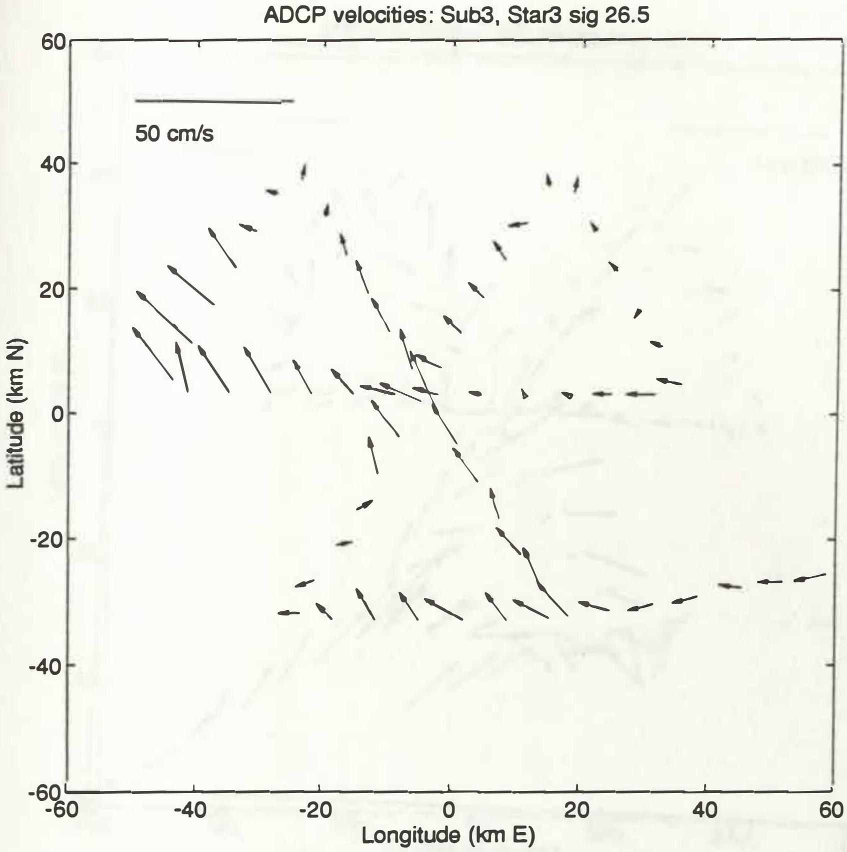


ADCP velocities: Sub3, Star2 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60



ADCP velocities: Sub3, Star2 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-5


ADCP velocities: Sub3, Star3 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

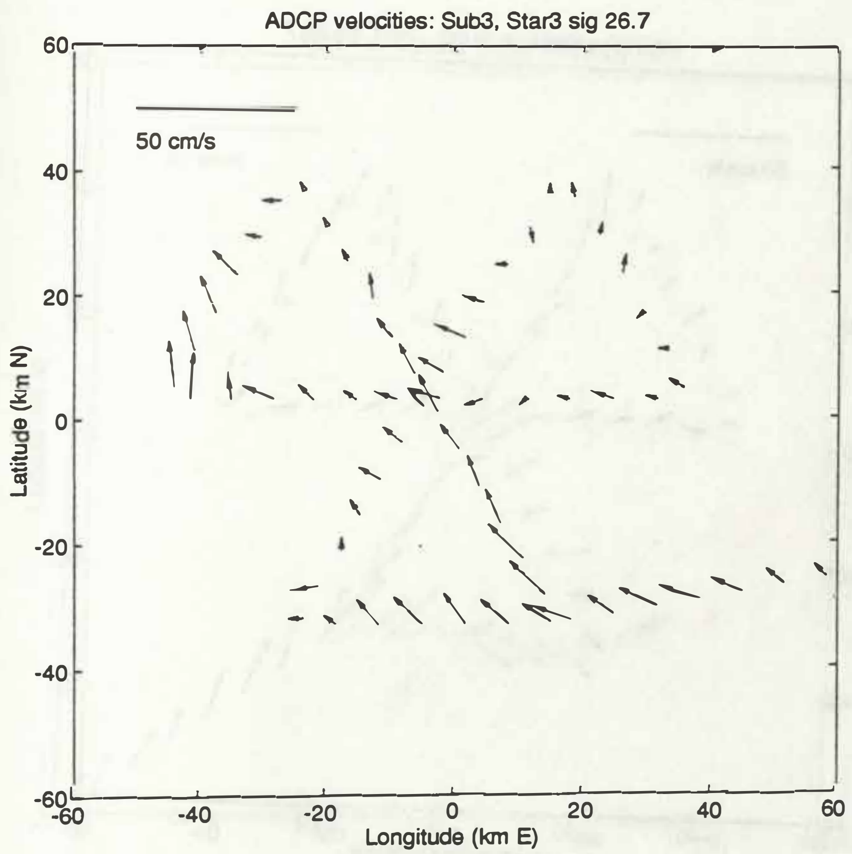

ADCP velocities: Sub3, Star3 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-6

