NOAA Technical Memorandum ERL AOML-71

SHIPBOARD ACOUSTIC DOPPLER CURRENT PROFILER DATA COLLECTED DURING THE SUBTROPICAL ATLANTIC CLIMATE STUDIES (STACS) PROJECT (1989-1990)

W. Douglas Wilson
J. Allison Routt

Atlantic Oceanographic and Meteorological Laboratory
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UNITED STATES DEPARTMENT OF COMMERCE

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Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Acknowledgements

Thanks go to the crew and officers of the the NOAA Ship MALCOLM BALDRIGE, especially to the survey department, for their assistance in data collection, and to the personnel from NOAA's Atlantic Marine Center for system installation and maintenance. We also thank Bob Molinari, Mark Bushnell, and Bill Jelke of AOML for help with data collection and processing. This work was funded as part of the Subtropical Atlantic Climate Program , a NOAA-sponsored study of climate variability in the North Atlantic.

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1. Introduction

The Subtropical Atlantic Climate Studies (STACS) Program of NOAA is directed at determining the role of ocean circulation in global atmospheric climate, providing data for numerical model verification, and developing monitoring strategies for climatically important circulation features. The initial emphasis of STACS was on the subtropics, where earlier studies suggested that oceanic heat flux in the Atlantic is a maximum (Molinari, 1989). Results of an intensive two-year study of the Florida Current at 27 ° N provided data on its role in Atlantic circulation and oceanic heat flux (Molinari, et. al. 1985; Leaman, et. al. 1987). The study also provided a system for monitoring this current on a long-term basis. Shipboard data from this study can be found in Williams et al. (1983), Leaman and Vertes (1983), Vertes and Leaman (1984), and Ratnaswamy et al. (1985).

From 1984-1986 STACS efforts were concentrated on the Florida Current and its relationship to circulation in the Caribbean Sea and the area of the Antillean Archipelago. Data from cruises during this period are presented in Wilburn et al. (1987a,b). STACS was further extended southward in 1987 in an effort to determine the contribution of cross-equatorial boundary currents to heat flux in the Atlantic basin; see Wilburn et al. (1988) and Wilburn and Wilson (1991) for data from these cruises.

Several of the STACS cruises were undertaken aboard the NOAA Ship MALCOLM BALDRIGE. In November of 1988 an acoustic Doppler current profiler (ADCP) manufactured by R D Instruments of San Diego, California was mounted aboard the BALDRIGE. The profiler measures current shear in the 300 - 400 meters below the ship; when referenced using accurate ship velocity measurements, the shears can be used to estimate absolute current velocities. This report presents the ADCP data obtained during STACS cruises in the western subtropical and tropical Atlantic in August 1989, June 1990 and September 1990. Table 1 presents a detailed summary of the cruises covered in this report.

2. The ADCP System

The ADCP system installed on the NOAA Ship MALCOLM BALDRIGE can be divided into several components; descriptions follow of the ADCP hardware (2.1), the ADCP Data Acquisition System software (DAS) (2.2), and the navigation instrumentation (2.3). The raw

Table 1. 1989 - 1990 STACS cruises on the NOAA Ship Malcolm Baldrige

August 1989 (STACS 34)

Actual dates: 22 August - 22 September, 1989
Chief Scientist: Dr. Robert Molinari, NOAA / AOML
Port Calls: Miami, FL, 22 August; Martinique, F.W.I, 27-28August; Martinique, F.W.I., 15-17 September; Miami, FL, 22 September.
Other Research Activities: CTD, XBT, Current meter moorings, Pegasus velocity profiler, XCTD, Inverted Echo Sounder moorings, oxygen and nutrient analysis

June 1990 (STACS 36)

Actual dates: 15 June - 11 July, 1990
Chief Scientist: Dr. Robert Molinari, NOAA / AOML
Port Calls: Miami, FL, 15 June; Hopetown, Abaco, Bahamas, 29 June; Miami, FL, 11 July
Other Research Activities: CTD, XBT, Pegasus velocity profiler, Current meter moorings, Inverted Echo Sounder moorings, oxygen, nutrients, and Freon analysis.

September 1990 (STACS 37)

Actual dates: 7 September, 1990 - 10 October , 1990
Chief Scientist: Dr. Robert Molinari
Port Calls: Miami, FL, 7 September; Martinique, F.W.I, 16 September; Martinique, F.W.I., 6 October; Miami, FL, 10 October.
Other Research Activities: CTD, XBT, Pegasus velocity profiler, Current meter moorings, Electromagnetic moorings, oxygen and nutrients analysis, Inverted Echo Sounder moorings.

ADCP shear data are edited, combined with the navigation data, and averaged in space and time using data processing procedures described in section 2.4.

2.1 ADCP Hardware

The ADCP on the MALCOLM BALDRIGE is a vessel-mounted 153.6 kHz RD Instruments high powered unit. A good description of the RD systems and general ADCP theory is found in the publication "Acoustic Doppler Current Profilers Principles of Operation: A Practical Primer", available from RD Instruments. The four-beam ADCP transducer has an overall diameter of 43.5 cm and is mounted in an open sea chest located just to starboard of centerline nearly halfway aft on the vessel, at a nominal depth of 6 meters. During these cruises, the beam 3 - beam 4 axis was aligned nominally parallel to the vessel's centerline, and the transducer was not removed between installation in 1988 and removal for routine maintenance following the September 1990 cruise. Each beam is inclined facing inward ("concave" configuration) 30 degrees from the vertical; the acoustic beams have an approximately 4 degree beam width.

The transducer is connected by cable to a deck box in the ship's computer room containing the power transformer and signal generation and processing equipment. The profiler deck box is connected to the data acquisition computer (an IBM-compatible 10 mHz 286/287 system). Ship's gyrocompass information is input into the deck box with .1 degree resolution via a synchro to digital interface.

2.2 Data Acquisition System

Data were collected using the RD Instruments DAS, version 2.32 in 1989 and version 2.48 in 1990. Standard setup parameters used for the cruises were: 55 8-meter bins; 4 meter blanking; 8 meter pulse length; continuous pings with one minute ensemble averaging; a reference layer of bins 5 to 20; error velocity screening at 30 cm/s; and no three beam solutions. Heading compensation was on so that averaging occurred in an earth coordinate sytem. Sound speed was kept fixed at 1536 cm/s so that post-processing corrections could be easily applied. In 1989 and June 1990, data were logged to 3.5 inch floppy disks; in September 1990 data were logged to a virtual disk on a microVAX via DECnet. A subset of each data ensemble containing

velocity data but without data quailty information was also exported via serial port to the ship's microVAX-based "SCS" data collection system for real time display and logging. Data commonly stored on the PC system were U, V, W, and error velocities; backscatter amplitude ("AGC"); percent good pings; and average spectral widths. Bottom track was turned on whenever water depths were less than 500 meters, with bottom and water track pings interleaved 1:1. With this configuration and the transducer's nominal depth of six meters, the first range bin covers the depths 10-18 meters, the second 18-26 meters, etc.

2.3 Navigation

Navigation data were logged using the MALCOLM BALDRIGE's microVAX-based data collection system. A Magnavox 1102 GPS/Transit satellite navigator output GPS fix information (time, position, course and speed over ground, and fix quality information) to the system at five second intervals when GPS coverage was available. All Transit fixes,including quality informaition, were also stored. The satellite navigation unit had course and speed inputs from the ship's gyro and a dual-axis Ametek-Straza speed log, for improved Transit fix accuracy.

3. Data Processing

The DEC VAX-VMS based ADCP processing system has been evolving since 1982 at AOML and has been described in Bitterman & Wilson (1983) and Wilson, et. al. (1988). In preparation for data processing, PC clock drift is determined from the ADCP data stored on the ship's data collection system by comparing PC time with GPS time. The ADCP DAS PC has shown a steady drift of 23.5 seconds per day; its clock is reset only at the beginning of each cruise to make time correction easier. The ensemble data are then transferred from the PC to a VMS machine and converted and stored in a standard binary format; corrected ensemble output times are included in this data set. If data from the ship's thermosalinograph are available, values of sound speed for each ensemble are calculated and the velocities are corrected accordingly; otherwise, velocities are corrected using sound speeds generated from the ADCP temperature sensor and an appropriate estimate of salinity. Depths of the velocity cells are not corrected for sound speed; nominal values (generally 8 meters) are used.

Continuous GPS data provide the best navigation; all data sets in this report were collected prior to the imposition of Selective Availablity position degradation on the GPS system. GPS data are processed as follows: Speed over ground and course over ground are converted to U and V velocity. Small gaps (10 - 60 seconds) in position and velocity are filled with interpolated values, and the position and the data are low pass filtered using a Butterworth filter with a one minute cutoff. Another velocity vector at each time is also generated by differentiating a running one-minute quadratic fit to the position data. Position and both velocity pairs are then averaged over ADCP ensemble intervals; means and standard deviations are stored. These ensemble values are quality checked based on standard deviation and by comparing the two velocity values. Restricting velocity values to those which agree to within 10 cm/s rejects a small percentage of potentially bad velocities and positions, usually associated with rapid course or speed changes. The mean of the two velocity estimates is used as the ship speed associated with the ensemble.

Ship speed estimates are also made using discrete navigation points; included in this data set are the Transit fixes (edited based on elevation and iteration criteria), and the first and last points of a set of continuous GPS fixes. This method, described in Kosro (1985) and Wilson and Leetmaa (1988), involves the intermediate calculation of a mean reference layer absolute velocity. Averaged between fixes, the reference level velocity is the difference between the ship's speed (corrected for heading bias) relative to the reference layer (a vertical average of several bins) and the ship's speed over the ground, based on the position fixes. This procedure is usually run several times, with fixes causing obviously spurious reference velocities removed after each run. The absolute reference layer velocities are discontinuous at position fixes; the reference layer velocity field, including values calculated from continuous GPS data, is smoothed with a 6-hour window. Resulting reference layer velocities are added to shears for each ensemble for a ship speed estimate; ship speeds are dead-reckoned forward in time to estimate a position for each ensemble. Since the best reference level is one of minimum velocity variability, we do this for several layers, i.e. deep, shallow, and full water column.

The primary data base used for further analysis consists of ensemble values of velocity and data quality information, plus one or more values of ship speed and position. When the data base is accessed, a ship speed and position source is selected, the velocities are corrected for heading bias, and velocity shear profiles are edited using selected amplitude and percent good

levels, and to remove bottom interference and other obvious errors. All of the plots in this report are based on fifteen minute averages of the data in this data base, with GPS navigation used when available, and an appropriate Transit-derived navigation set used otherwise.

4. Calibration

While the ADCP transducer is carefully installed to be properly aligned with the centerline of the ship, this is a difficult task and rarely acheived within the required tolerance. Due to the ship's relatively high speed through the water, the effects of transducer misalignment are amplified - the error introduced into the cross-track velocity component is proportional to the sine of the misalignment angle. A one degree misalignment results in cross-track velocity error of 12 cm/s at 14 knots. Standard calibration procedures are described in Joyce(1988) and Pollard and Read (1989). Misalignment errors are divided into a rotational misalignment and a scale factor, which can be determined empirically from the data. Using a method of comparing underway currents just before and after a station to the on-station currents, we estimated a misalignment of 0.8 degrees and a scale factor of 1.01. These numbers remained constant for all three cruises, attesting to: 1) their representativeness of the actual misalignment; and 2) relatively stable behaviour by the ship's gyrocompass.

5. Data Presentation

Two types of velocity figures are presented in this report, plan view vector plots of current velocites averaged over a vertical range, and cross-sections of eastward or northward current velocity. Both types are based on fifteen-minute averages of the shear and navigation ensembles. Whenever available, GPS navigation was used for velocity referencing; otherwise, the best available Transit / reference layer velocities were chosen. Trackline diagrams preceding each cruise section show the distribution of GPS and Transit satellite navigation data.

In the vector plots, fifteen minute data are horizontally and vertically averaged onto a square grid, with the resultant current vector centered in the grid. Grid size is listed in the figure captions. In the cross-section plots, the data are first interpolated to 10 meter depths. Positions are projected onto a section representing a linear fit to all the data positions in the section, and horizontally gridded for contouring. The horizontal grid size varies with the scale of the section;

grid size is listed in the figure captions. Data may be linearly interpolated through single grid point gaps; larger gaps are left blank in the plots. Latitudes and longitudes along the X-axis represent the endpoints of the section. Contour intervals are 10 cm / second. Velocity is resolved into eastward and northward components (U and V in common oceanographic terminology) regardless of section orientation. In plots of eastward component, **westward** flow is shaded; in plots of northward component, **southward flow** is shaded.

References

Bitterman, D. and D. Wilson, 1983. Ocean current profiling with a shipboard Doppler acoustic backscatter system, **OCEANS '83, 1**, 27-31, 1983.

Joyce, T. M., 1989. On in-situ "calibration" of shipboard ADCP's. **J. Atmos. Oceanic Technol., 6**, 169-172.

Kosro, P. M., 1985. Shipboard acoustic current profiling during the Coastal Ocean Dynamics Experiment, Ph.D. thesis, **SIO Ref 85-8**, 119 pp., Scripps Institute of Oceanography, La Jolla, CA

Leaman, K. D., R. L. Molinari, and P. S. Vertes, 1987. Structure and variability of the Florida Current at 27 ° N: April 1982 - July 1984. **J. Phys. Oceanogr., 17,** 565 - 583.

Leaman, K. D., and P. S. Vertes, 1983. The Subtropical Atlantic Climate Studies (STACS), 1982. Summary of RSMAS Pegasus Observations in the Florida Straits. Technical Report, UM RSMAS No. 83012, 154 pp.

Molinari, R. L., W. D. Wilson, and K. D. Leaman, 1985. Volume and heat transport of the Florida Current: April 1982 through August 1983. **Science, 227**, 295-297.

Molinari, R. L. 1989. Subtropical Atlantic Climate Studies (STACS): An update. **Oceanography**, 32 - 35.

Pollard, R. and J. Read, 1989. A method for calibrating ship-mounted acoustic Doppler current profilers, and the limitations of gyrocompasses. **J. Atmos. Oceanic Technol., 6**, 859 - 865.

Ratnaswamy, M. J., D. Wilson, and R. L . Molinari, 1985. Current velocity and hydrographic observations in the Straits of Florida: Subtropical Atlantic Climate Study (STACS), 1983 and 1984. NOAA Data Report ERL AOML-05.

RD Instruments, 1989. Acoustic Doppler Current Profilers Principles of Operation: A Practical Primer. 36 pp. RD Instruments, San Diego, CA.

Vertes, P. S., and K. D. Leaman, 1984. The Subtropical Atlantic Climate Studies (STACS), 1983. summary of RSMAS Pegasus Observations in the FLorida Straits. Technical Report UM RSMAS No. 84002, 172 pp.

Wilburn, A. M., E. Johns, and M. Bushnell, 1987a. Current velocity and hydrographic observations in the Straits of Florida, the Caribbean Sea, and offshore of the Antillean Archipelago: Subtropical Atlantic Climate Studies (STACS), 1984 and 1985. NOAA Data Report ERL AOML-8, 194 pp.

Wilburn, A. M., E. Johns, and M. Bushnell, 1987b. Current velocity and hydrographic observations in the Straits of Florida, the Caribbean Sea, and offshore of the Antillean Archipelago: Subtropical Atlantic Climate Studies (STACS), 1986. NOAA Data Report ERL AOML-10, 247 pp.

Wilburn, A. M., E. Johns, and M. Bushnell, 1988. Current velocity and hydrographic observations in the southwestern North Atlantic Ocean: Subtropical Atlantic Climate Studies (STACS), 1987. NOAA Data Report ERL AOML-12, 86 pp.

Wilburn, A. M., and D. Wilson, 1991. Shipboard acoustic Doppler current profiler data collected during the Subtropical Atlantic Climate Studies (STACS) Project (1983 - 1986). NOAA Data Report ERL AOML-20, 172 pp.

Williams, E. J., E. Marmolejo, D. Wilson, and R.L. Molinari, 1983. Current velocity profiles from the Straits of Florida from the Pegasus current profiler: Subtropical Atlantic Climate Studies (STACS), 1982. NOAA Technical Memorandum ERL AOML-55, 181 pp.

Wilson, D., C. Roffer, and D. Bitterman, 1988. The shipboard acoustic Doppler current program at AOML. **EOS, Trans, AGU, 67(44)**, p. 1061.

Wilson, D. and A. Leetmaa, 1988. Acoustic Doppler current profiling in the equatorial Pacific in 1984. **J. Geophys. Res., 93**, 947 - 966.

Appendix A Data from STACS 34 August 1989

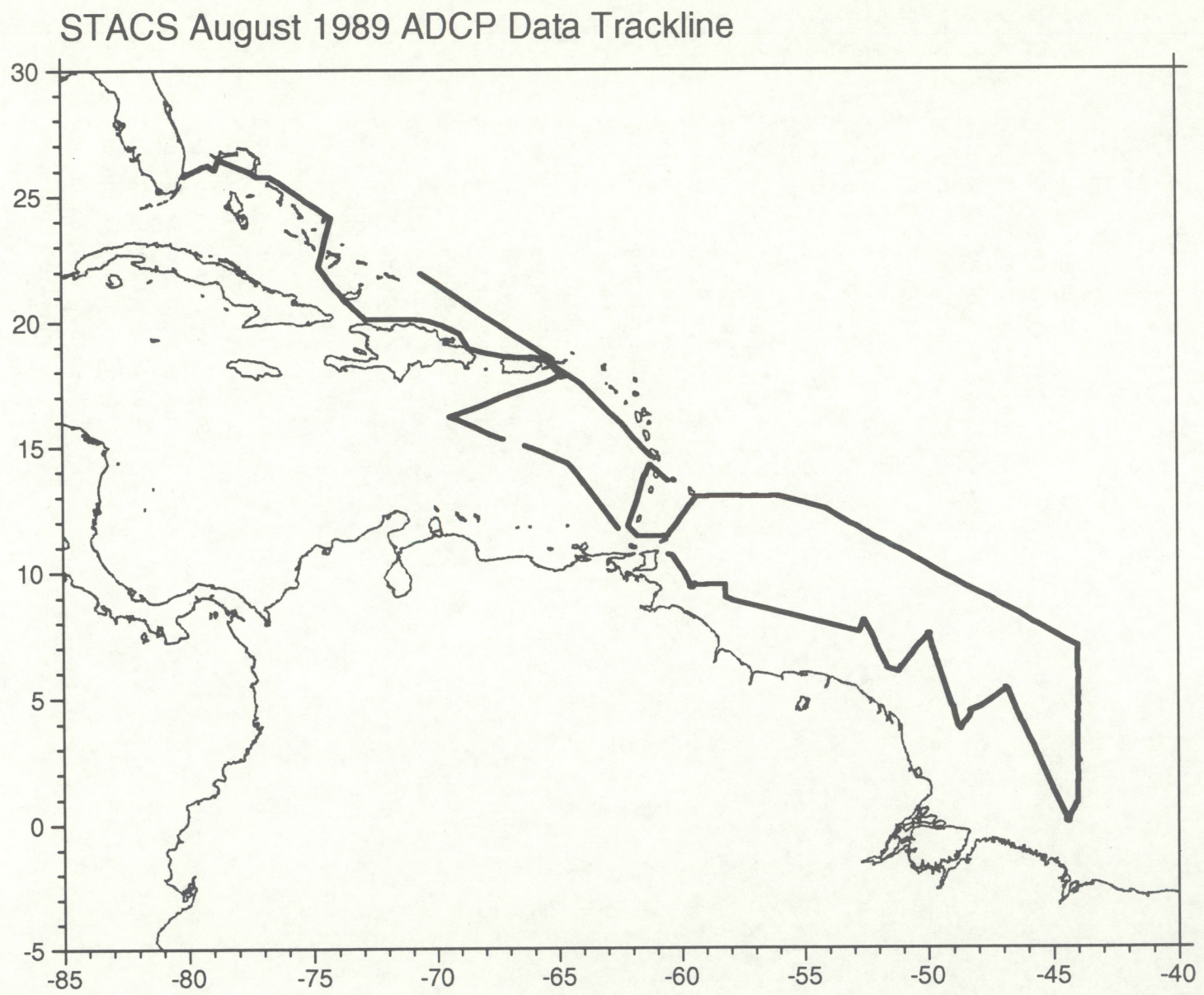
STACS August 1989 ADCP Data Trackline
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Figure A.1

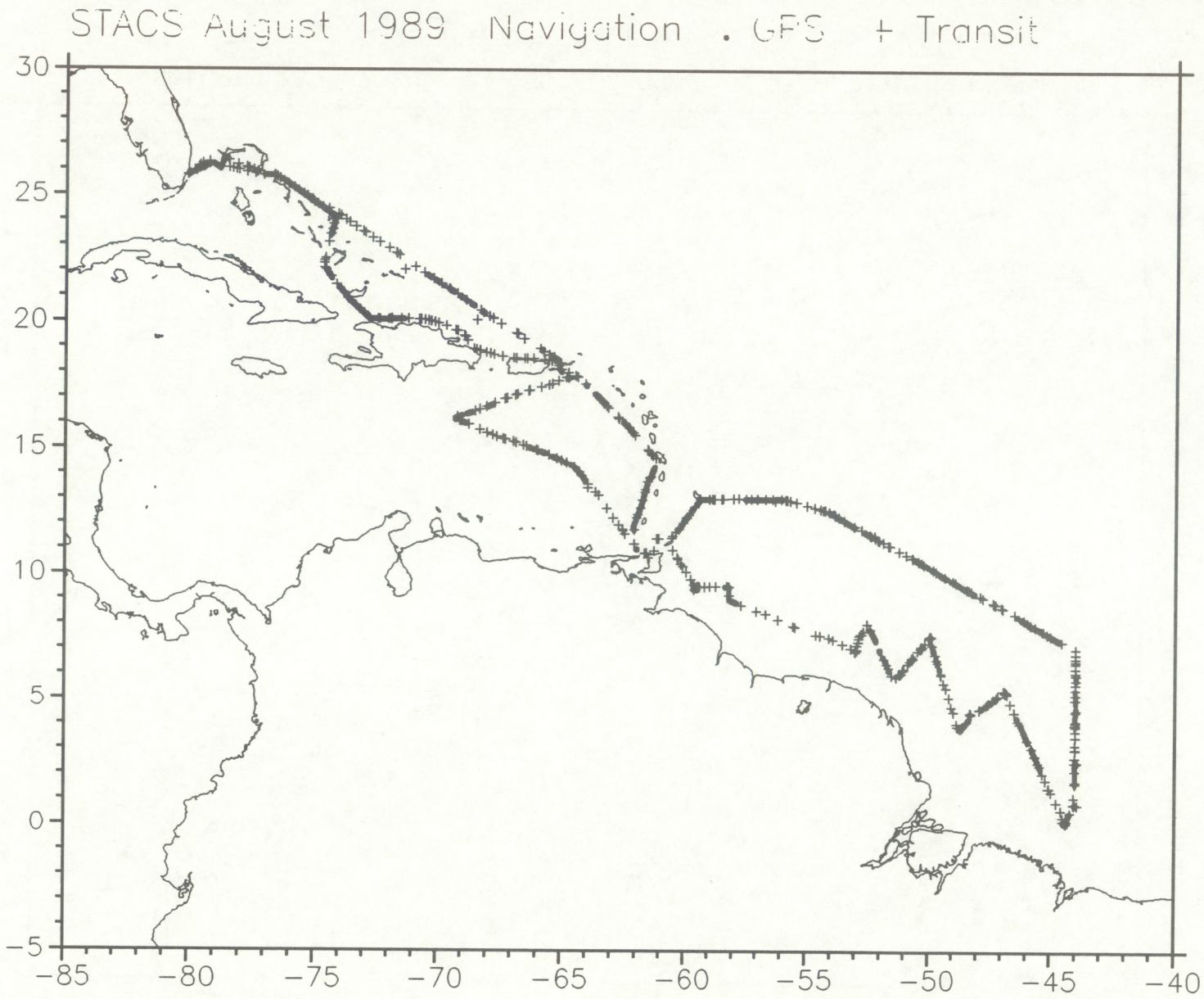


Figure A.2 Navigation Coverage

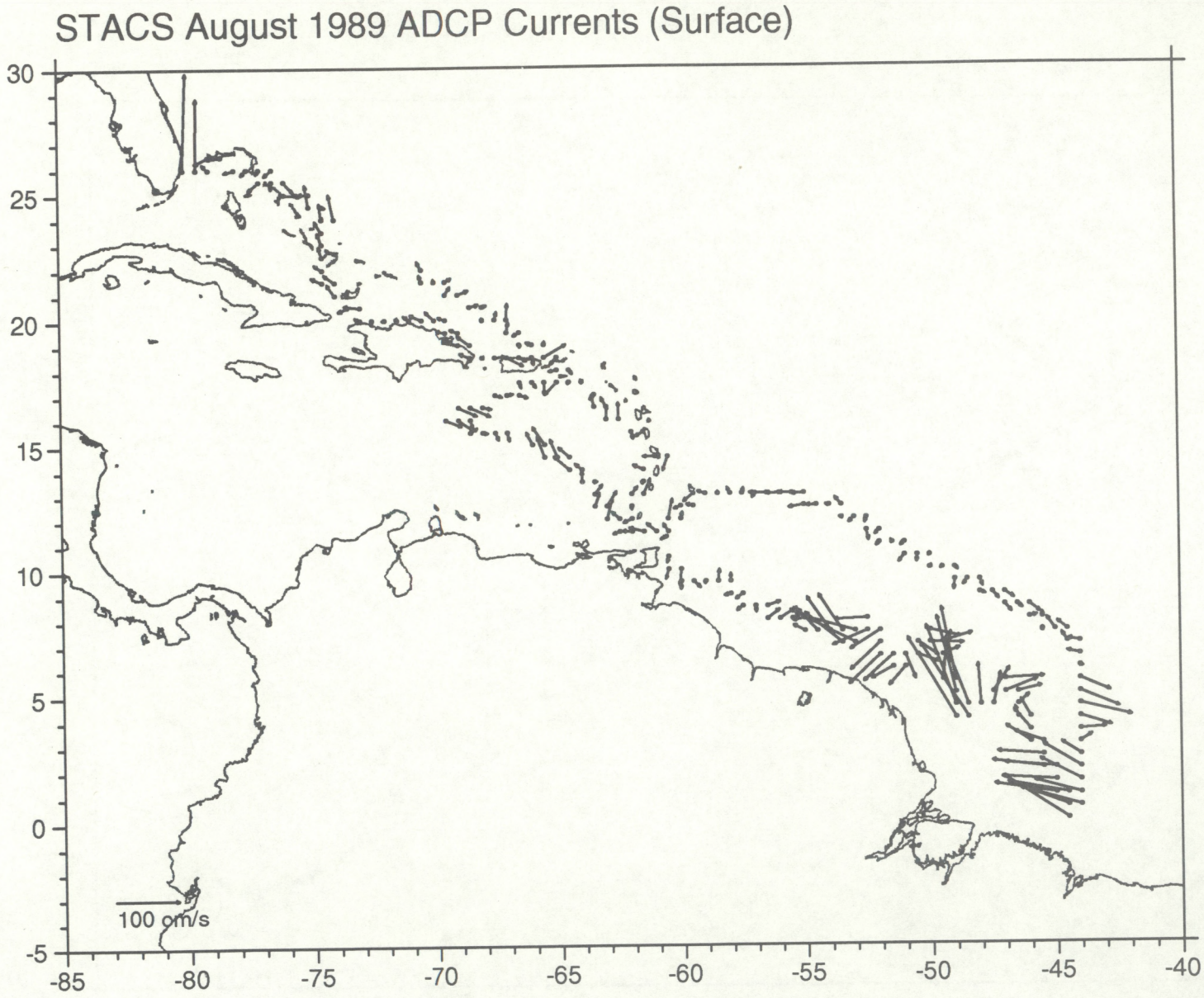
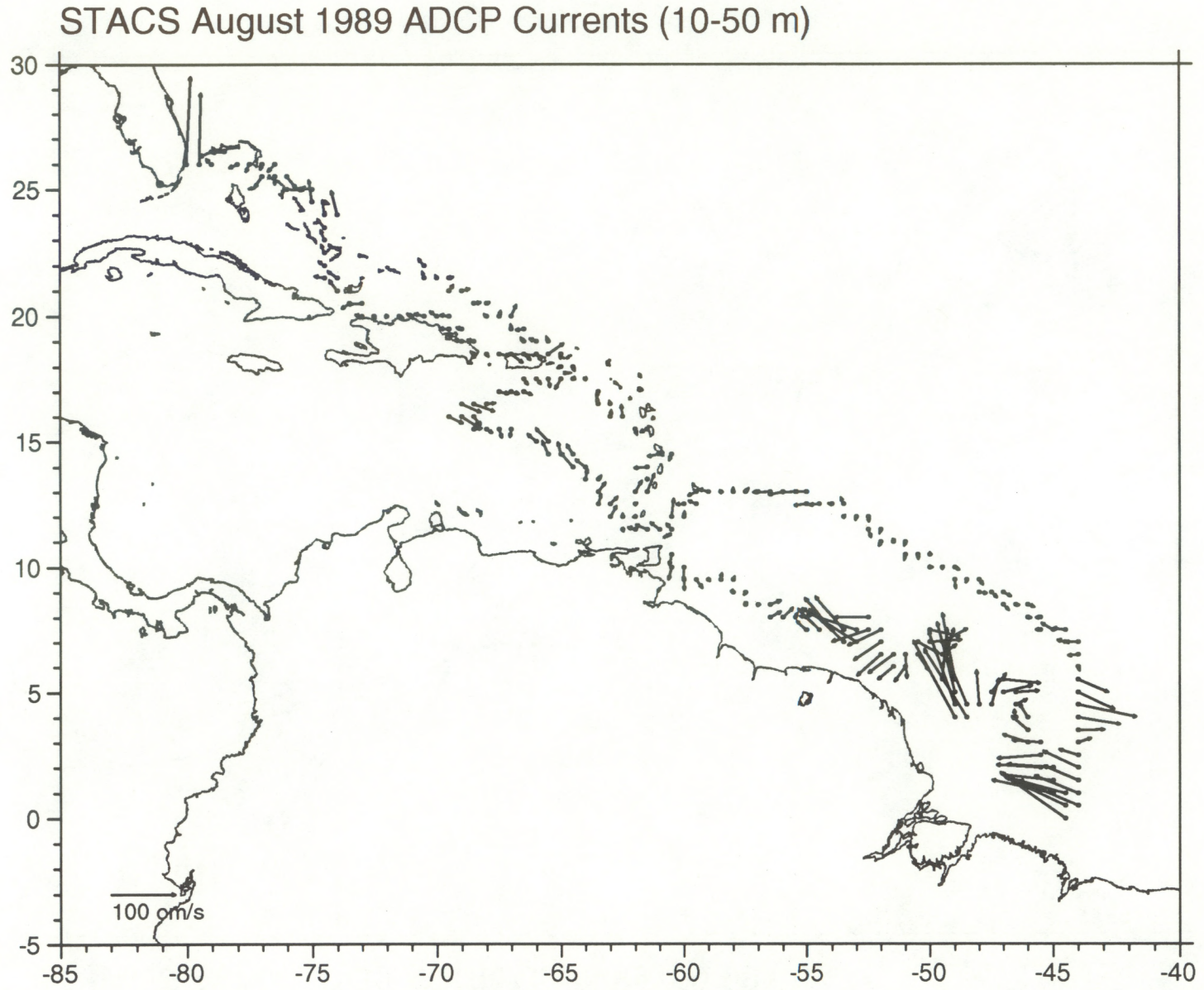


Figure A.3 0.5 Degree Grid



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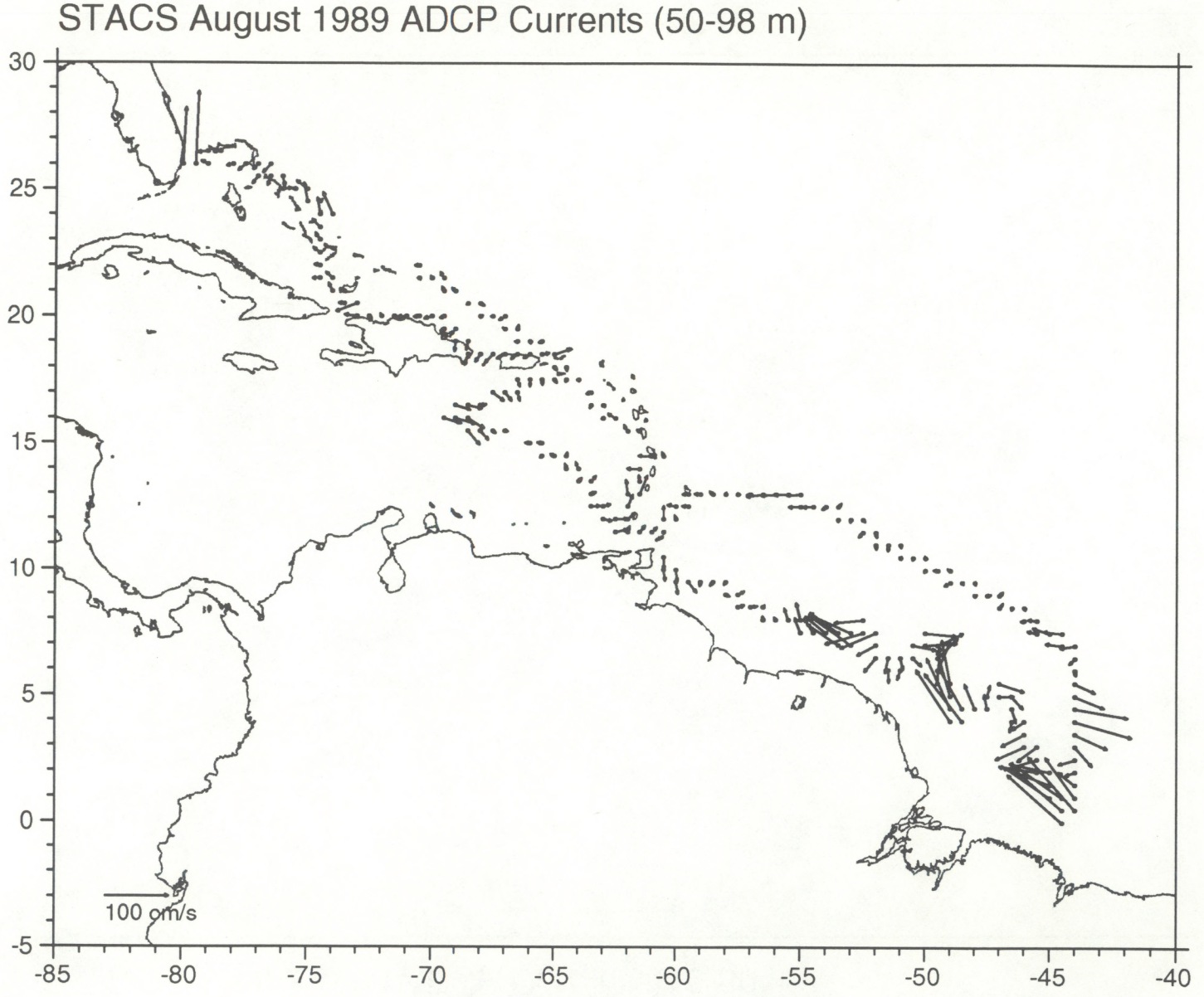

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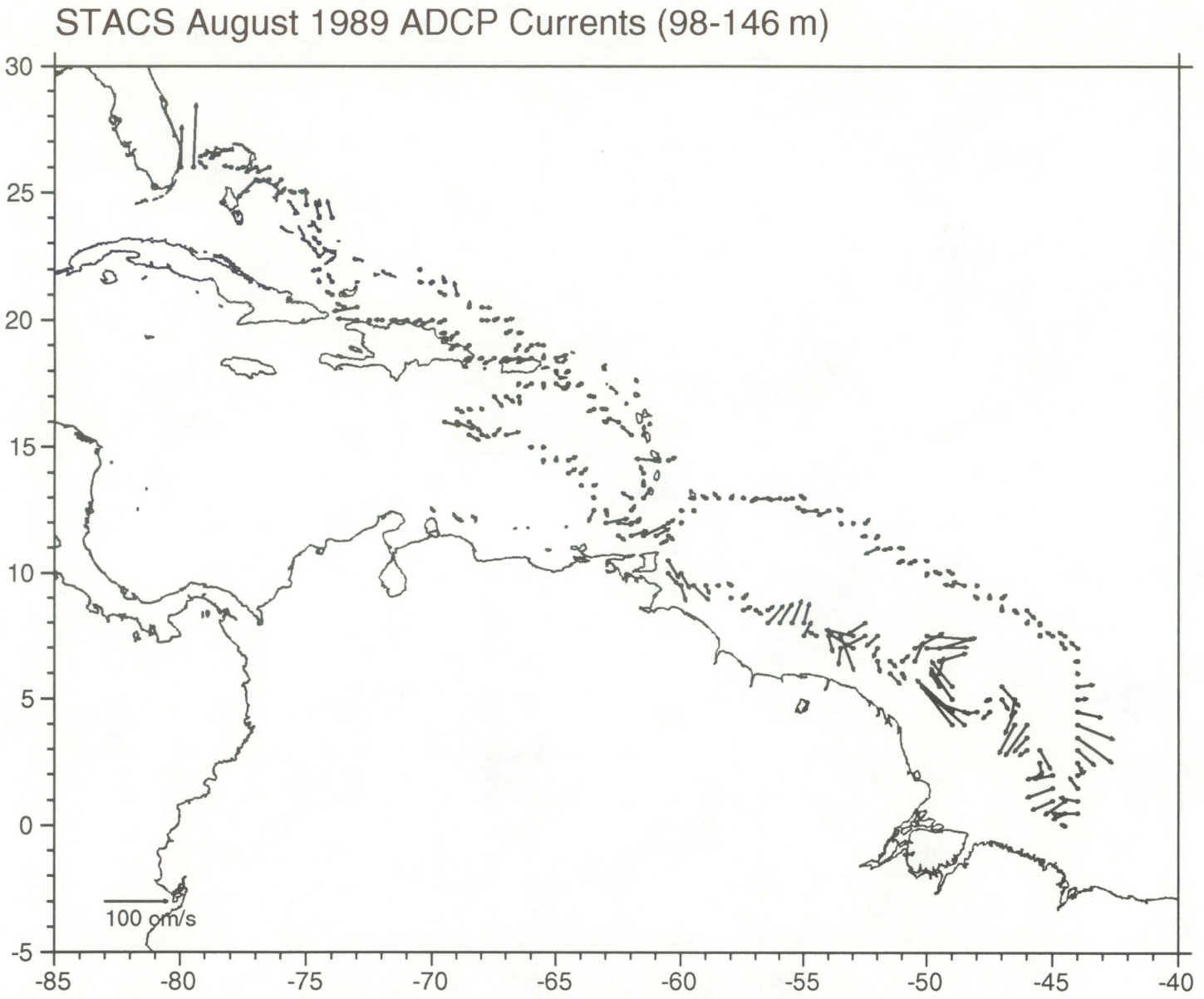

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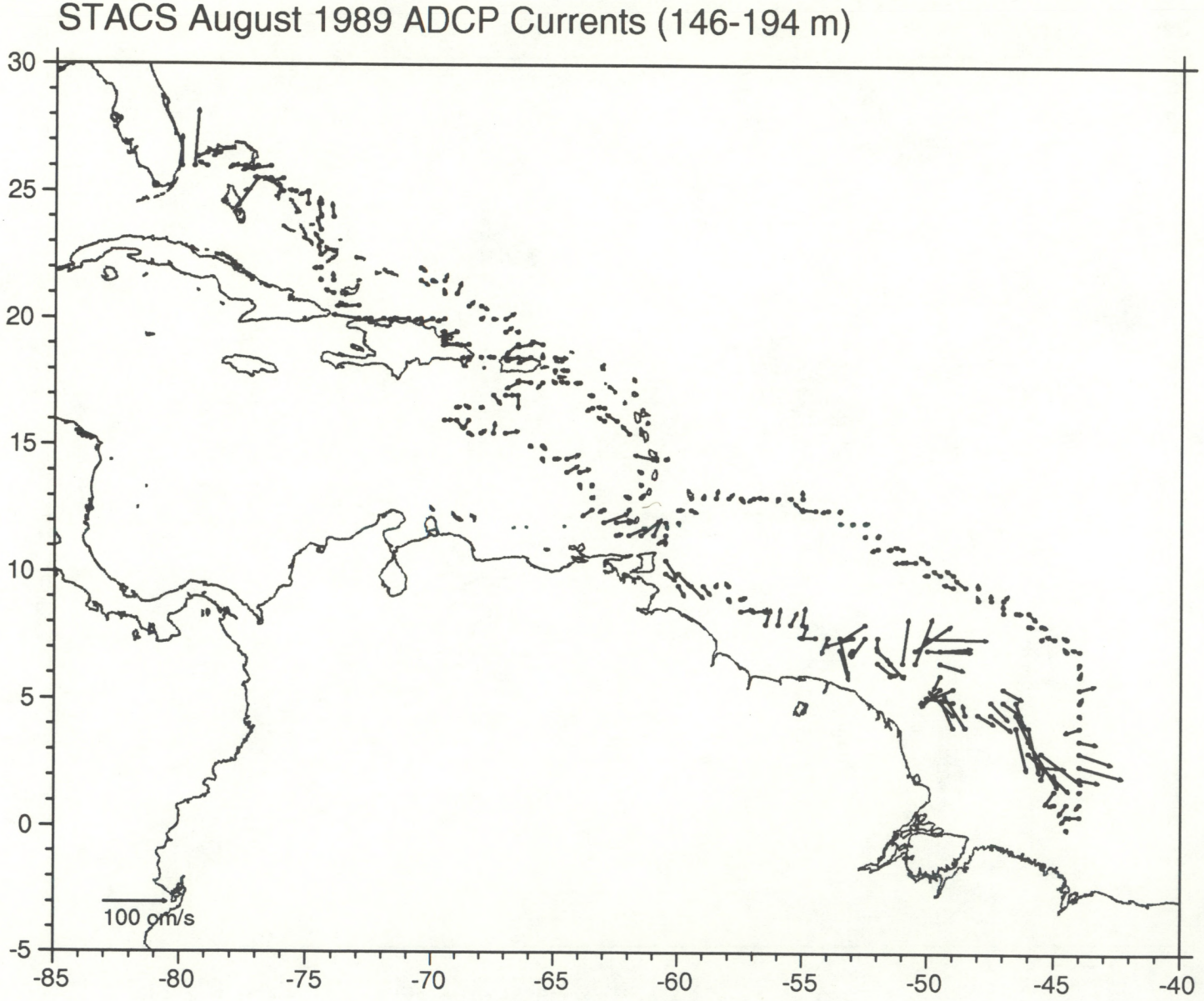

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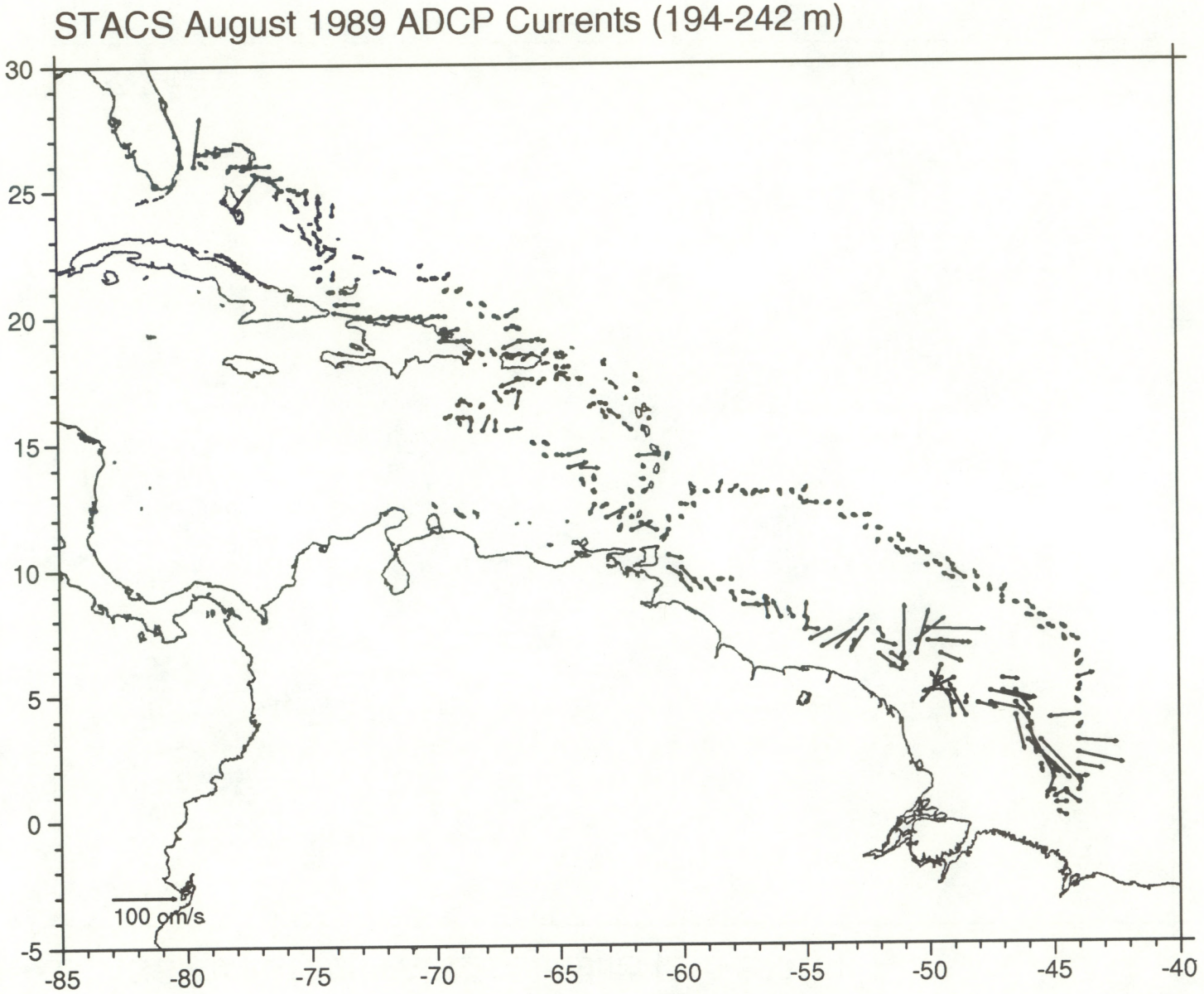

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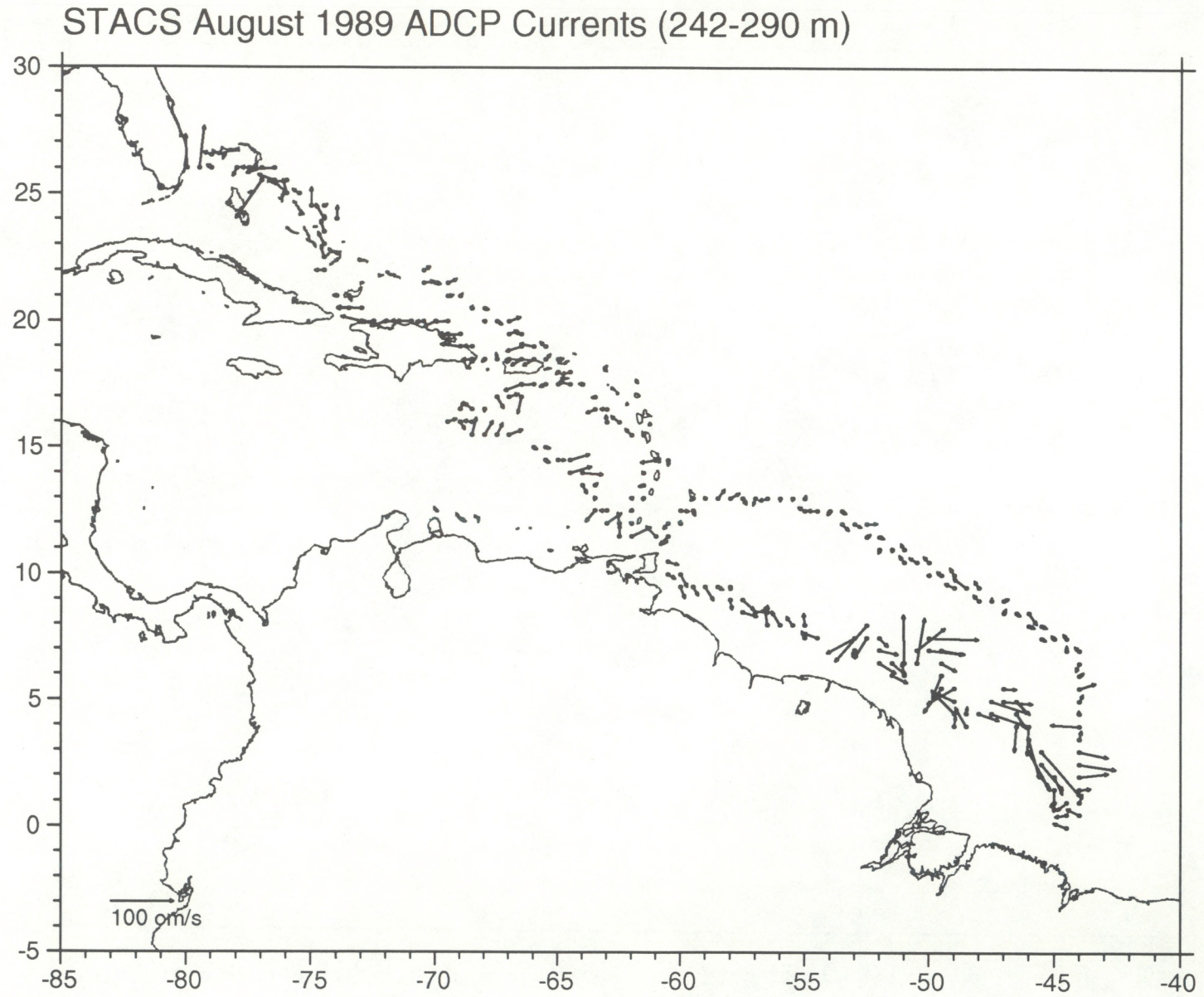