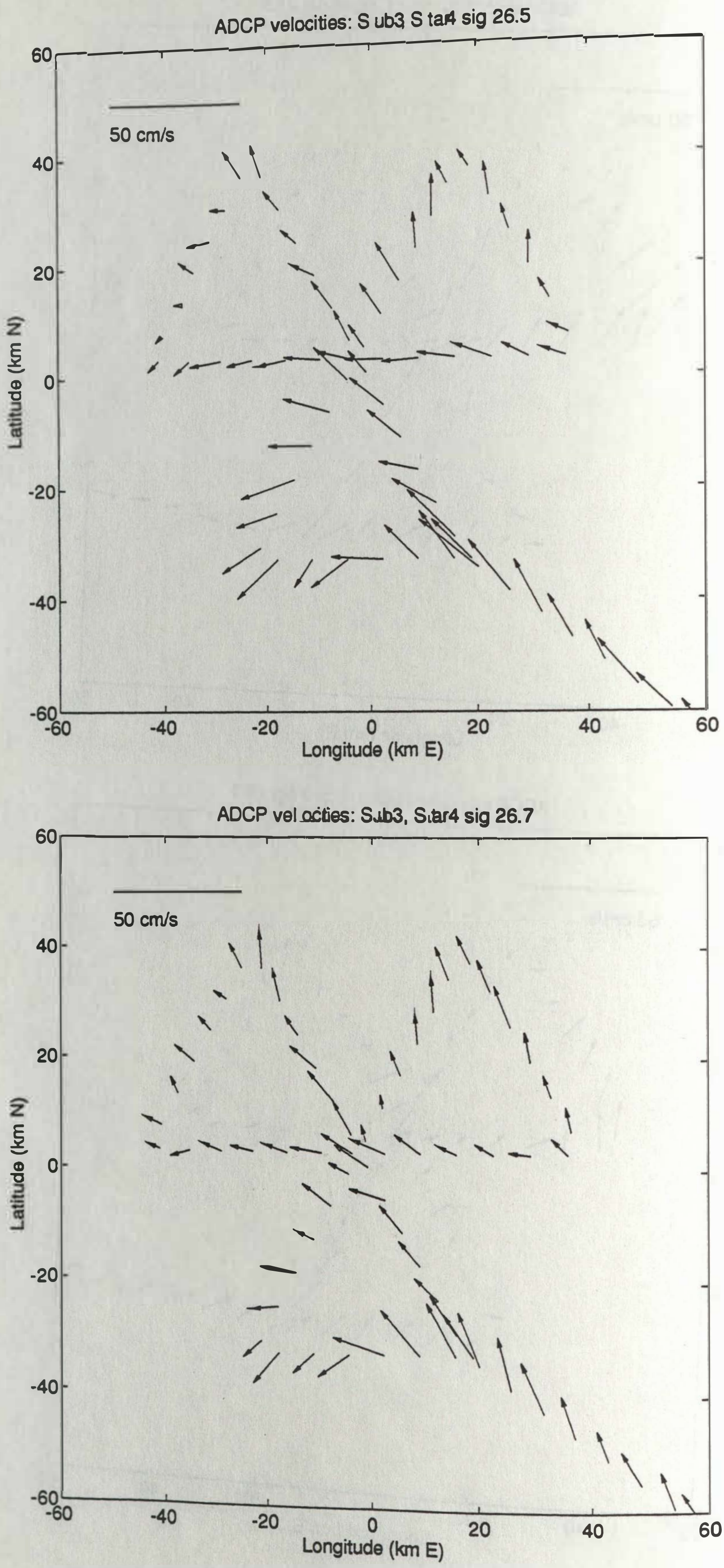
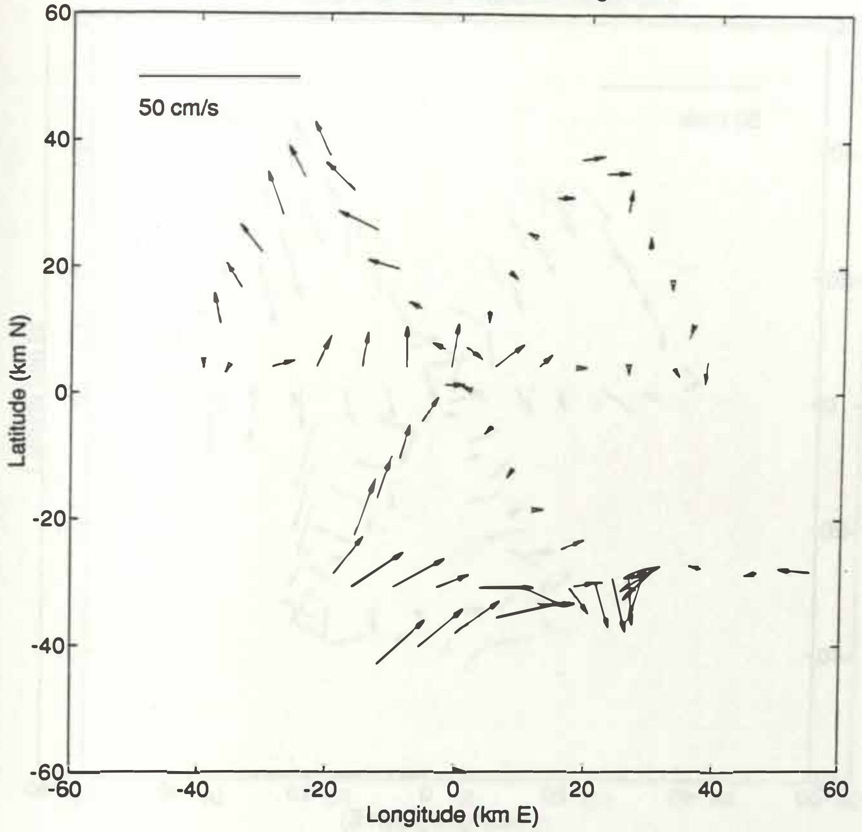