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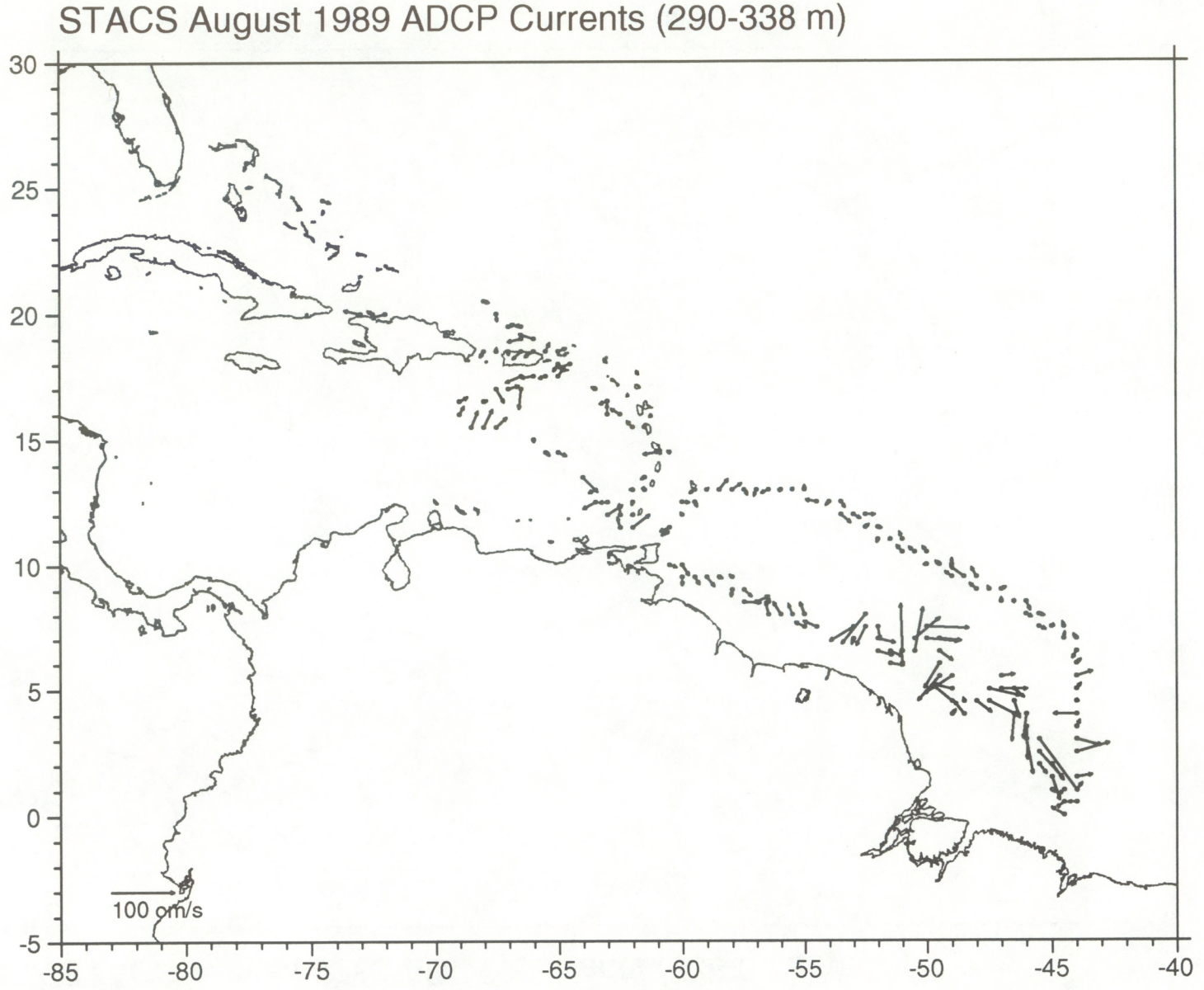

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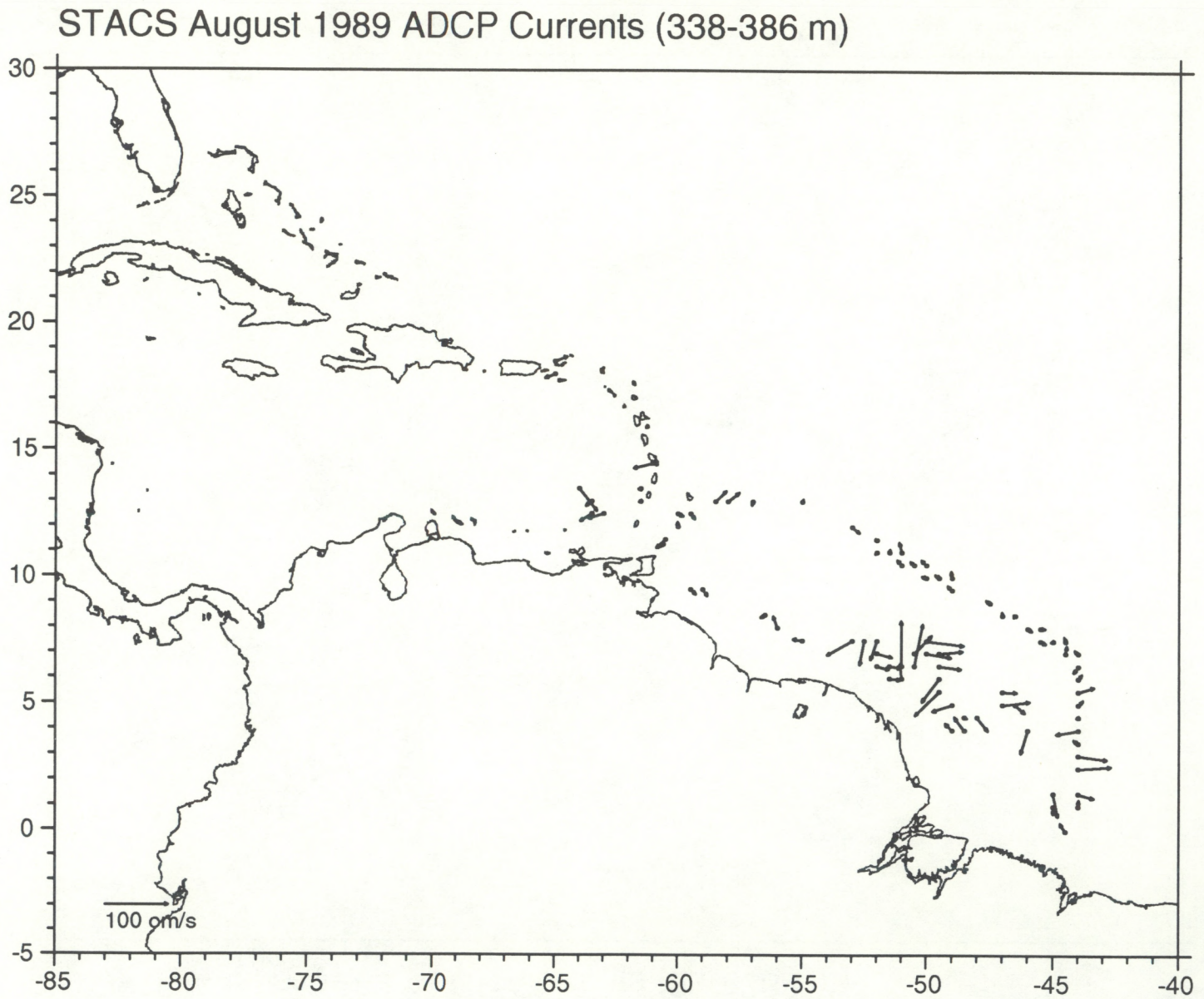

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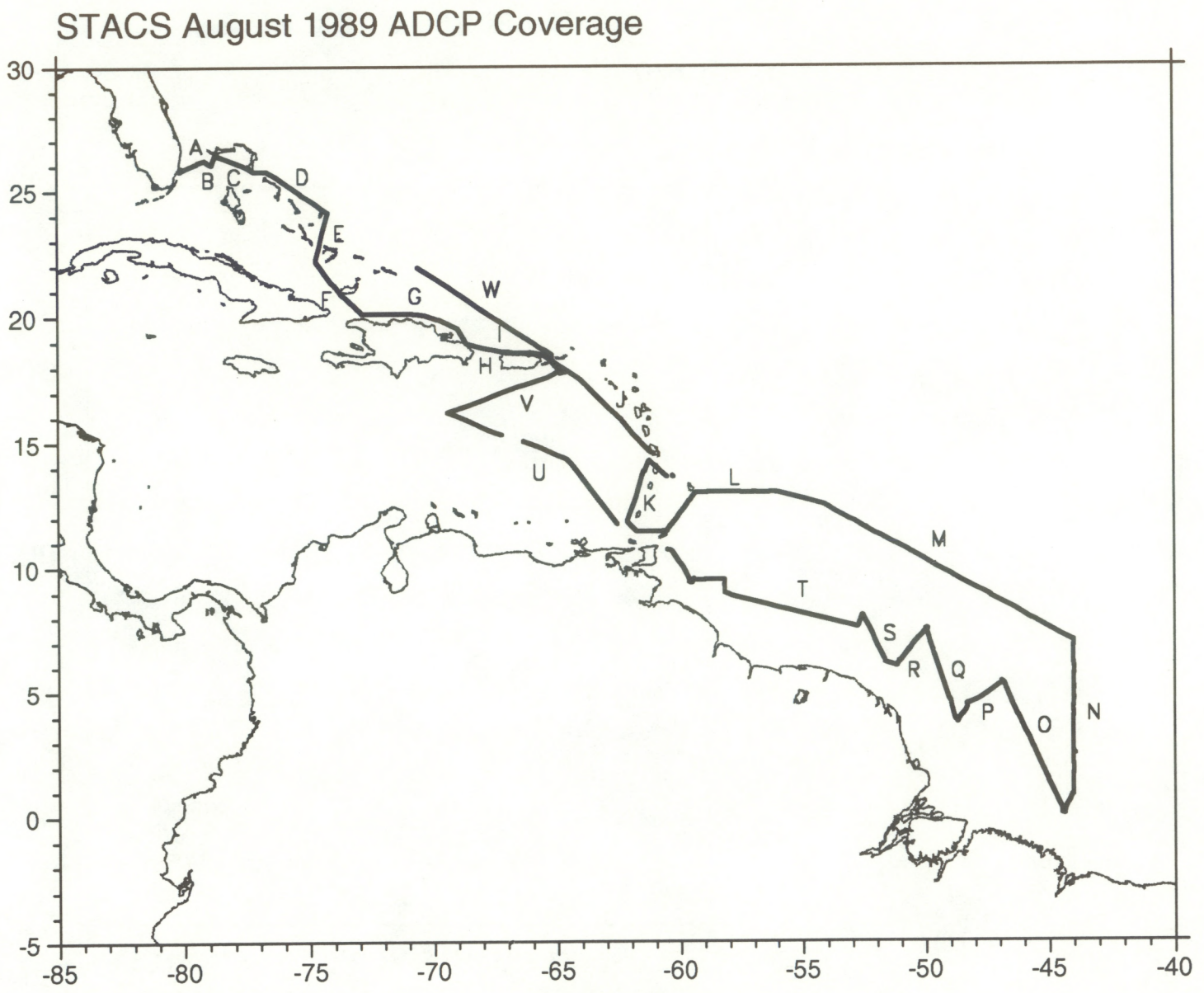
STACS August 1989 ADCP Coverage
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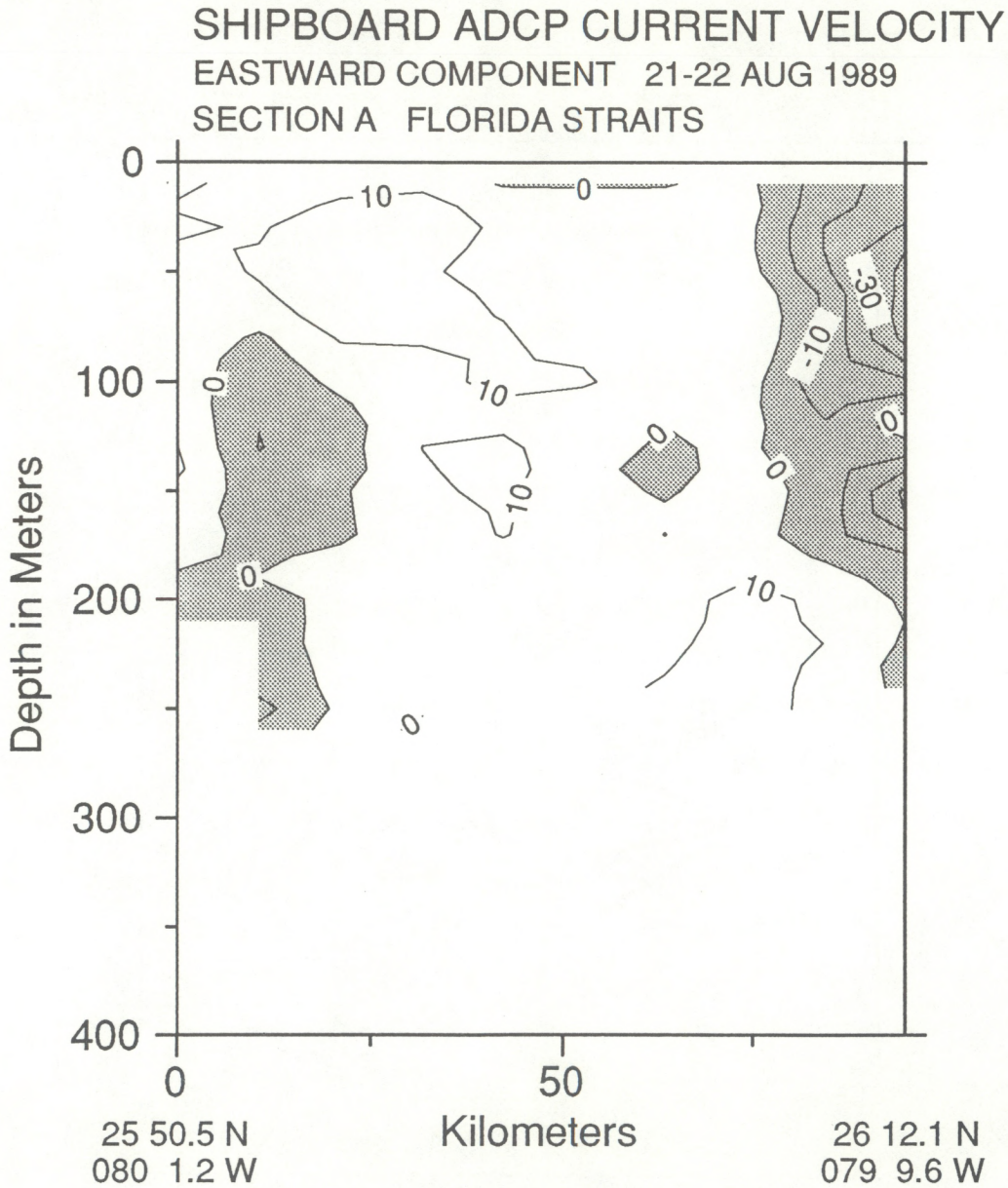
Figure A.12



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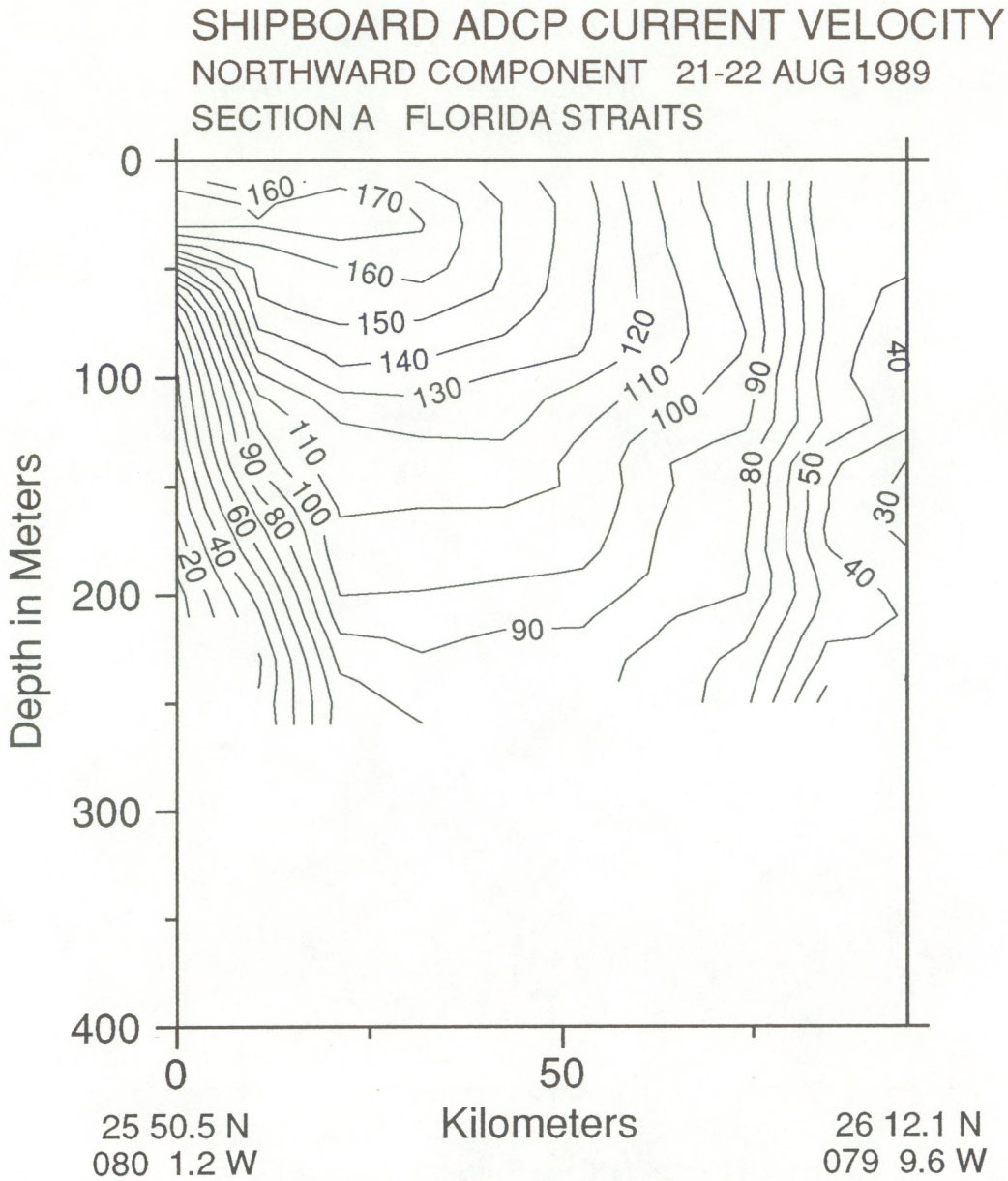

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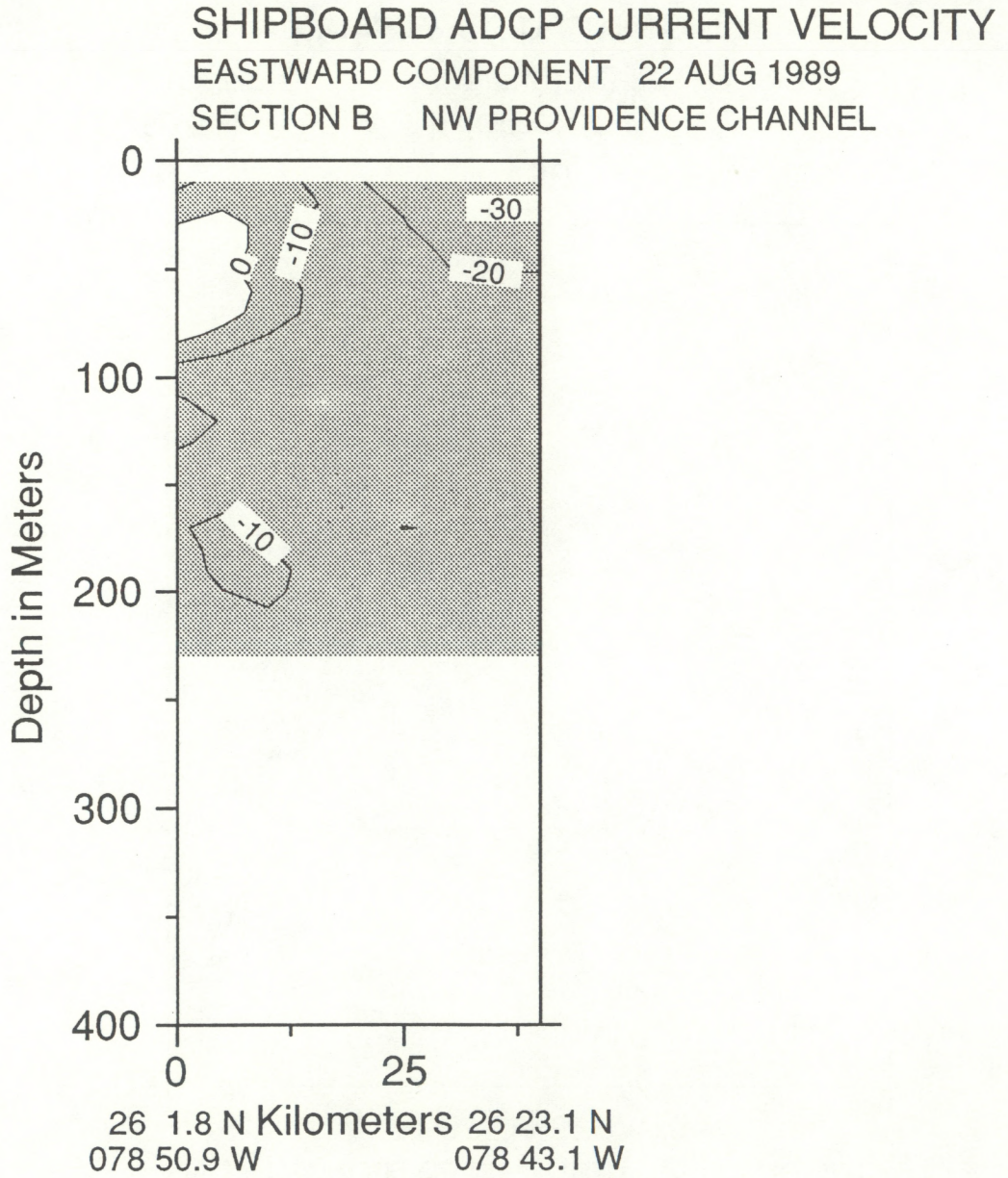

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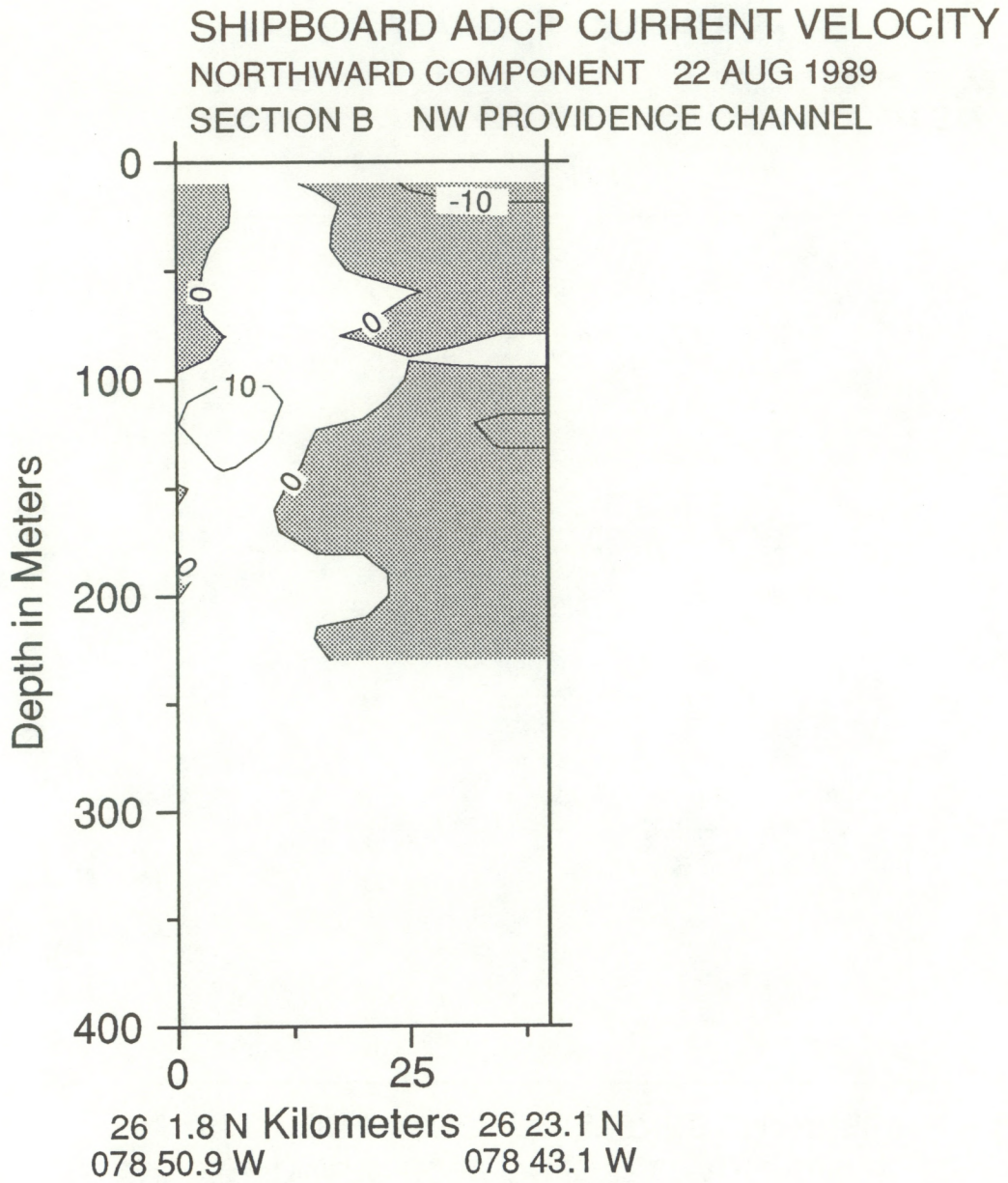

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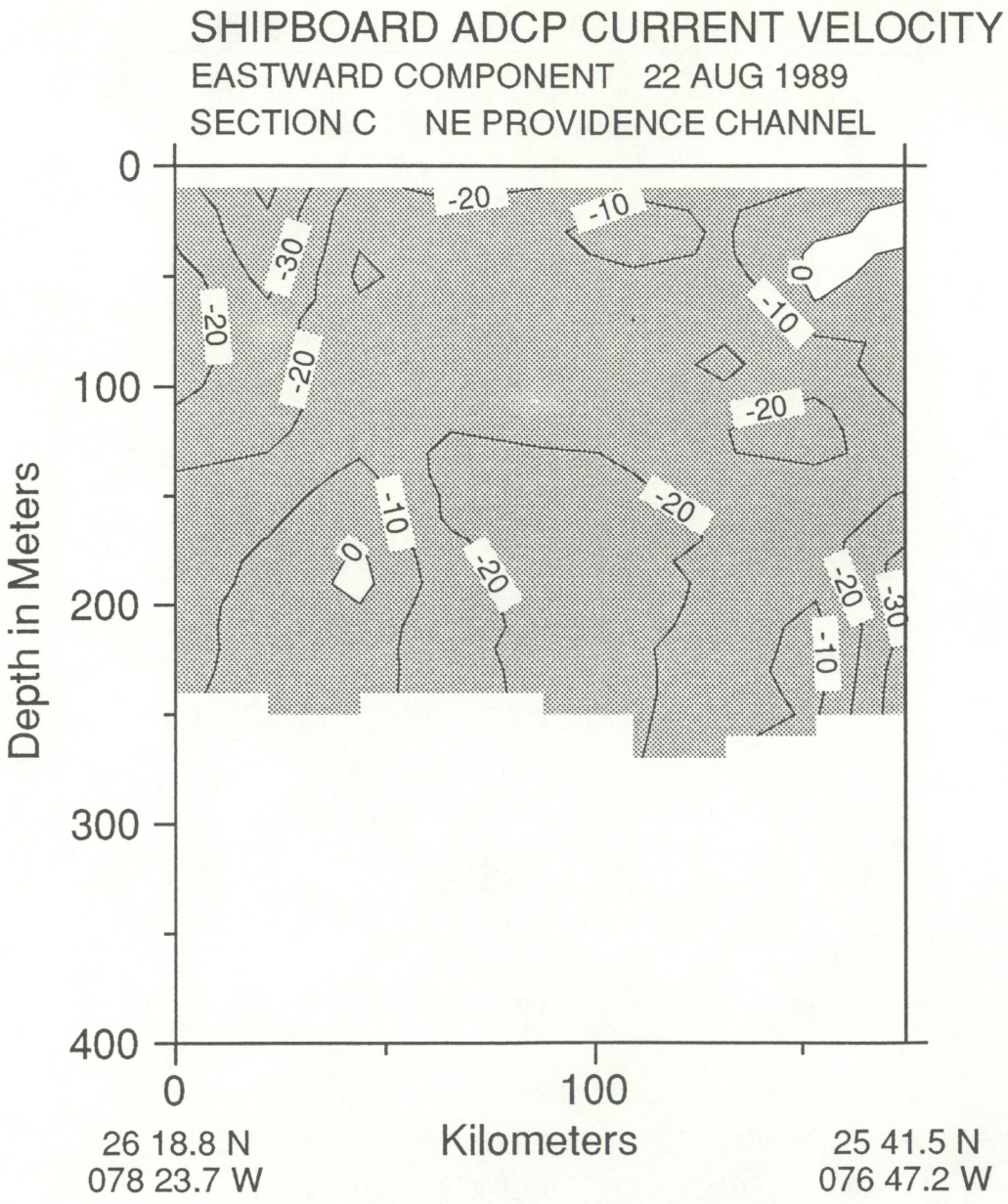

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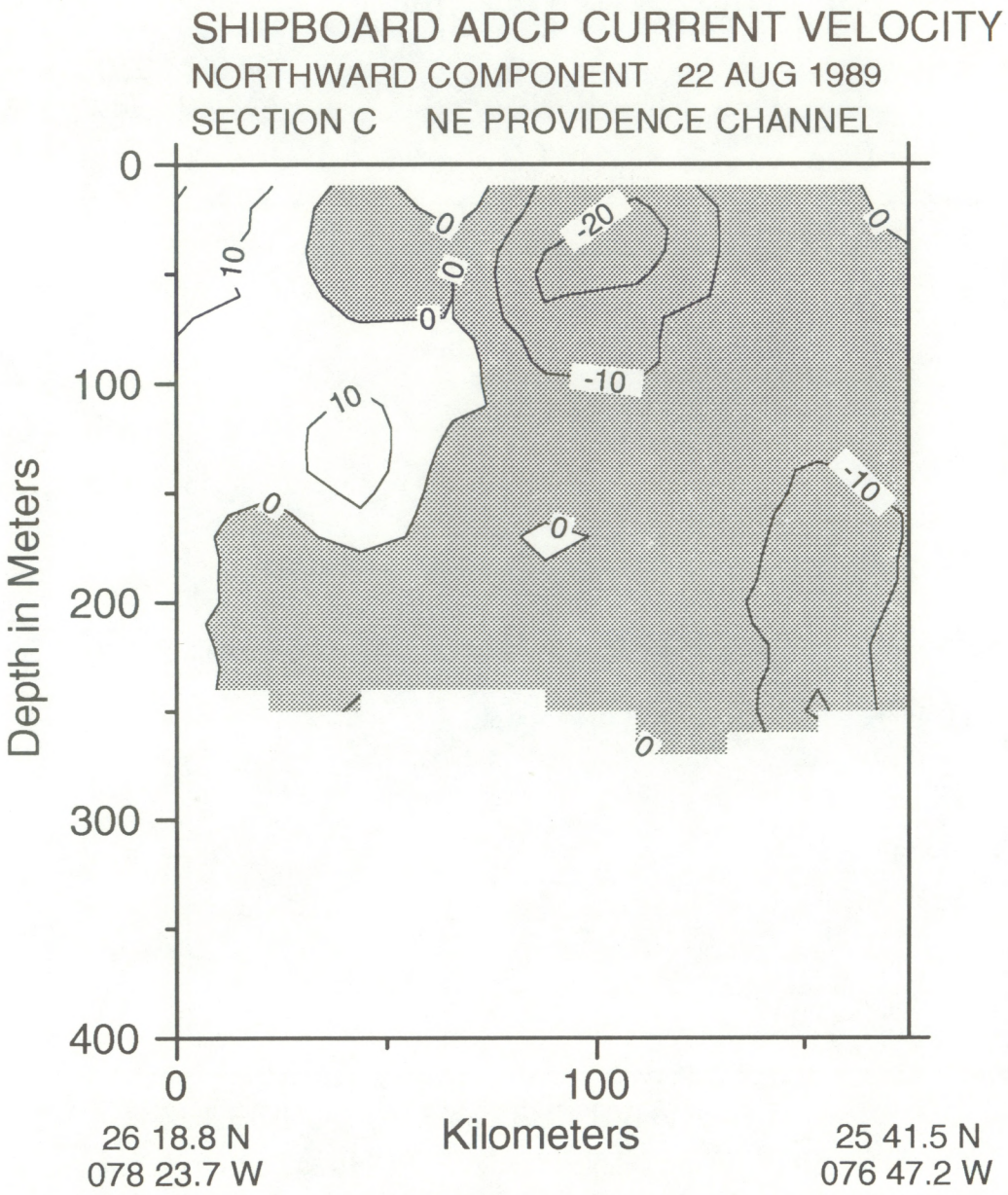

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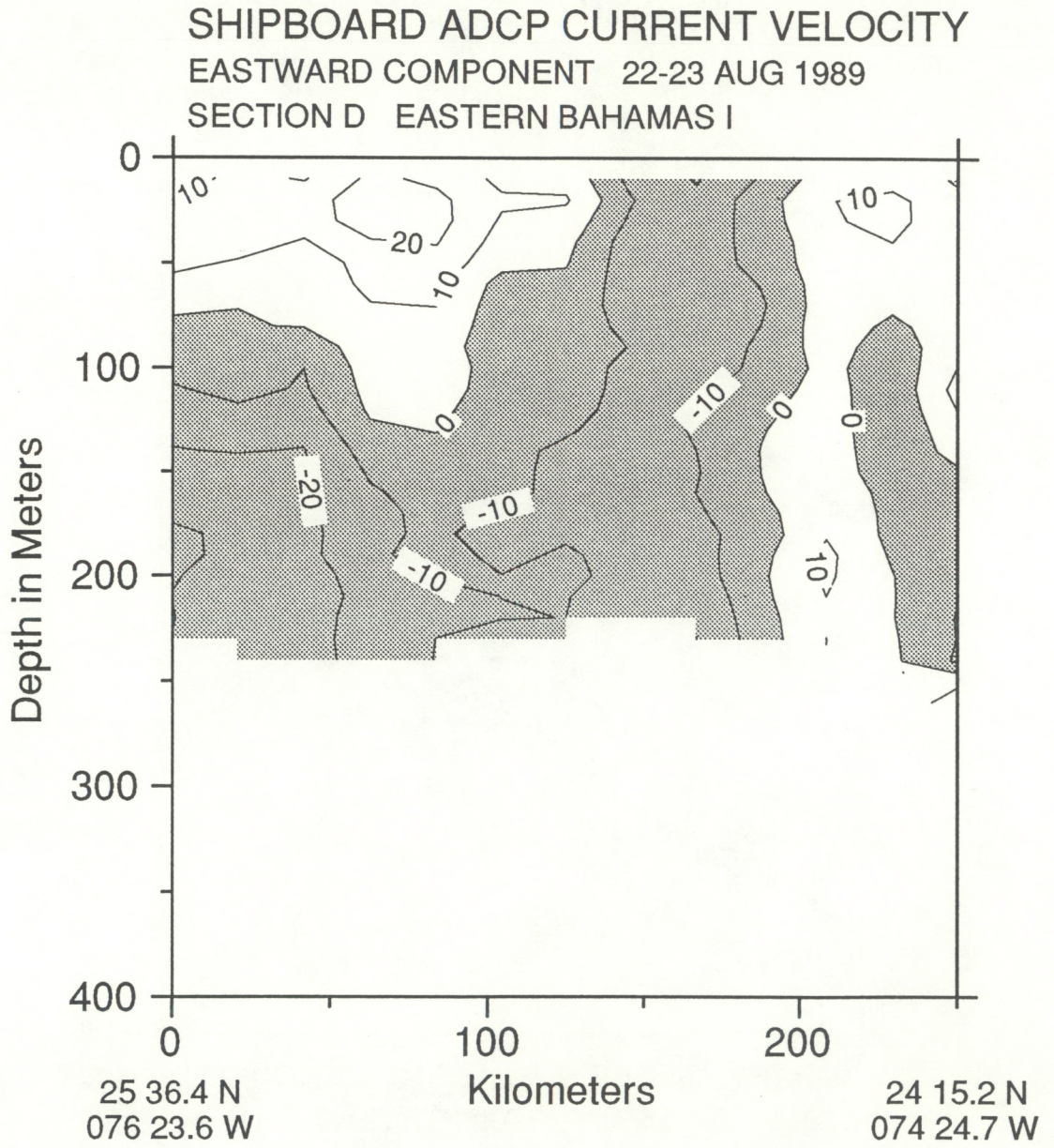

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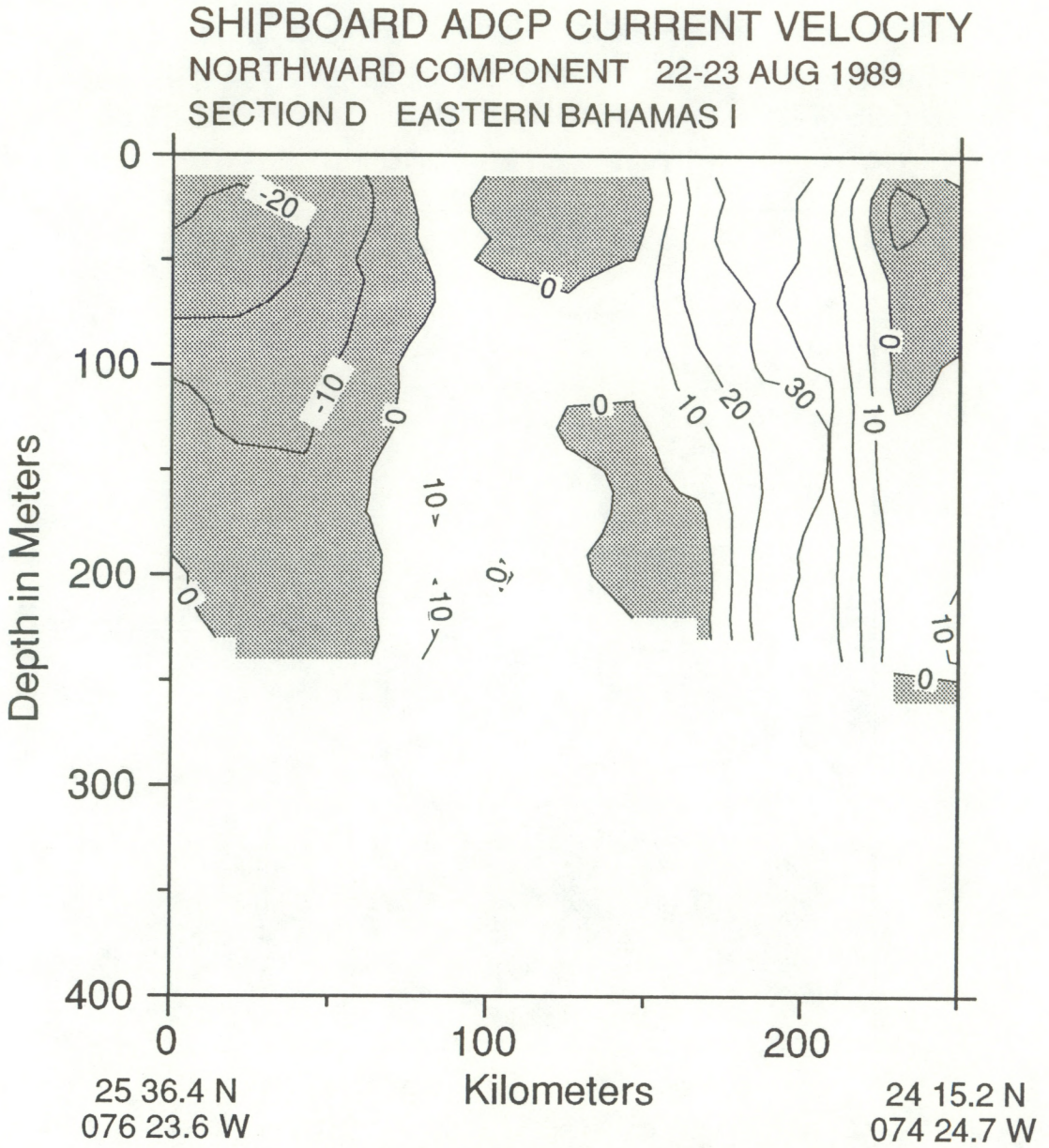

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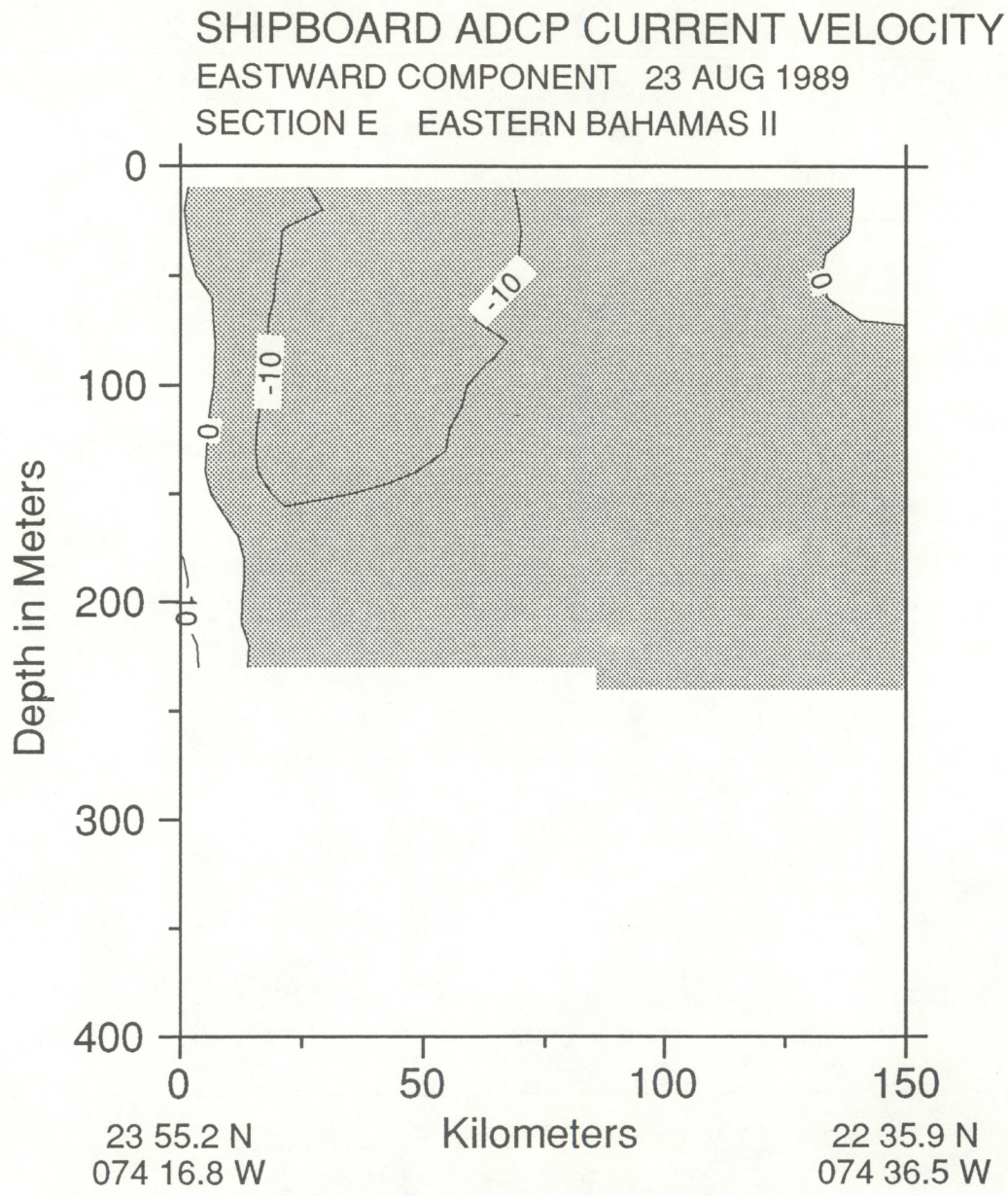

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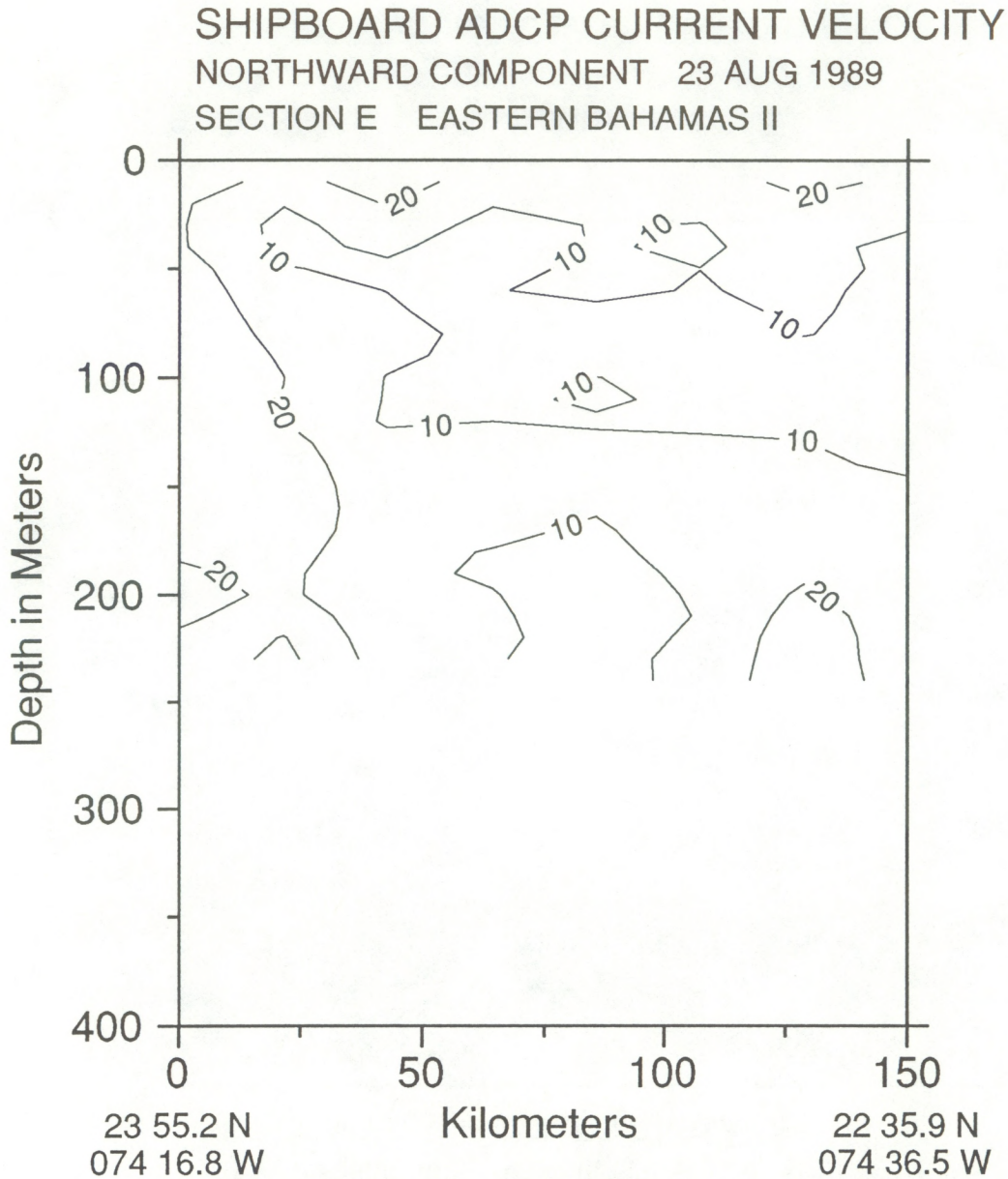

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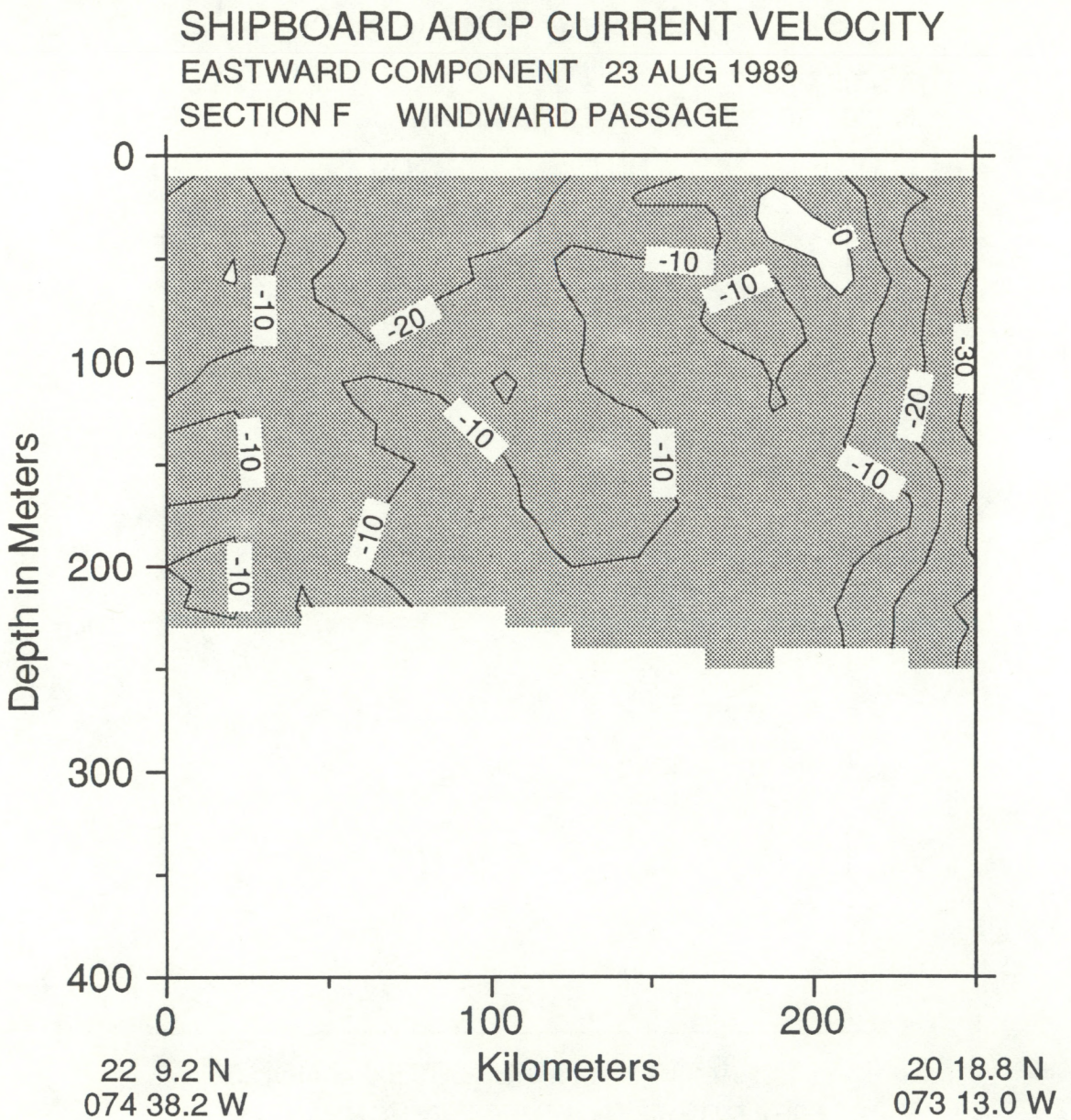

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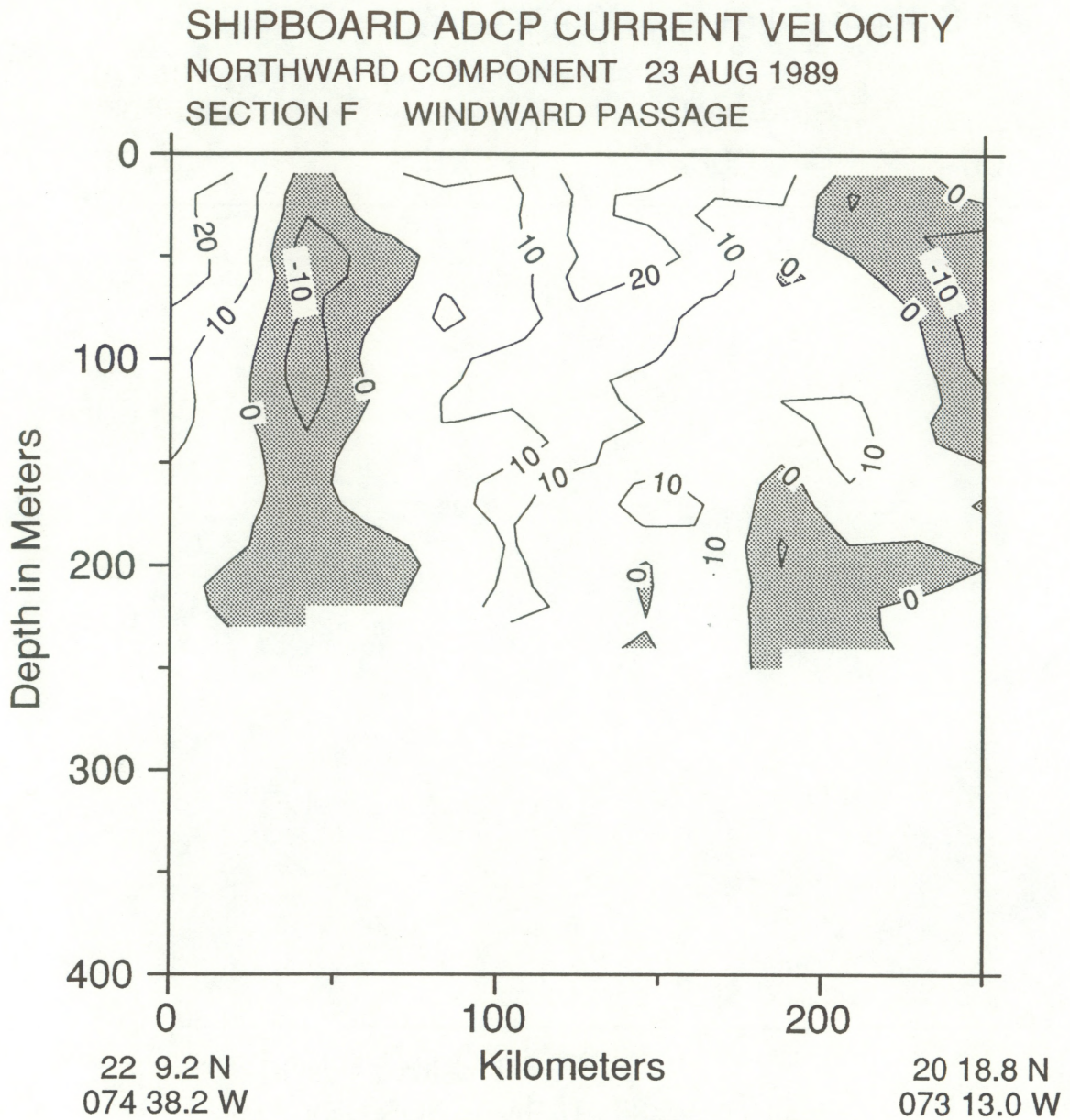