ADCP velocities: Sub3, Star4 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
ADCP velocities: Sub3, Star4 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)

Figure E-7

ADCP velocities: Sub3, Star5 sig 26.5



ADCP velocities: Sub3, Star5 sig 26.7

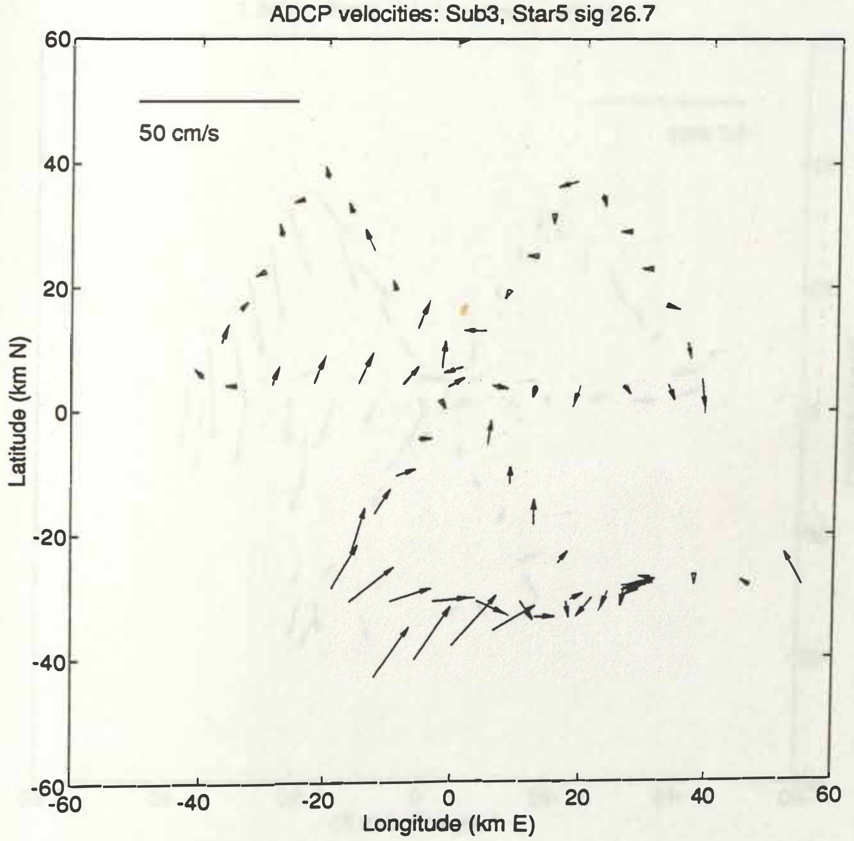
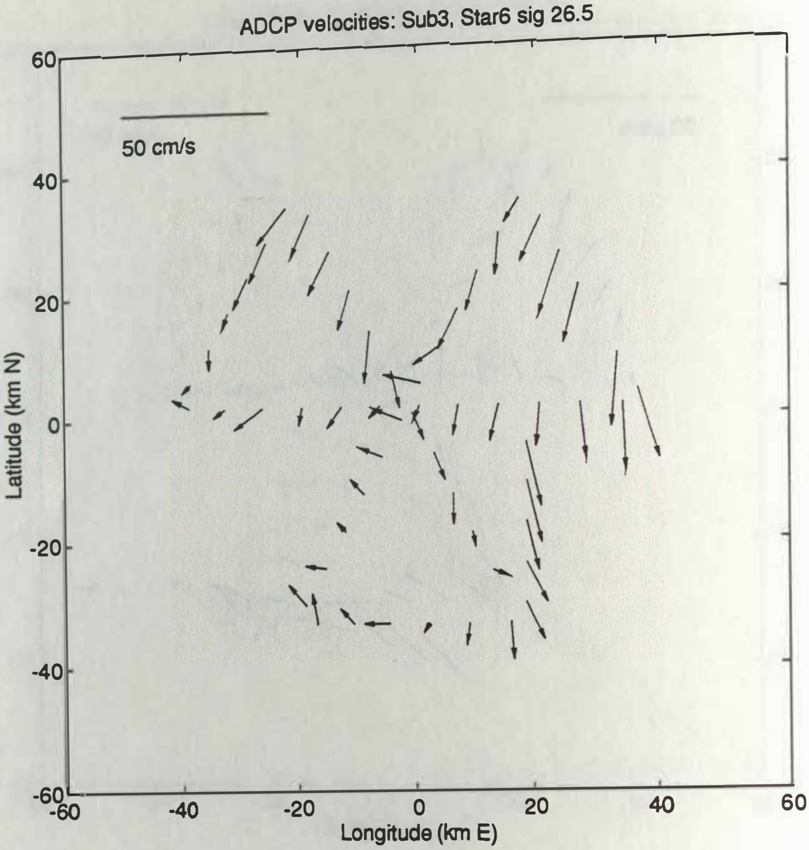


Figure E-8


ADCP velocities: Sub3, Star6 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

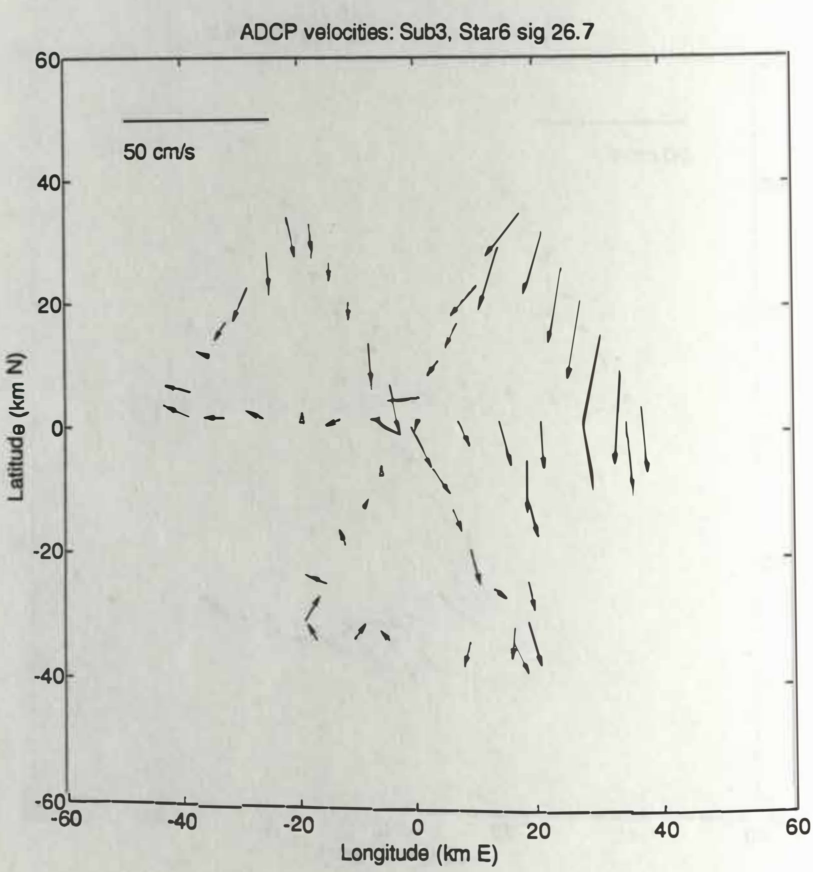

ADCP velocities: Sub3, Star6 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-9