Figure A.18.b 20 km grid

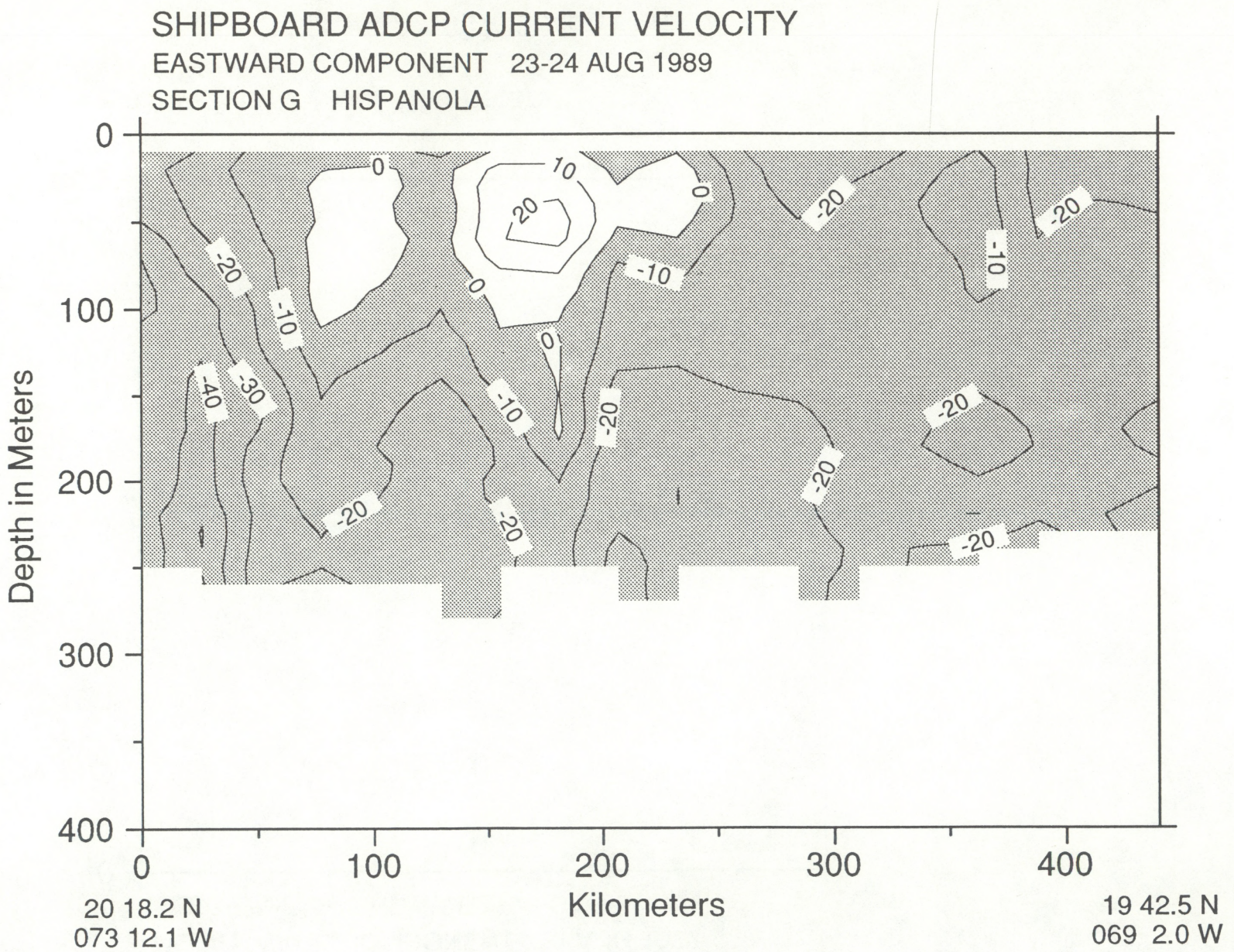

Figure A.19.a 25 km grid

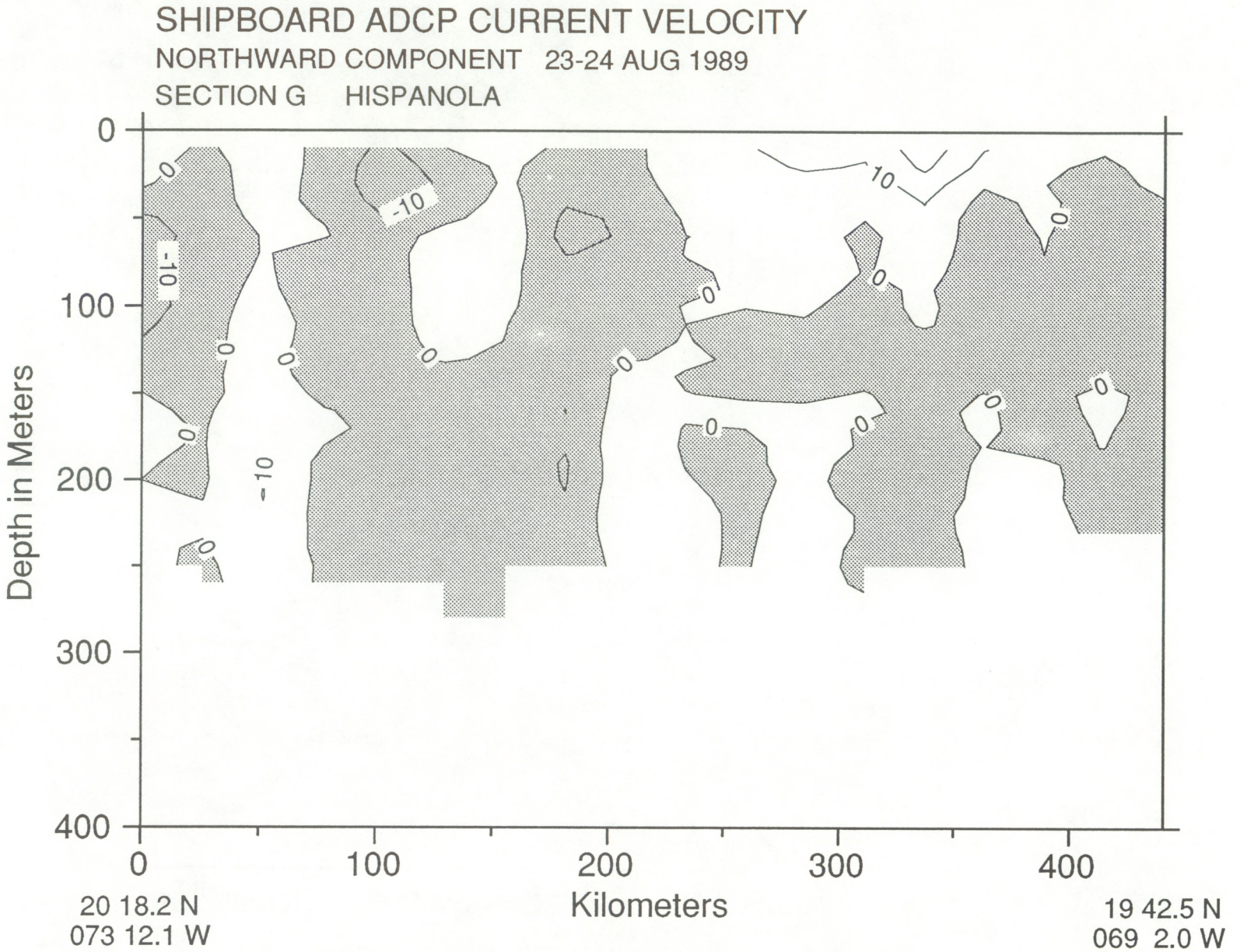

Figure A.19.b 25 km grid

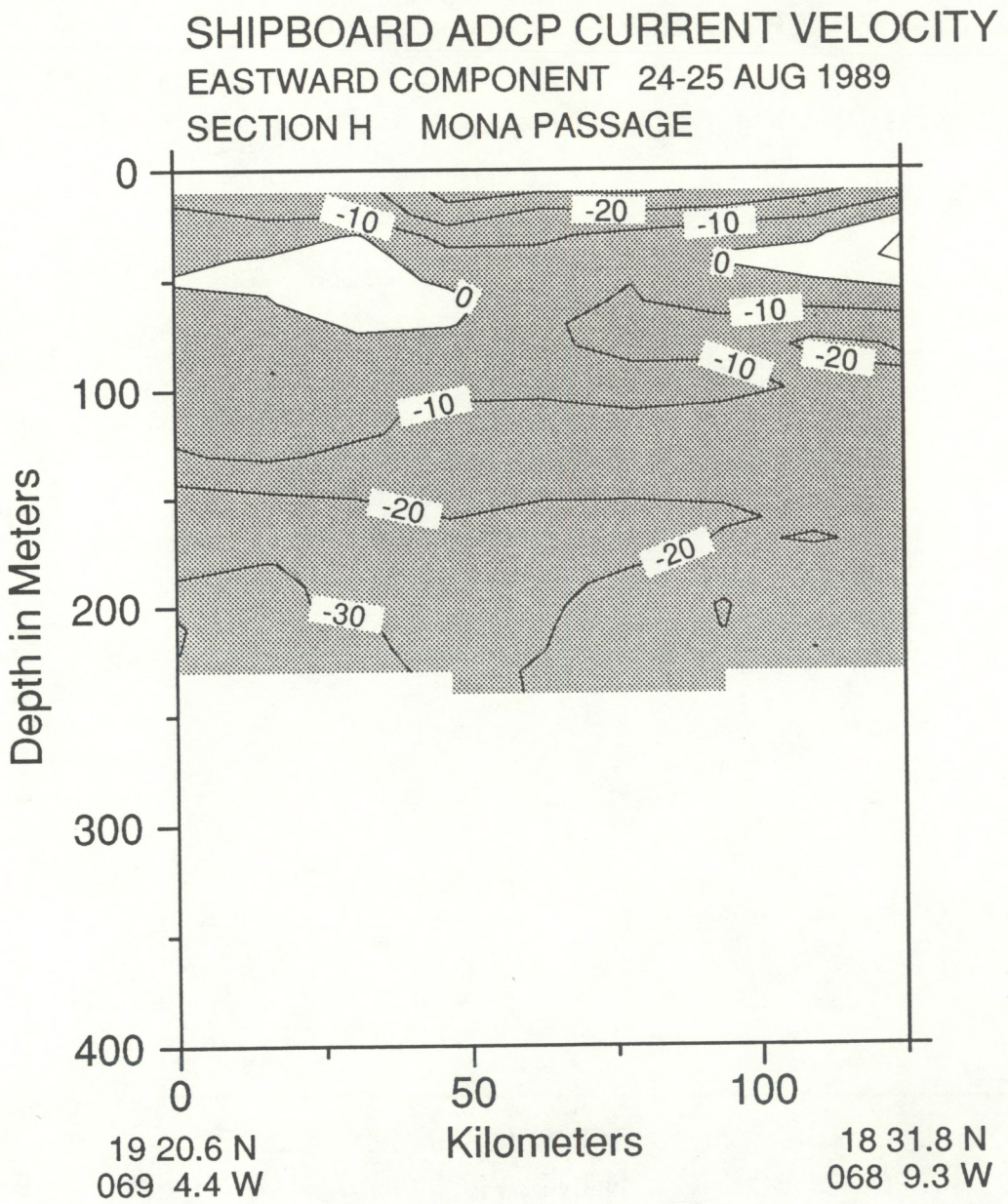

Figure A.20.a 15 km grid

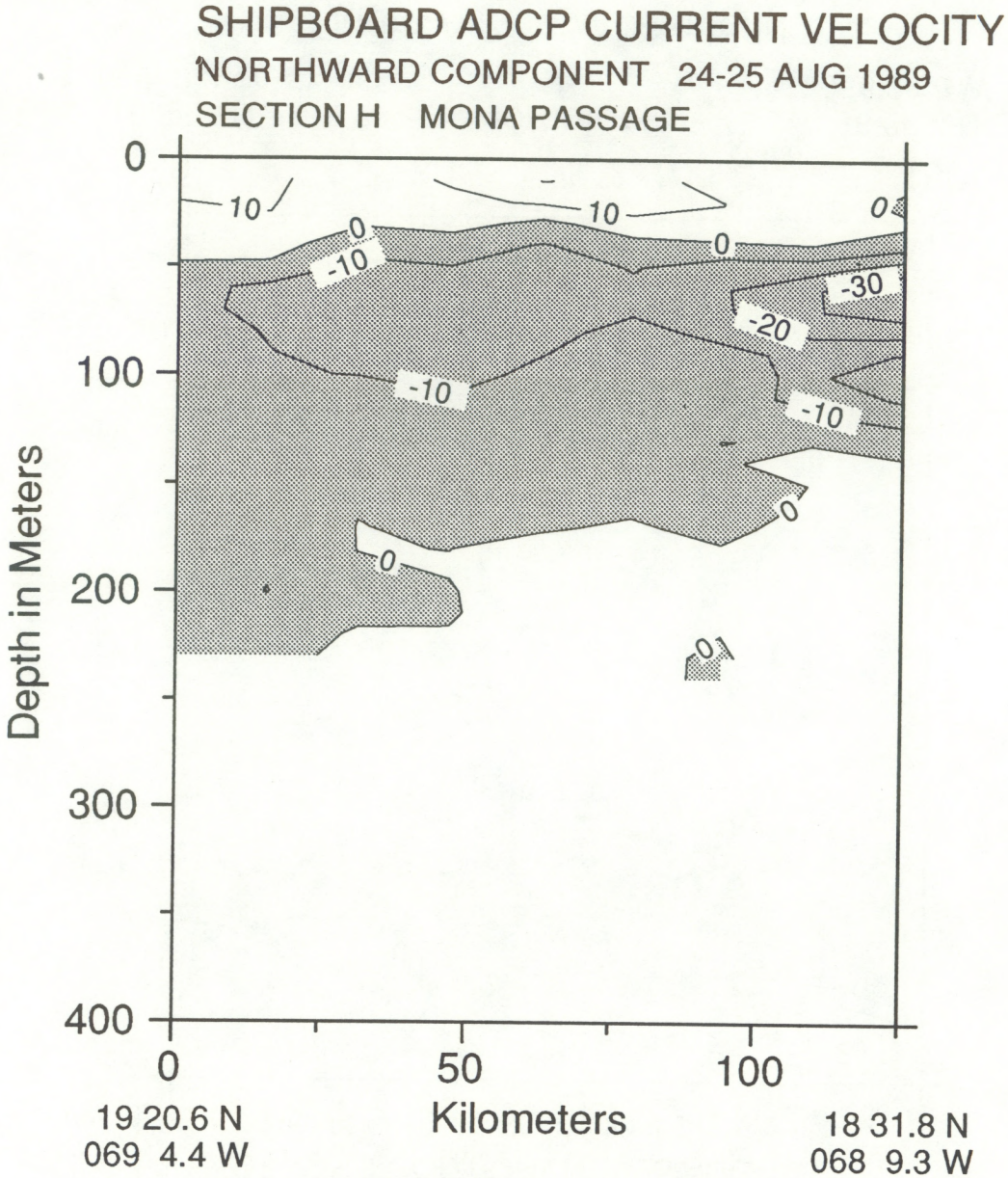

Figure A.20.b 15 km grid

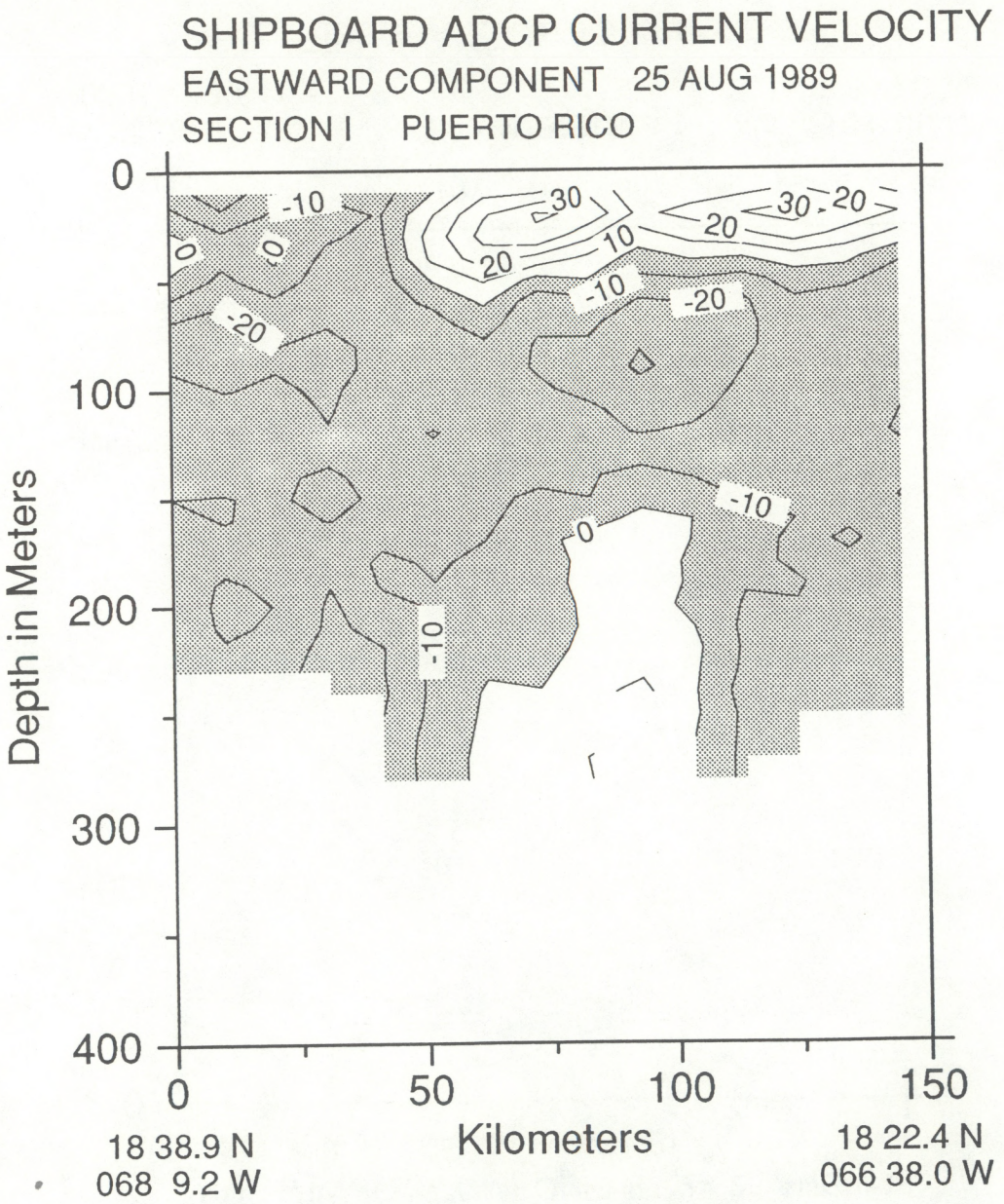

Figure A.21.a 10 km grid

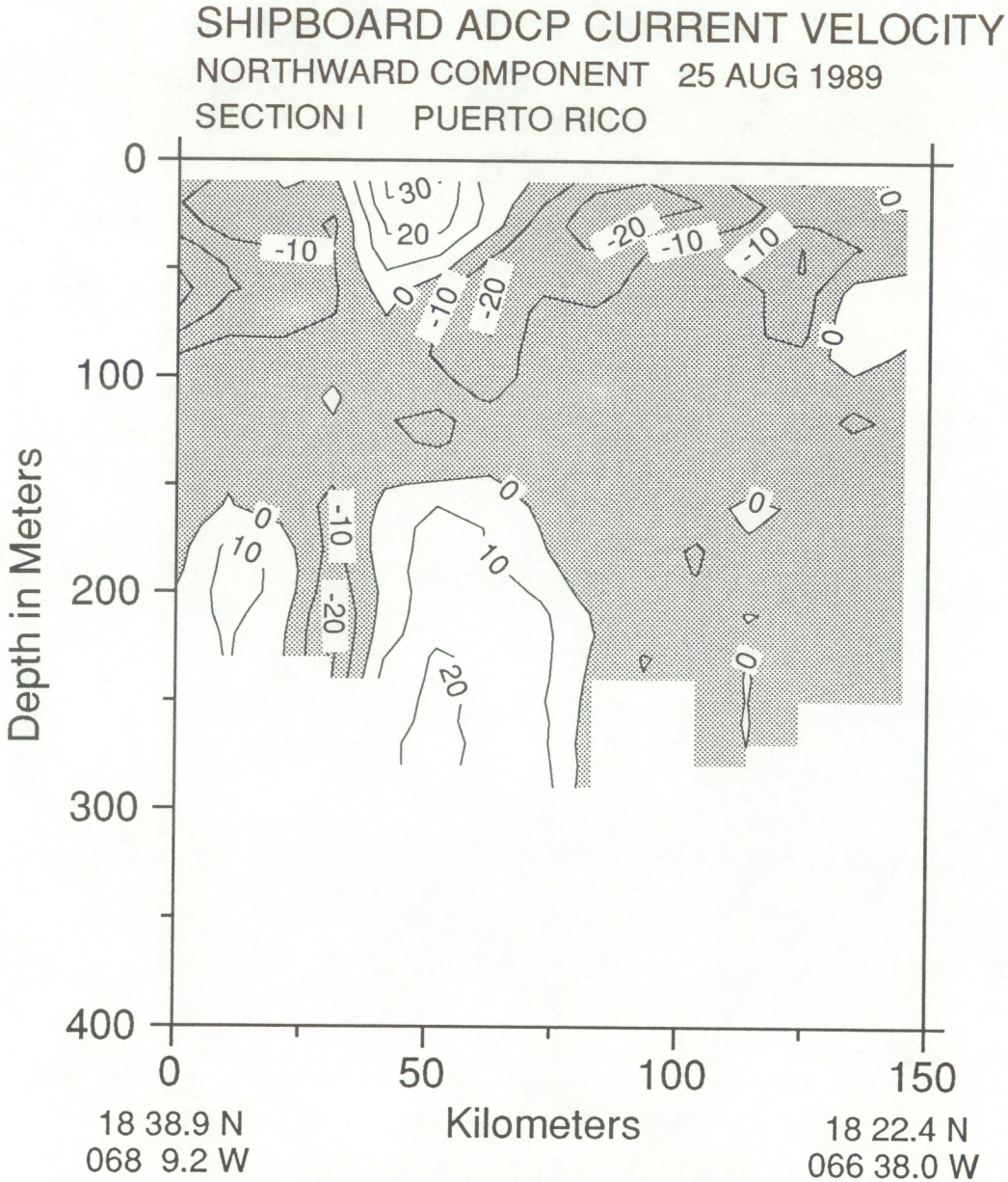

Figure A.21.b 10 km grid

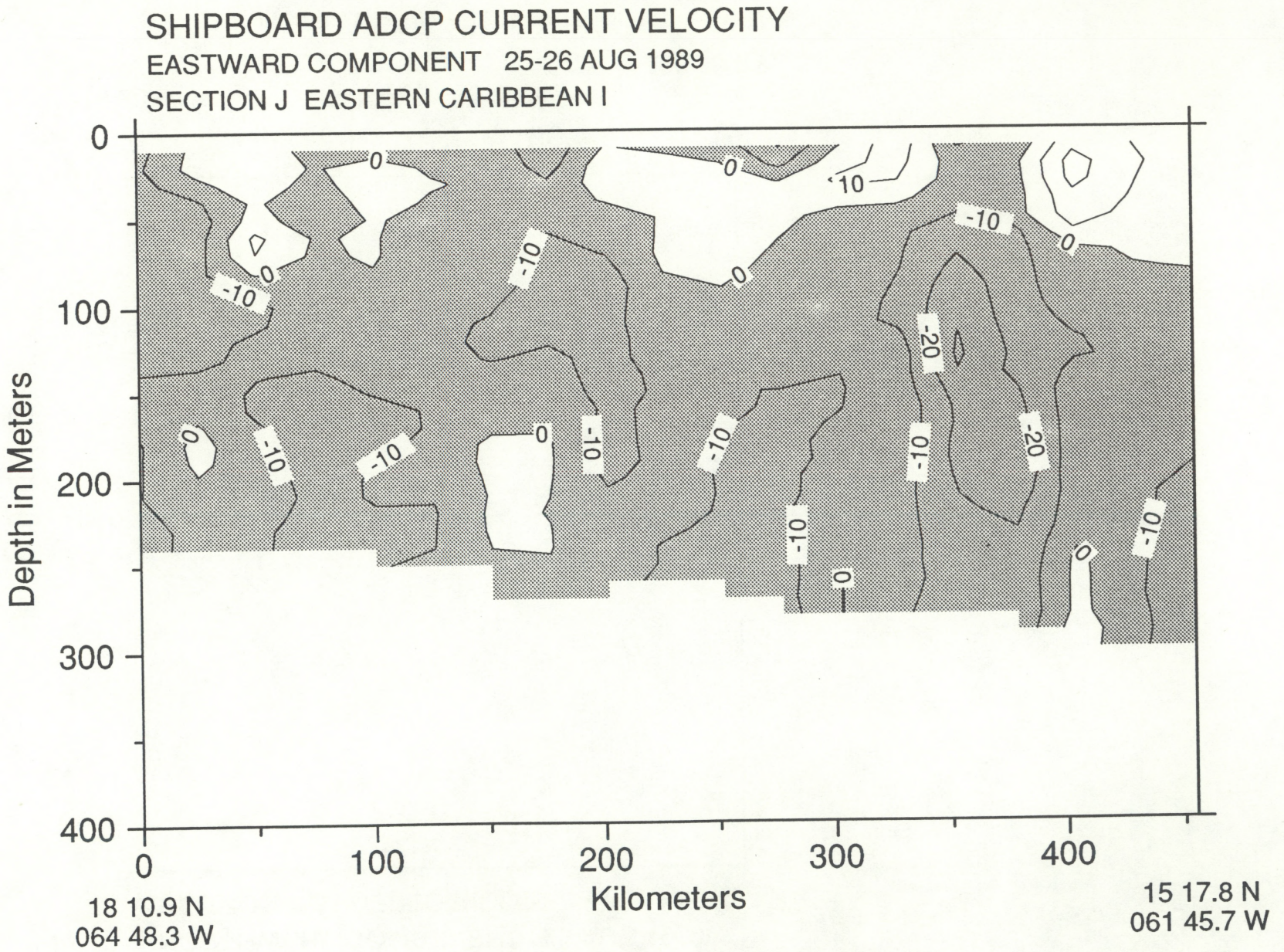

Figure A.22.a 25 km grid

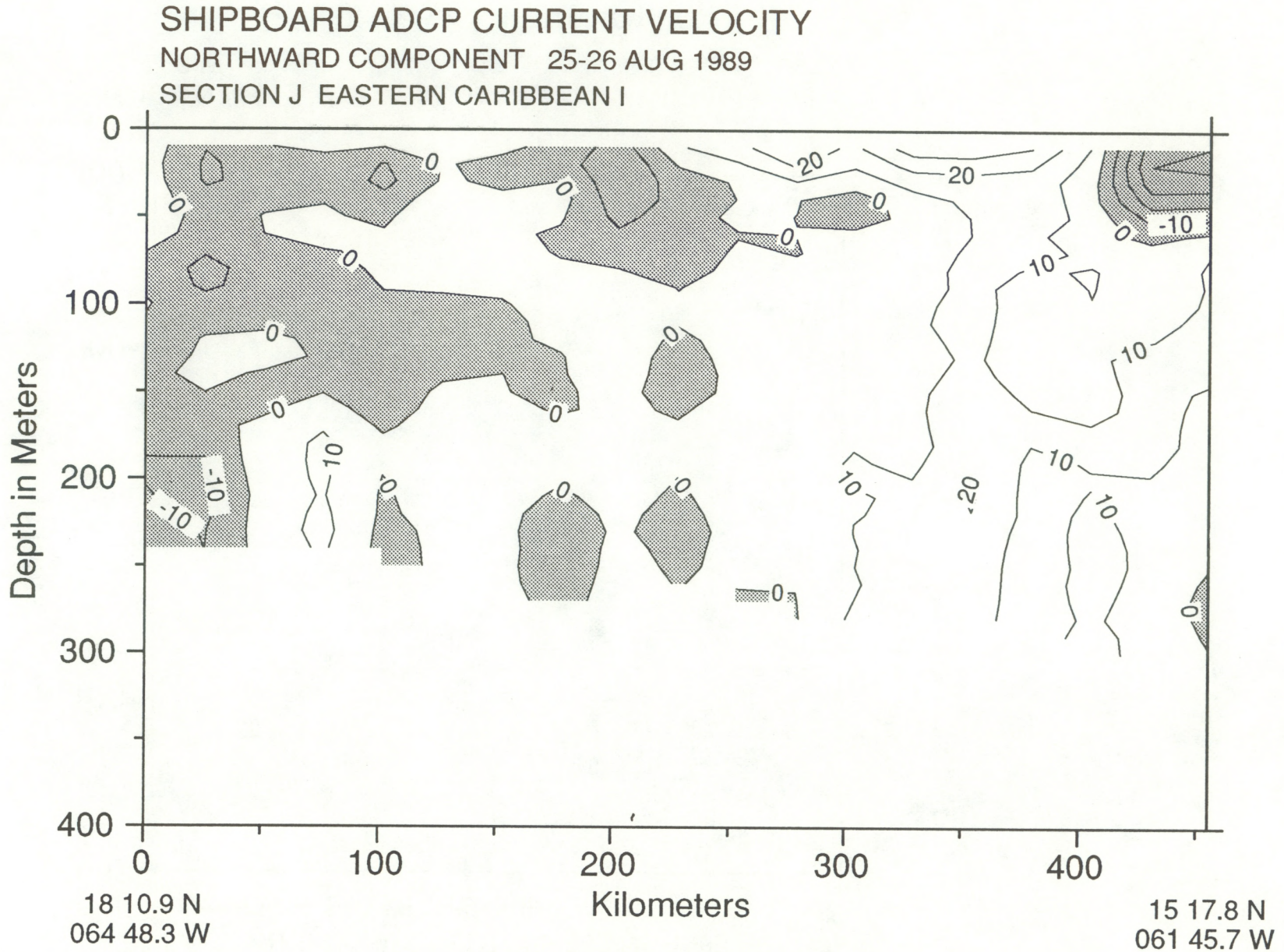

Figure A.22.b 25 km grid

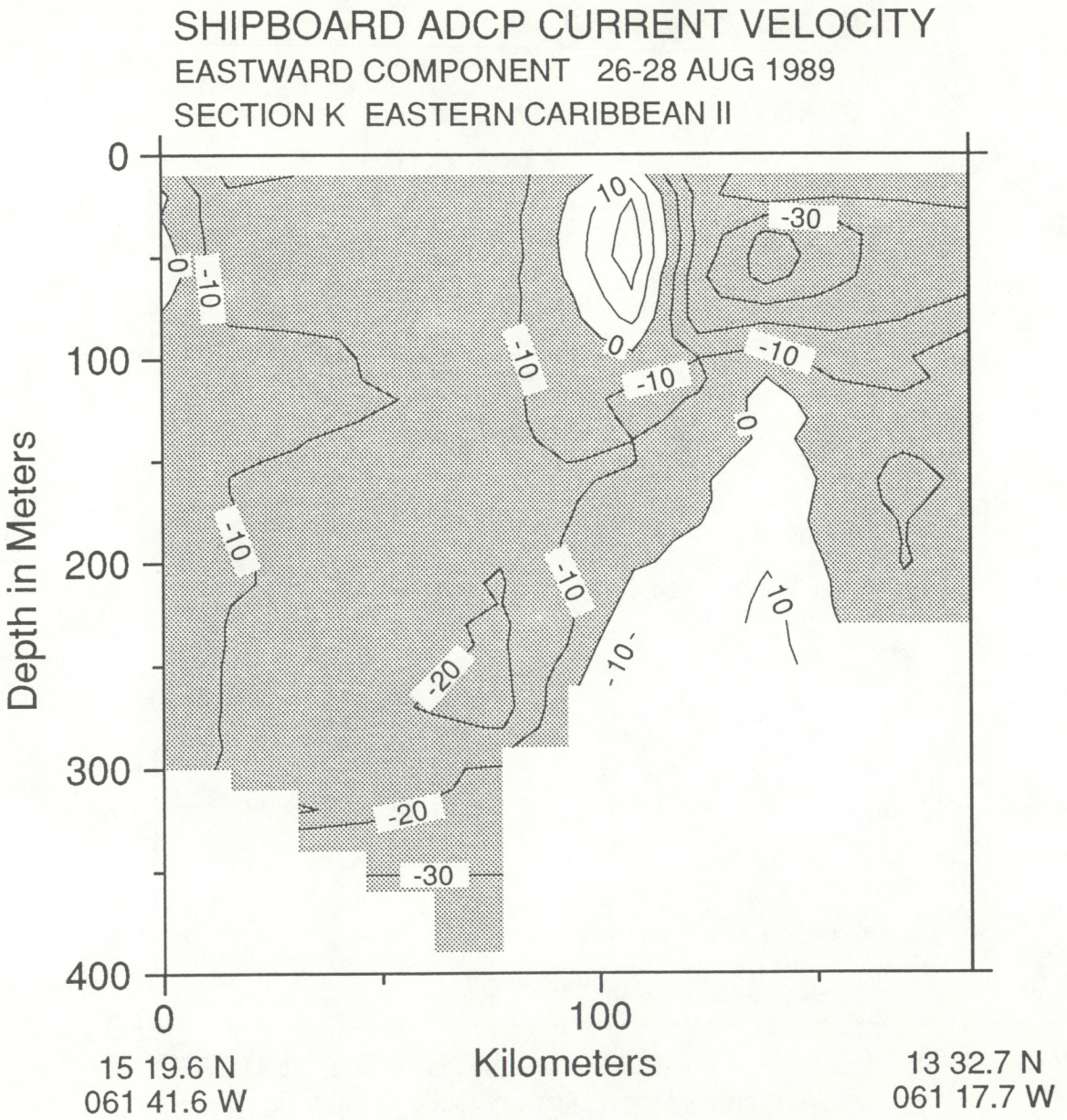

Figure A.23.a 15 km grid

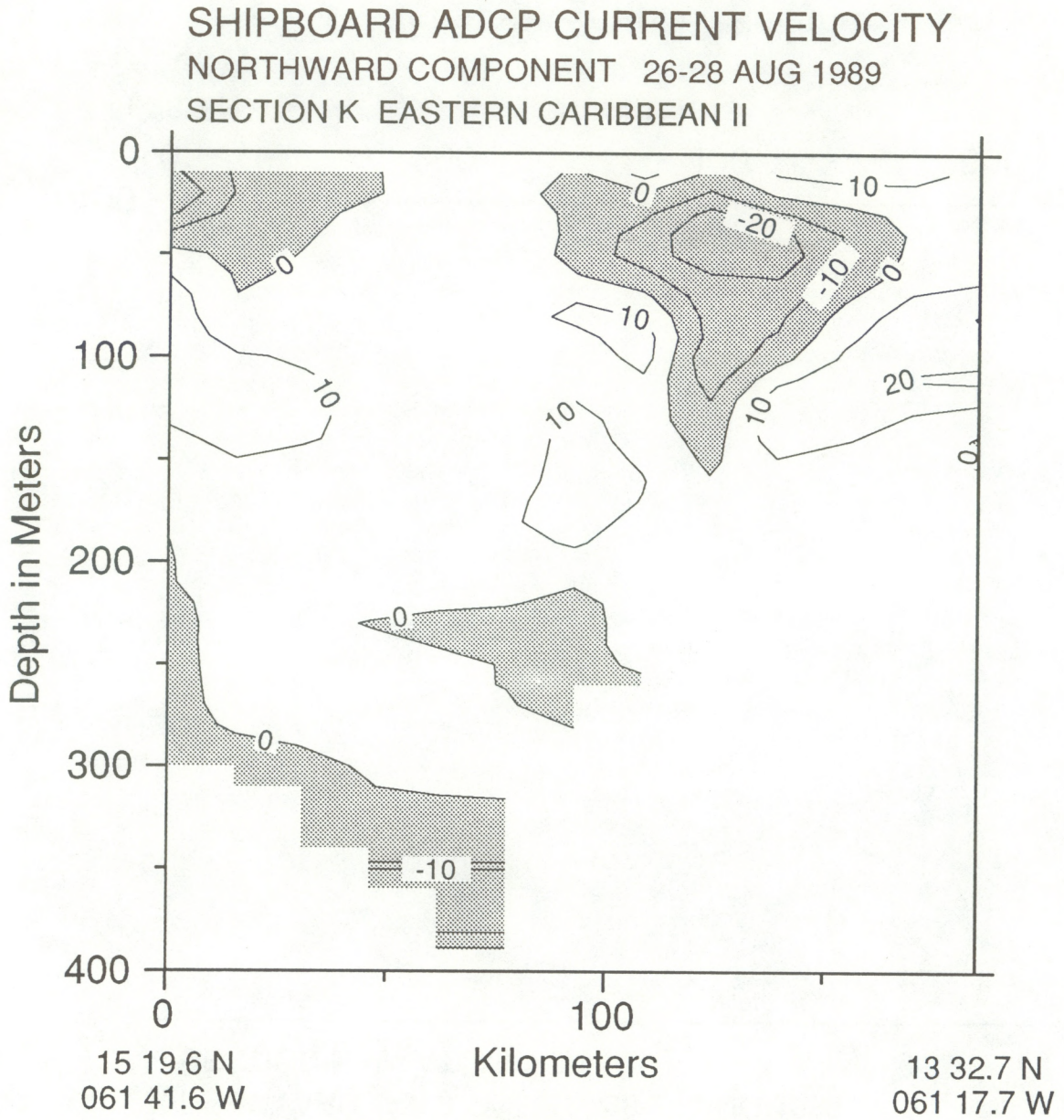

Figure A.23.b 15 km grid

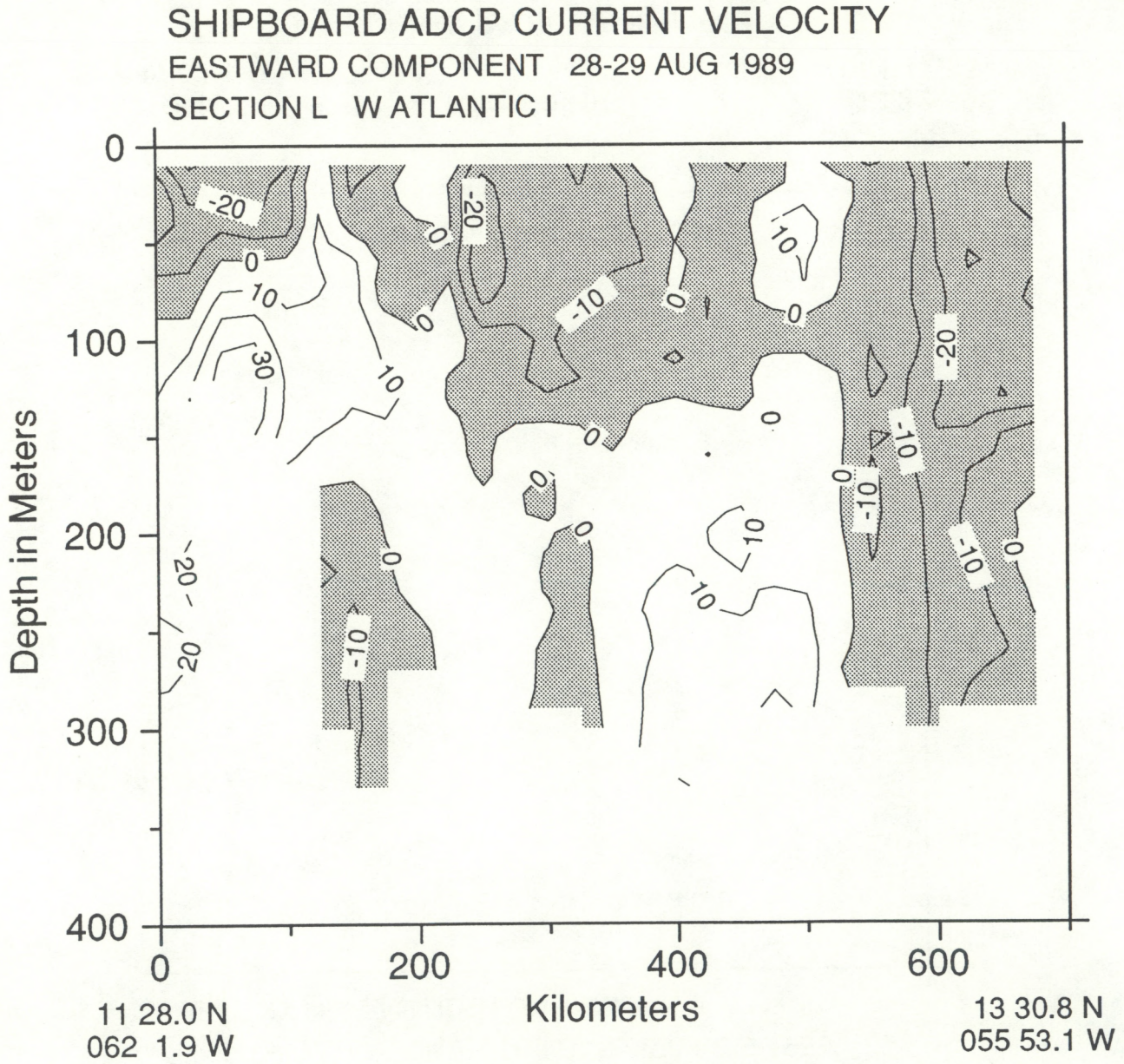

Figure A.24.a 25 km grid

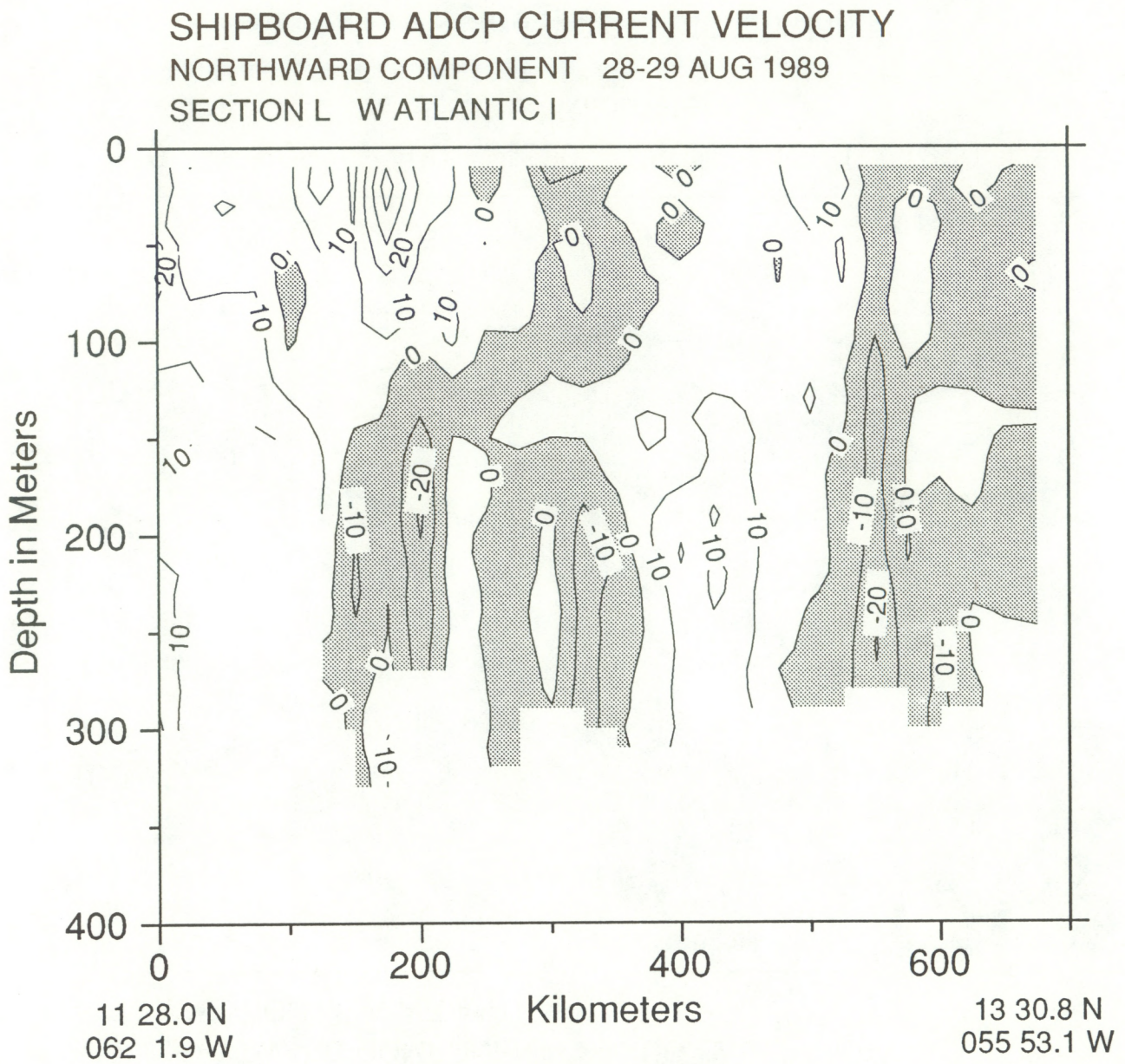

Figure A.24.b 25 km grid

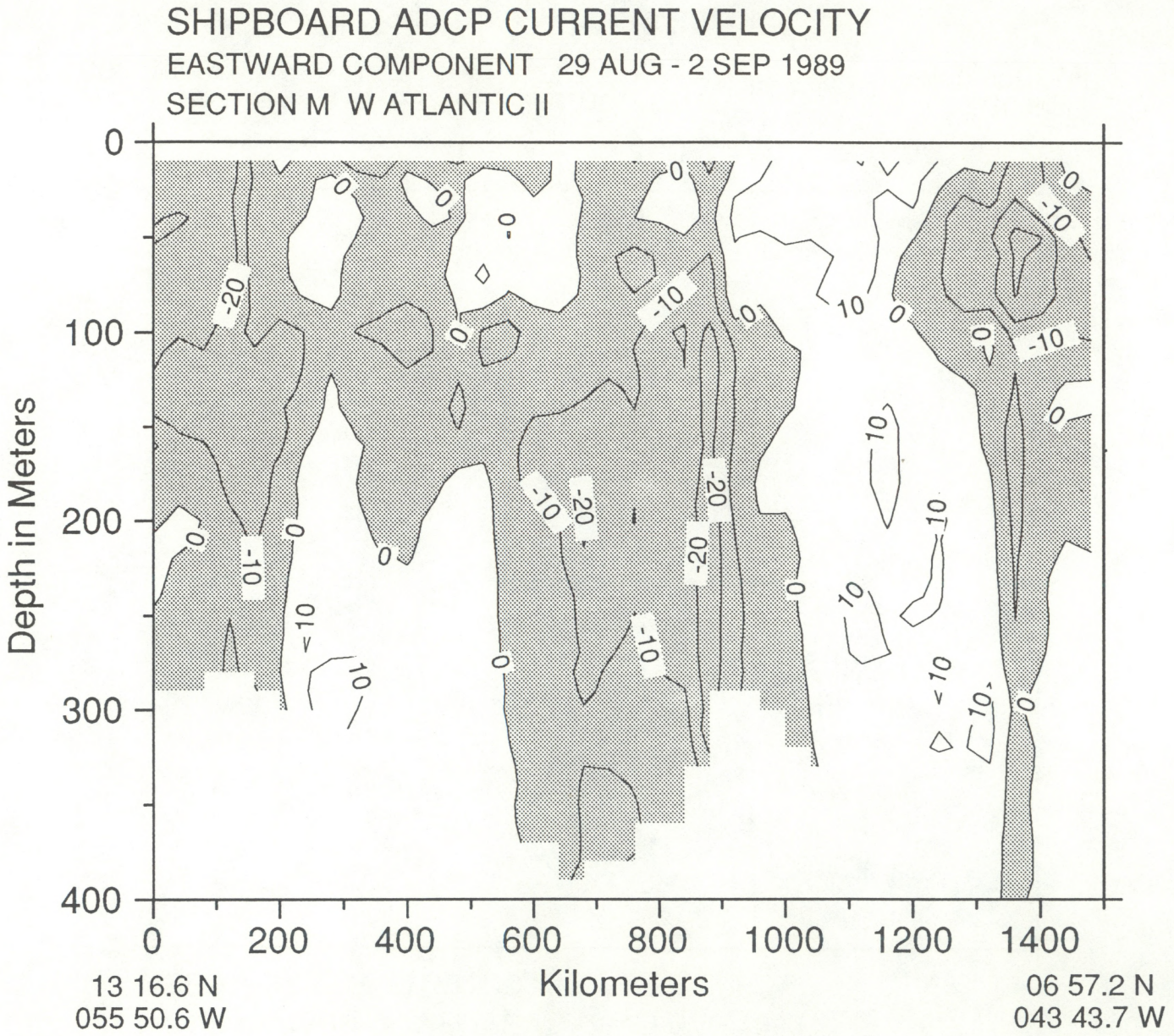

Figure A.25.a 40 km grid

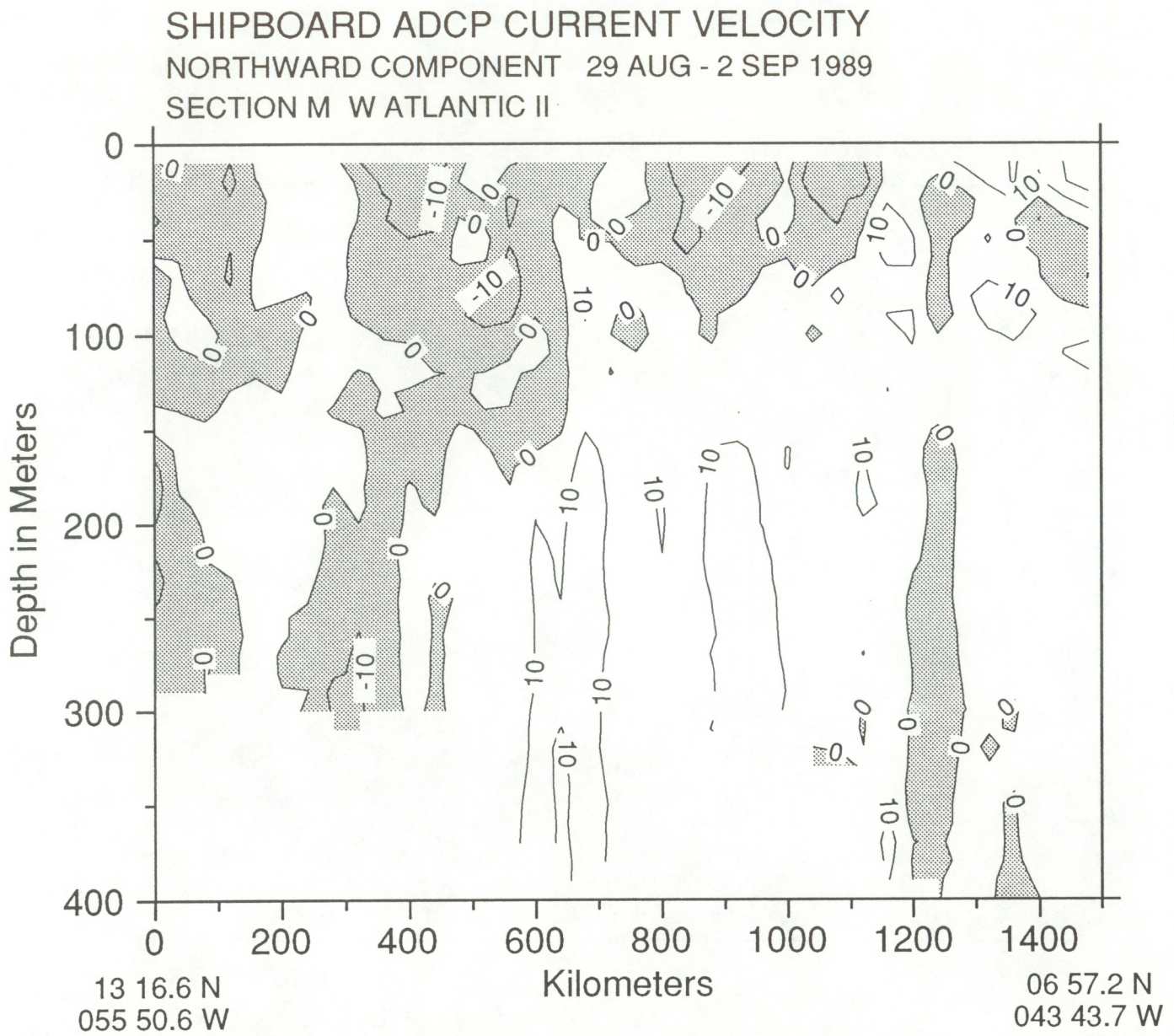

Figure A.25.b 40 km grid

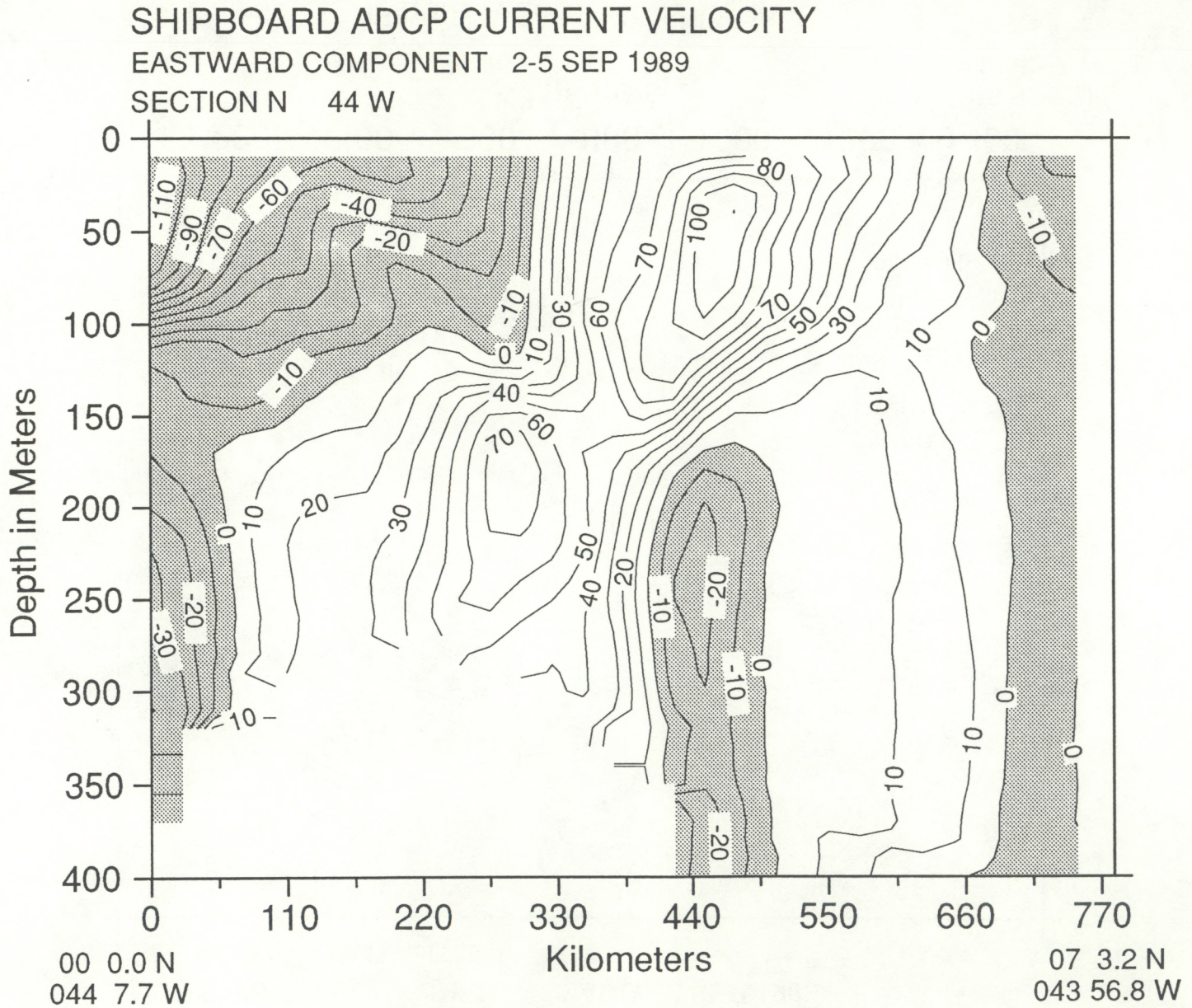

Figure A.26.a 25 km grid

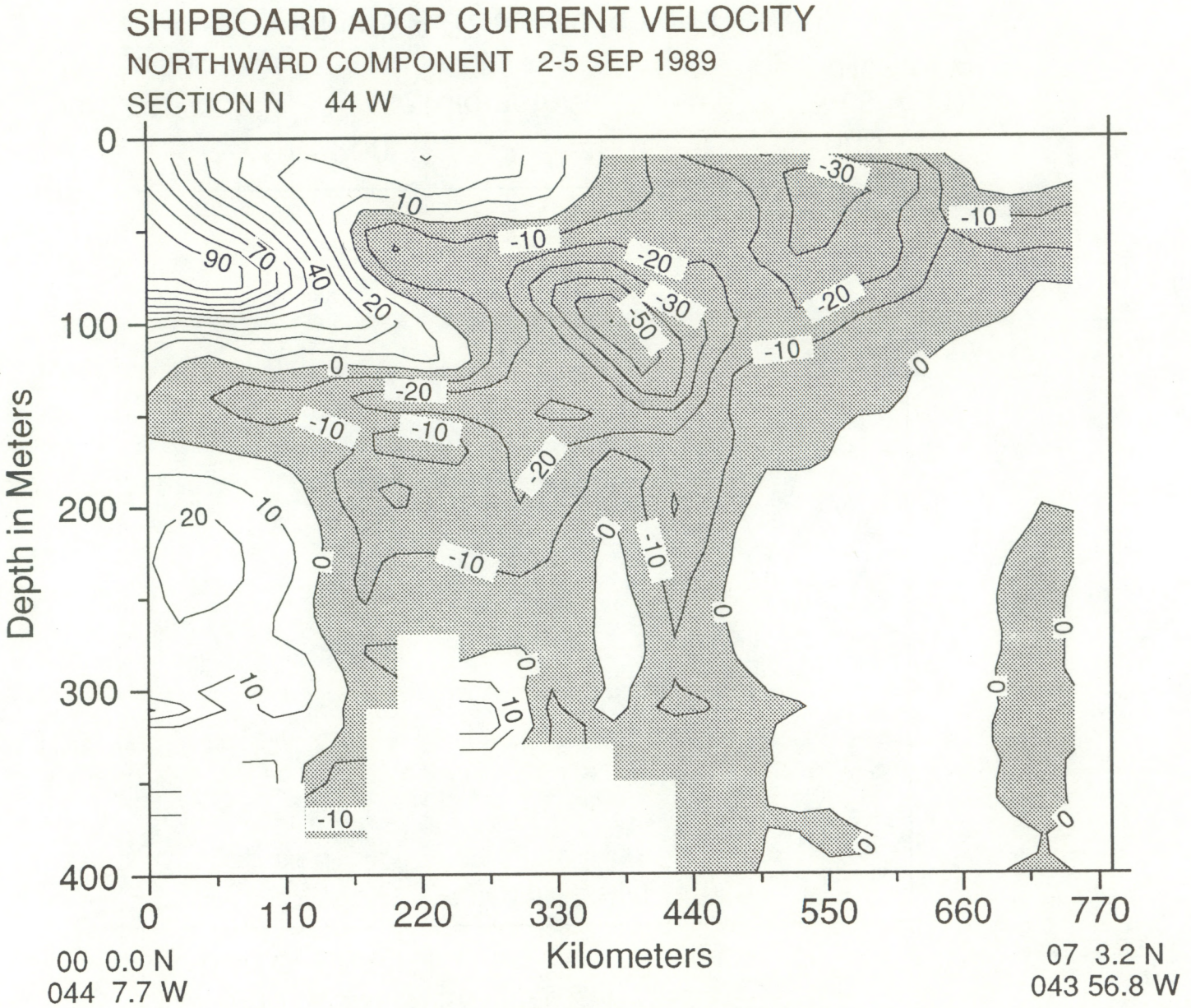

Figure A.26.b 25 km grid

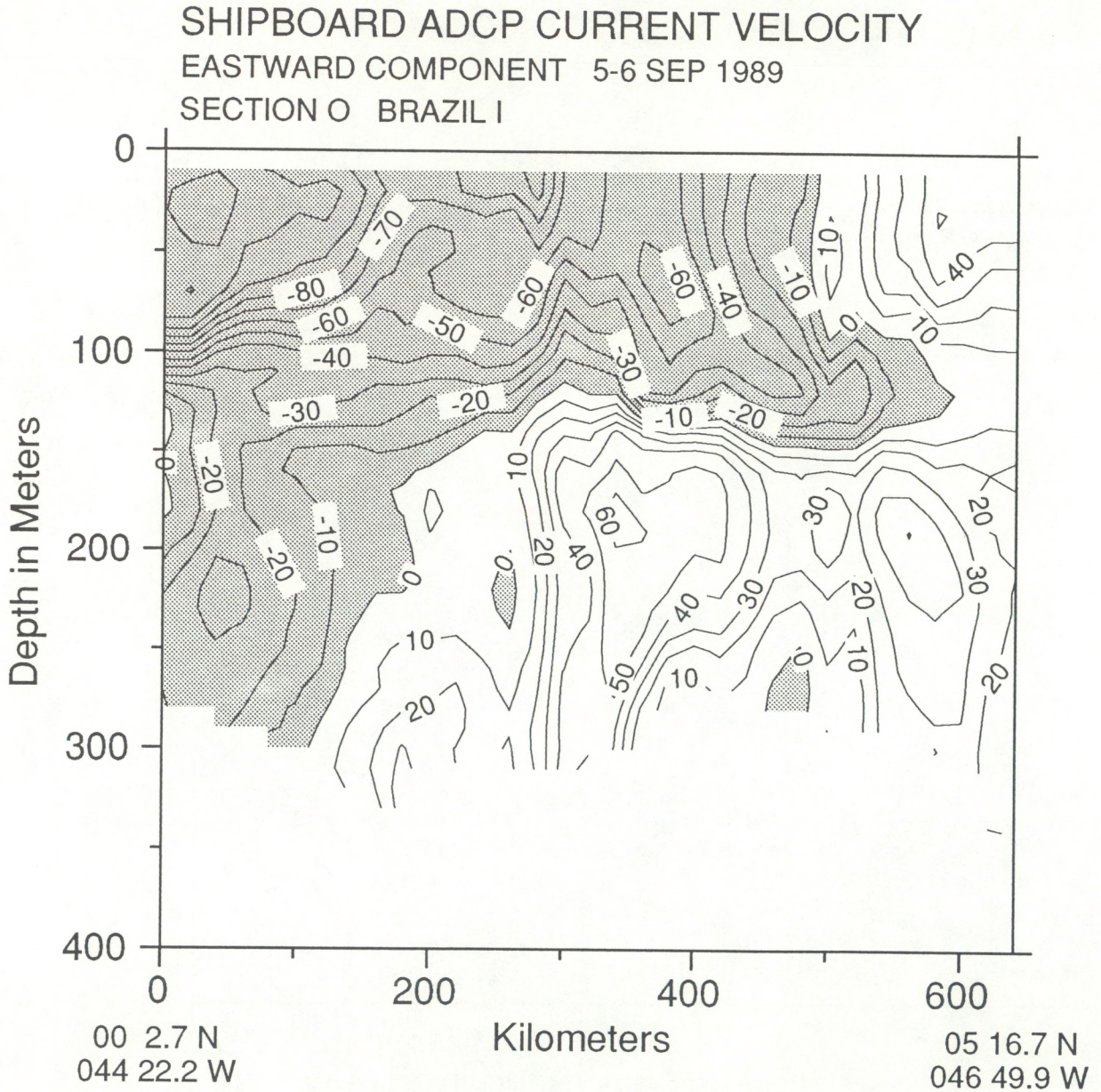