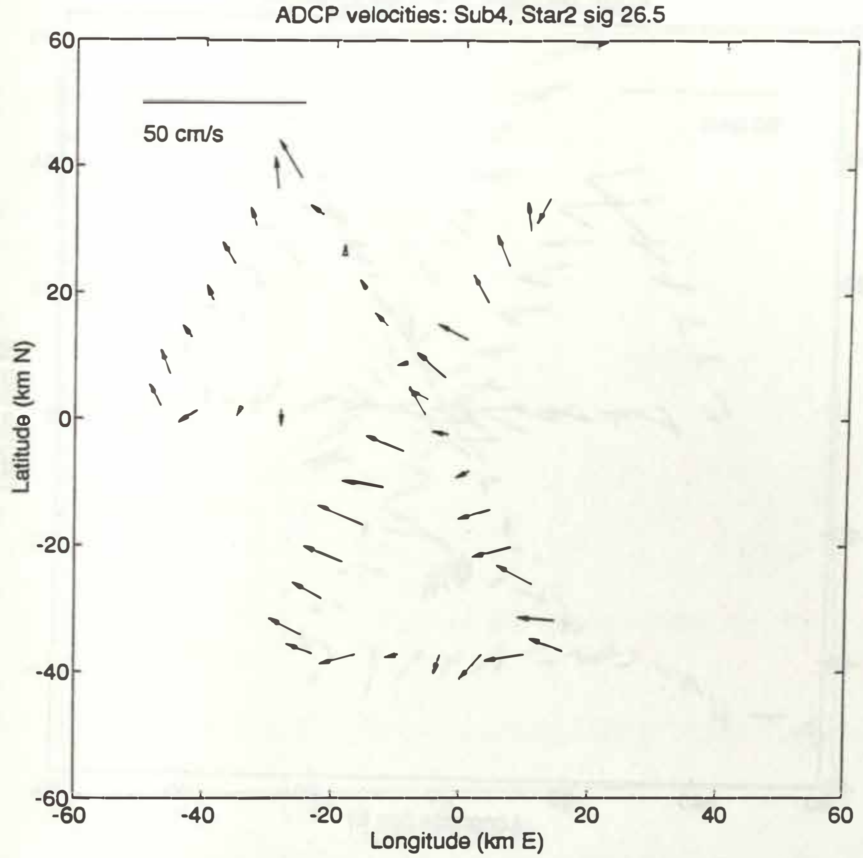
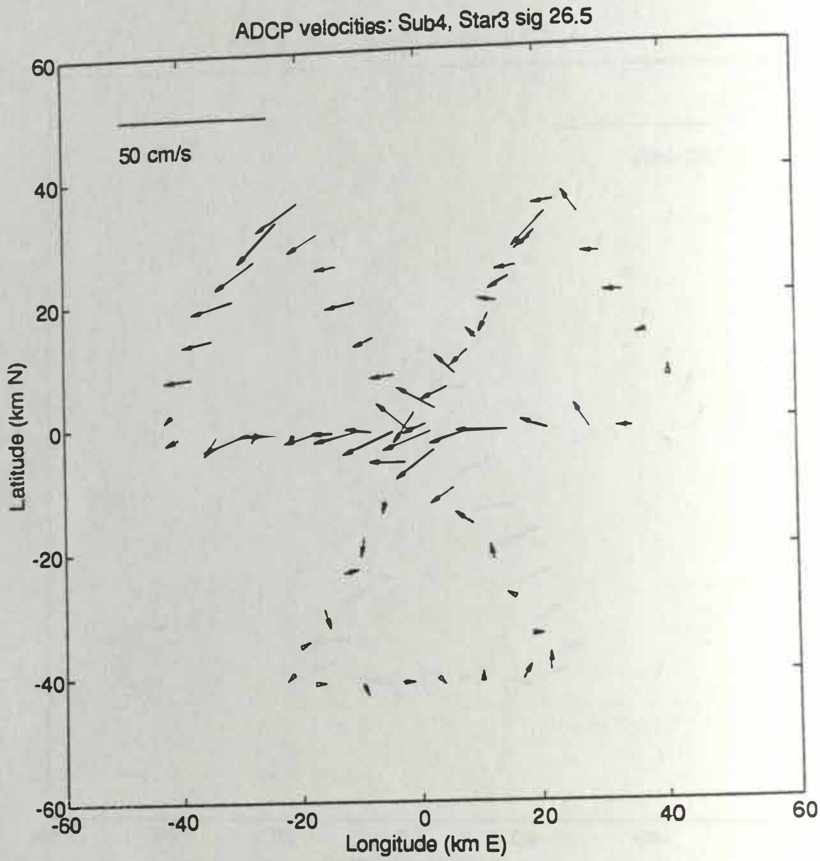
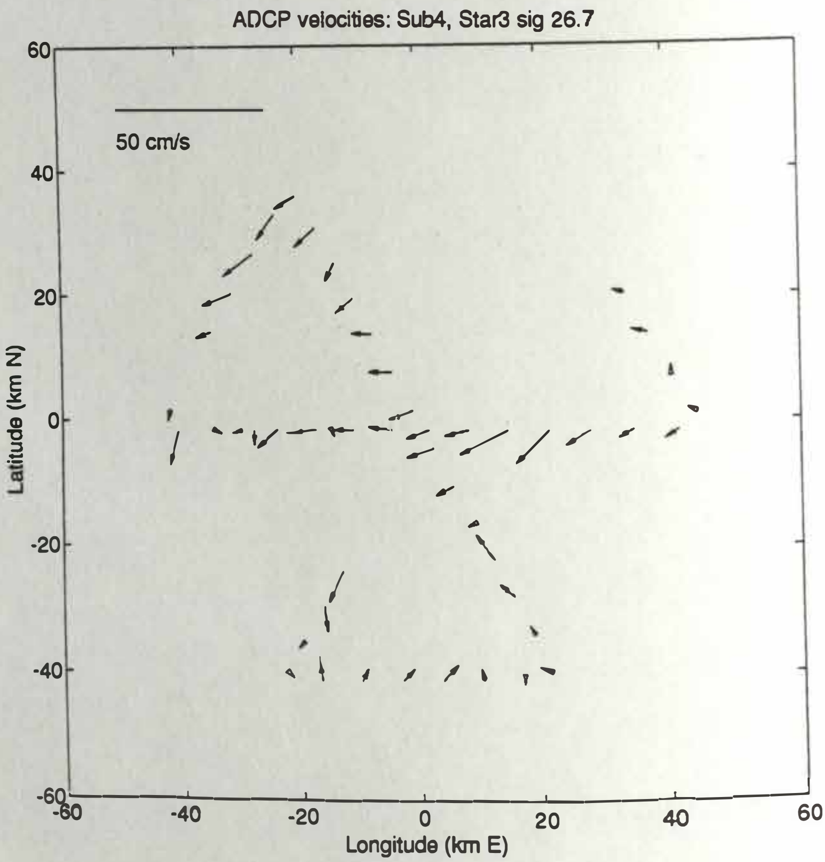