Figure A.27.a 20 km grid

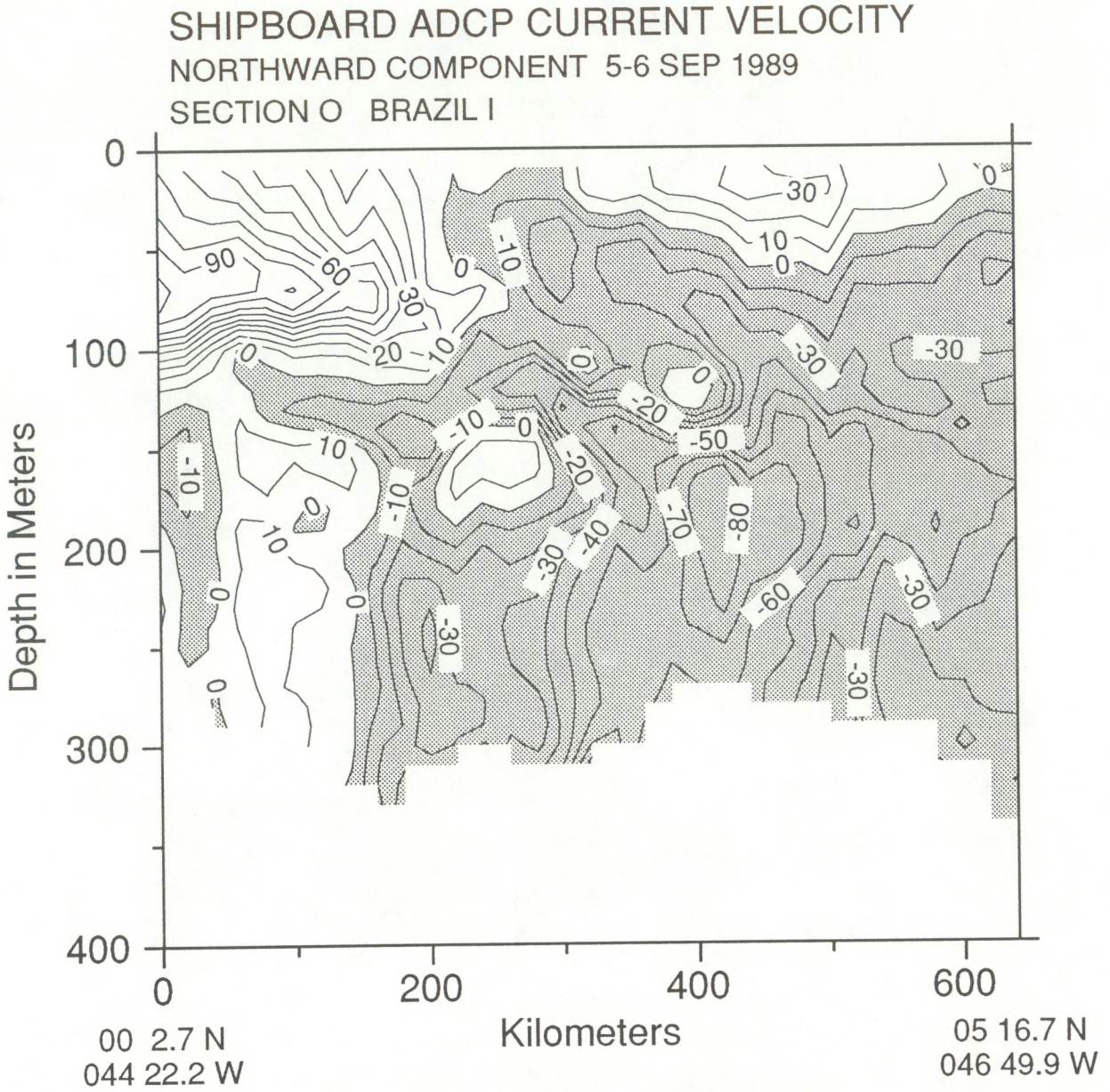

Figure A.27.b 20 km grid

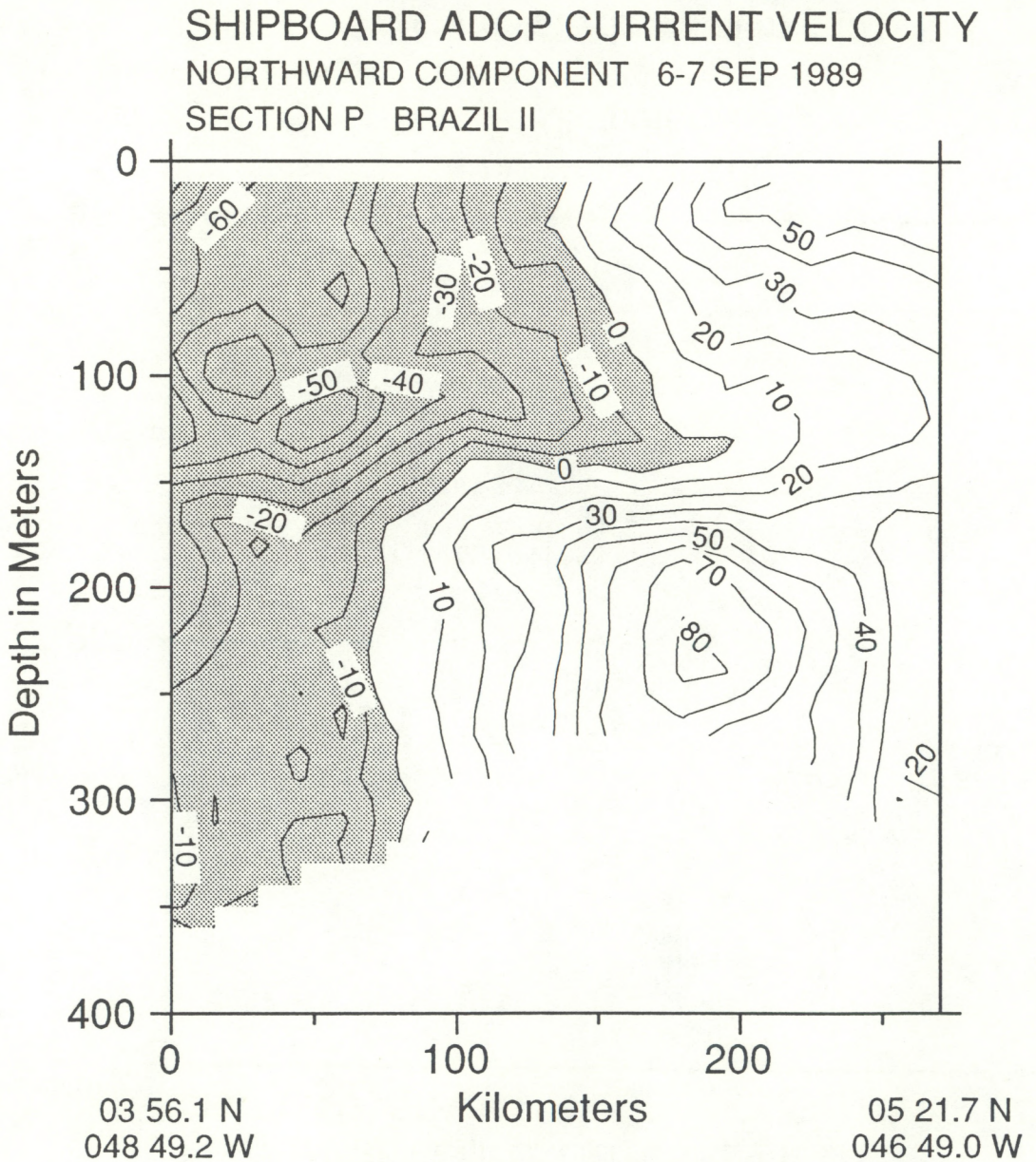

Figure A.28.a 15 km grid

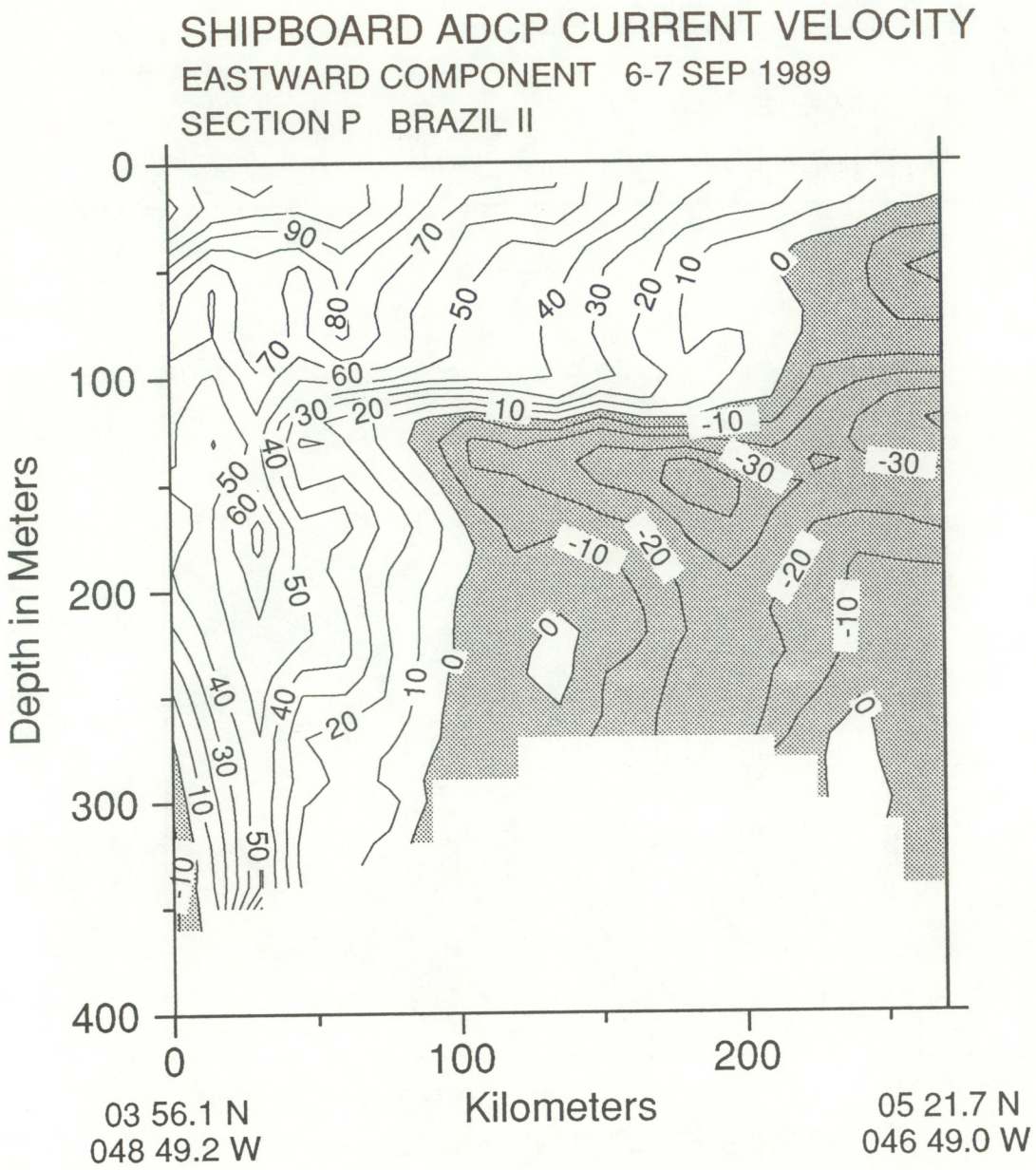

Figure A.28.b 15 km grid

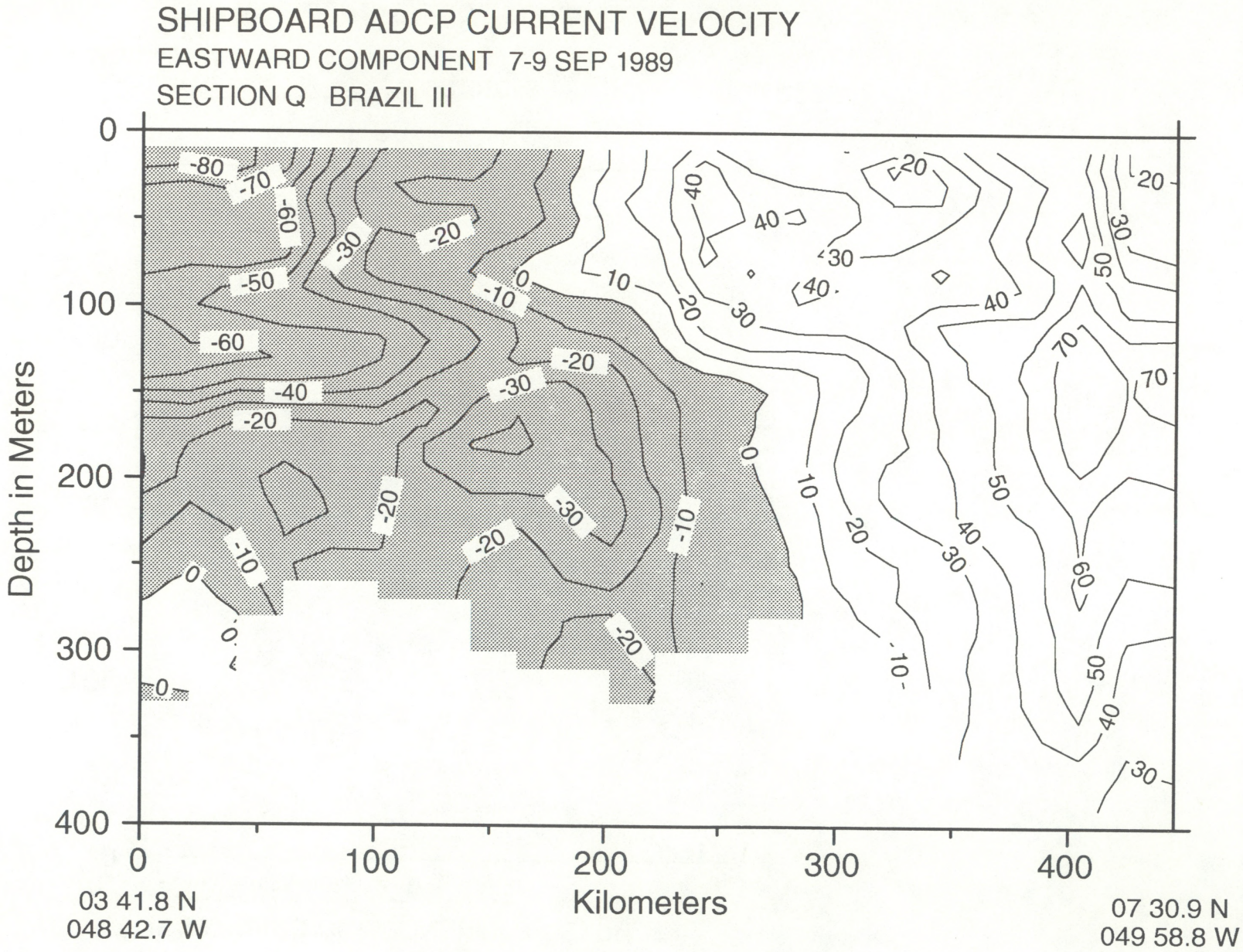

Figure A.29.a 20 km grid

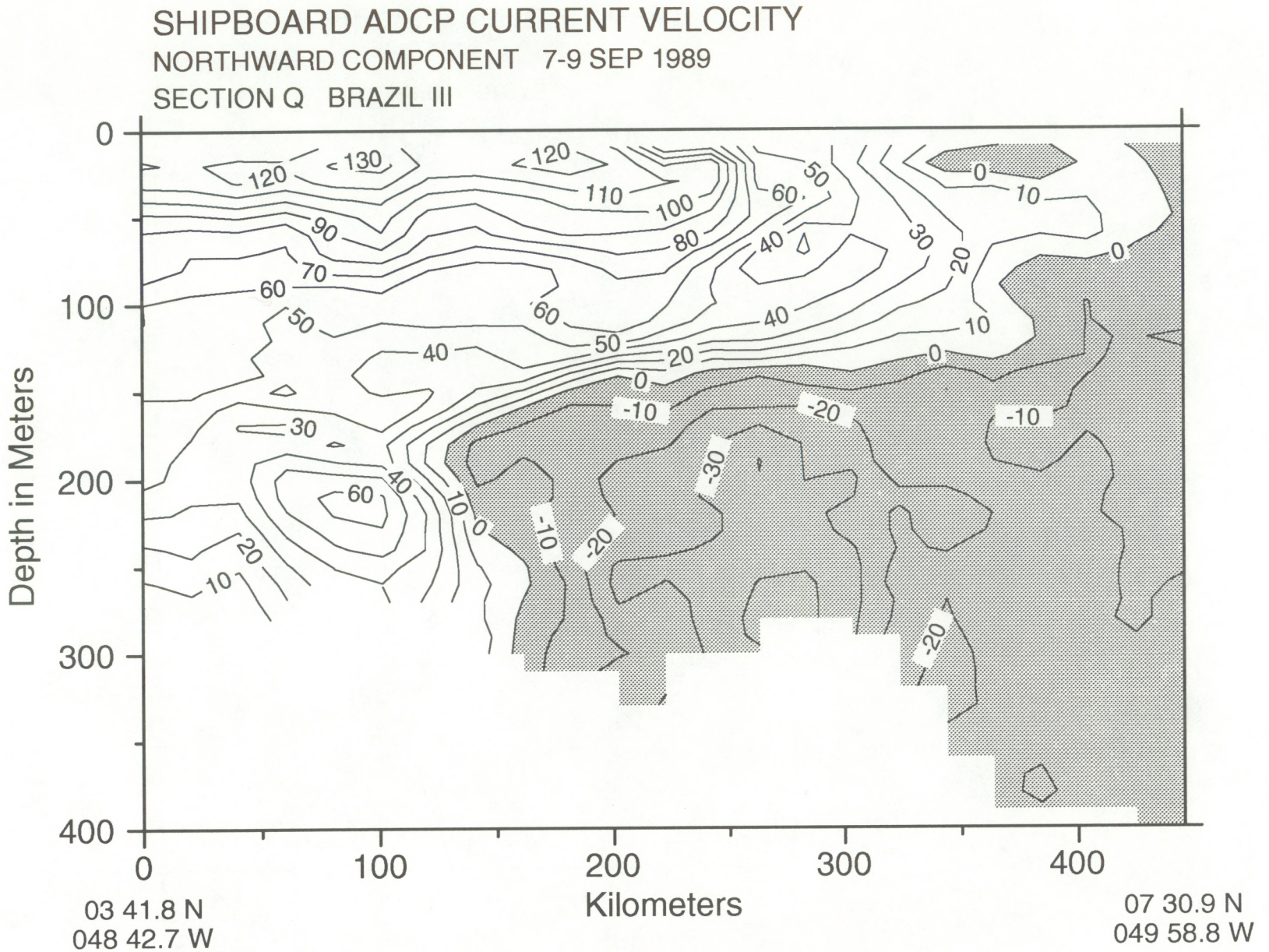

Figure A.29.b 20 km grid

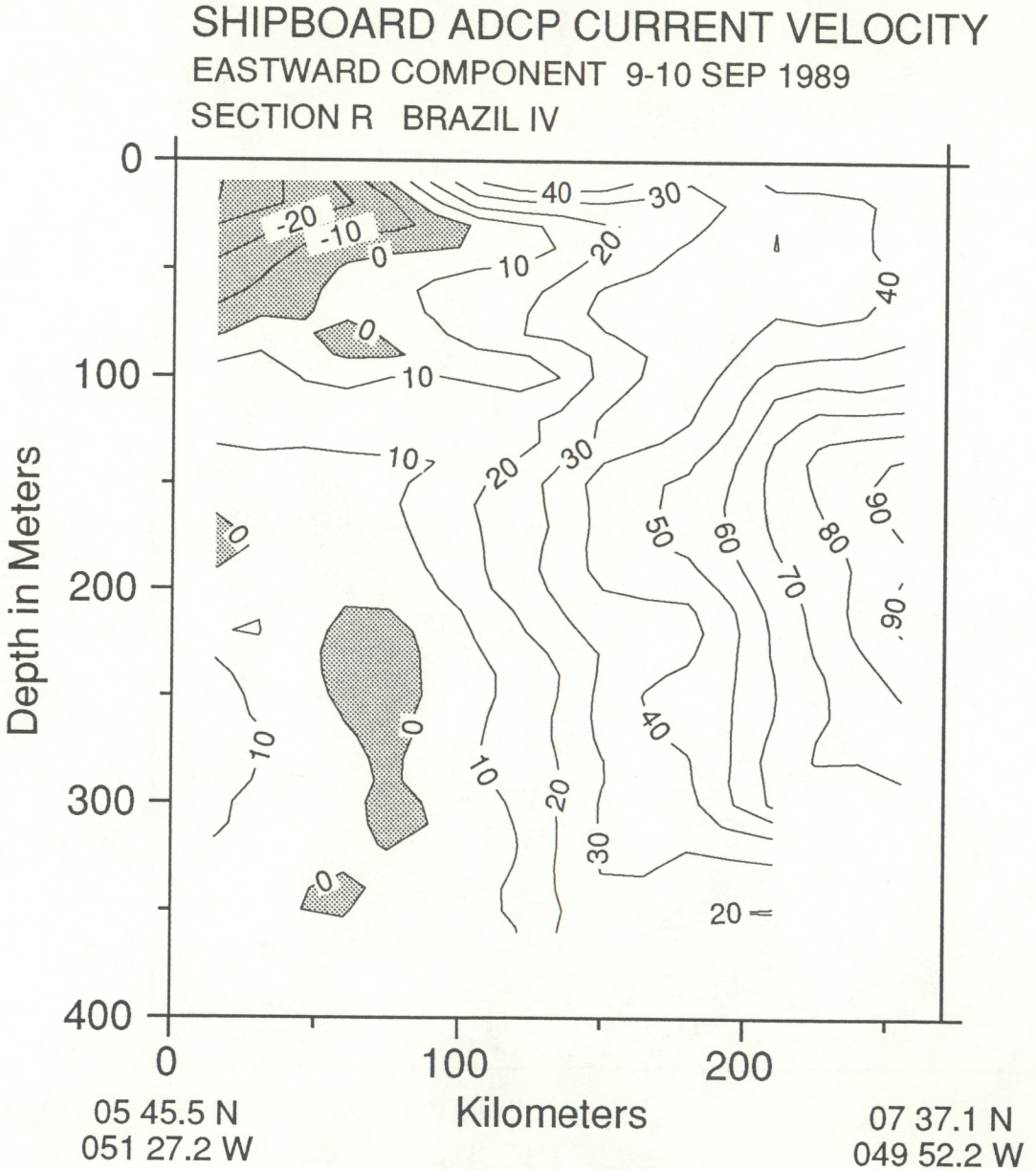

Figure A.30.a 15 km grid

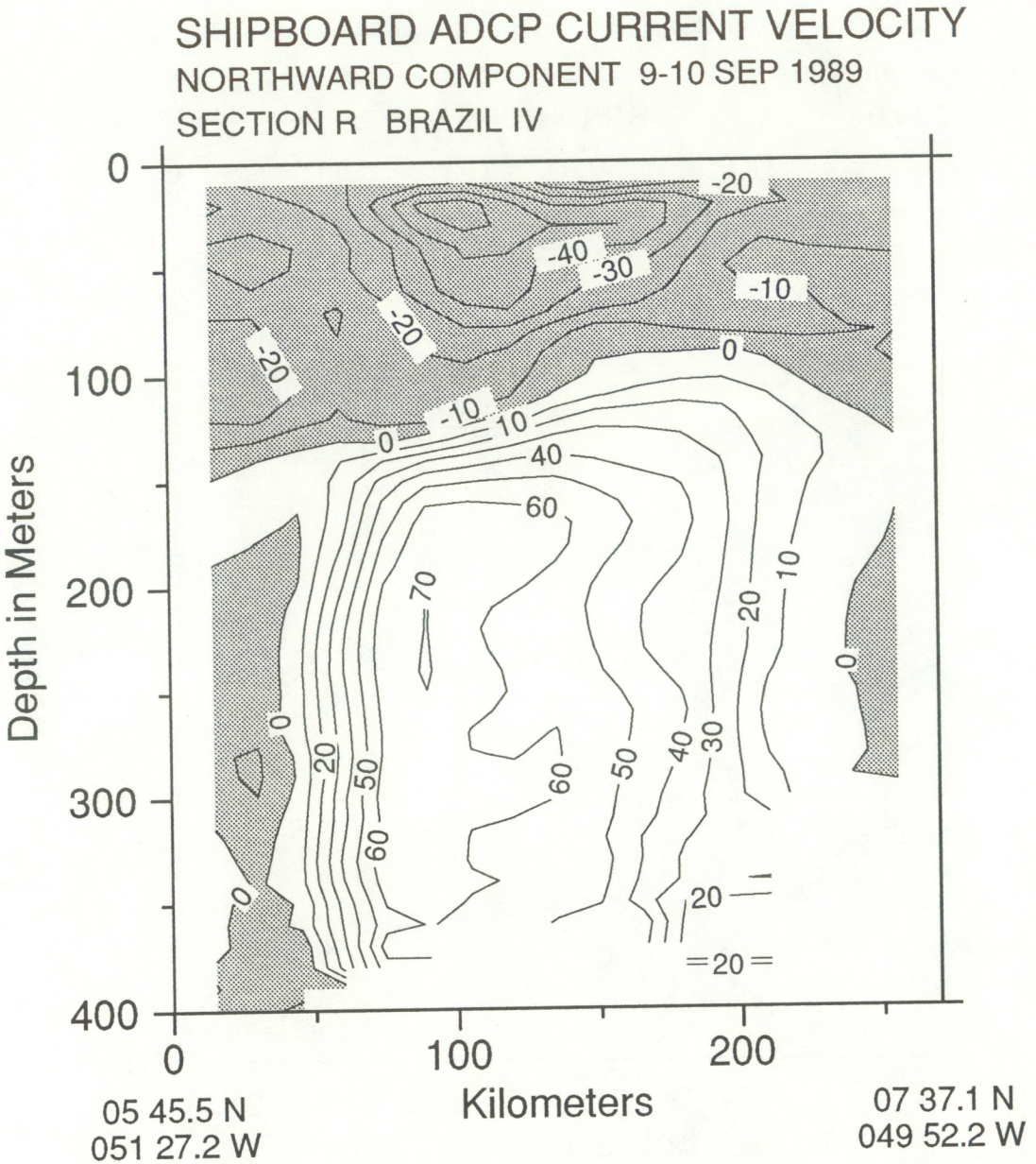

Figure A.30.b 15 km grid

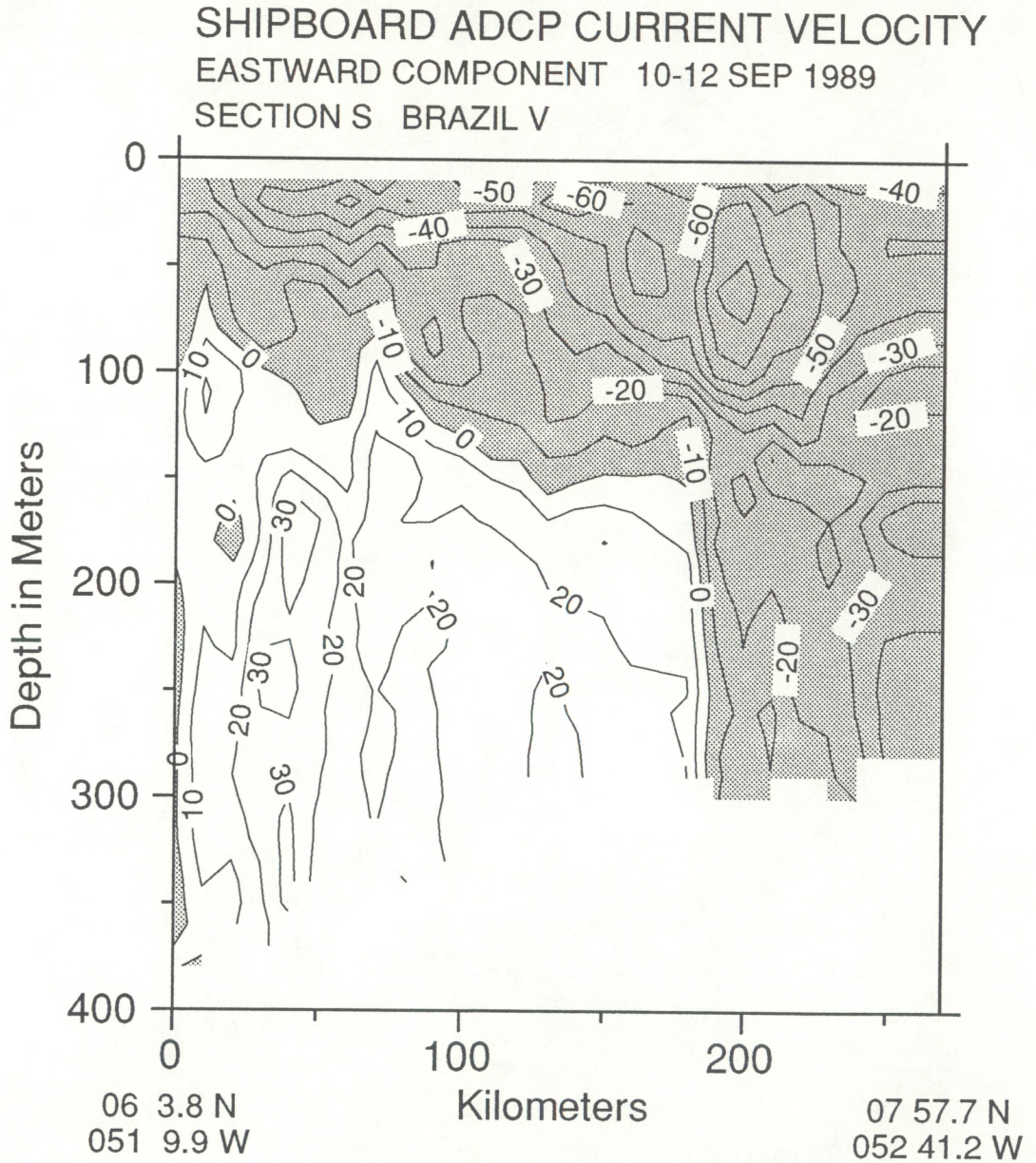

Figure A.31.a 10 km grid

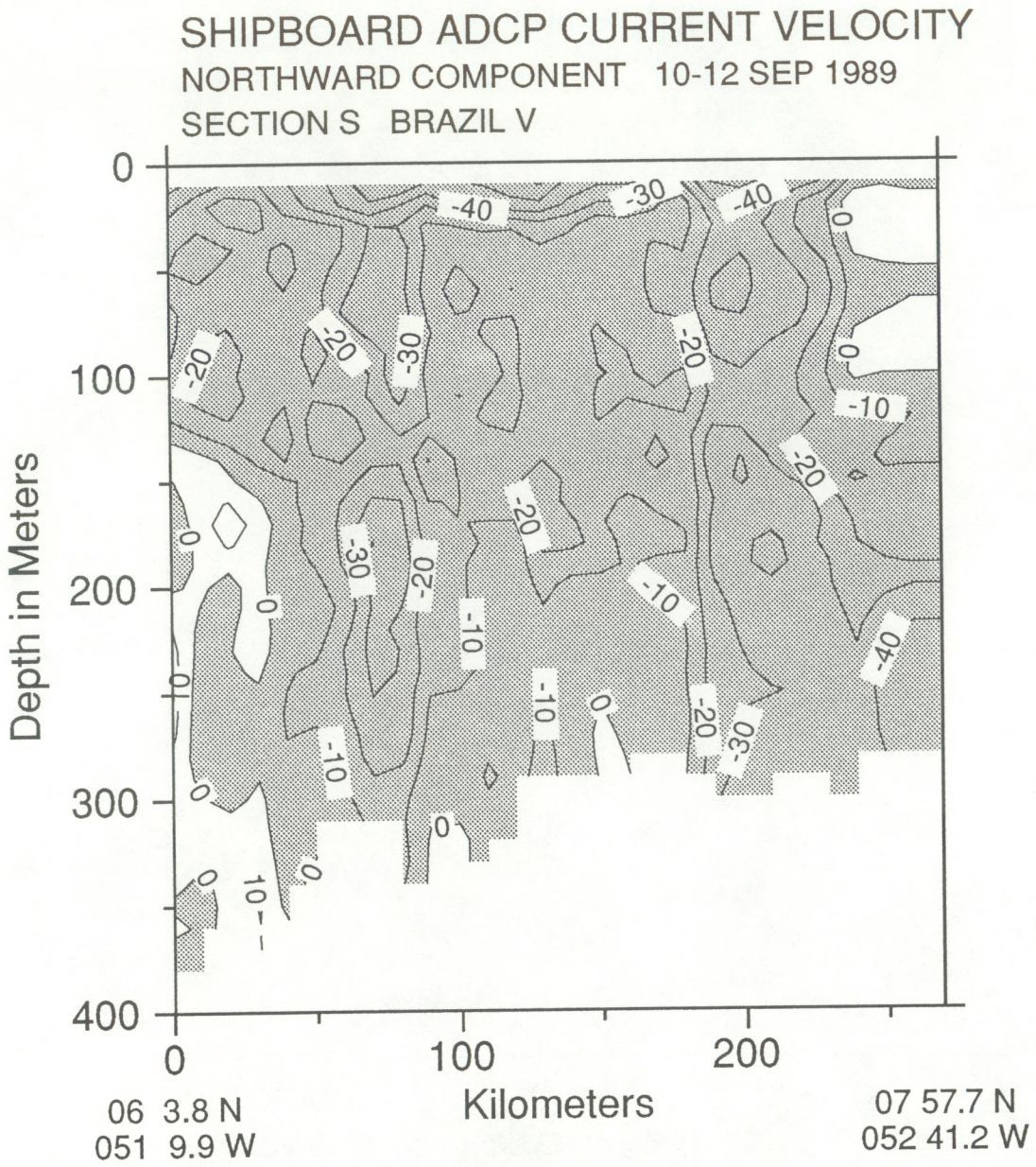

Figure A.31.b 10 km grid

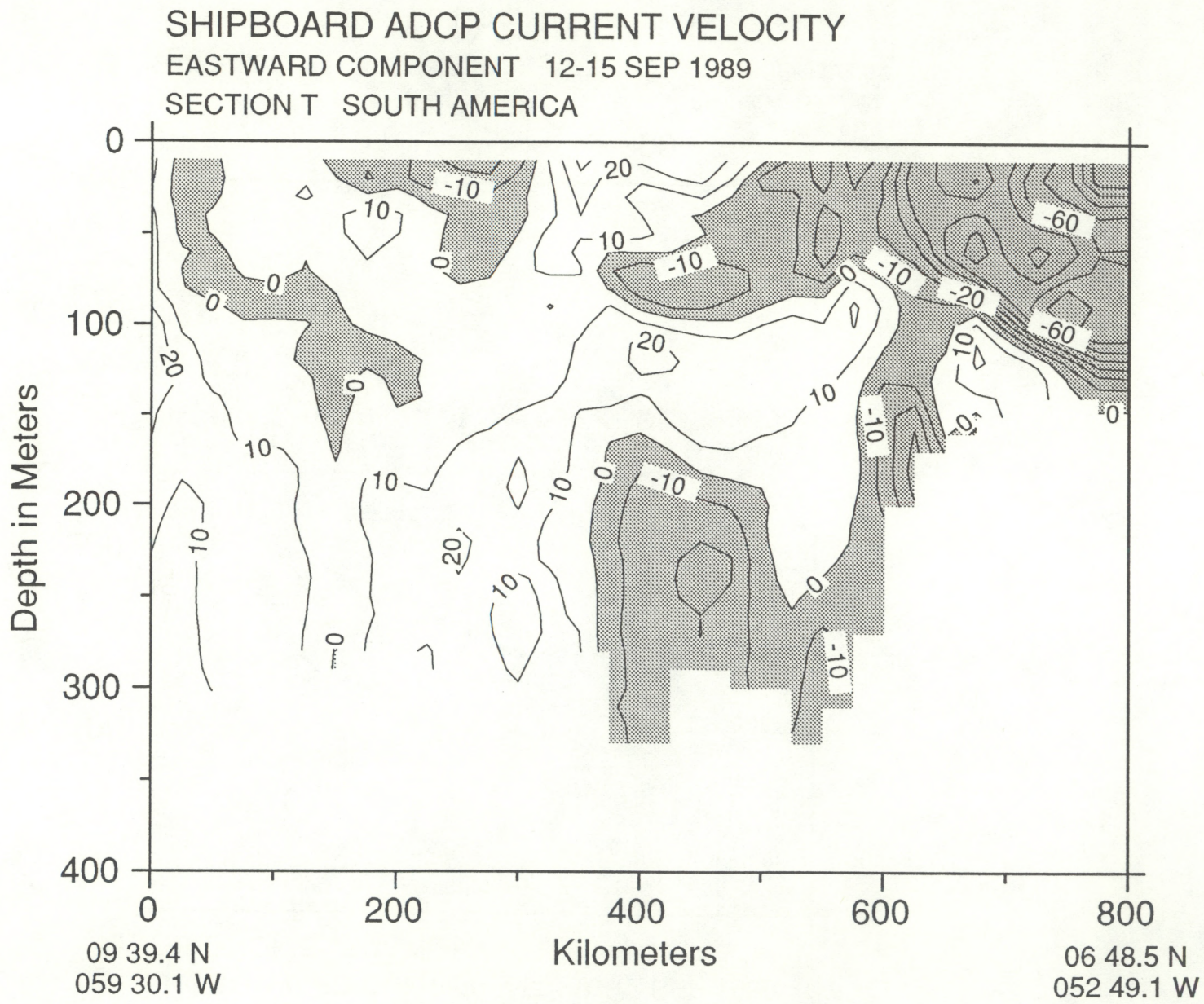

Figure A.32.a 25 km grid

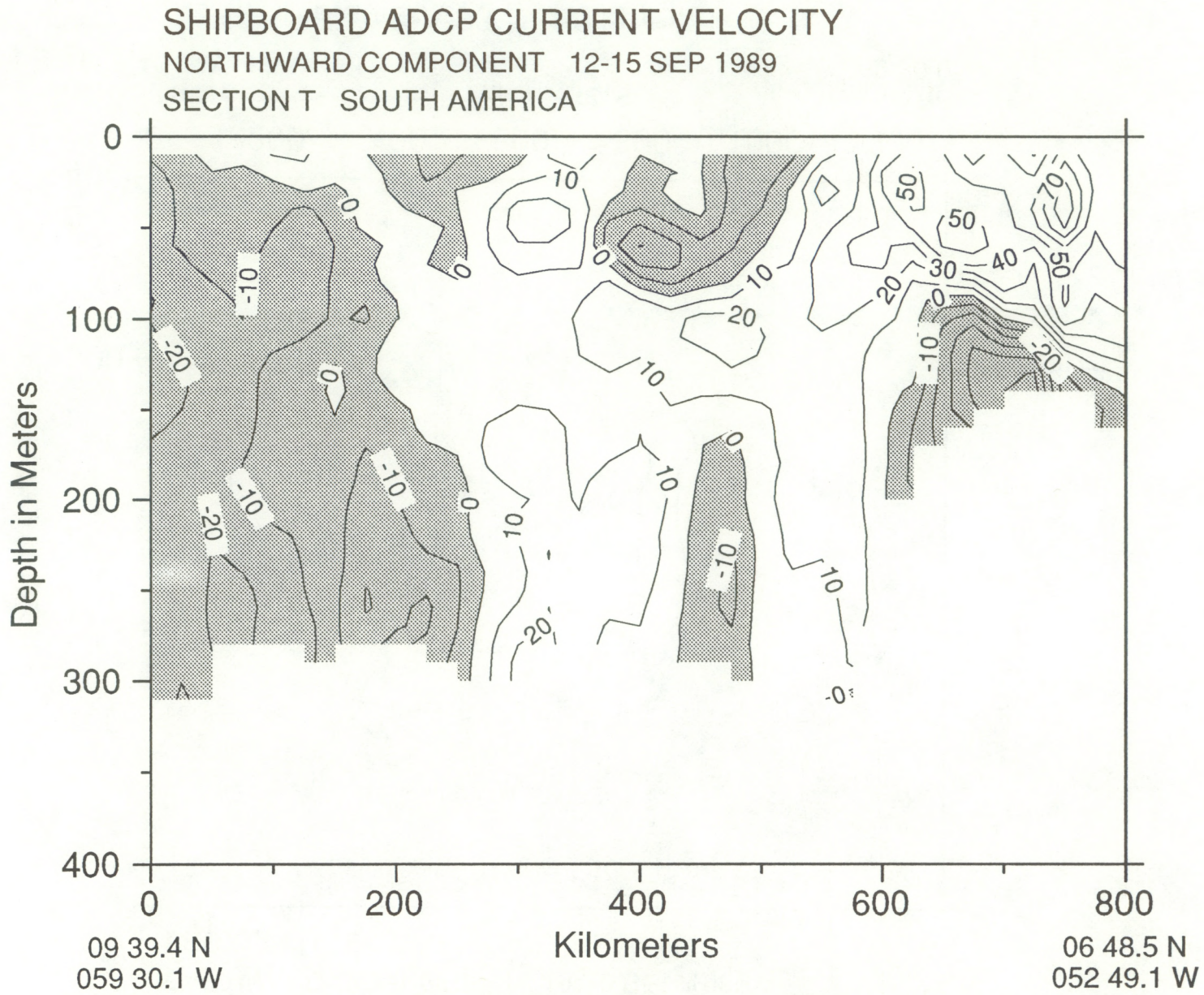

Figure A.32.b 25 km grid

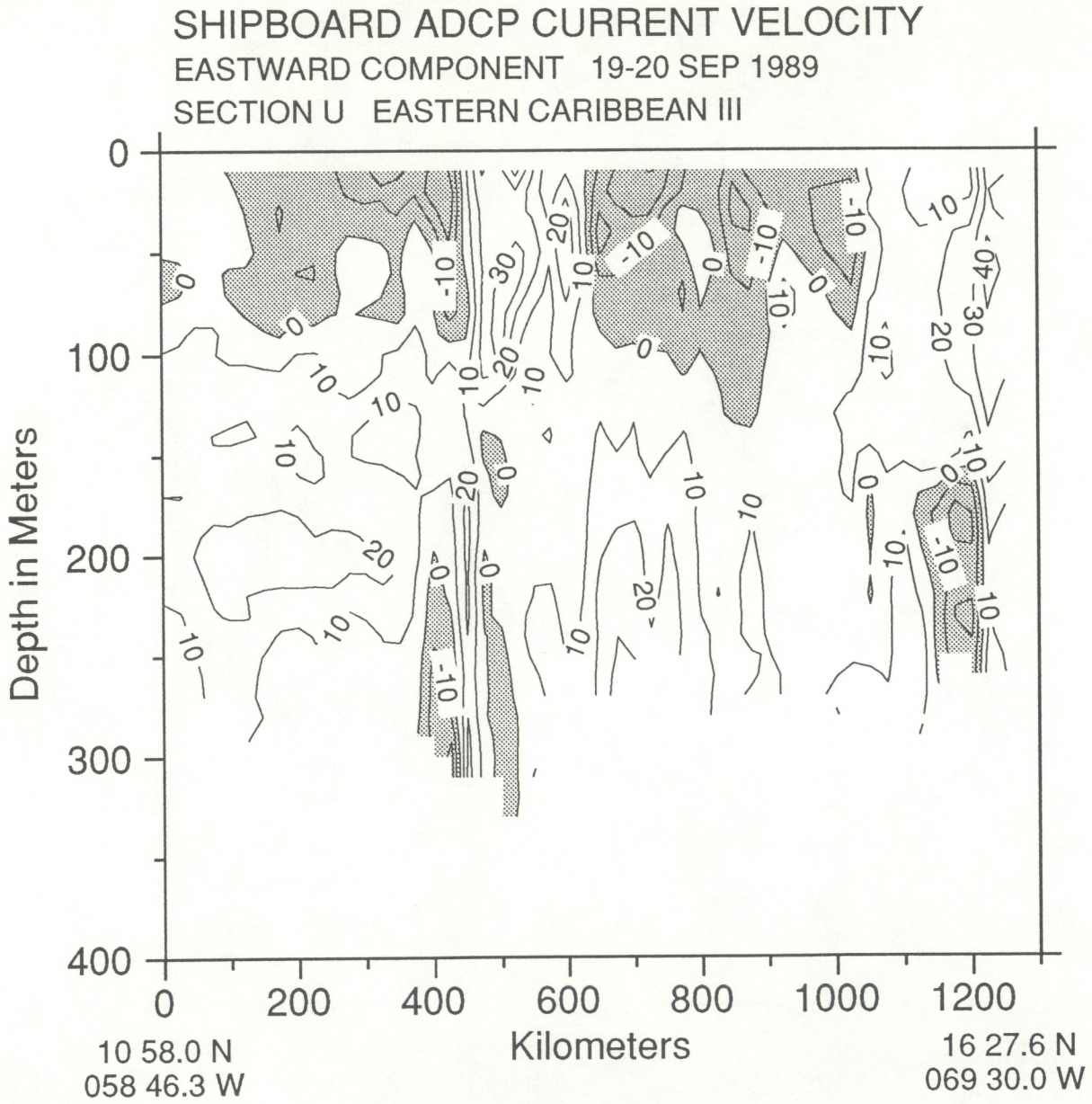

Figure A.33.a 25 km grid

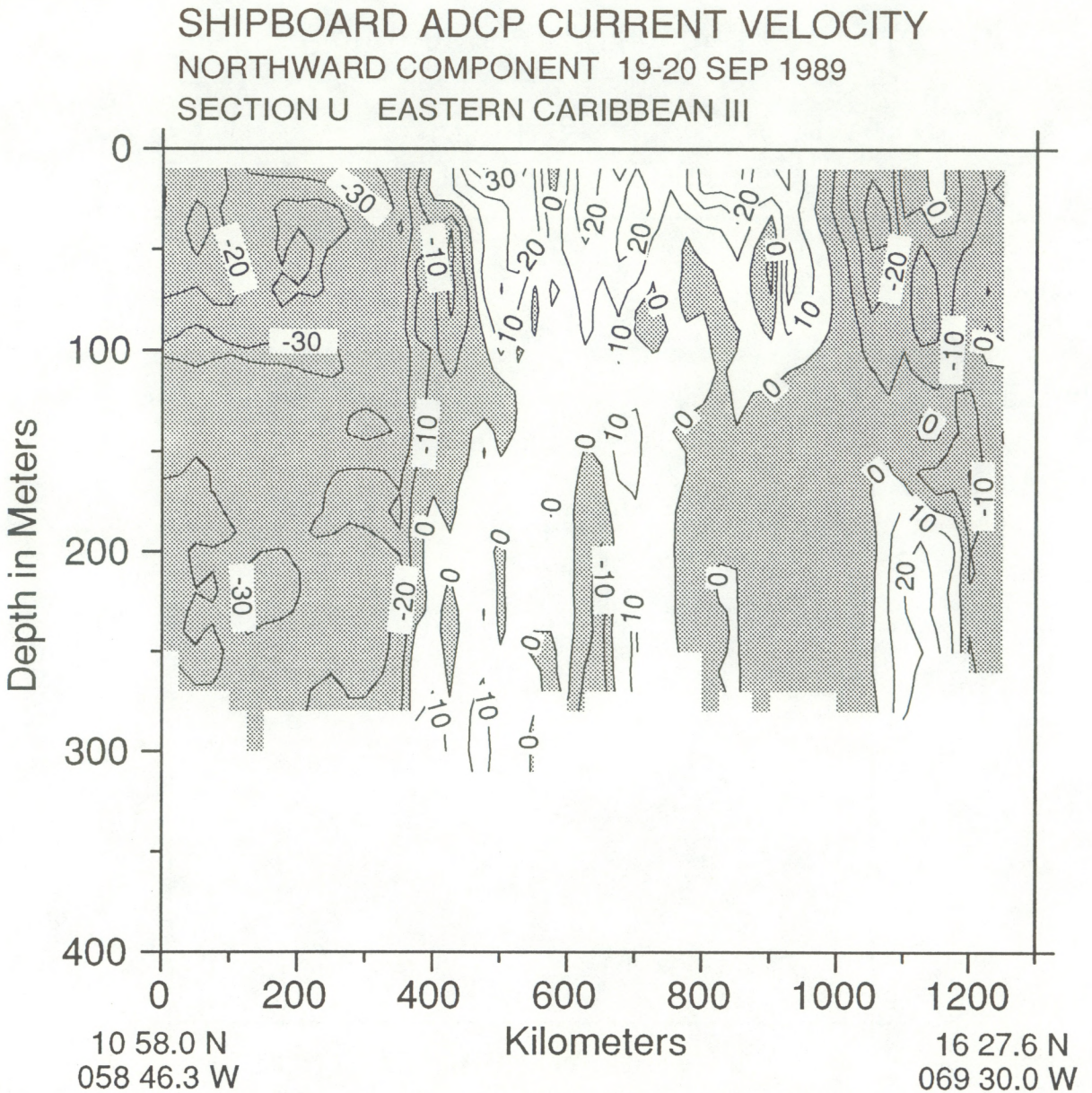

Figure A.33.b 25 km grid

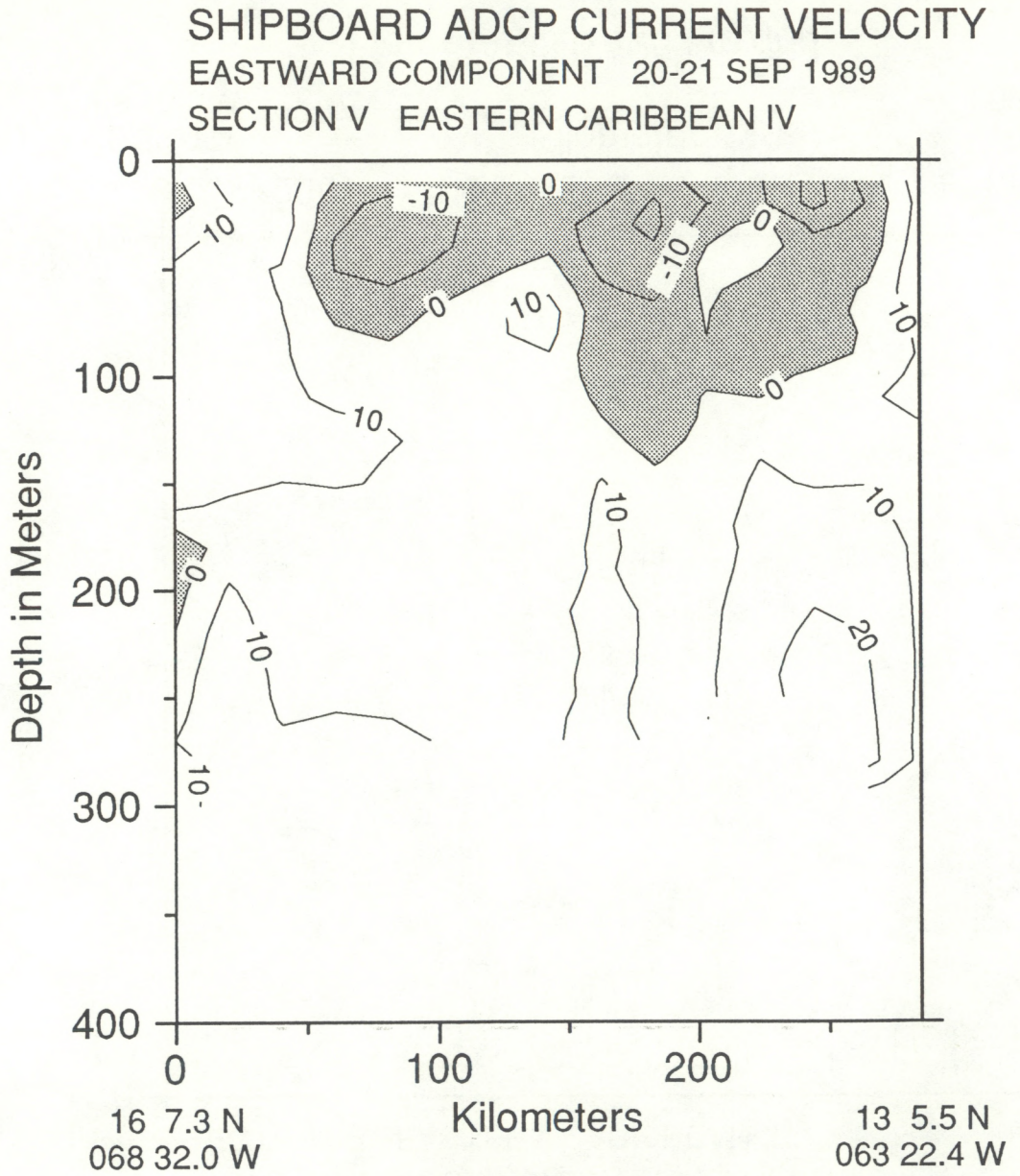

Figure A.34.a 20 km grid

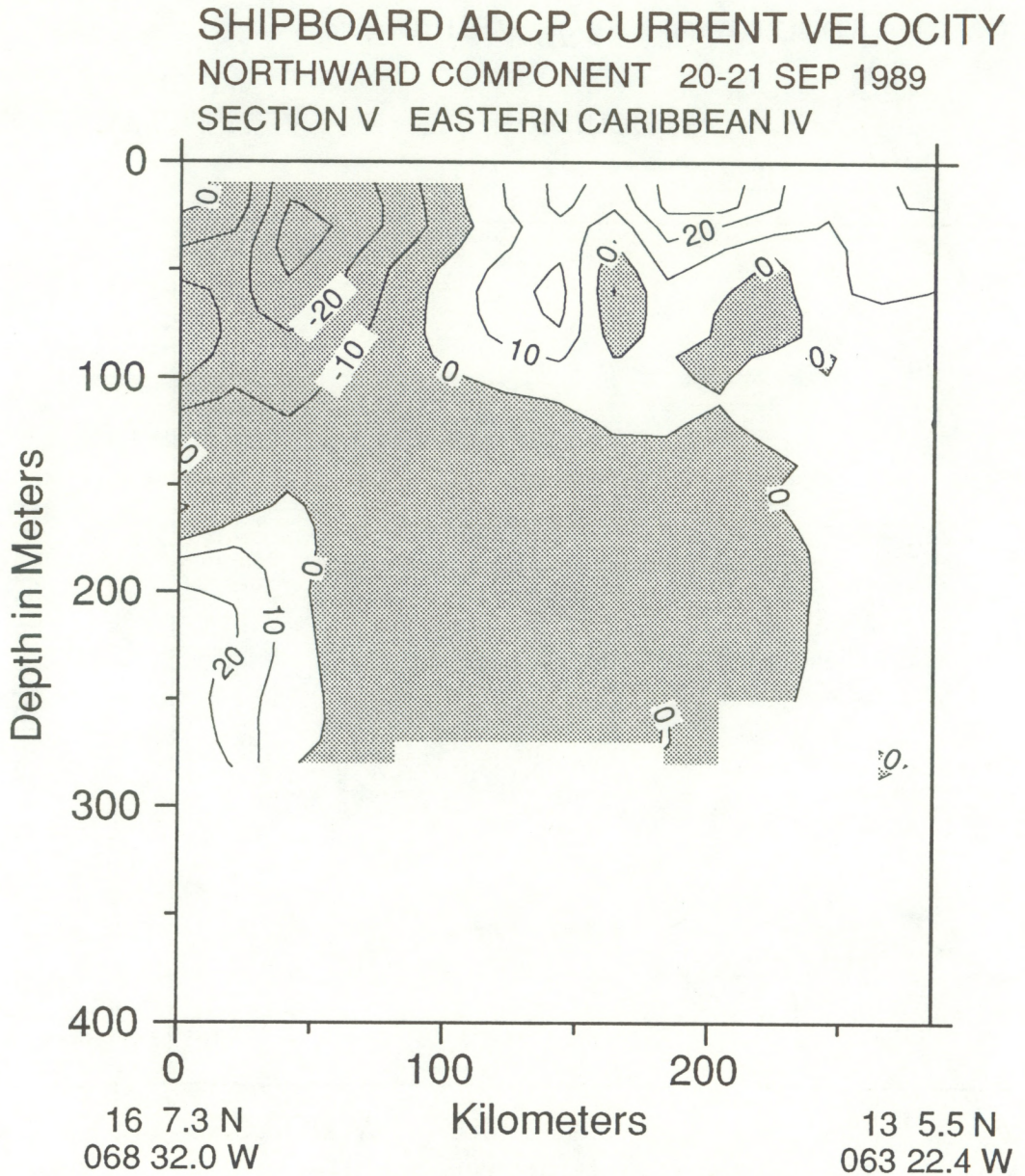

Figure A.34.b 20 km grid

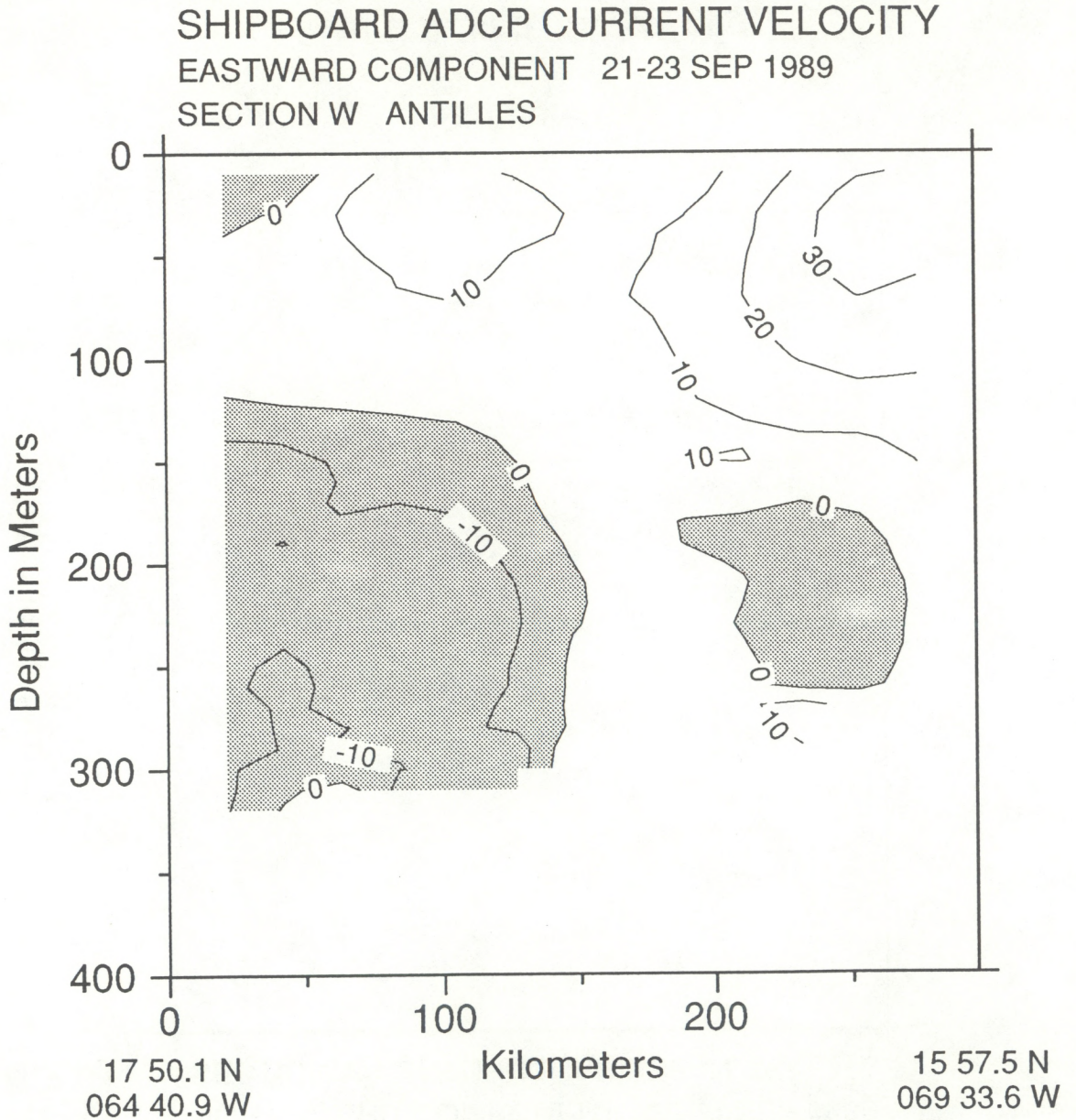

Figure A.35.a 20 km grid