ADCP velocities: Sub4, Star2 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-10

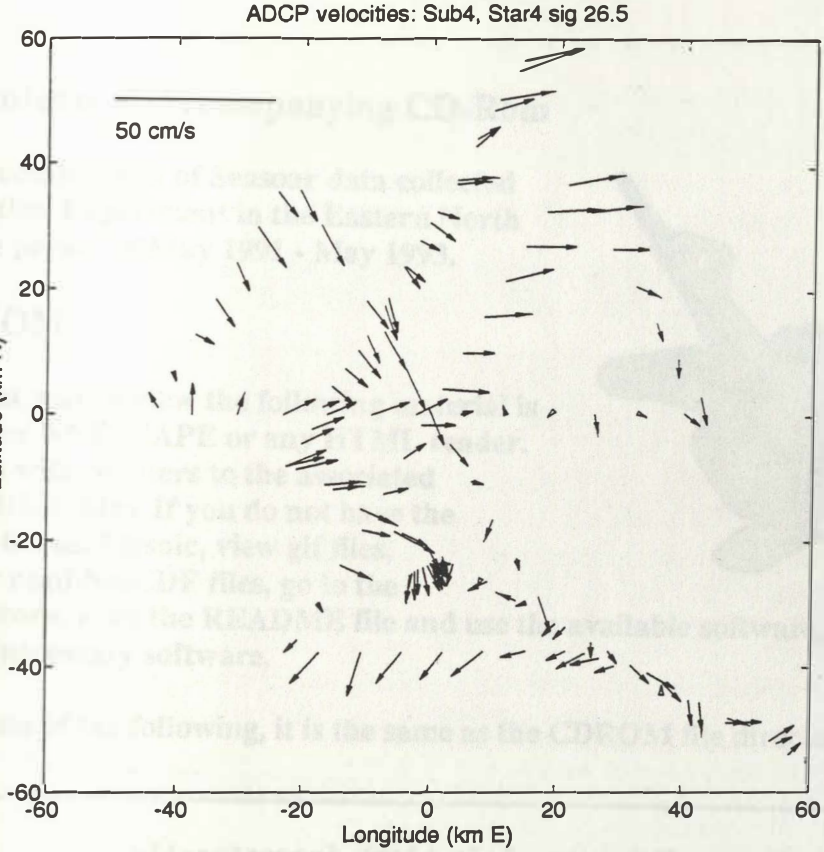


ADCP velocities: Sub4, Star3 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60



ADCP velocities: Sub4, Star3 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-11


ADCP velocities: Sub4, Star4 sig 26.5
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

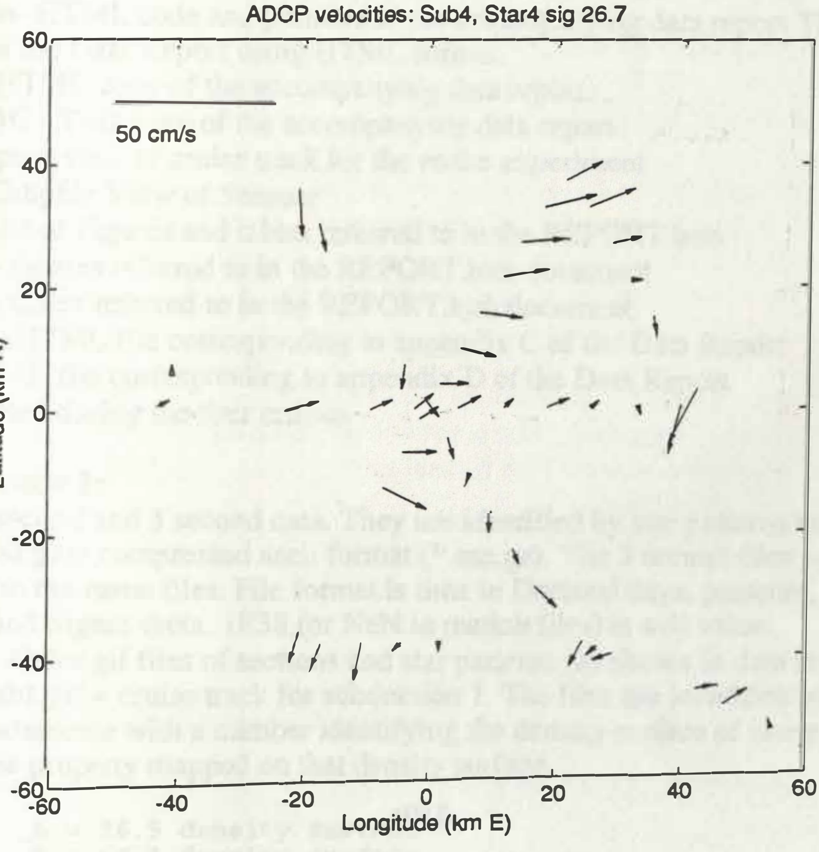

ADCP velocities: Sub4, Star4 sig 26.7
50 cm/s
Latitude (km N)
Longitude (km E)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60

Figure E-12

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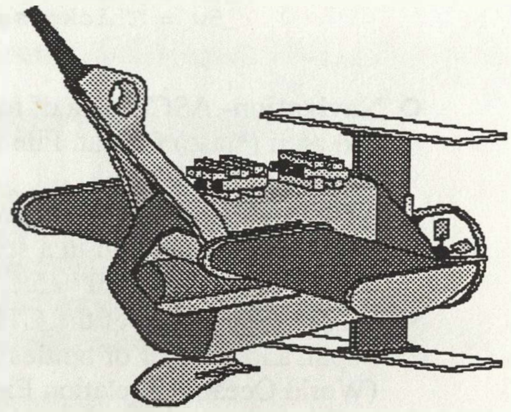
Appendix F: Contents of Accompanying CD-Rom



This CDROM is a compilation of Seasoar data collected during the Subduction Experiment in the Eastern North Atlantic during the period of May 1991 - May 1993.

TO READ CDROM

The most convenient way to view the following material is by using MOSAIC or NETSCAPE or any HTML reader. This file is repeated with pointers to the associated directories in README.htm. If you do not have the necessary software to run Mosaic, view gif files, uncompress files or read NetCDF files, go to the miscellaneous directory, read the README file and use the available software, or instructions on how to retrieve the necessary software.

The CDROM consists of the following, it is the same as the CDROM file directory structure:

- **README** - Readme file (same as this without html code)
- **REPORT.htm**- HTML code and pointers to the accompanying data report TEXT.htm. Start with this file to view the Data Report using HTML format.
- **TEXT.htm** - HTML copy of the accompanying data report.
- **REPORT.DOC** - Text copy of the accompanying data report
- **map.gif** - Graphic view of cruise track for the entire experiment
- **seasoar.gif** - Graphic View of Seasoar
- **figure.con** - List of Figures and tables referred to in the REPORT.htm
- **figure1-9.gif** - figures referred to in the REPORT.htm document
- **table1-2.doc** - tables referred to in the REPORT.htm document
- **transect.htm** - HTML file corresponding to appendix C of the Data Report
- **star.htm** - HTML file corresponding to appendix D of the Data Report
- **Photos** - collected during the four cruises

- **Subduction Cruise 1:**
  - **Data** - 1 second and 3 second data. They are identified by star patterns in both matlab (*.mat) and gzip compressed ascii format (*.asc.gz). The 3 second files are delineated by an _3 added to the name files. File format is time in Decimal days, pressure, temperature, Salinity, and Sigma-theta. 1E38 (or NaN in matlab files) is null value.
  - **Gif files** - Color gif files of sections and star patterns (as shown in data report in black and white). Sub1.gif = cruise track for subduction 1. The files are identifies by star pattern name, plus an underscore with a number identifying the density surface of interest, and a letter to identify the property mapped on that density surface.

```
_5 = 26.5 density surface
_7 = 26.7 density surface
```

```
_9 = 26.9 density surface
_5p = pressure on density surface 26.5
_5t = Theta on density surface 26.5
_5w = Thickness on density surface 26.5
```

- **Navigation**- ASCII data of navigation averaged over 15 minute intervals in matlab (*.mat) and ascii (*.asc) format. File format is time in Decimal days, longitude (E), latitude (N) and number of fixes.
- **ADCP** - ASCII data of adcp vector files for star patterns. File format is 89 column. For each 30 minute time period in a star pattern time, latitude, longitude and u,v pairs from 16 - 352 m every 8m. 1E38 is null value.
- **CTD** - ASCII files of the CTD stations taken during this cruise. Station locations, time, max depth, and number of bottles is described in the file OC240_2.sum. The files are in WOCE (World Ocean Circulation Experiment) format and each has an header with the date of the cruise, station number cast number, number of records and parameter names and units. There is also a quality flag as described below:

```
1 = Not calibrated with water samples
2 = Acceptable measurement
3 = Questionable measurement
4 = Bad measurement
5 = Not Reported
6 = Interpolated value
9 = Not samples
Bad data value = -9.00
```

Explanation of the WOCE format is described in *WOCE Operations Manual: Volume 3: Section 3.1: Part 3.1.2: Requirements for WHP Data Reporting*. WHP Office Report WHPO 90-1, WOCE Report No. 67/91. July 1991. Rev. 1. Woods Hole, MA USA.