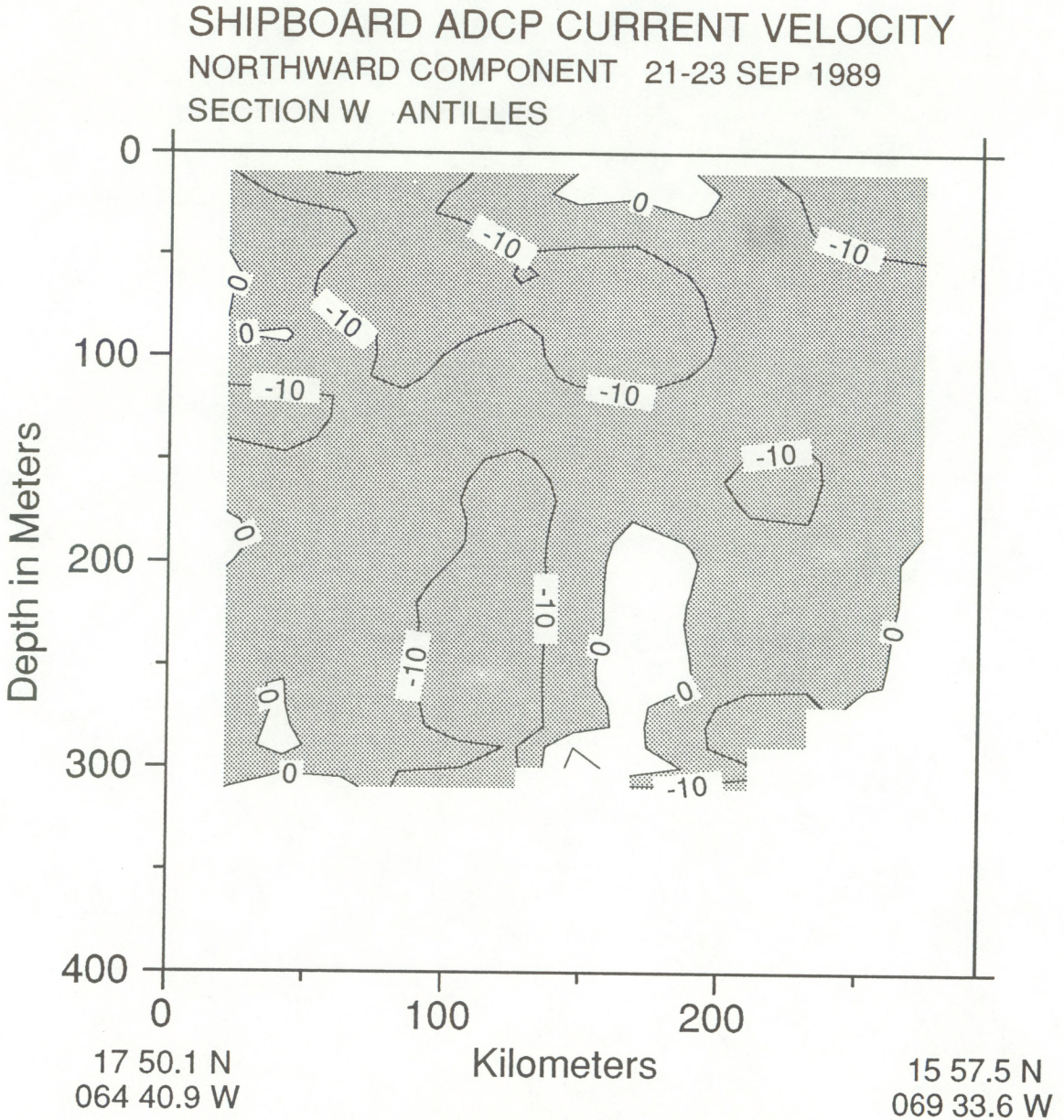

Figure A.35.b 20 km grid

Appendix B Data from STACS 36 June 1990

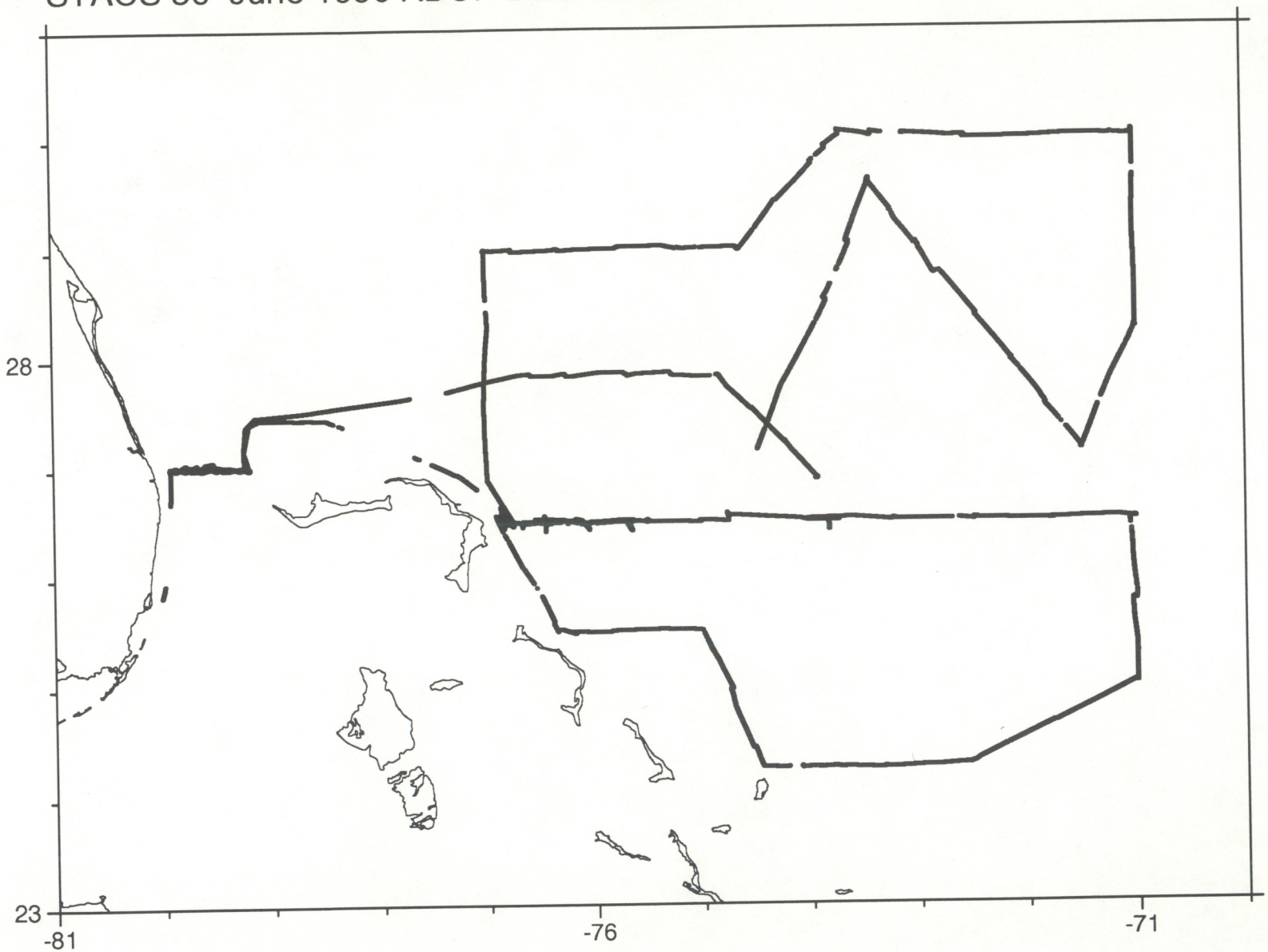

Figure B.1

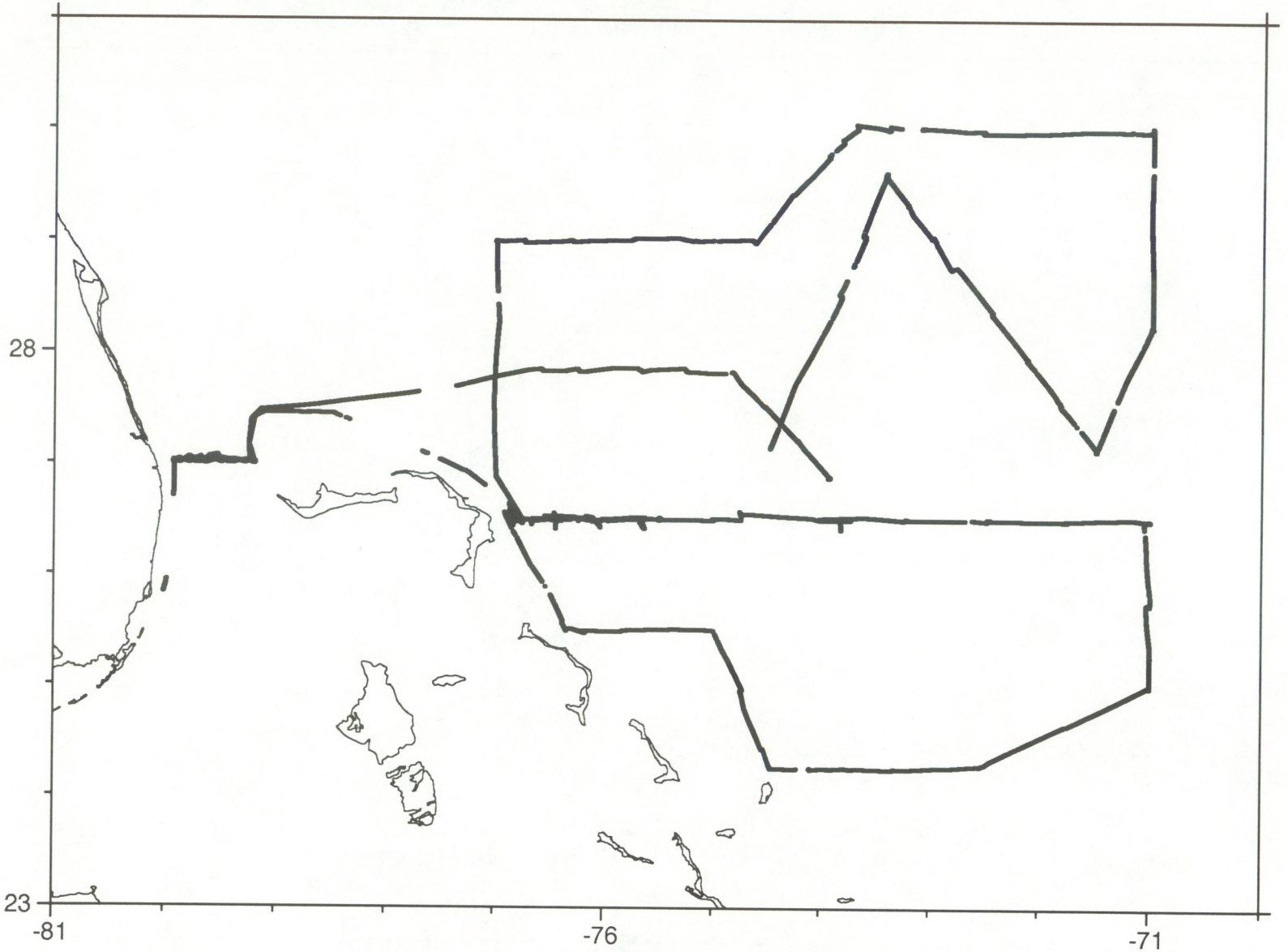

Figure B.2 Navigation Coverage

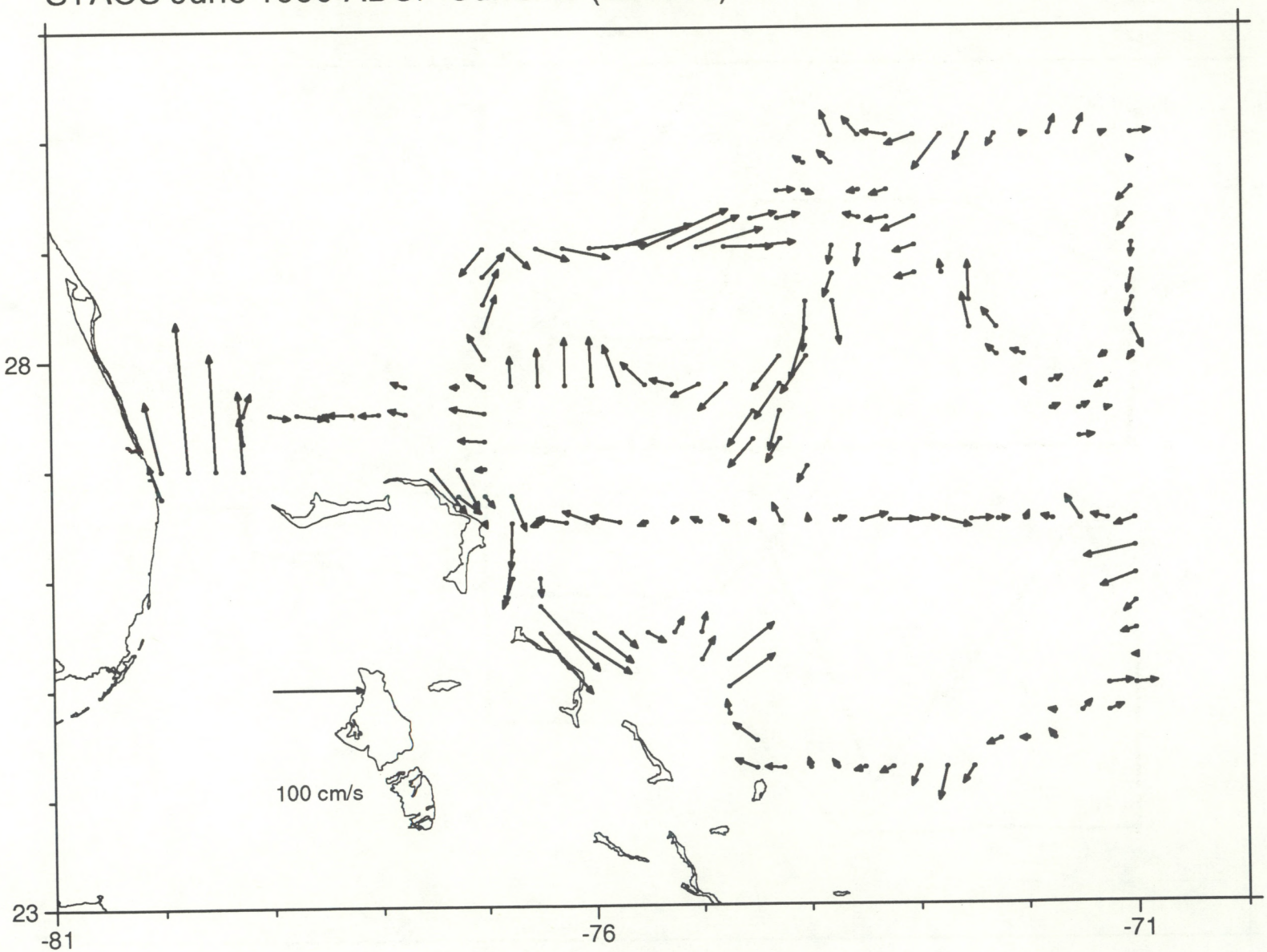

Figure B.3 0.25 Degree Grid

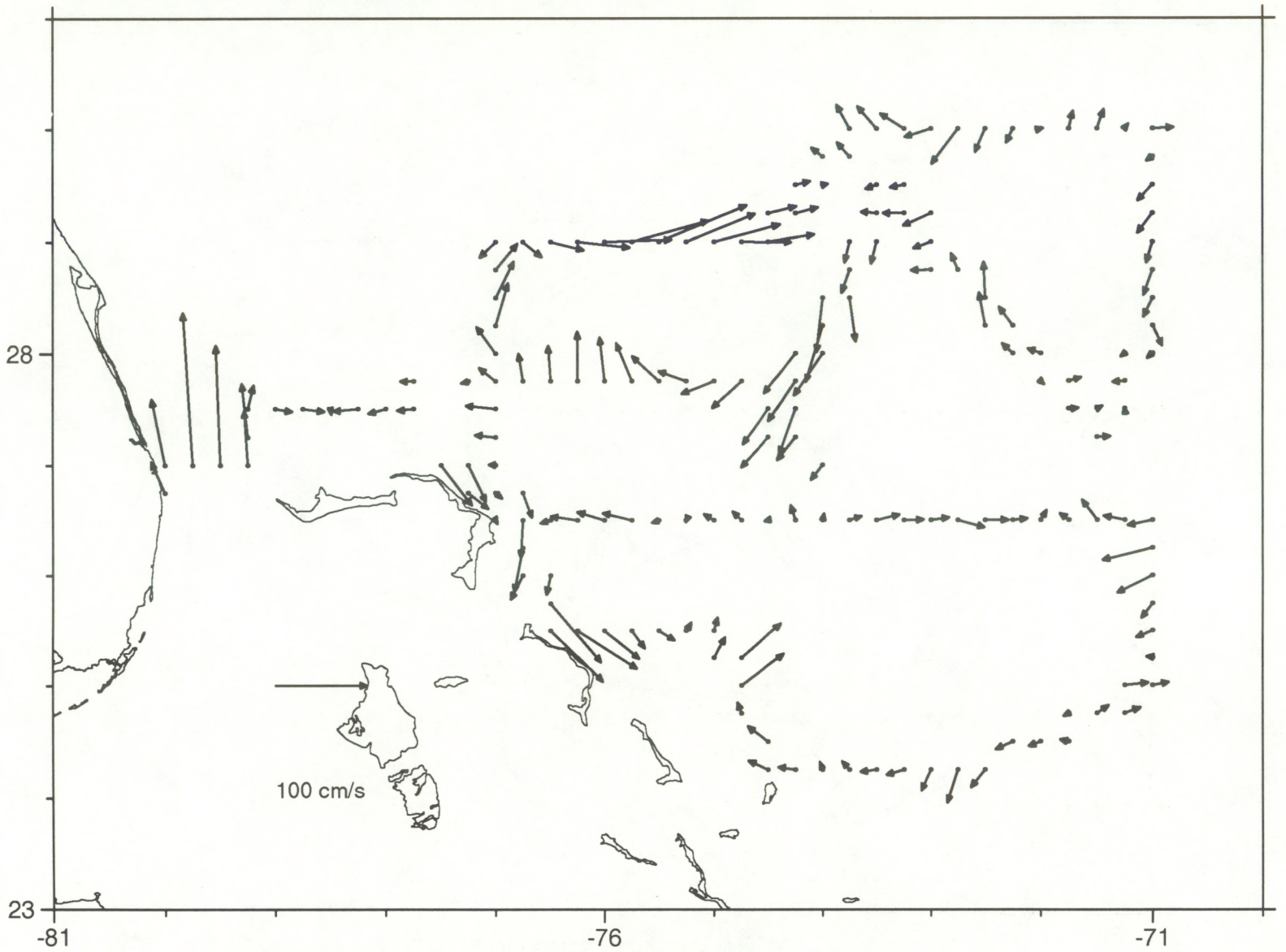

Figure B.4 0.25 Degree Grid

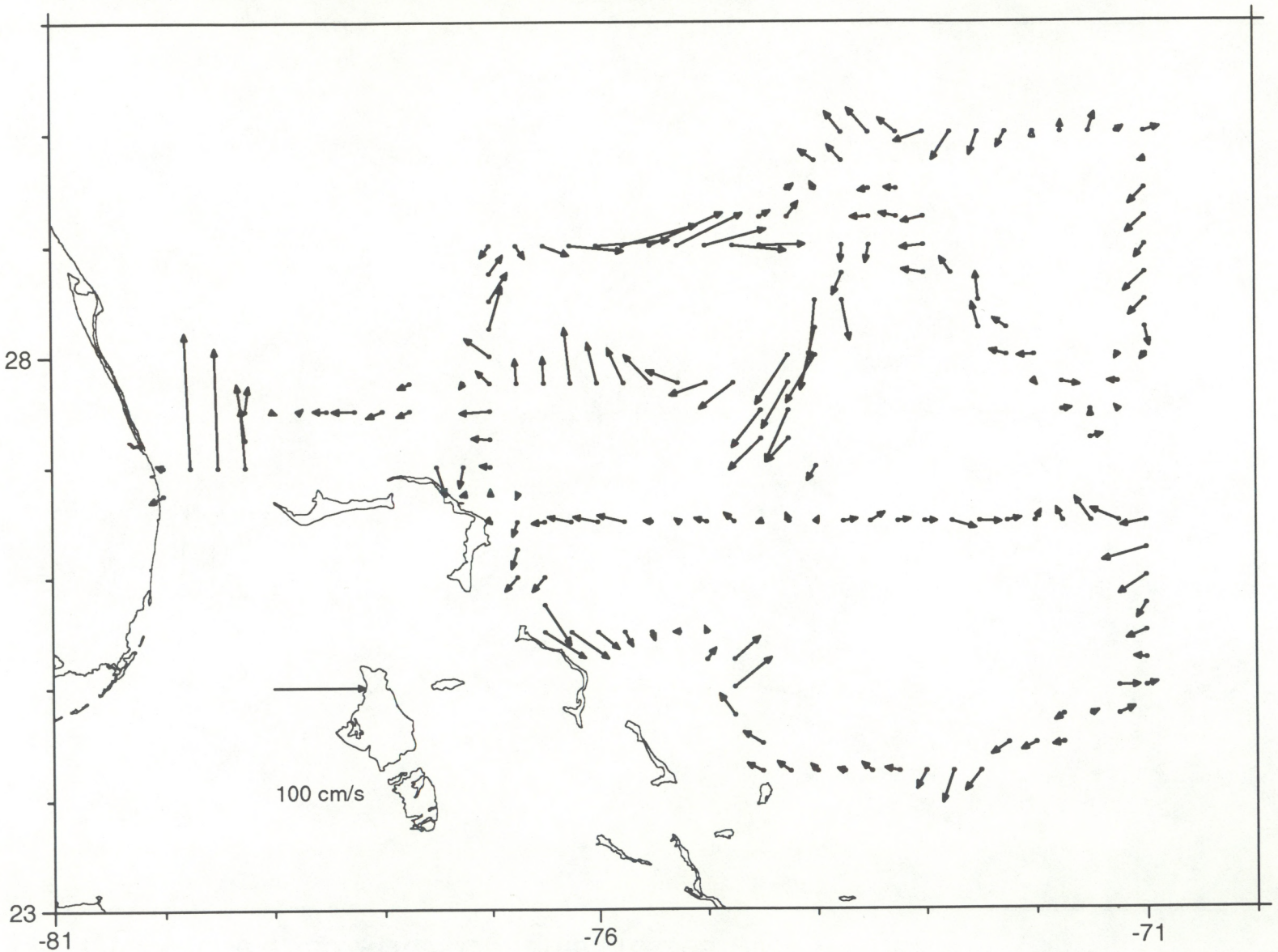

Figure B.5 0.25 Degree Grid

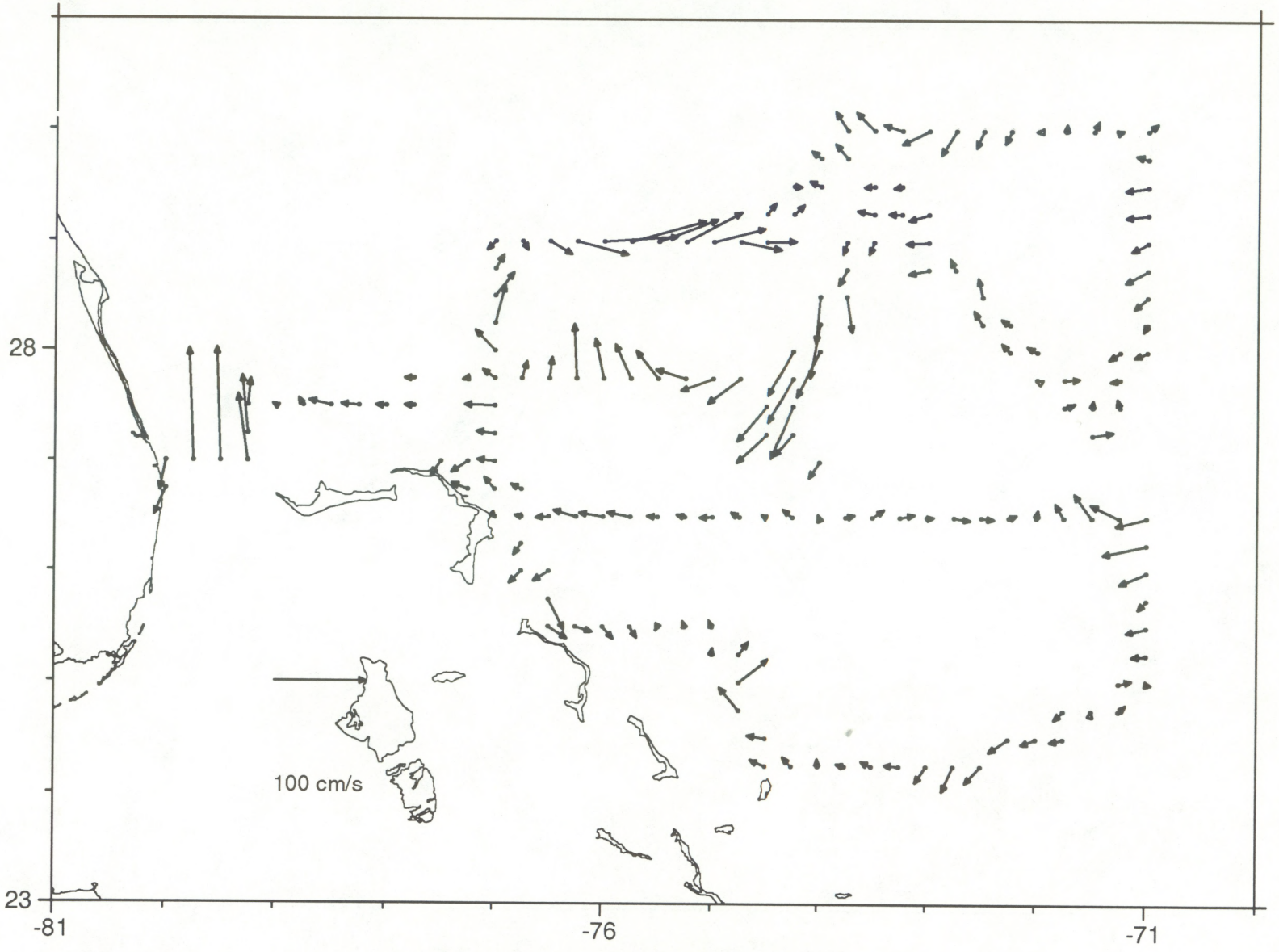

Figure B.6 0.25 Degree Grid

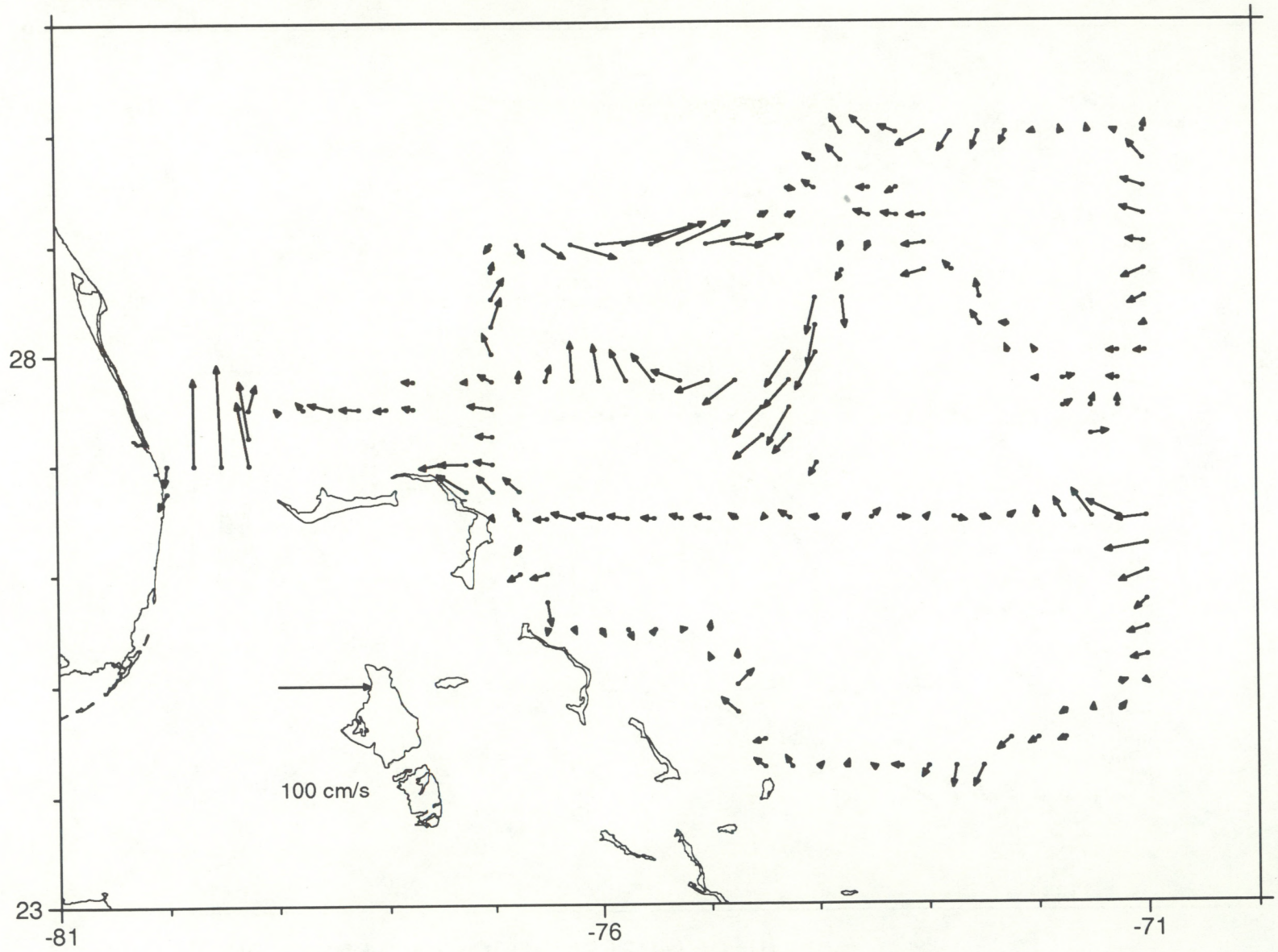

Figure B.7 0.25 Degree Grid

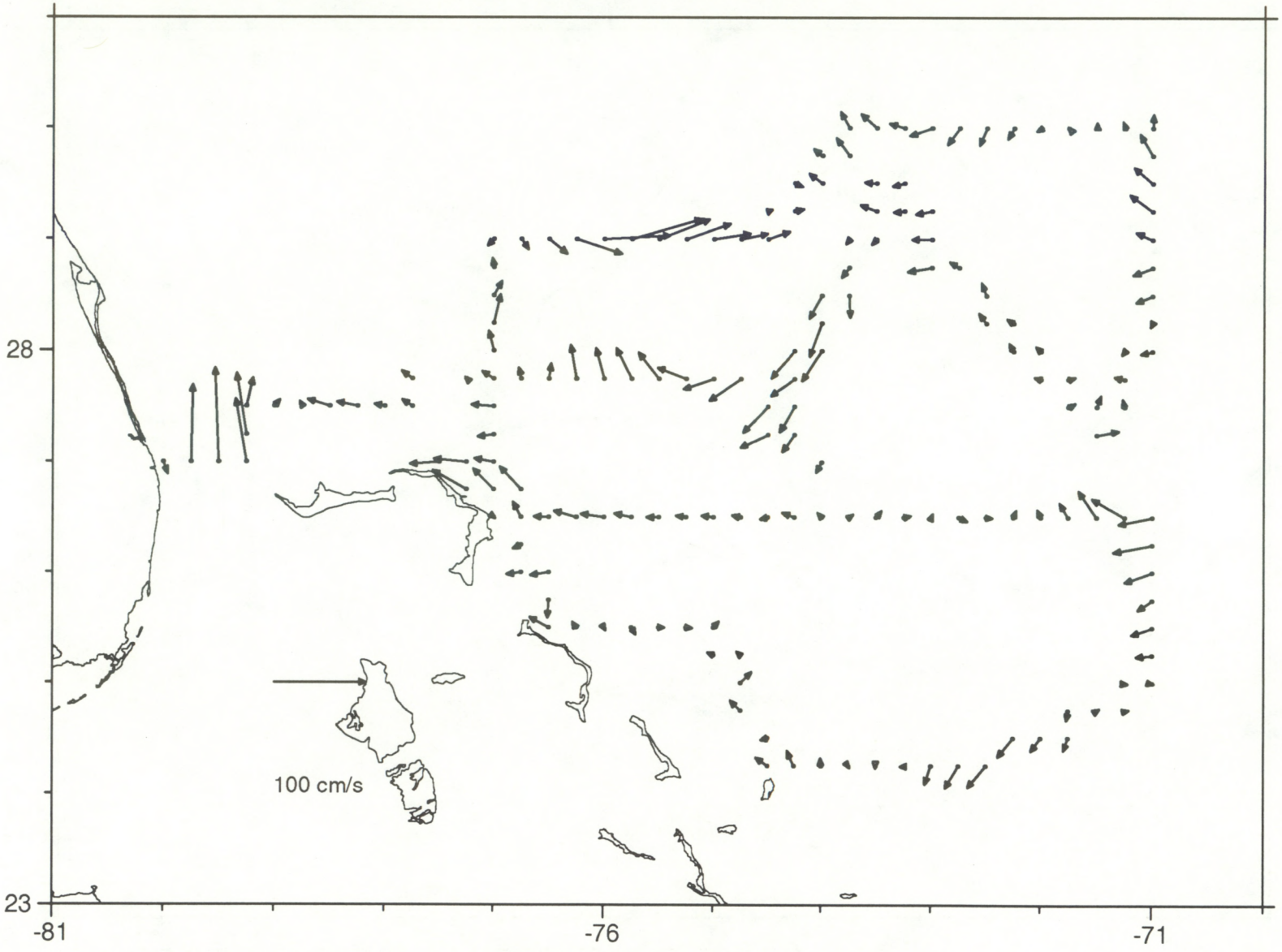

Figure B.8 0.25 Degree Grid

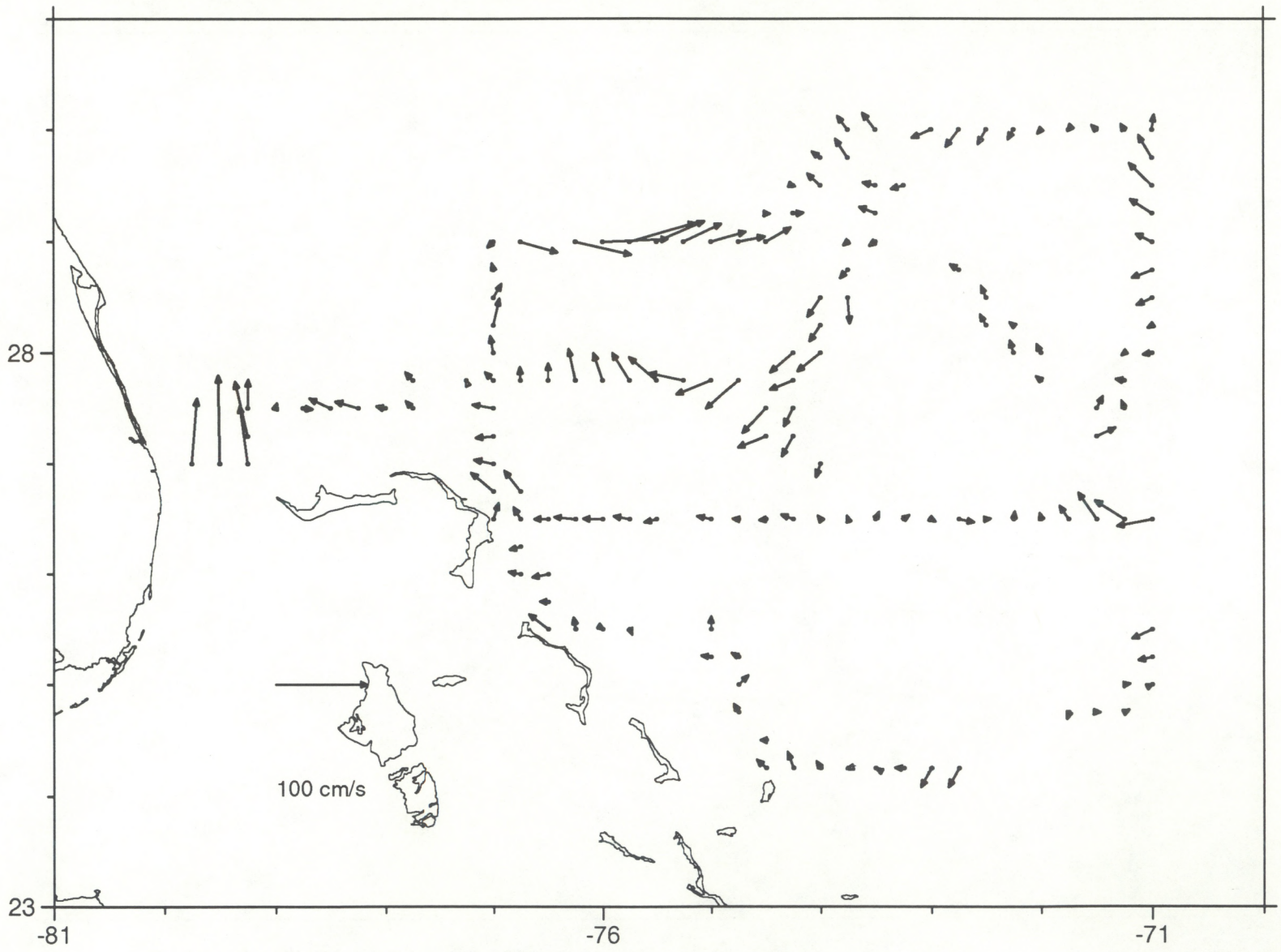

Figure B.9 0.25 Degree Grid

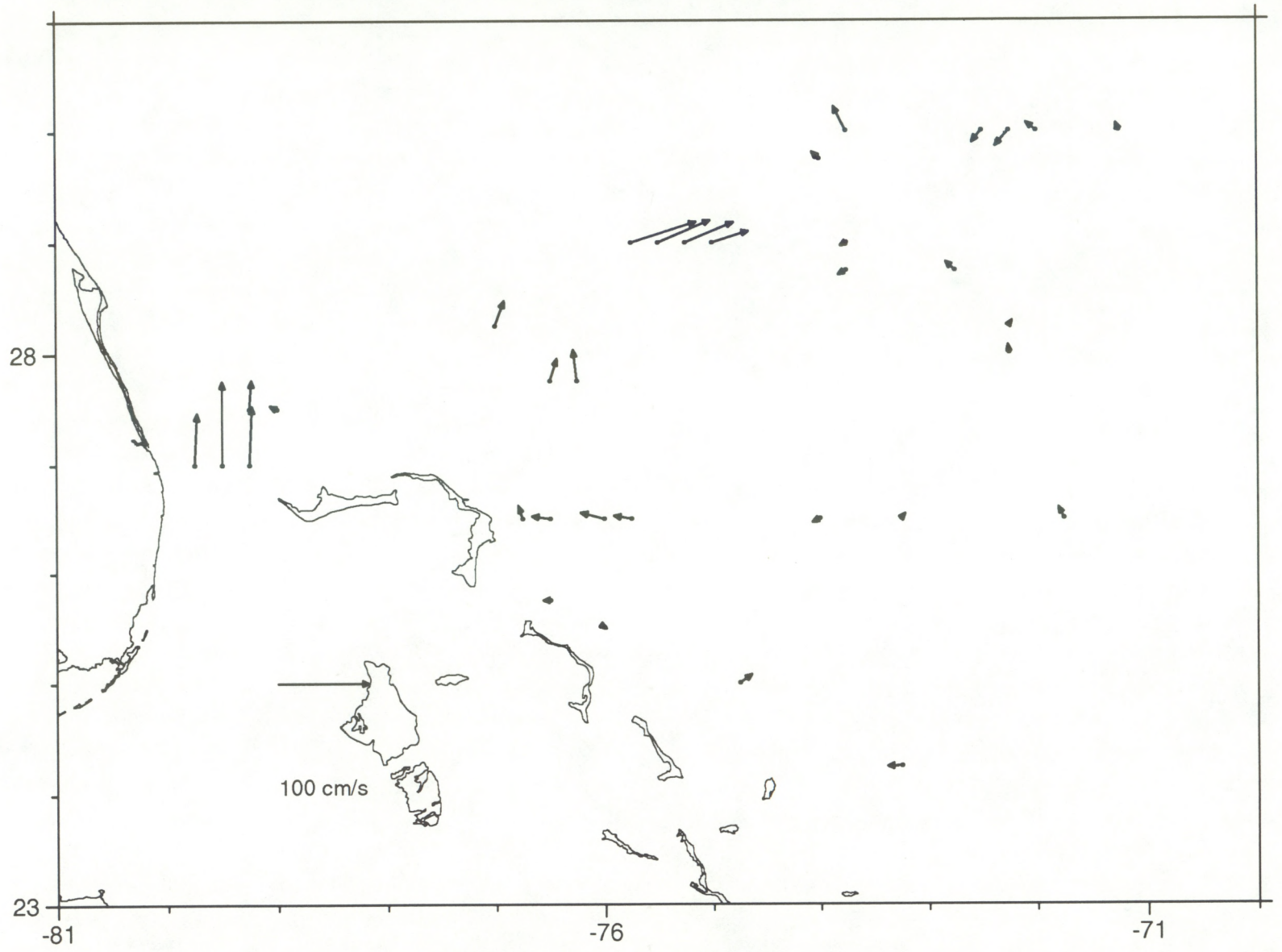

Figure B.10 0.25 Degree Grid

Appendix C Data from STACS 37 September 1990

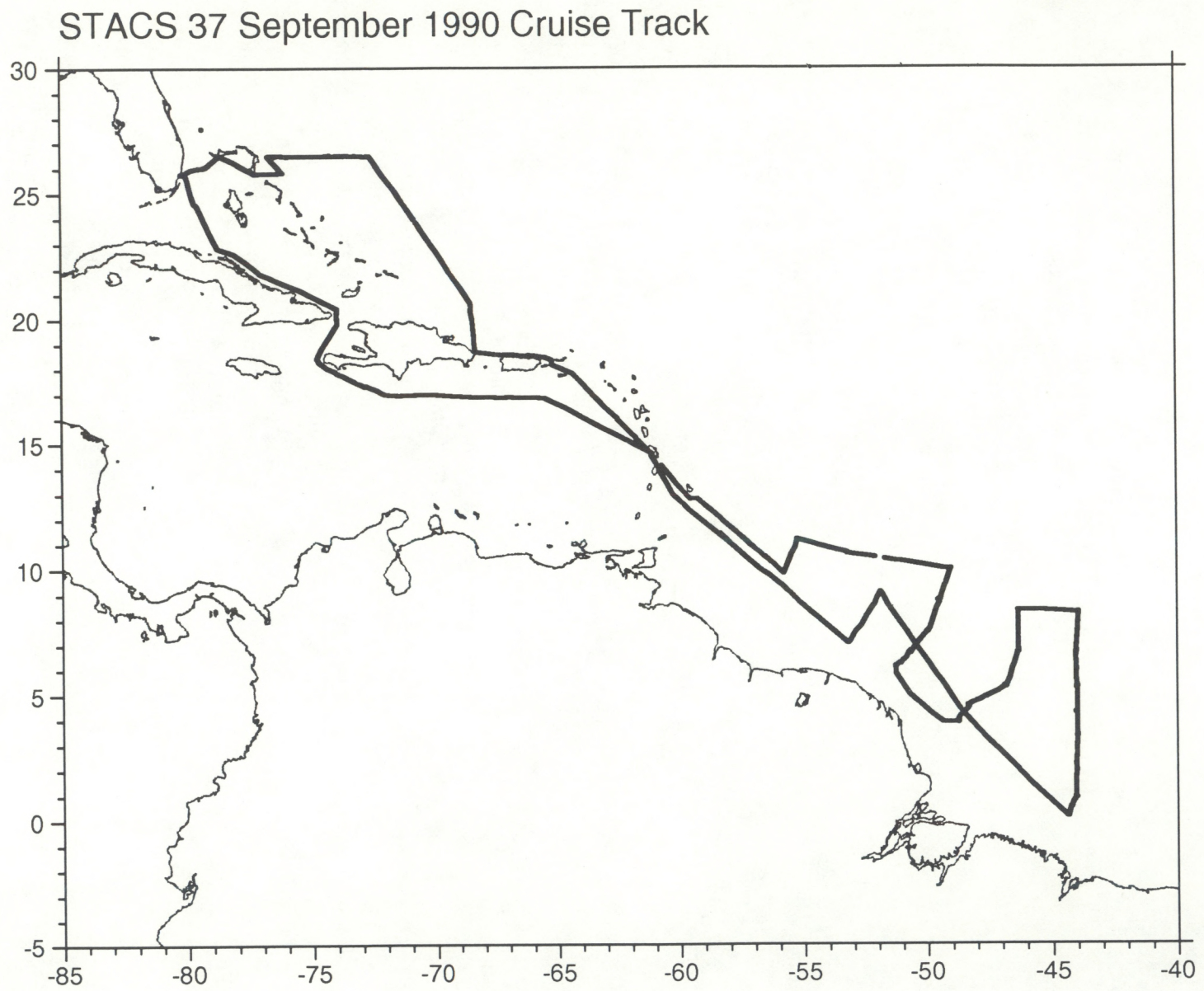
STACS 37 September 1990 Cruise Track
30
25
20
15
10
5
0
-5
-85
-80
-75
-70
-65
-60
-55
-50
-45
-40

Figure C.1

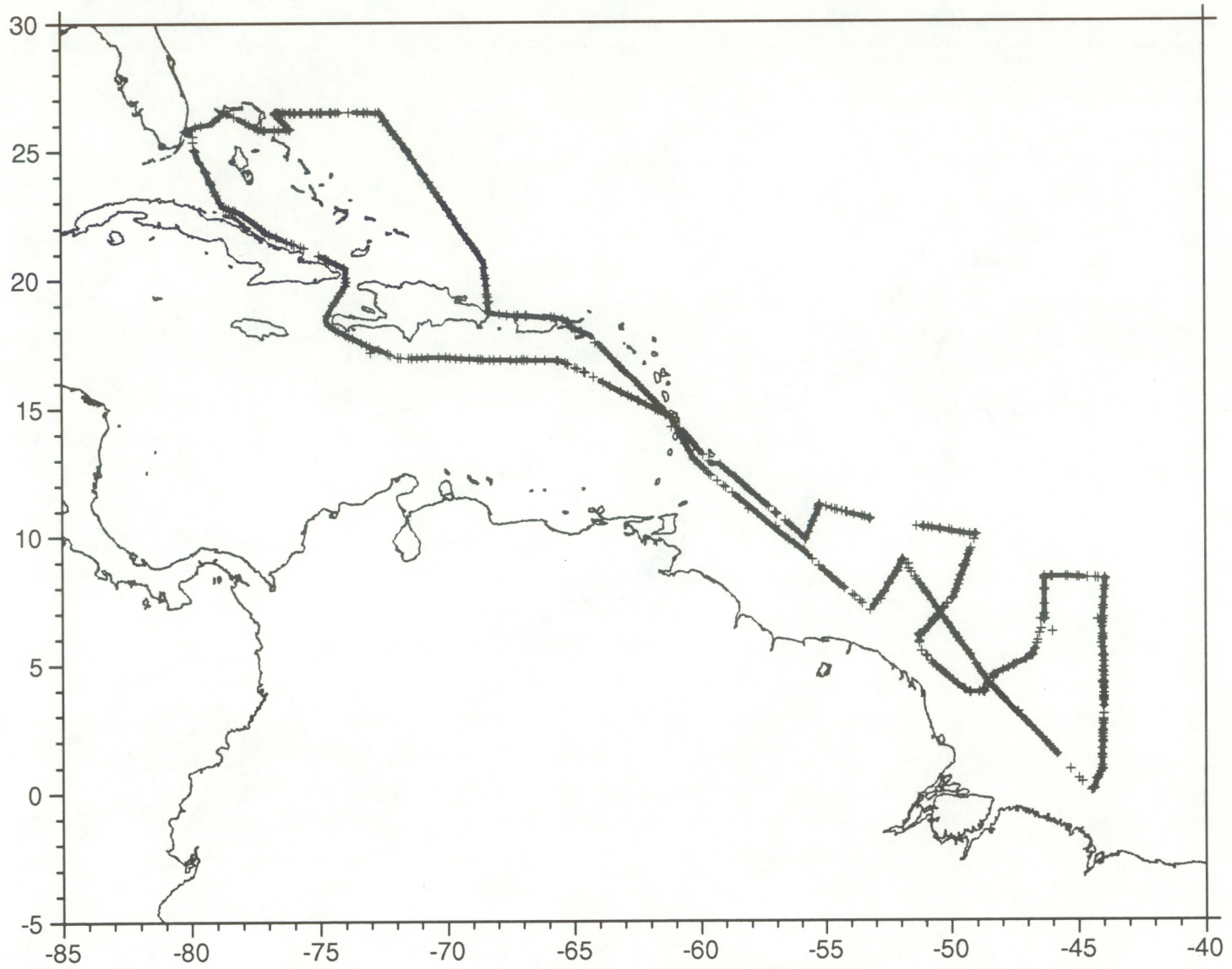
STACS 37 September 1990 Navigation + Transit . GPS
30
25
20
15
10
5
0
-5
-85
-80
-75
-70
-65
-60
-55
-50
-45
-40

Figure C.2

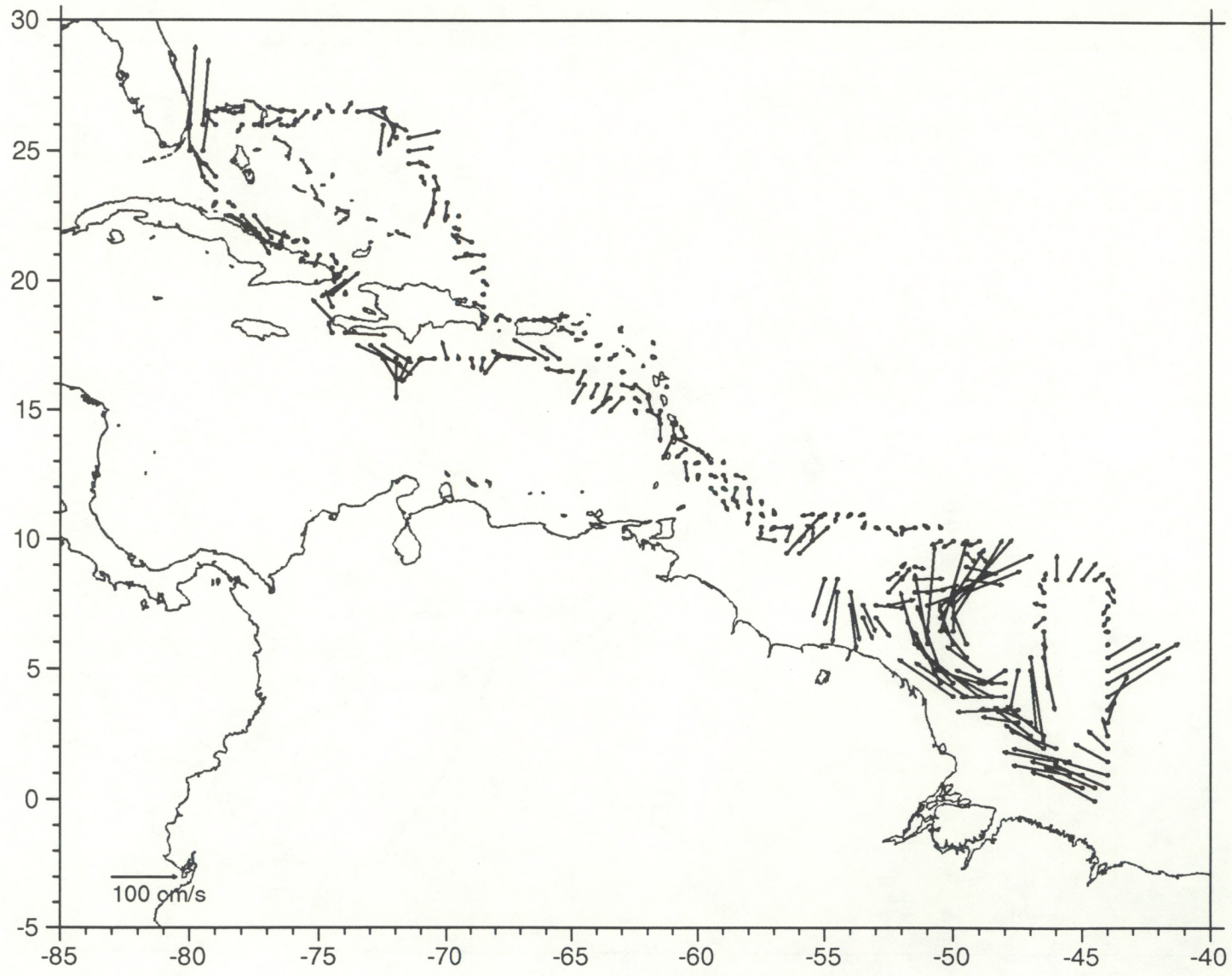

Figure C.3 0.5 Degree Grid

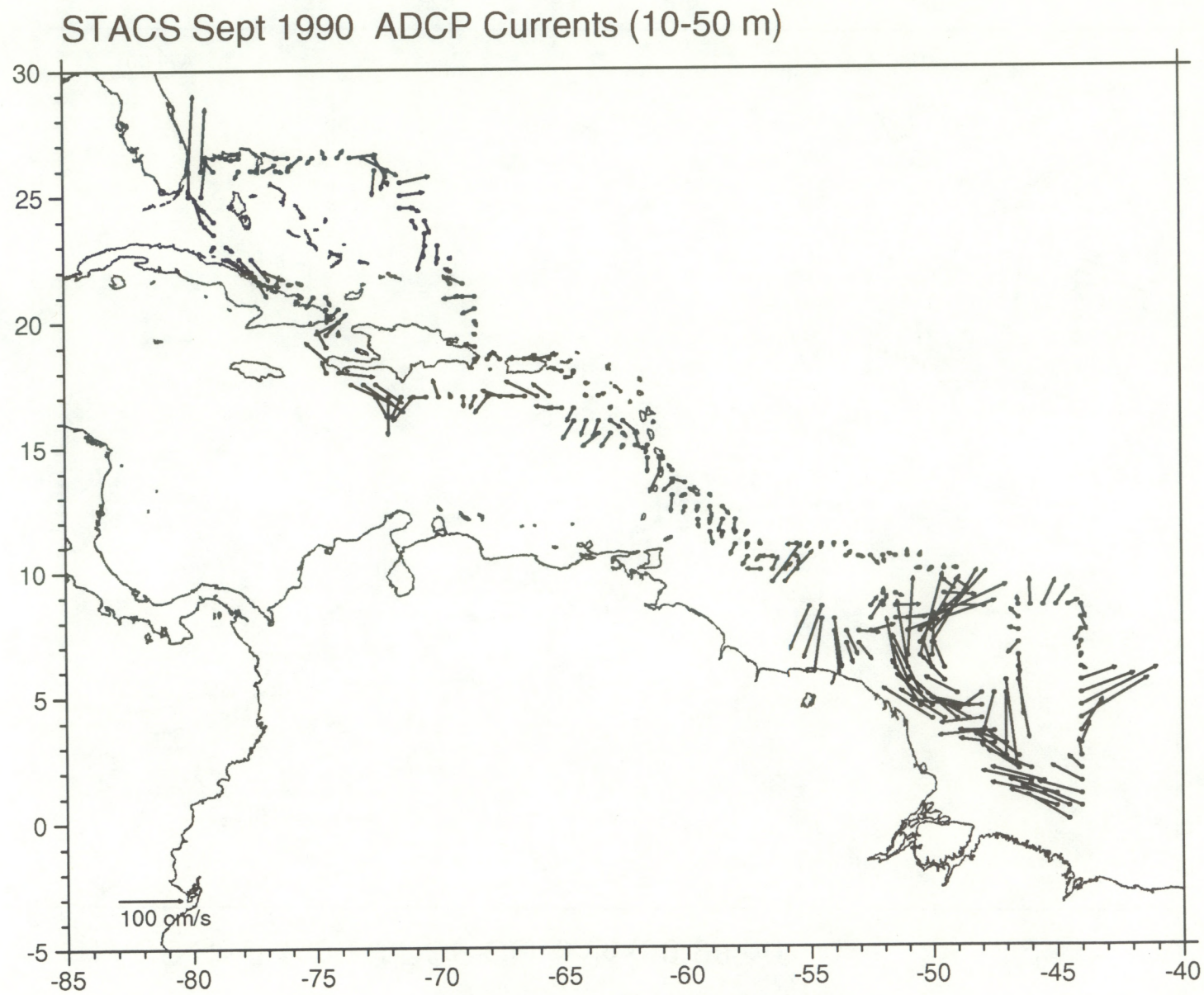

Figure C.4 0.5 Degree Grid

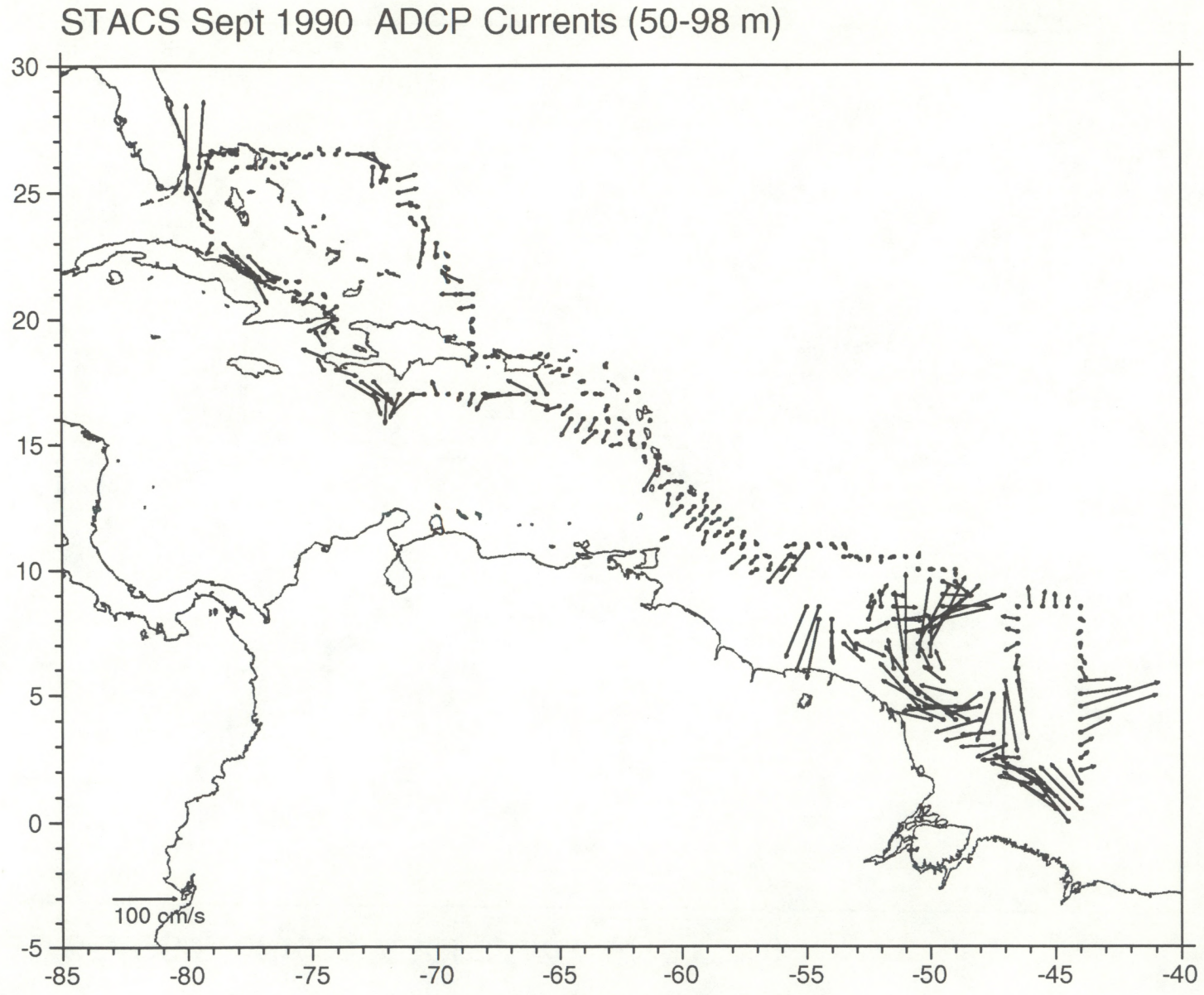

Figure C.5 0.5 Degree Grid

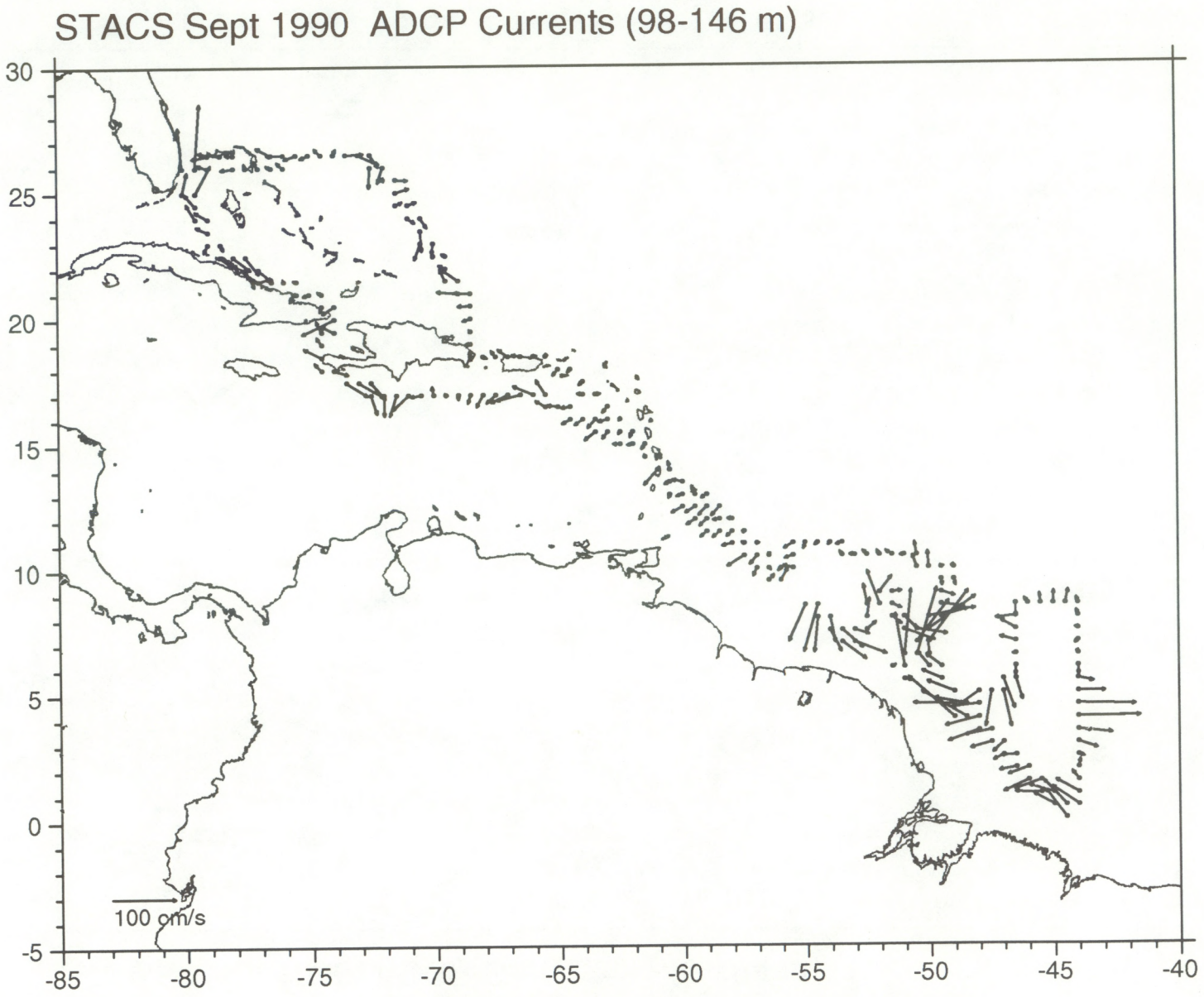

Figure C.6 0.5 Degree Grid

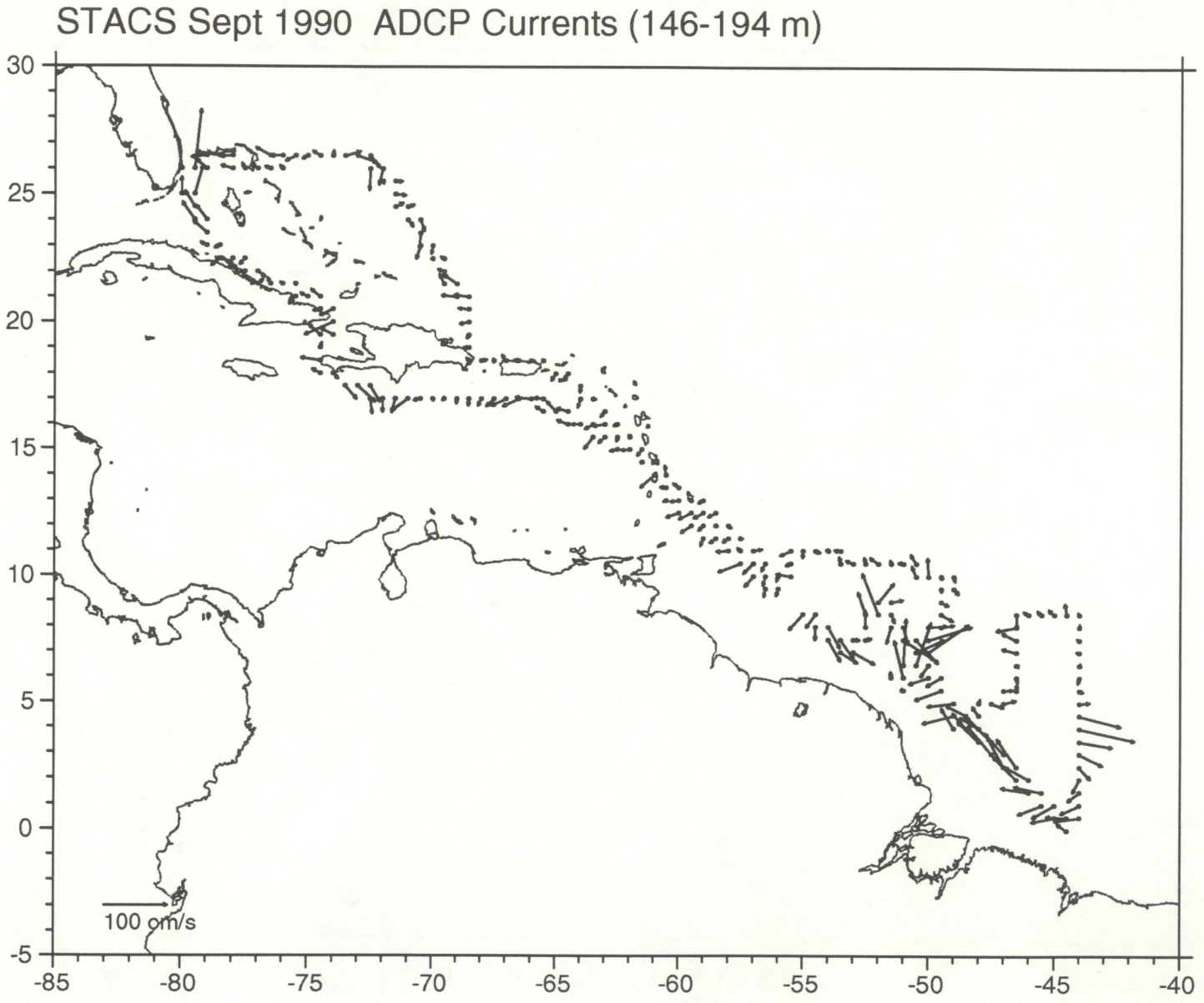

Figure C.7 0.5 Degree Grid

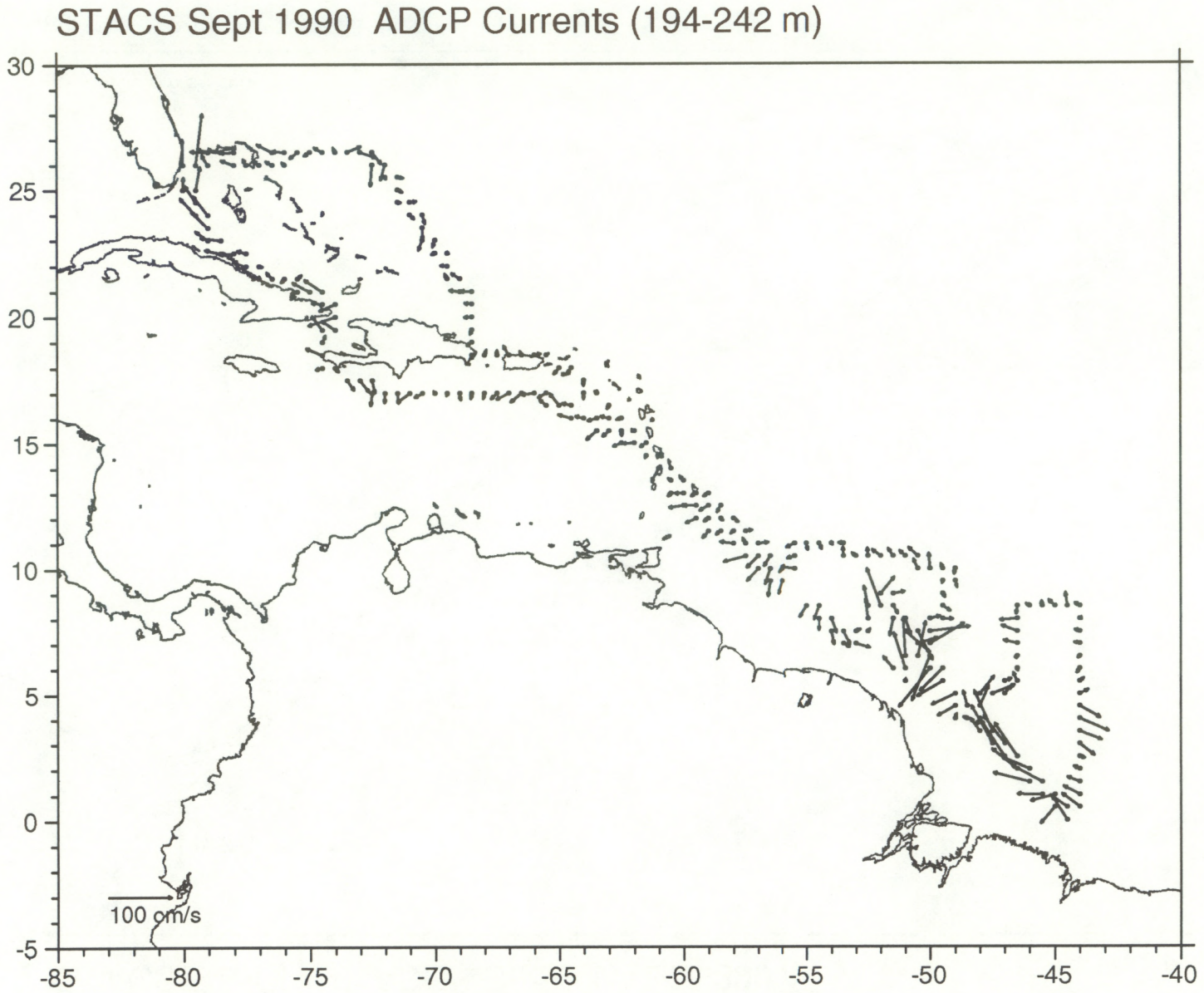

Figure C.8 0.5 Degree Grid

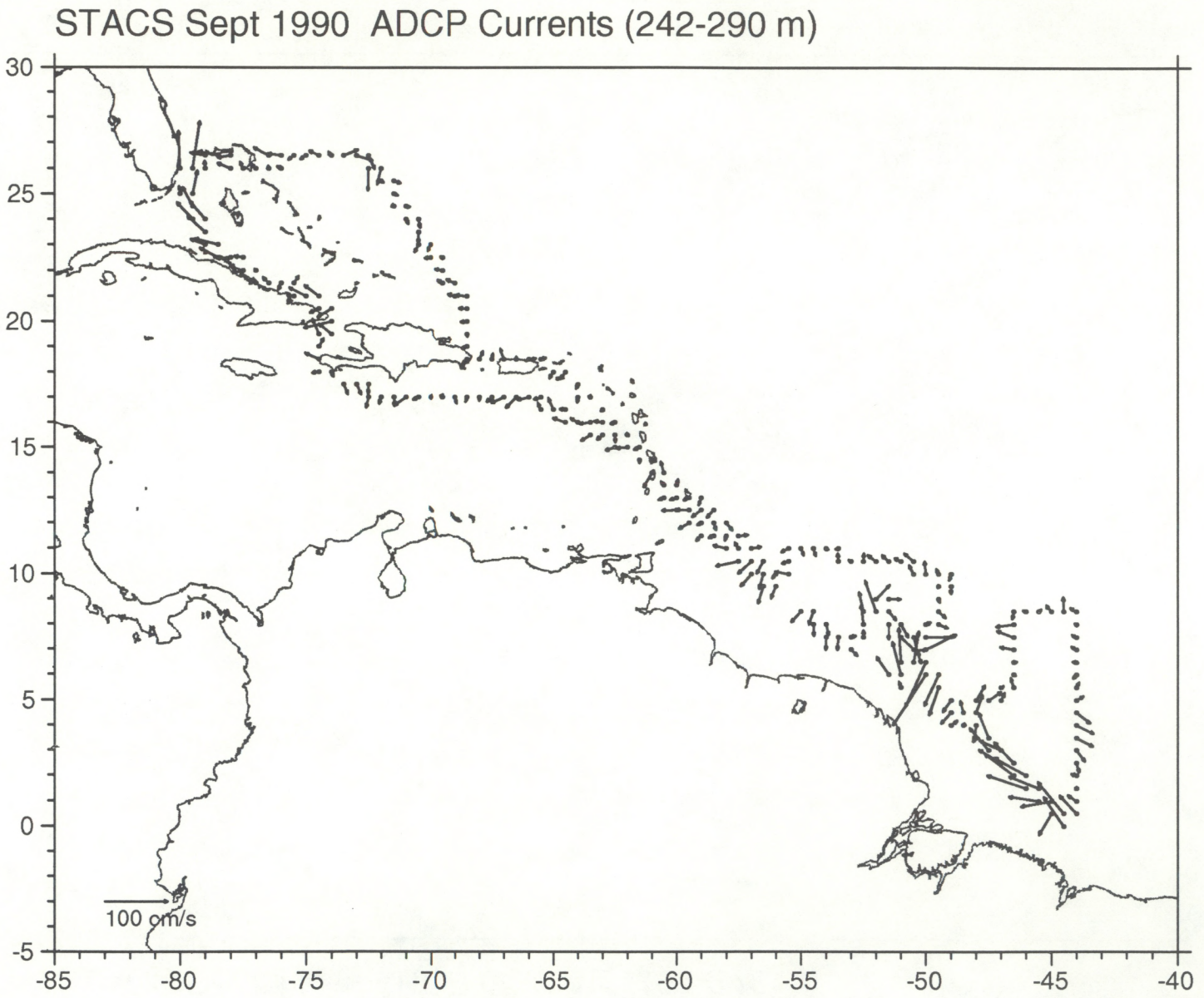

Figure C.9 0.5 Degree Grid

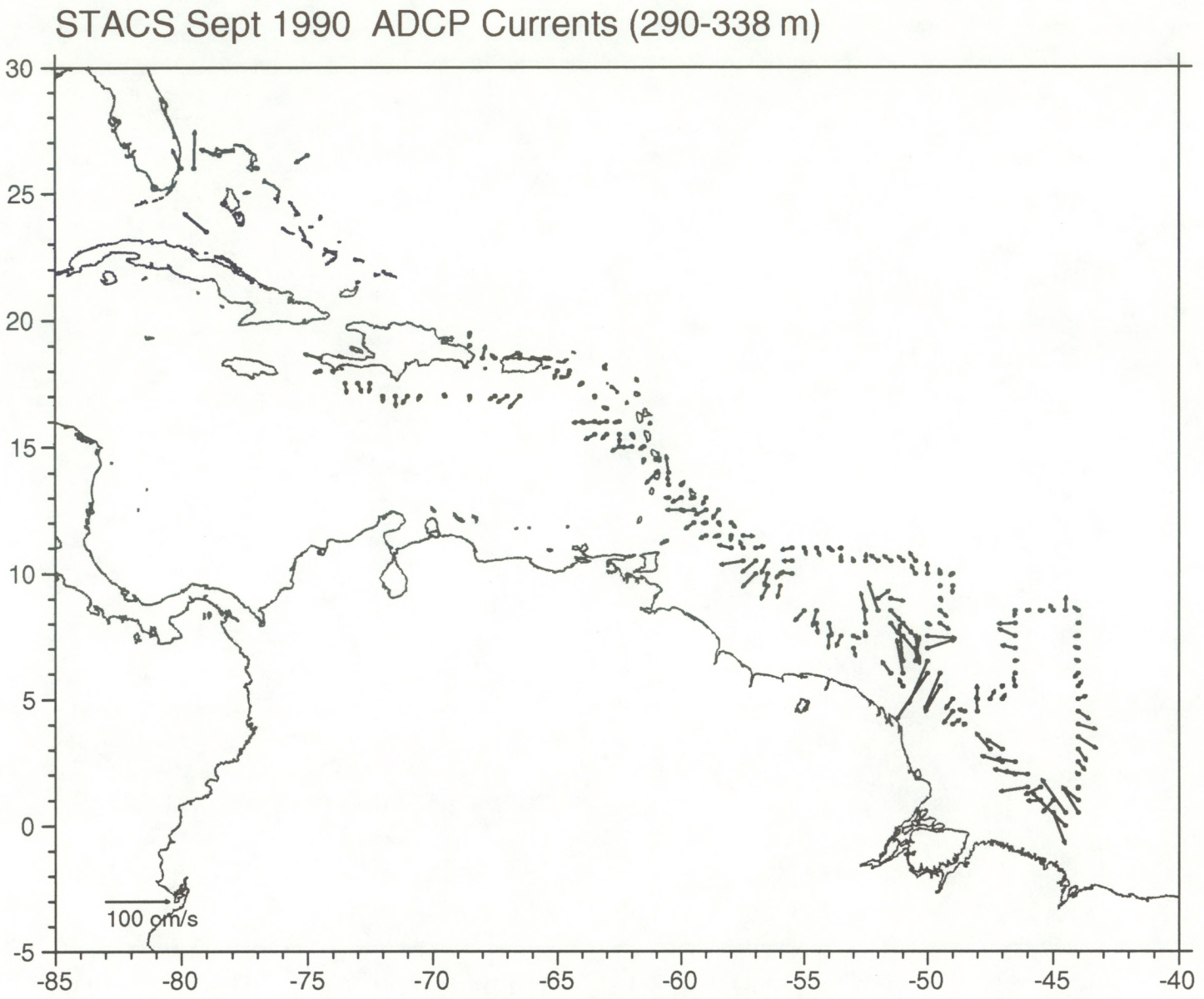

Figure C.10 0.5 Degree Grid

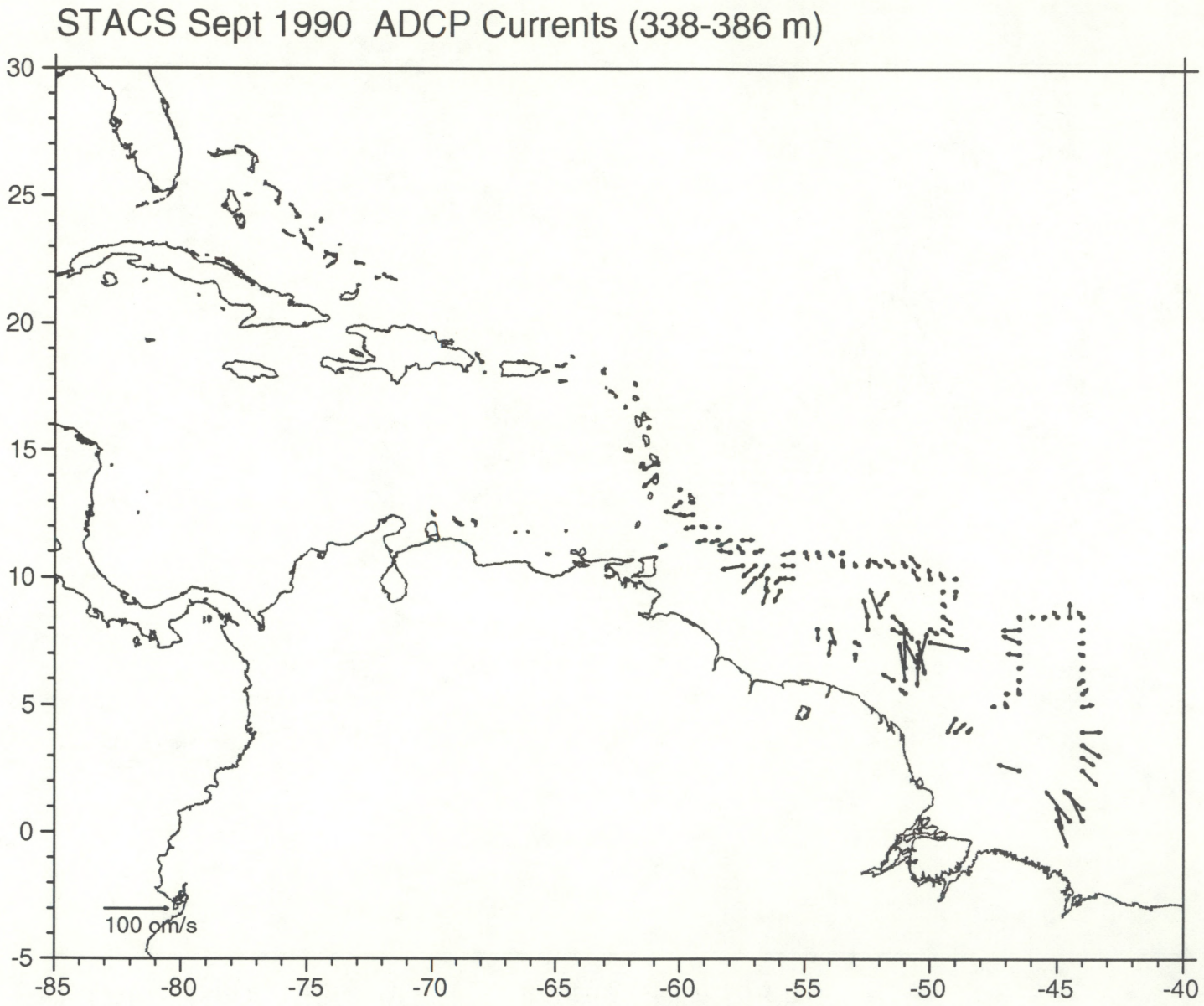

Figure C.11 0.5 Degree Grid

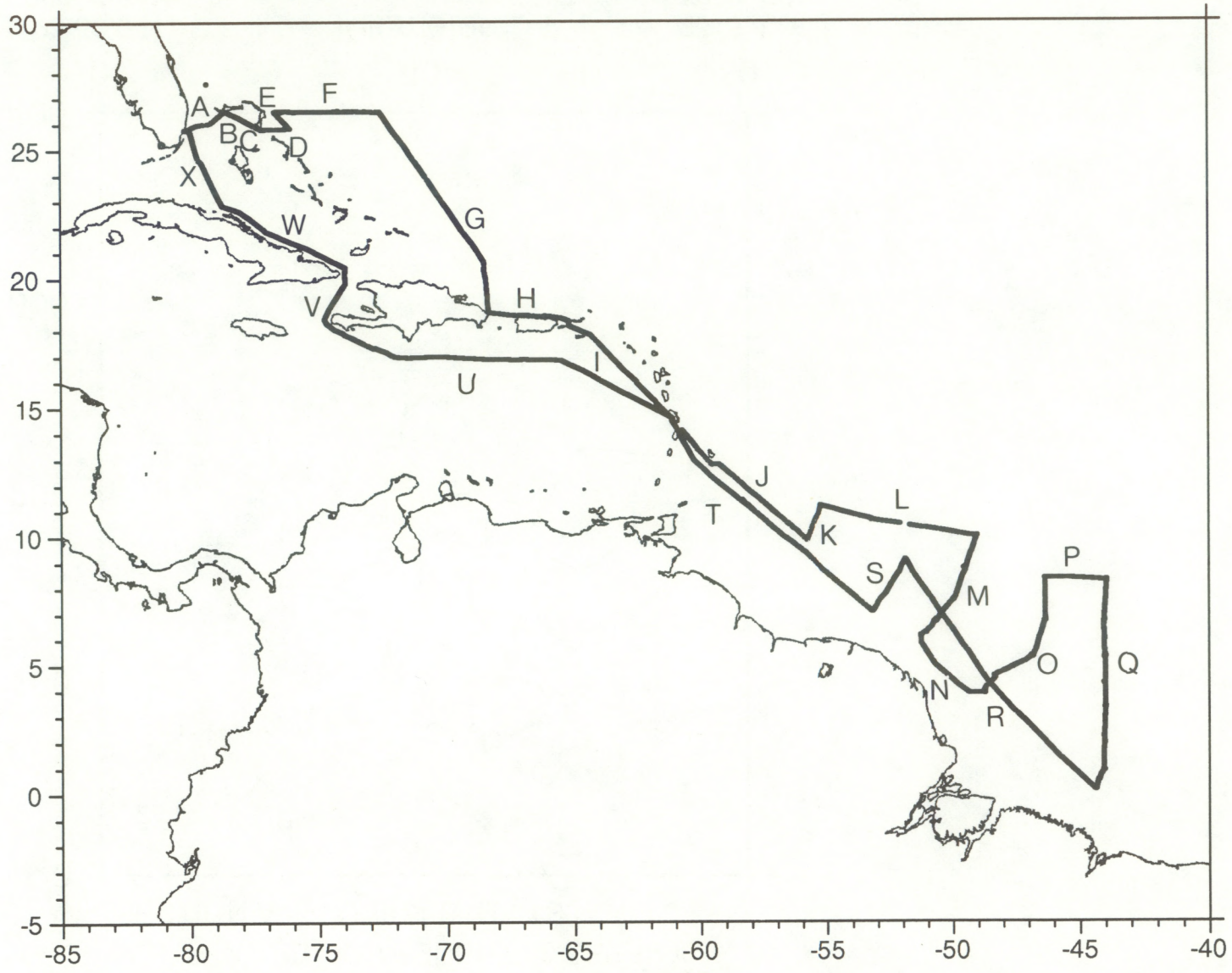
STACS 37 September 1990 ADCP Sections
30
25
20
15
10
5
0
-5
-85
-80
-75
-70
-65
-60
-55
-50
-45
-40
A
E
F
B
C
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Figure C.12