- **Frontal Surveys**
  - **Sub1** - CTD data from the SeaSoar is provided in 15 minute temporal by 8 m vertical bins and stored in netcdf format. One frontal survey was completed during Subduction 1 data is in file sub1c.cdf. The netcdf format is independent of operating system and/or platform, making it a convenient means of data exchange. Netcdf software is available from ftp.unidata.ucar.edu in /pub/netcdf. A set of matlab routines to read and write netcdf files is available from crusty.er.usgs.gov in /pub/mexcdf. The visualization tool FERRET allows the netcdf files to be examined interactively. FERRET is available from abyss.pmel.noaa.gov in /pub for a variety of machines. The netcdf headers for each file are listed in *c.cdl.
  - **Sub2** - see description above. Two frontal surveys were completed for Subduction 2 in files sub2s1.cdf and sub2s2c.cdf.
  - **ADCP** - ADCP data is provided in 15 minute temporal by 8 m vertical bins and stored in netcdf format. The files are named *a.cdf and *a.cdl.
- **Subduction Cruise 3:**
  - **Data** - See description of Subduction 1
  - **Gif files** - See description of Subduction 1
  - **Navigation** - One navigation file for all entire cruise. File format same as Subduction 1.
  - **ADCP** - See description of Subduction 1
  - **CTD** - See description of Subduction 1. Summary of CTD stations is located in file OC254_4.sum.
- **Subduction Cruise 4:**

- **Data** - See description of Subduction 1
- **Gif files** - See description of Subduction 1
- **Navigation** - See description of Subduction 1
- **ADCP** - See description of Subduction 1. ADCP data not available until midway through the 2nd star pattern (5/31 14:10).
- **CTD** - See description of Subduction 1. Summary of CTD stations is located in file OC258_3.sum.

- **Engineering Data:** - For more detailed information read the README file.
  - **Programs** - Basic programs. Sub3cd.exe (Subduction 3 executable), Sub4cd.exe (Subduction 4 executable). *.bas are the quick basic program.
  - **Subduction 3 Data** - Subduction 3 - Star 3 data in ascii format used for above program.
  - **Subduction 4 Data** - Subduction 4 transit 3-5 (this includes engineering test of "flying" the Seasoar) in ascii format used for above program.
- **Miscellaneous:** - For more detailed information read the README file.
  - **gifview** - viewers for gif files without and within Mosaic. (dos, Sun4 versions)
  - **gzip** - used to uncompress ascii data files with .gz suffix(dos, Sun4 versions).
  - **MexCDF** - Reader for Netcdf files in conjuction with MATLAB (dos, Sun4 versions).
  - **Mosaic** - Mosaic for reading html files and viewing data (dos, Sun4 versions).
- **BACKUP Directory:**
  - **Subduction 1**- Processed Matlab data files used in objective mapping for star patterns during Subduction 1.
  - **Subduction 3**- Processed Matlab data files used in objective mapping for star patterns and long transects during Subduction 3.
  - **Subduction 4**- Processed Matlab data files used in objective mapping for star patterns and long transects during Subduction 4.

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16. Abstract (Limit: 200 words)

The overall objective of the Subduction Accelerated Research Initiative (ARI) was to bring together several techniques to address the formation and evolution of newly formed water masses. The Seasoar component provided surveys of temperature and salinity to help determine the spatial variability of the temperature, salinity and density fields in both the active frontal regions and in the vicinity of subducting water tagged by bobbers. Data were collected in the eastern North Atlantic Ocean in spring 1991, sinter 1992, winter 1993 and spring 1994. "Star" patterns were used to study the mesoscale variability. Temperature, pressure and thickness for each pattern were objectively mapped on potential density surfaces of 26.5, 26.7 and 26.9 kg/m^3. Acoustic Doppler Current Profiles (ADCP) maps were also created for the the two shallower density surfaces. We describe the Seasoar data collected during the four cruises. A CD-Rom includes 1- and 3-second conductivity-temperature-depth (CTD), cruise navigation, ADCP and Seasoar engineering data, as well as color figures of these data. This data report can also be viewed using an internet information browser (i.e., Mosaic, Netscape) using the provided CD-Rom.

17. Document Analysis a. Descriptors

Seasoar
subduction
ADCP

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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