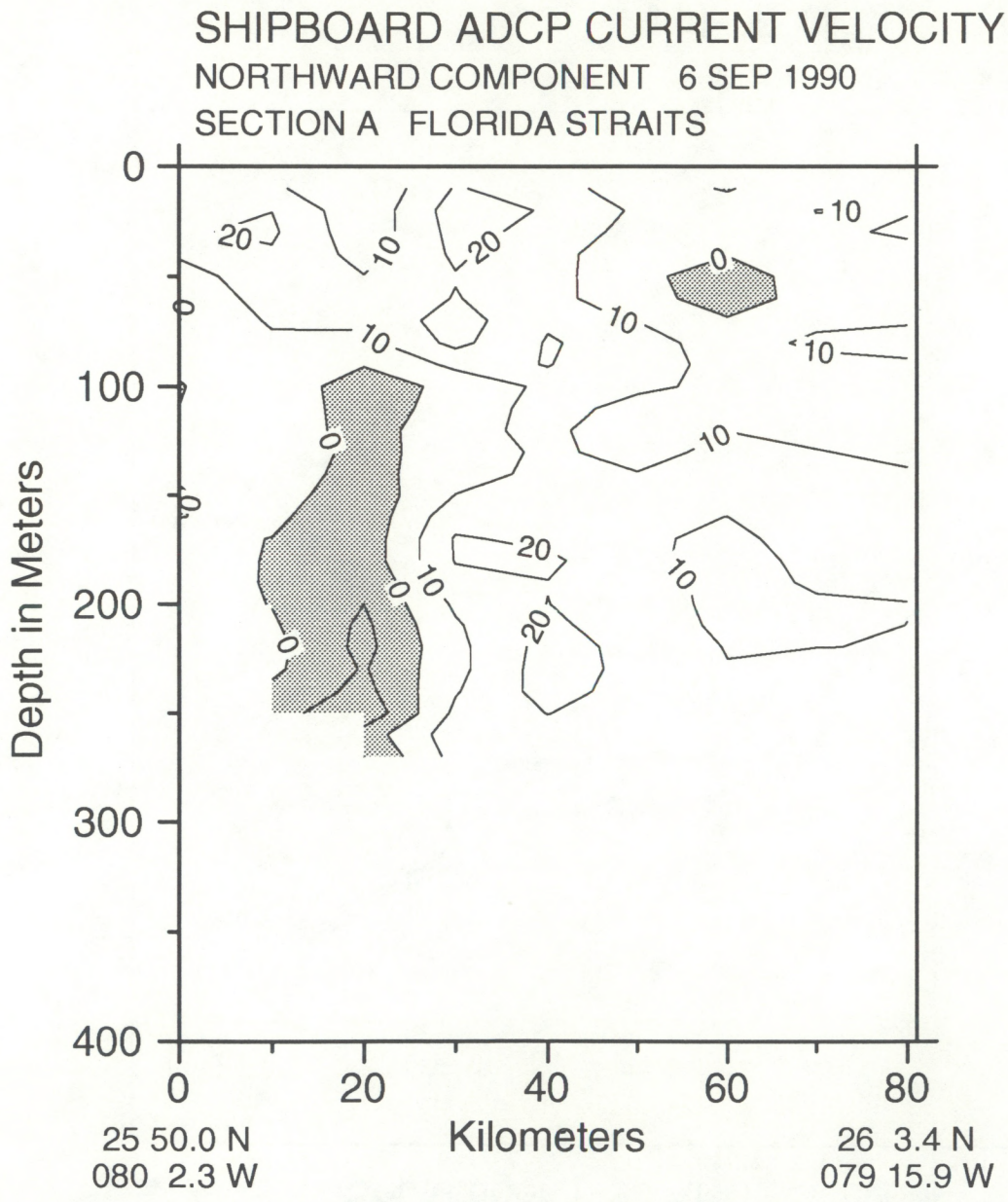


Figure C.13a 10 km Grid

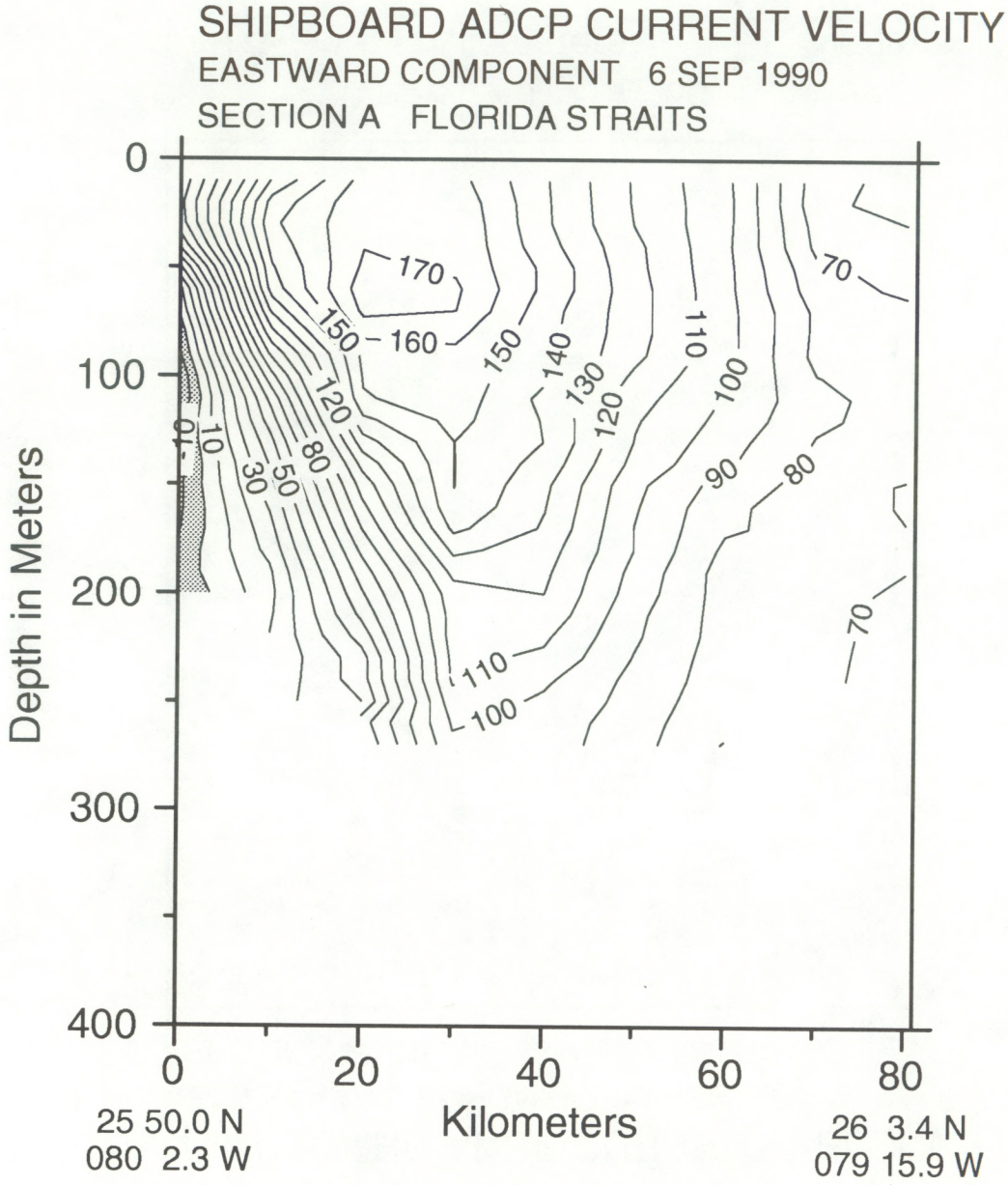


Figure C.13b 10 km Grid

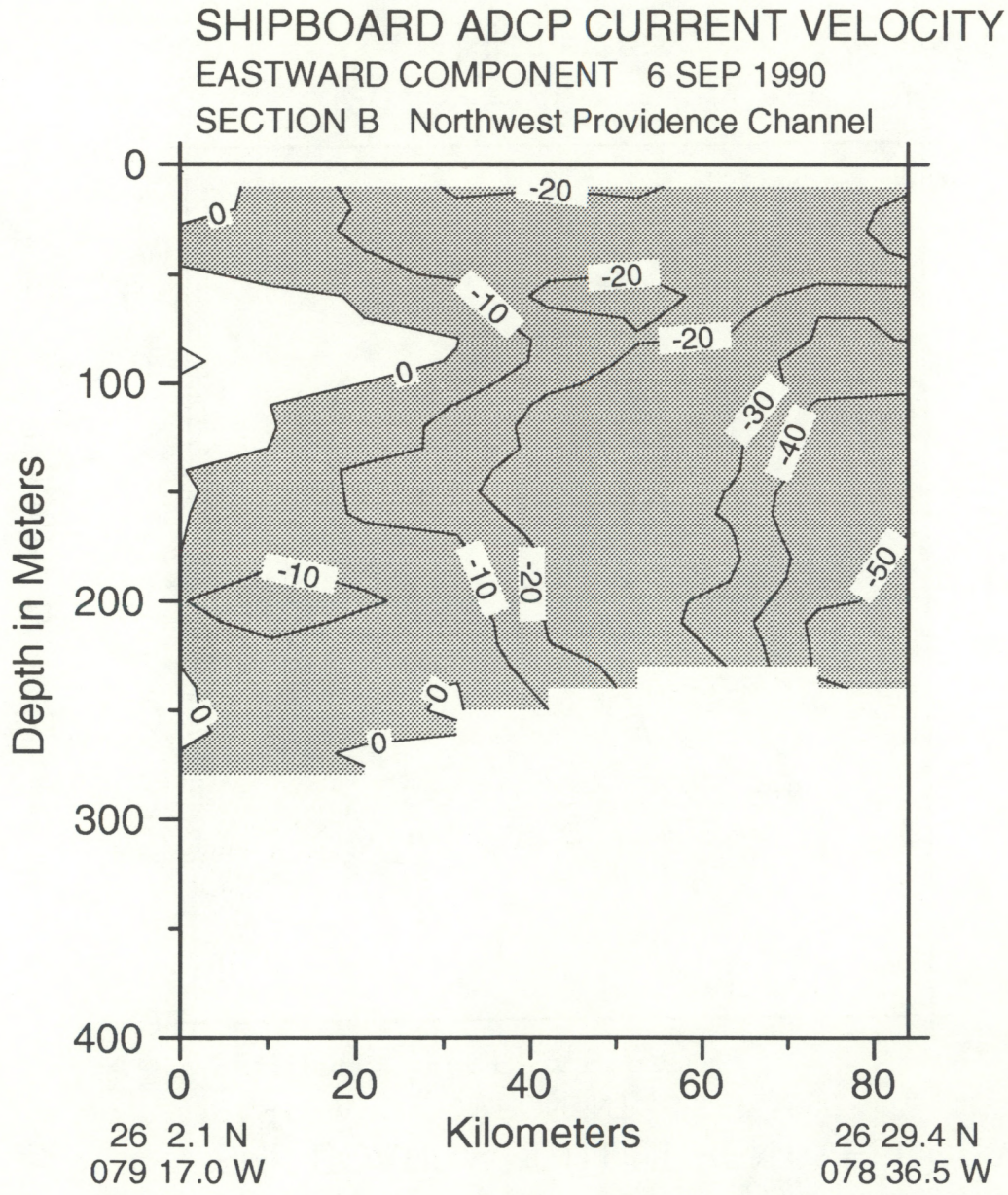


Figure C.14a 10 km Grid

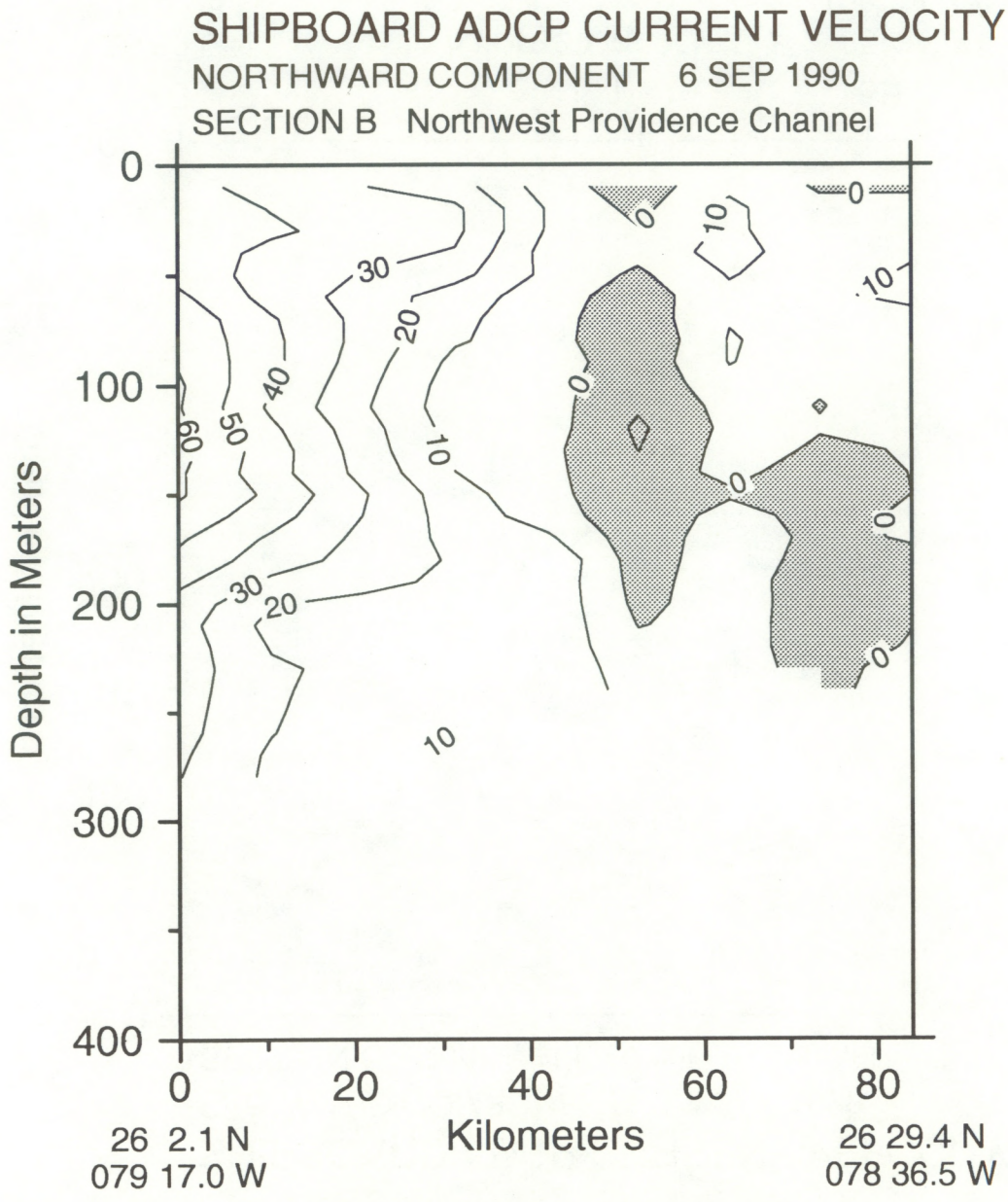


Figure C.14b 10 km Grid

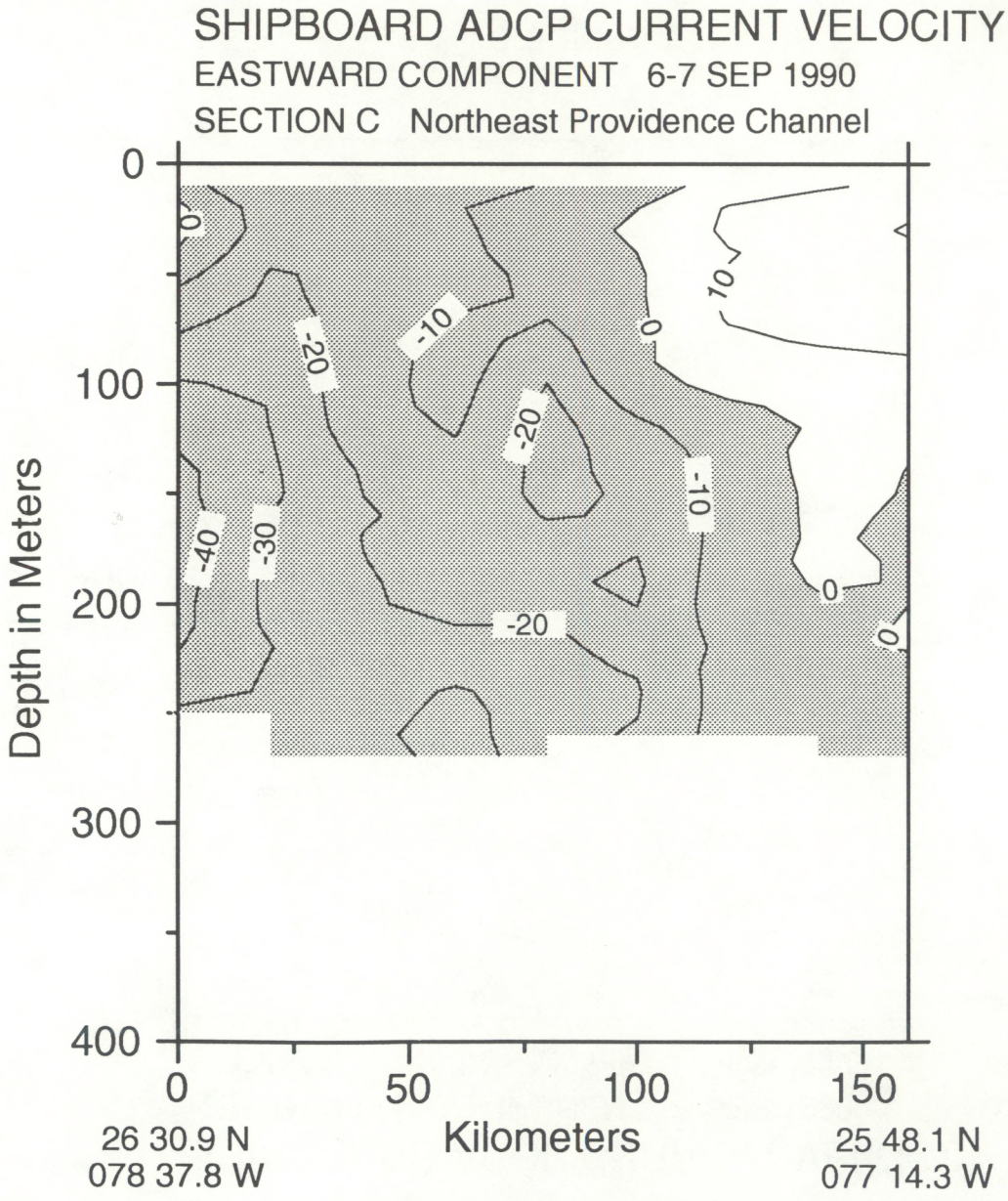


Figure C.15a 20 km Grid

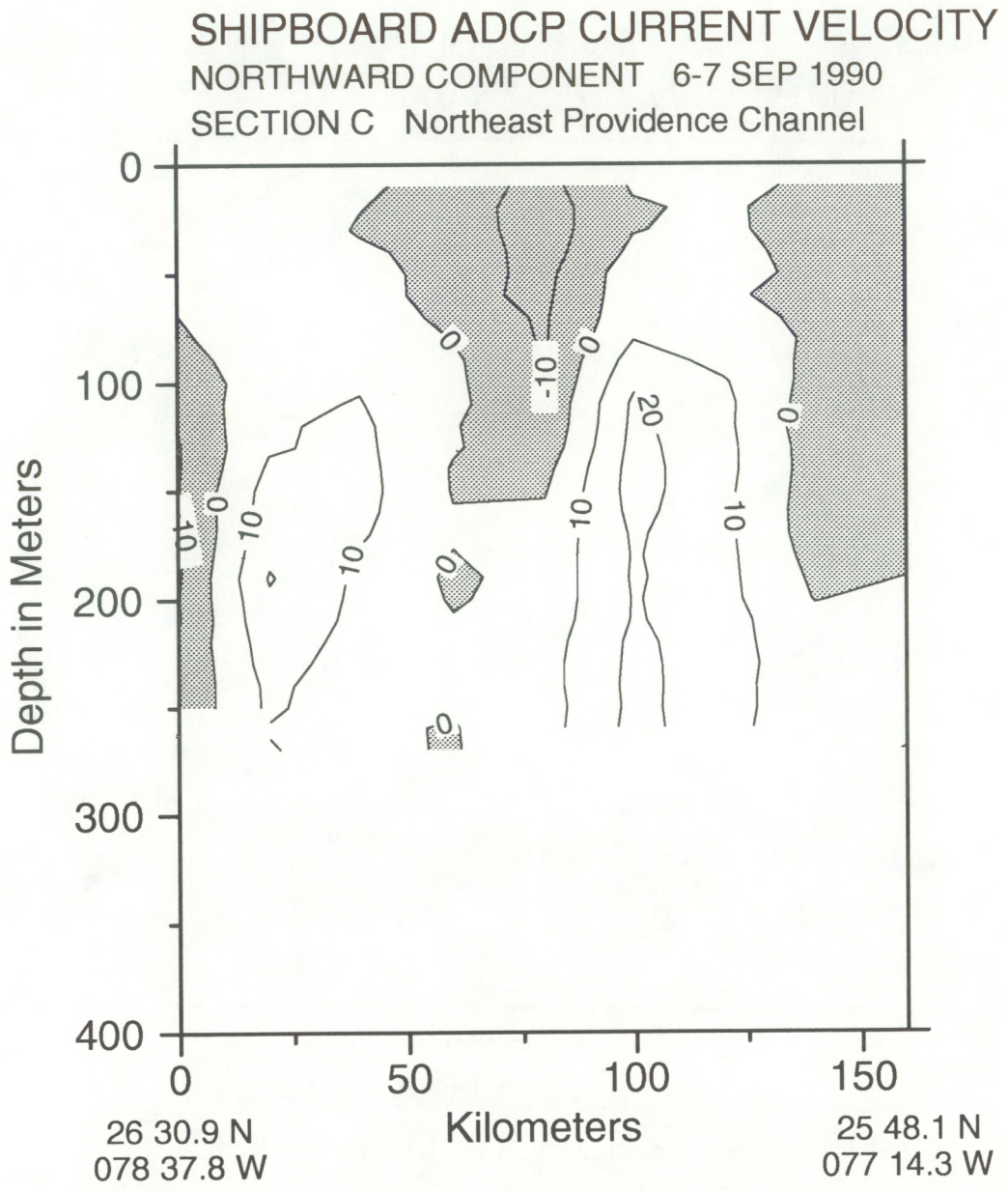


Figure C.15b 20 km Grid

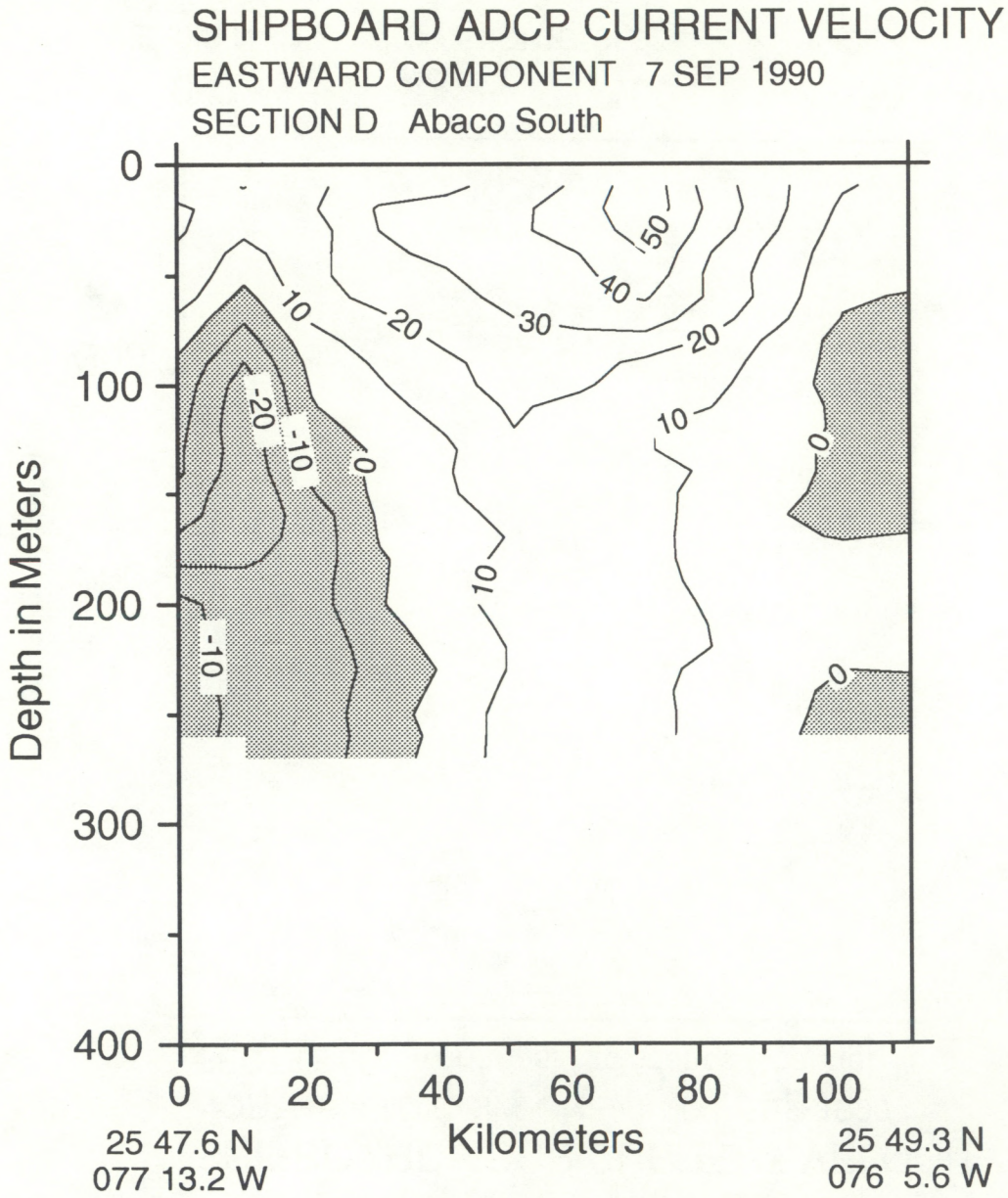


Figure C.16a 10 km Grid

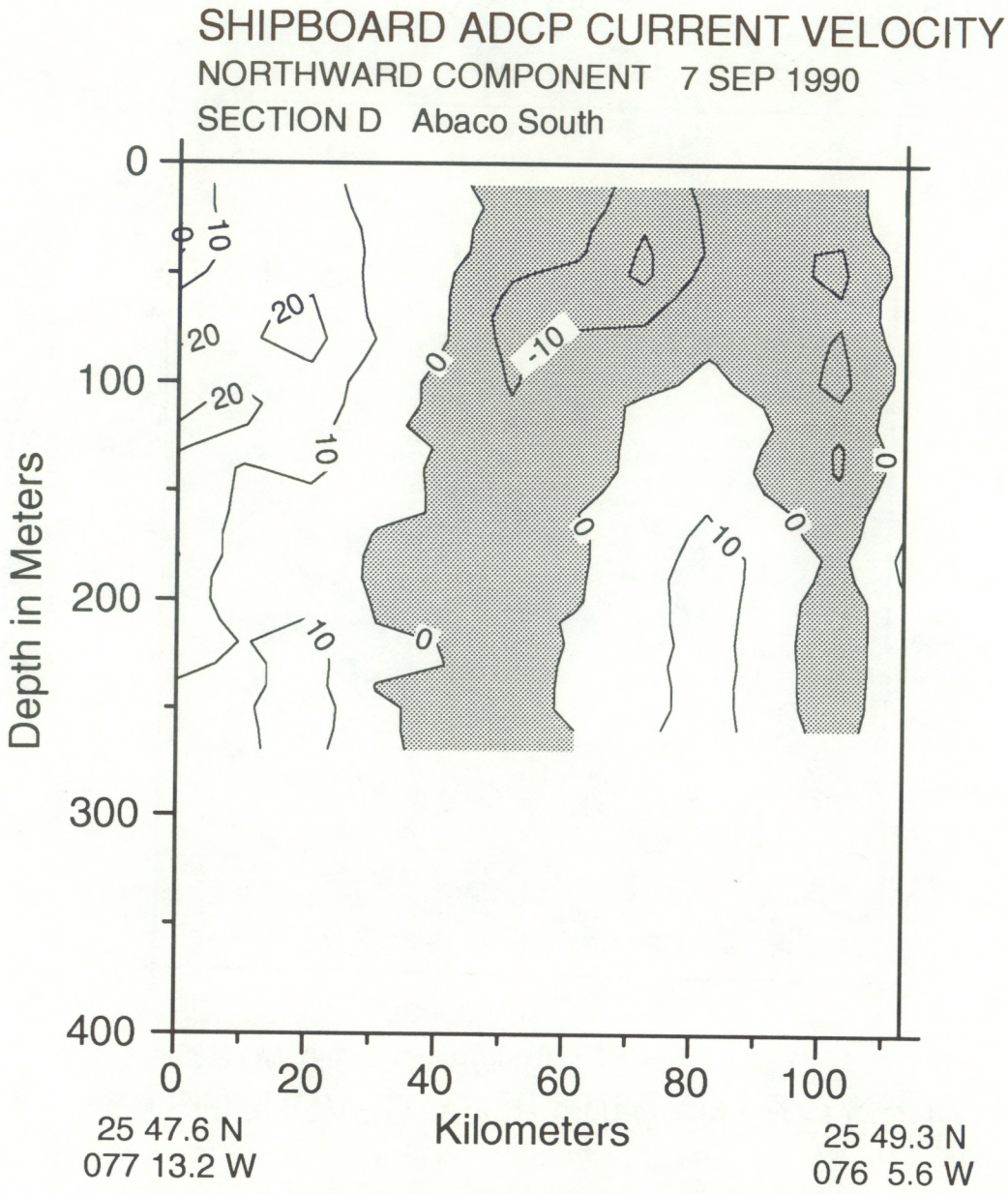


Figure C.16b 10 km Grid

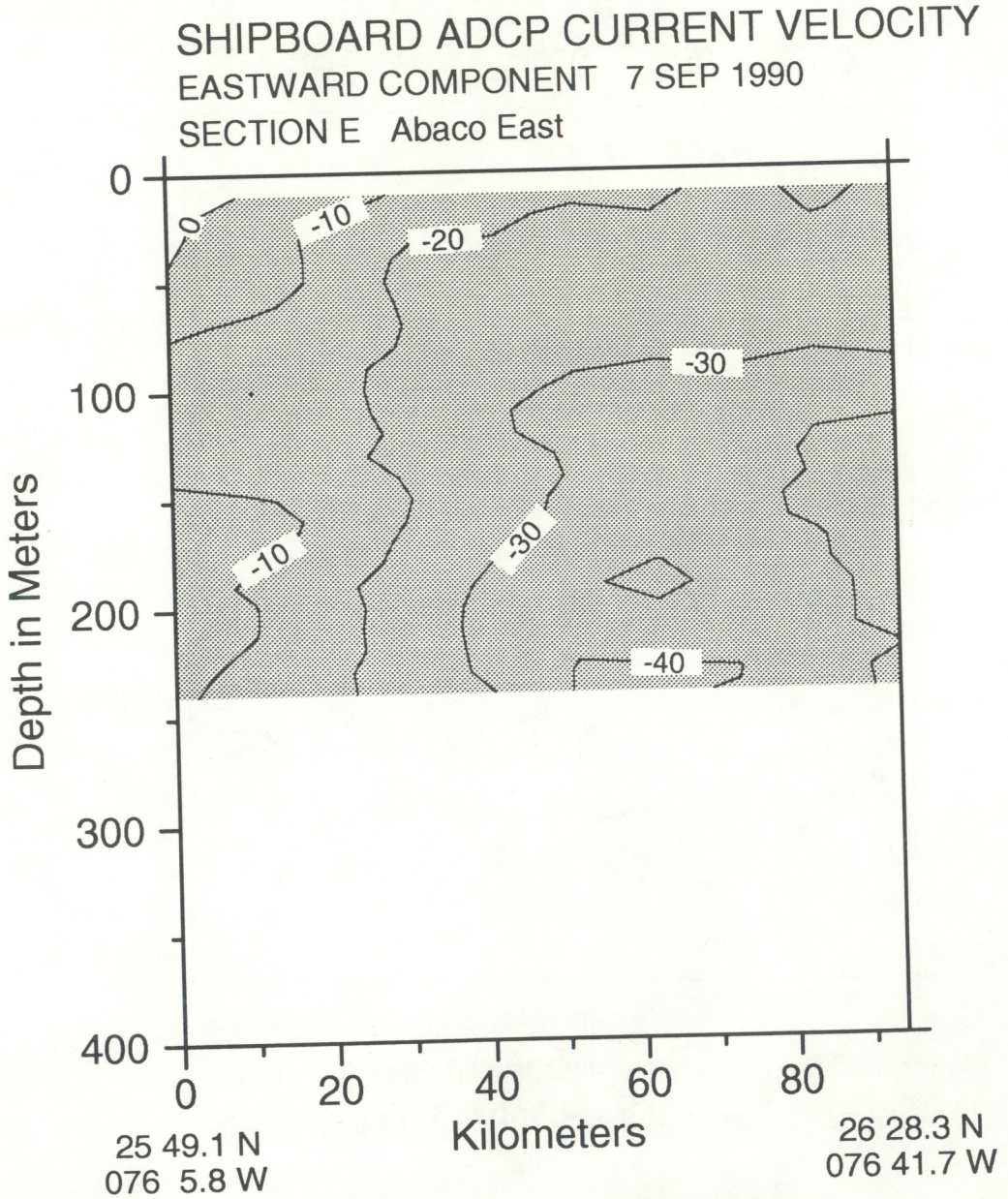


figure C.17a 10 km Grid

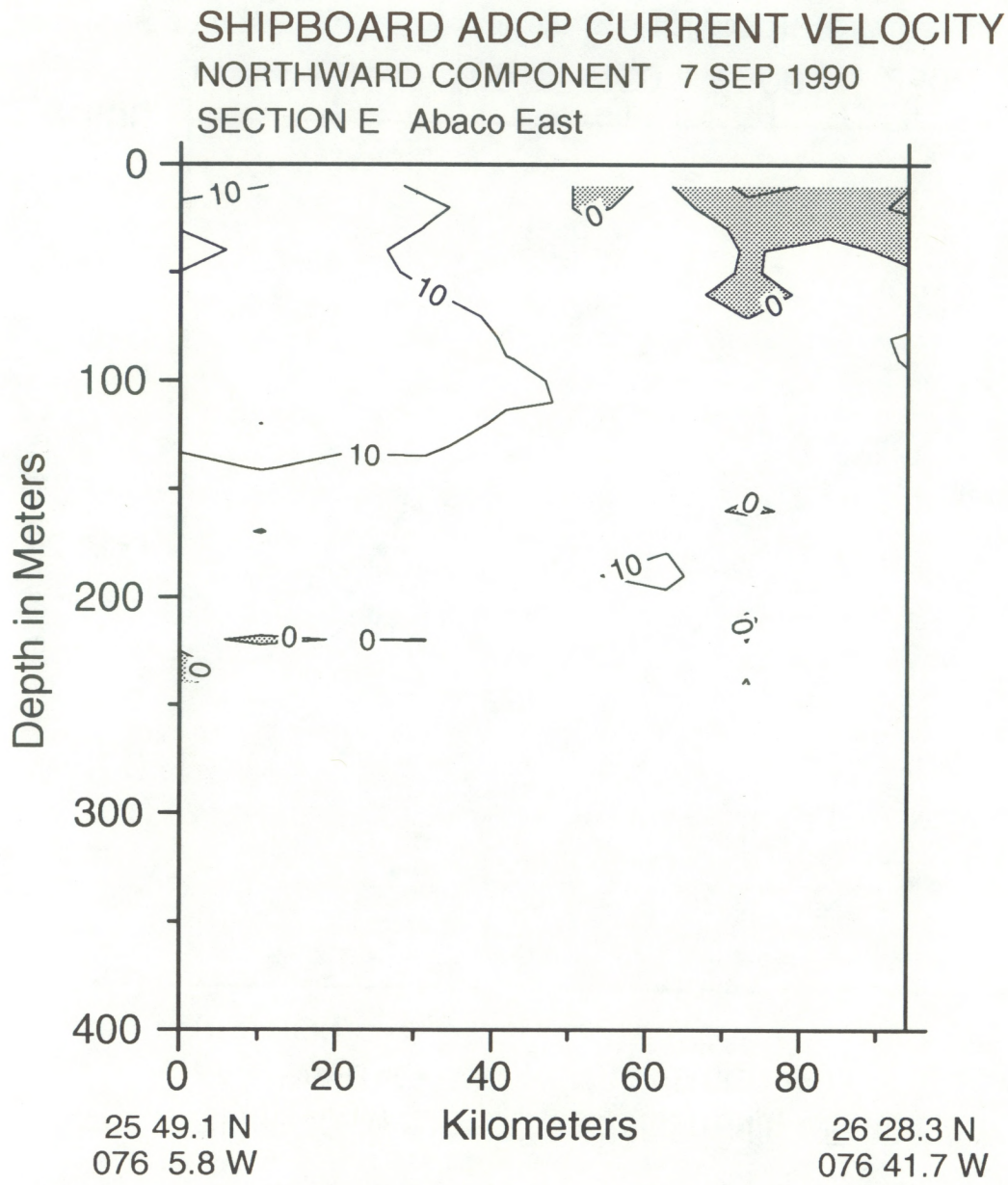


Figure C.17b 10 km Grid

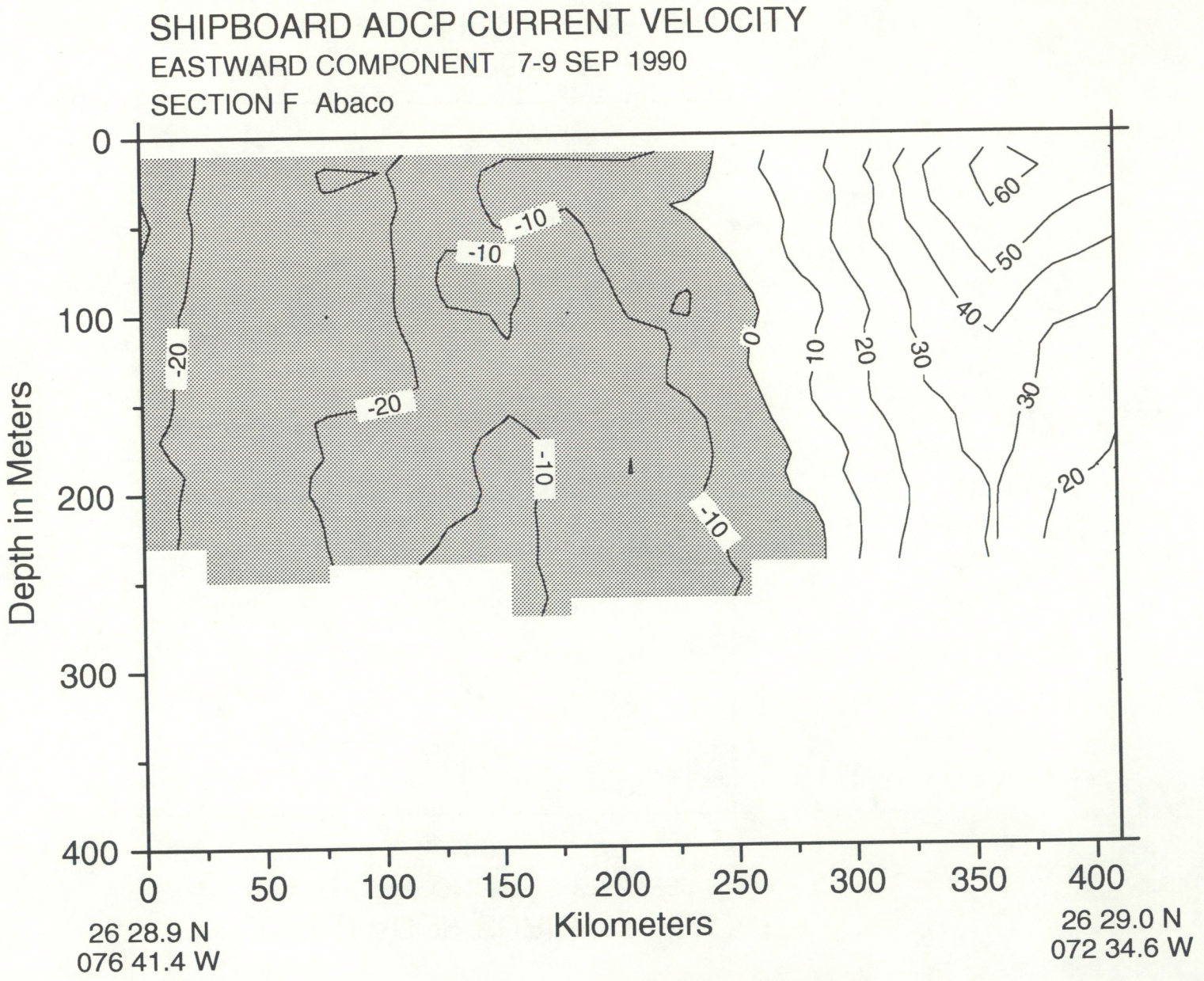


Figure C.18a 25 km Grid

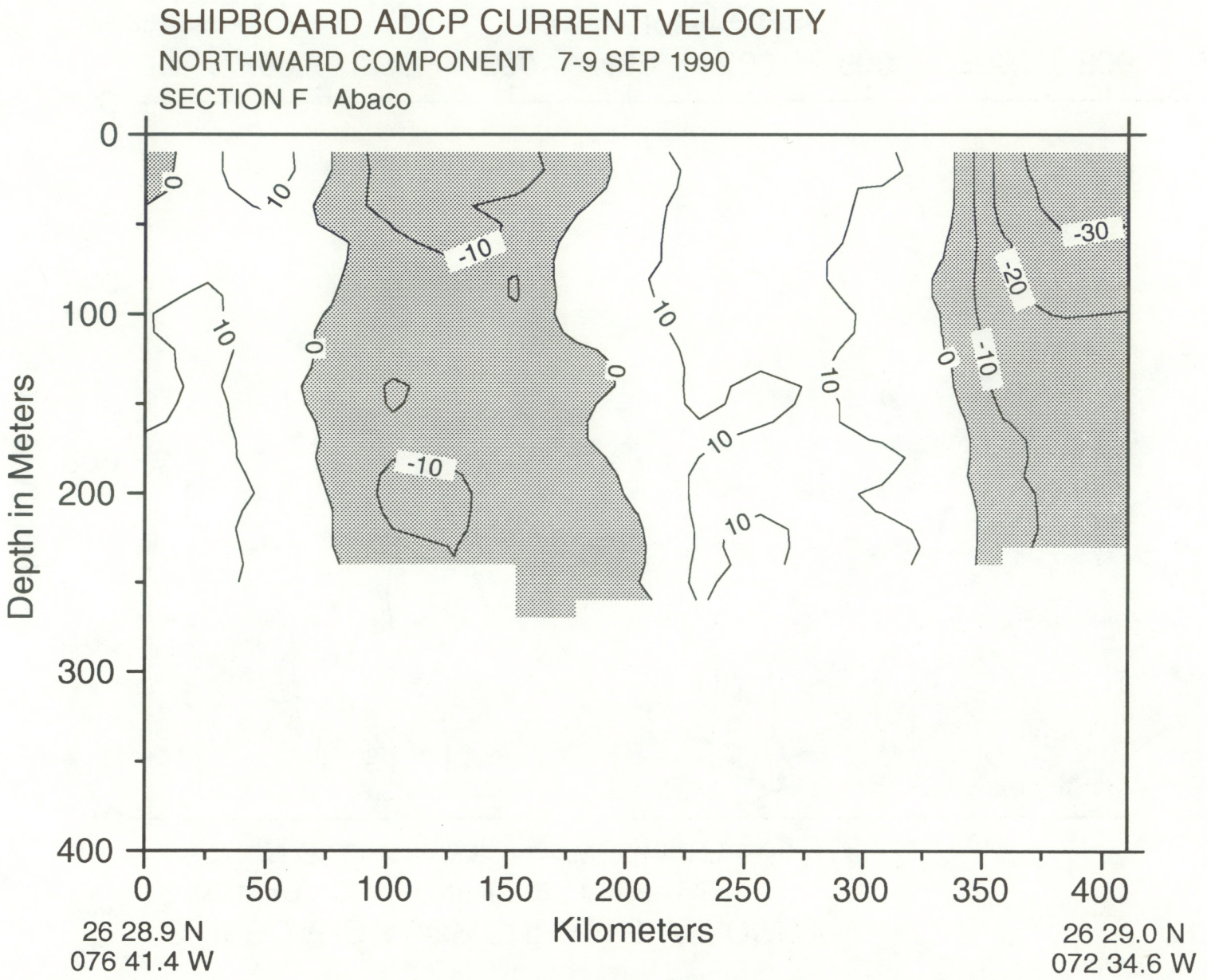


Figure C.18b 25 km Grid

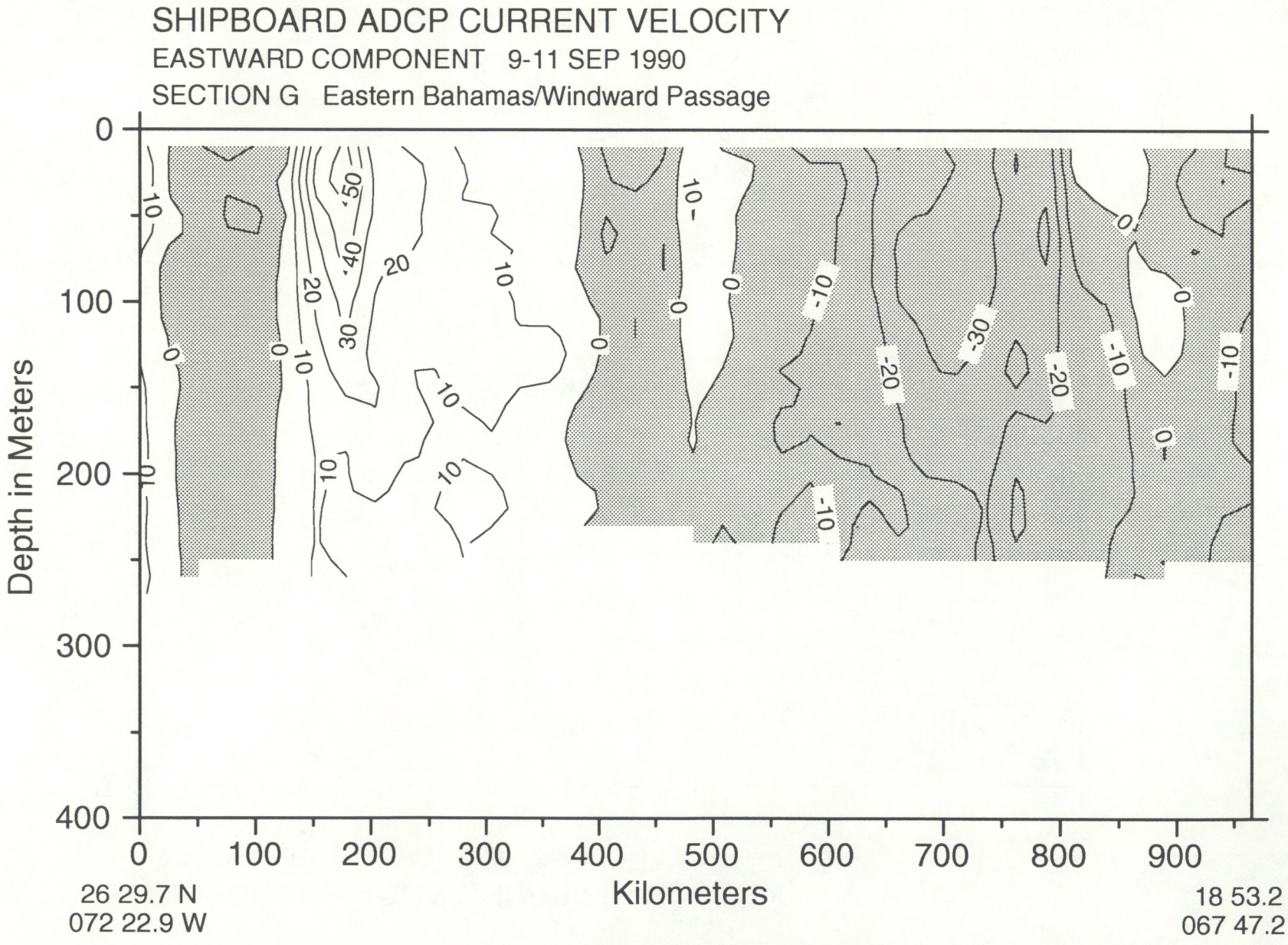


Figure C.19a 25 km Grid

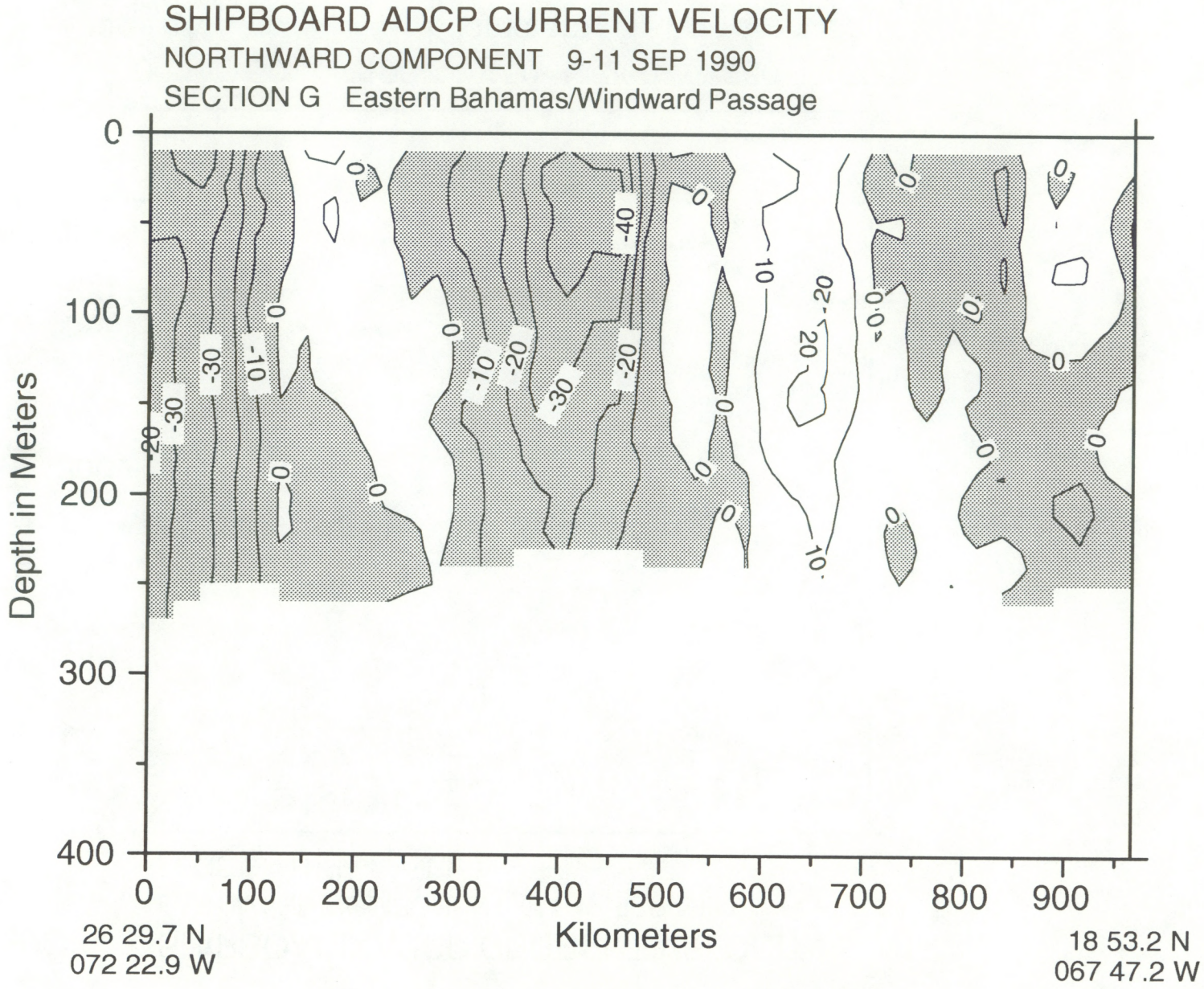


Figure C.19b 25 km Grid

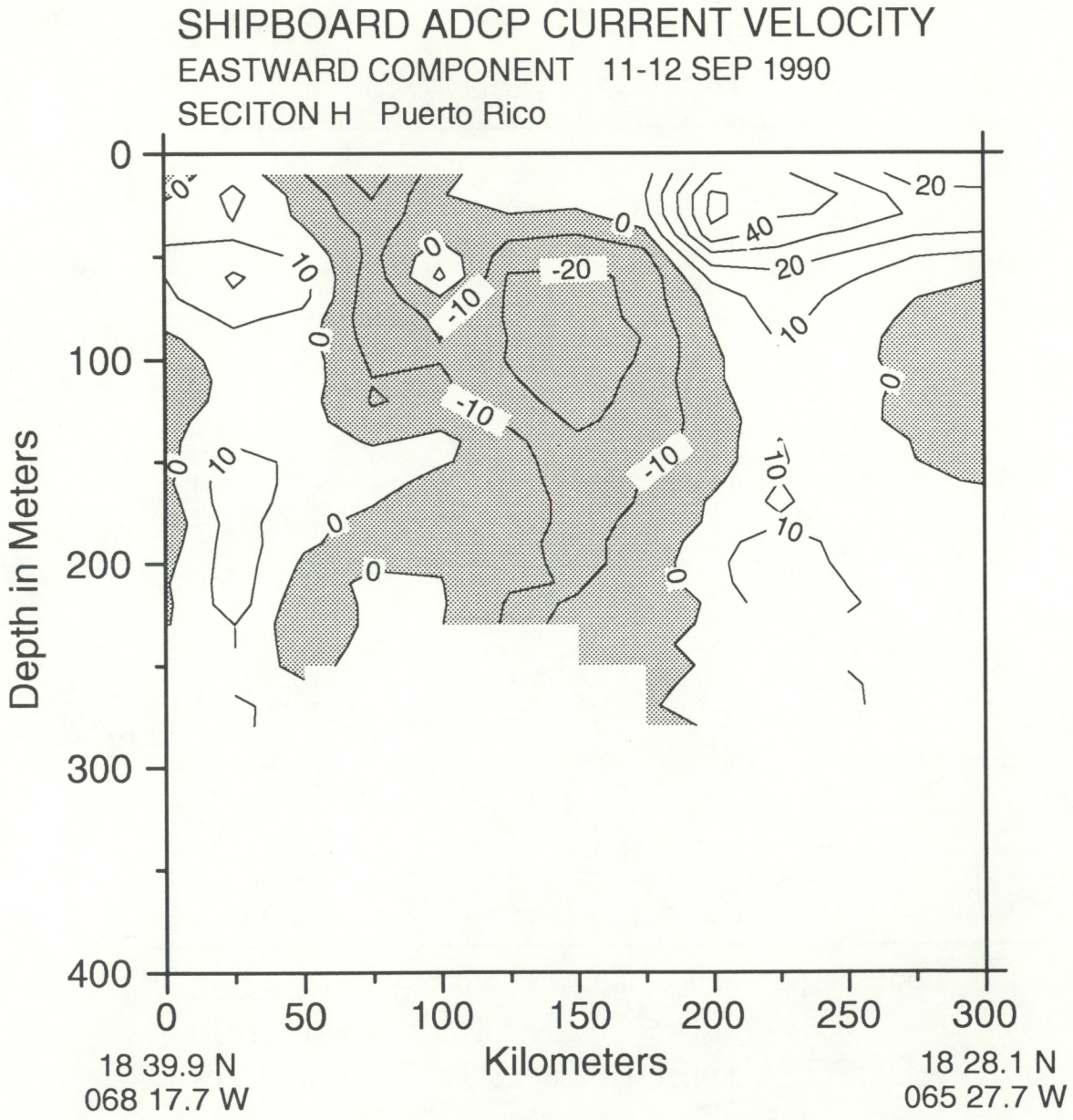


Figure C.20a 25 km Grid

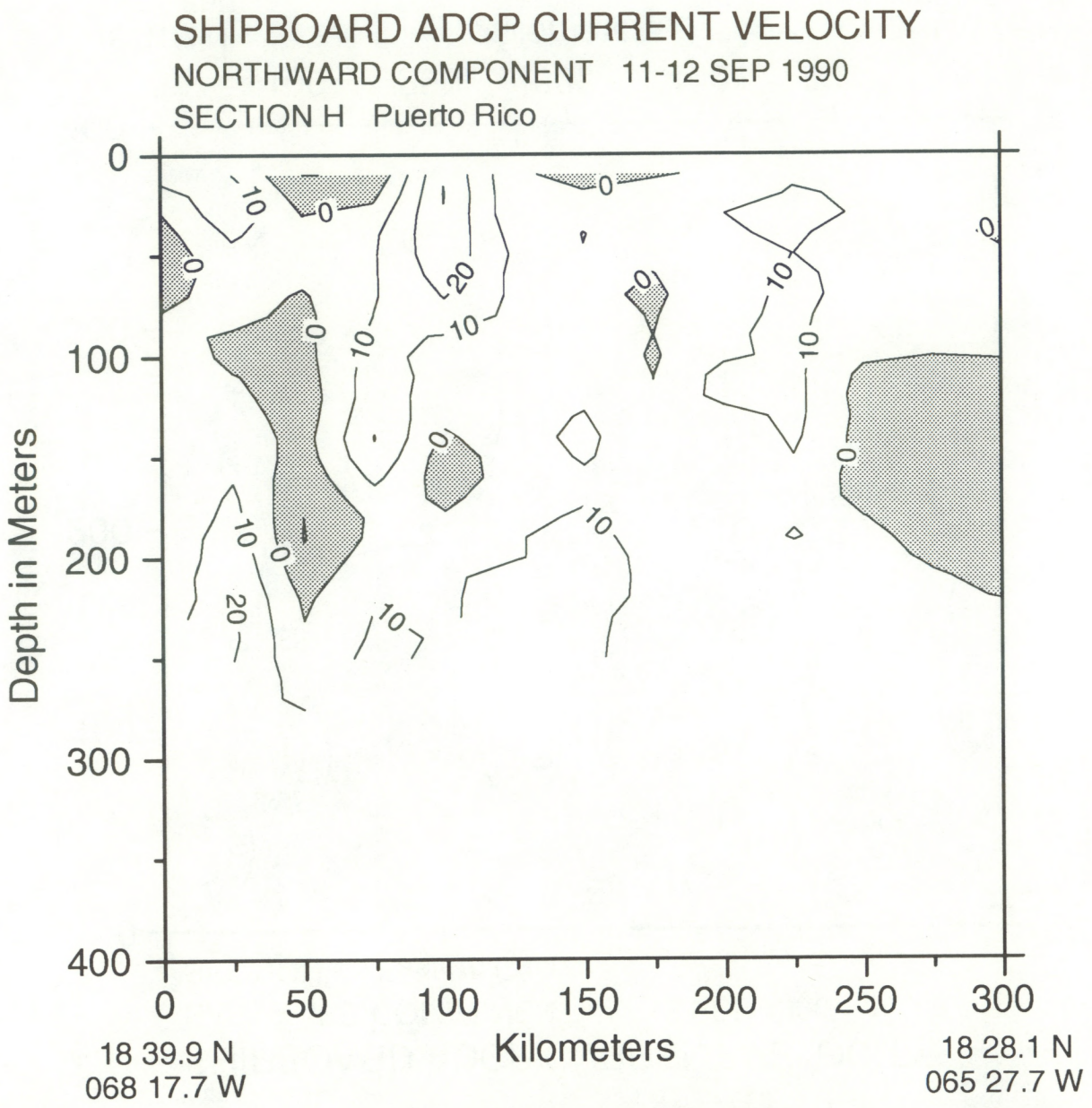


Figure C.20b 25 km Grid

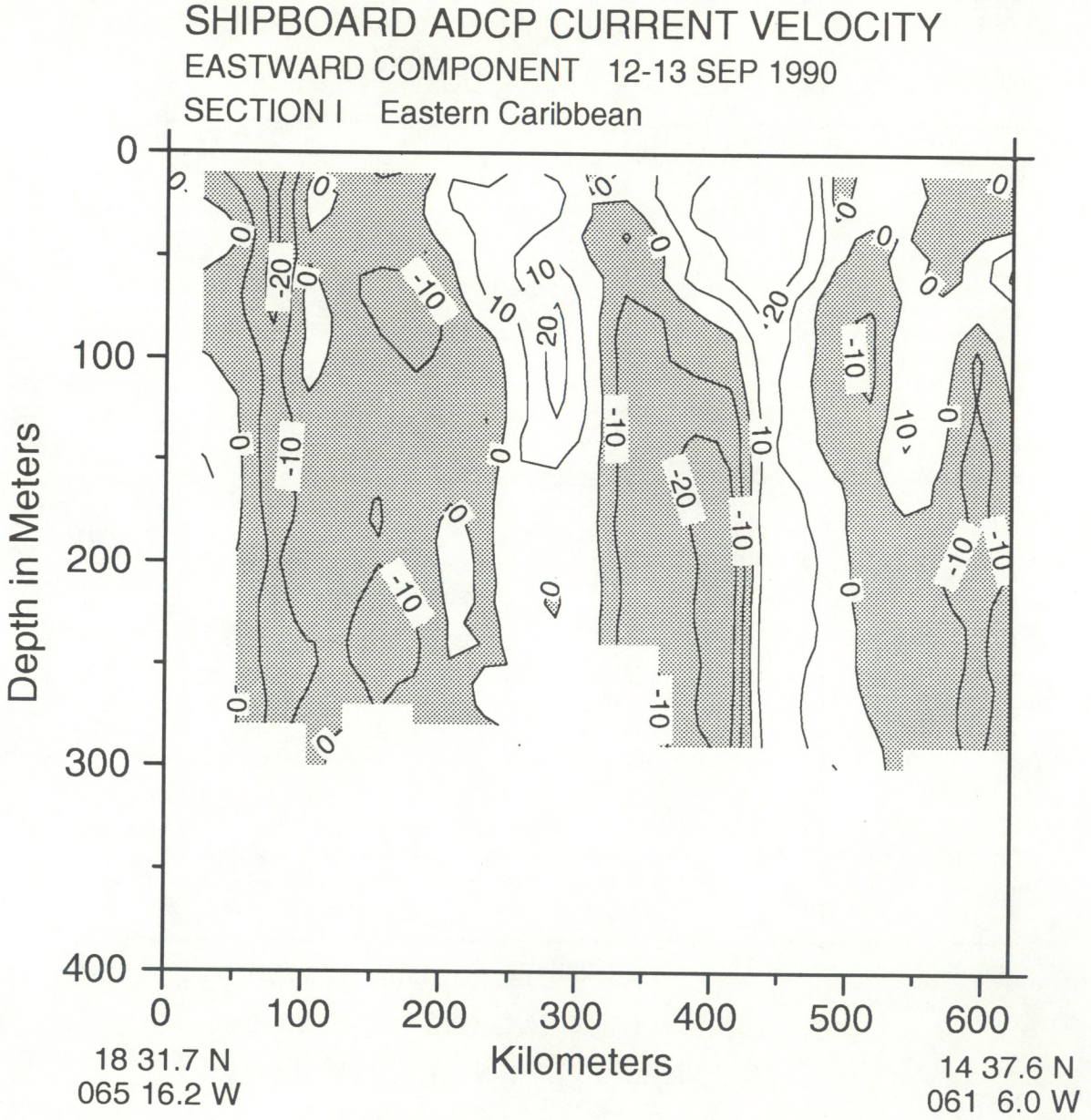


Figure C.21a 25 km Grid

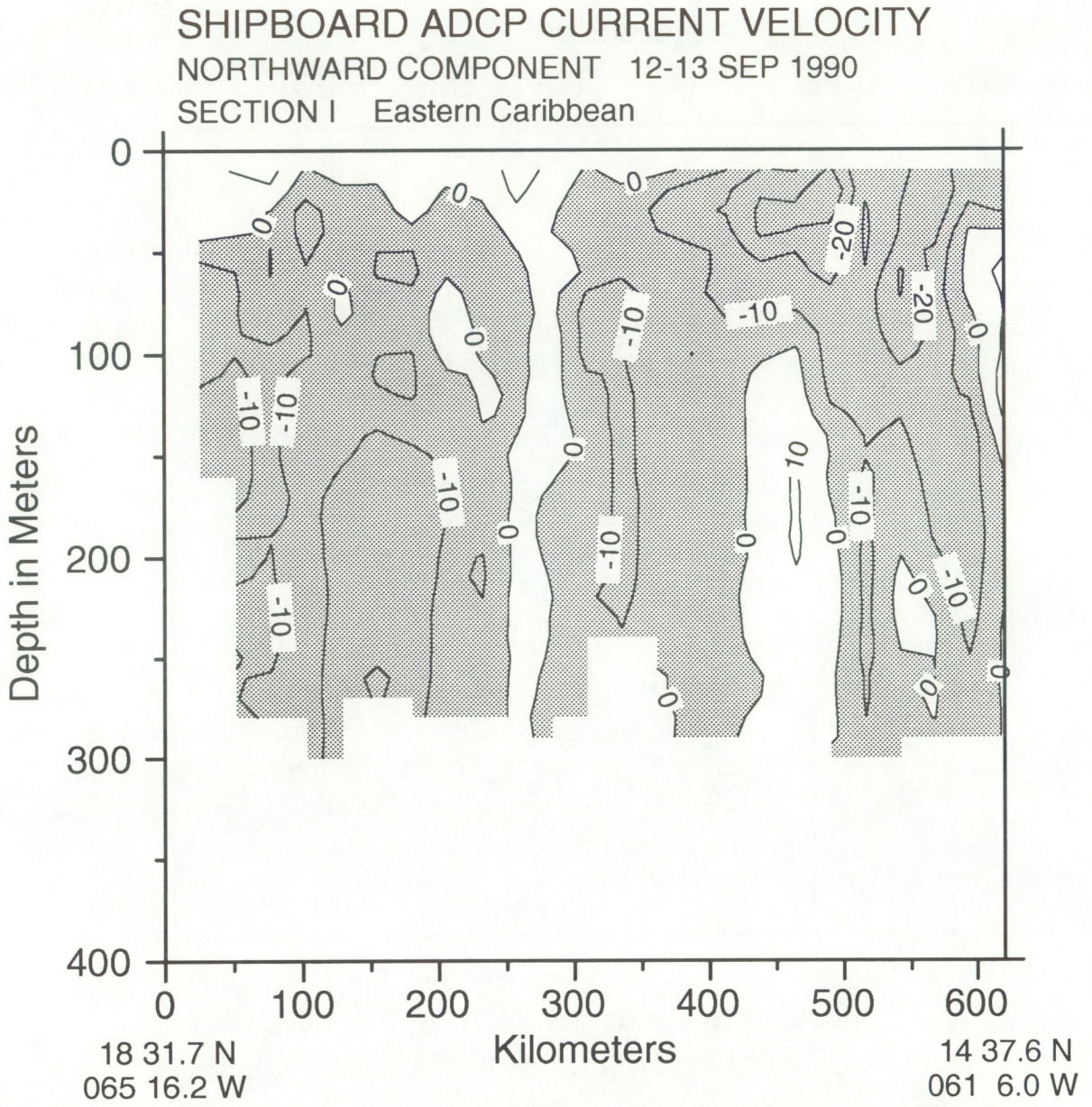


Figure C.21b 25 km Grid

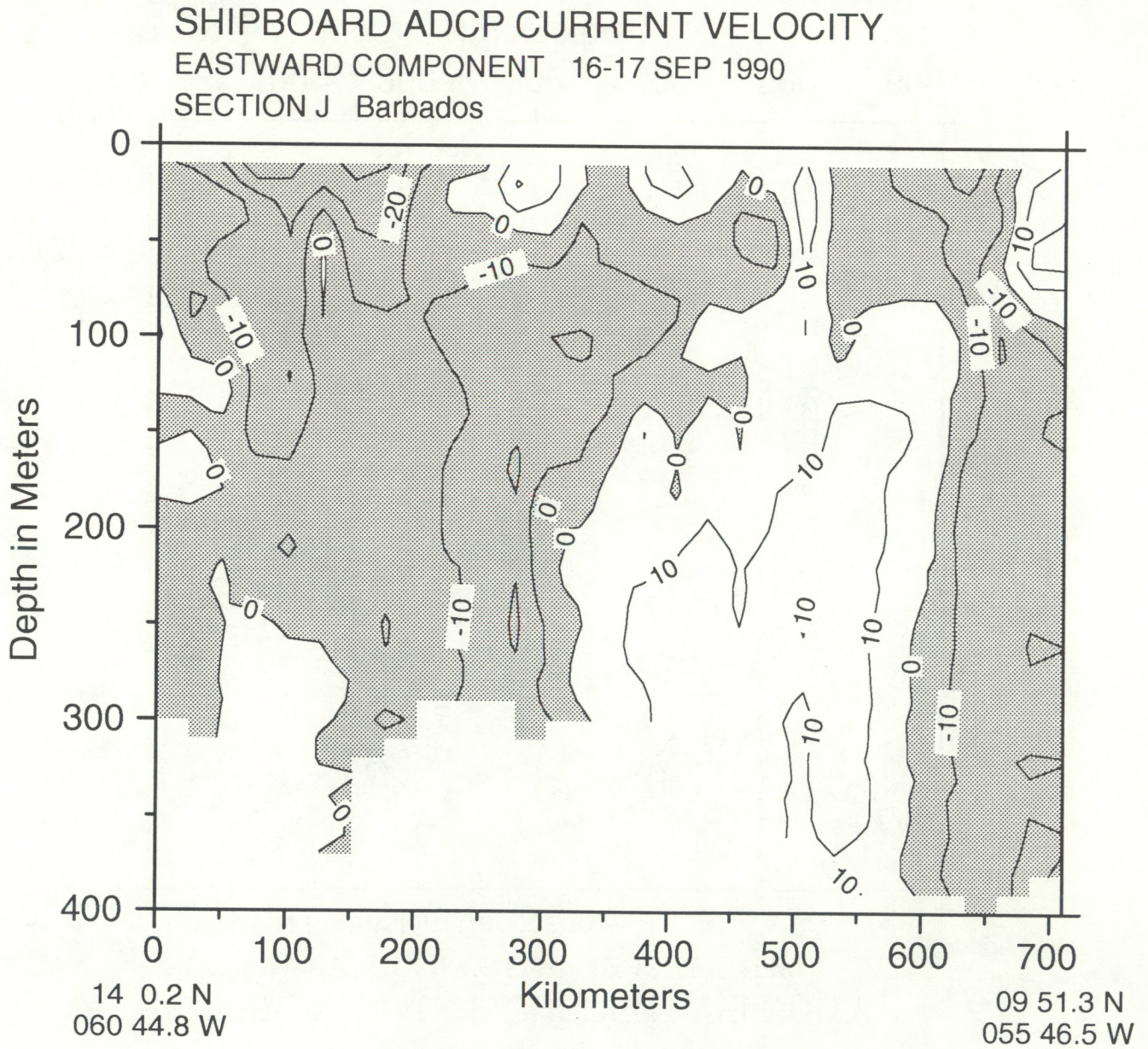


Figure C.22a 25 km Grid

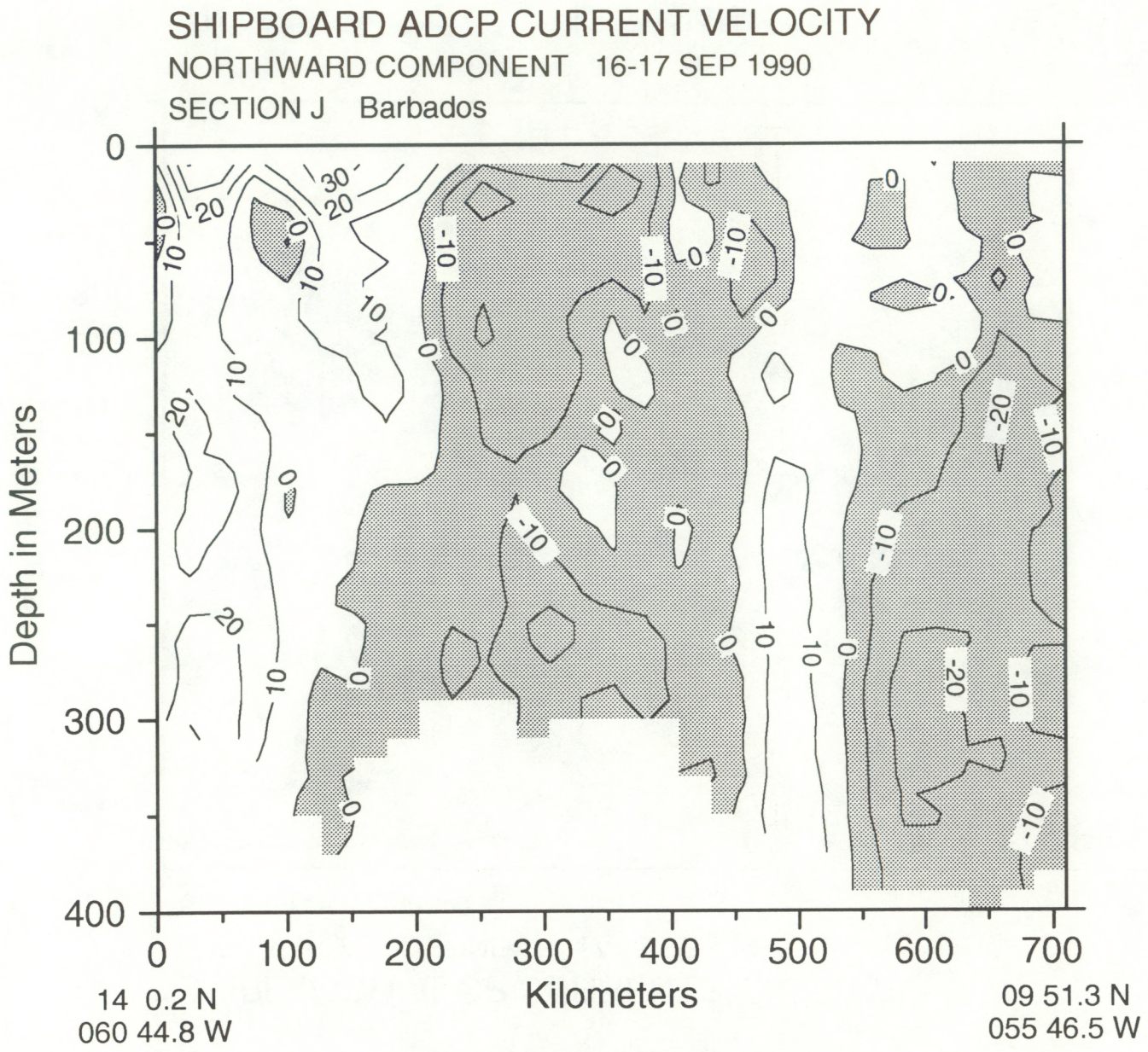


Figure C.22b 25 km Grid

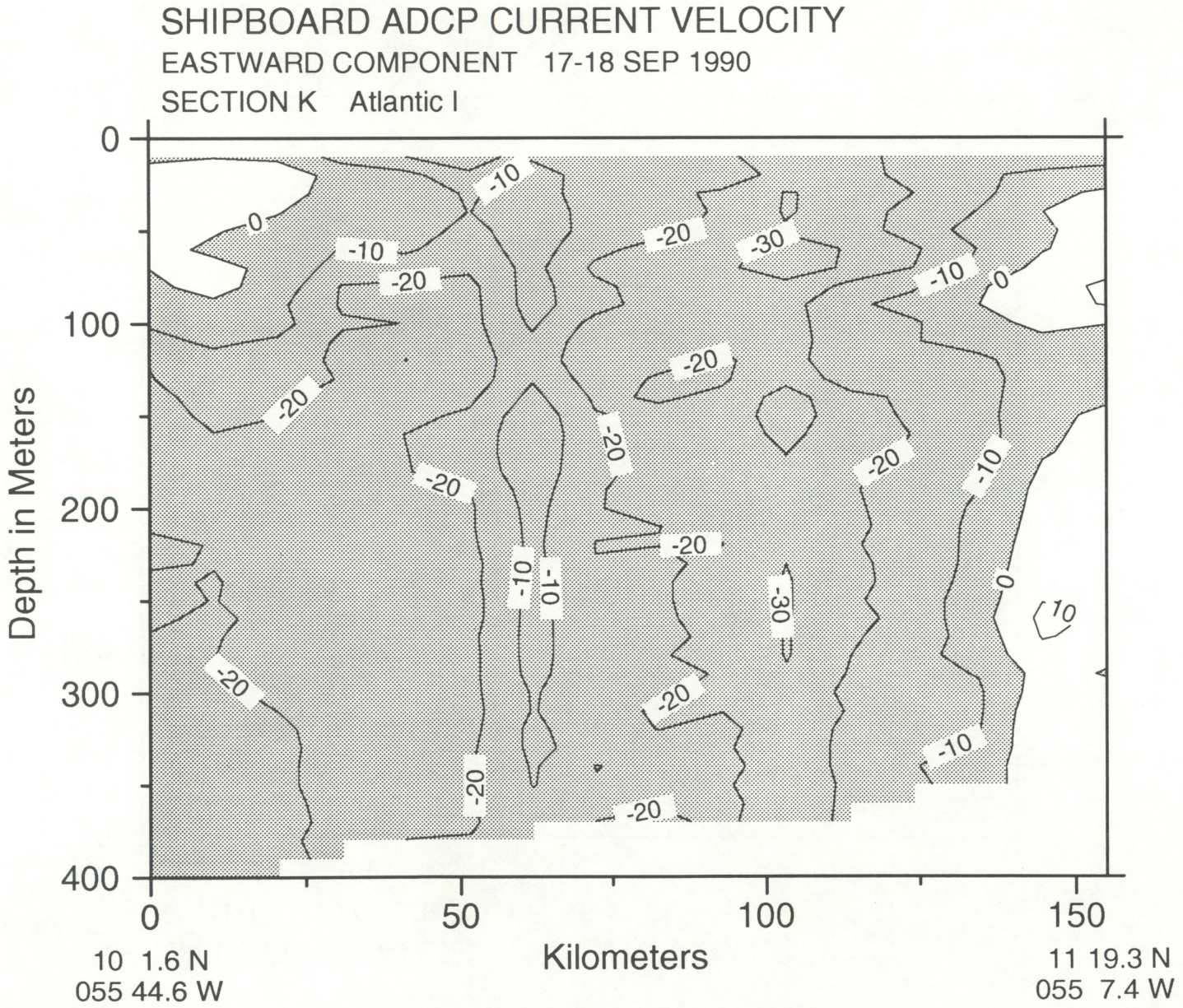


Figure C.23a 10 Km Grid

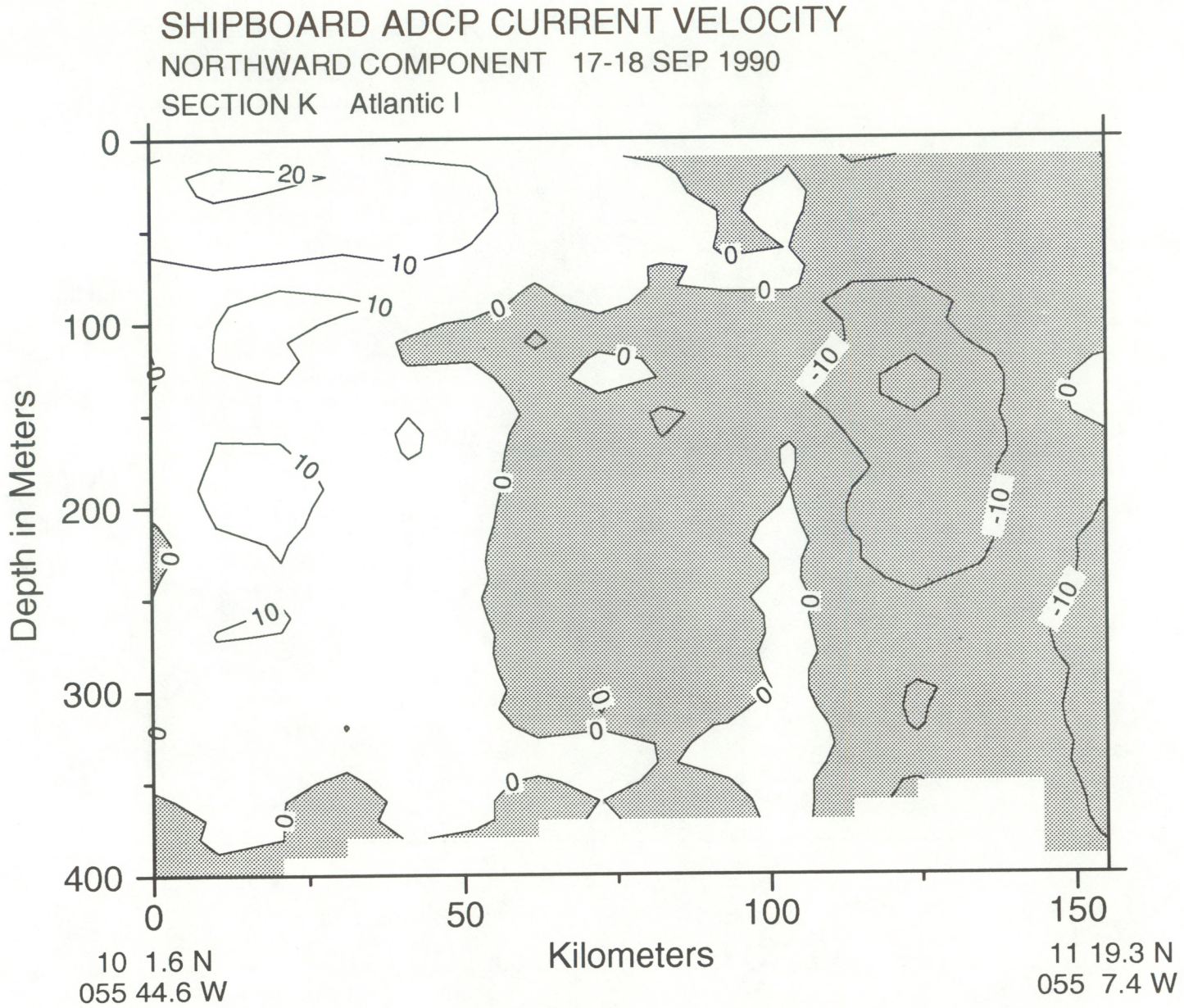


Figure C.23b 10 Km Grid

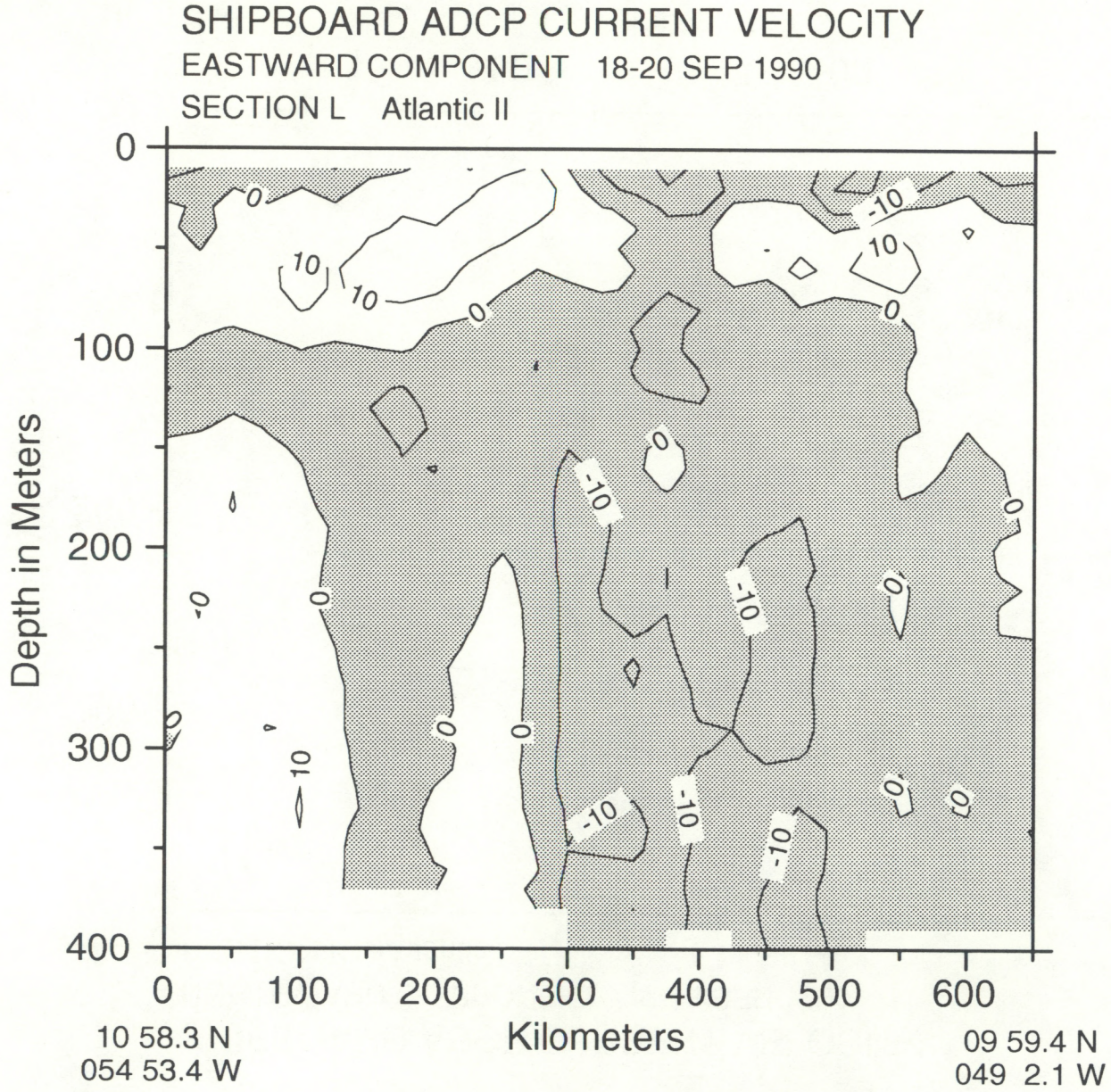


Figure C.24a 25 Km Grid

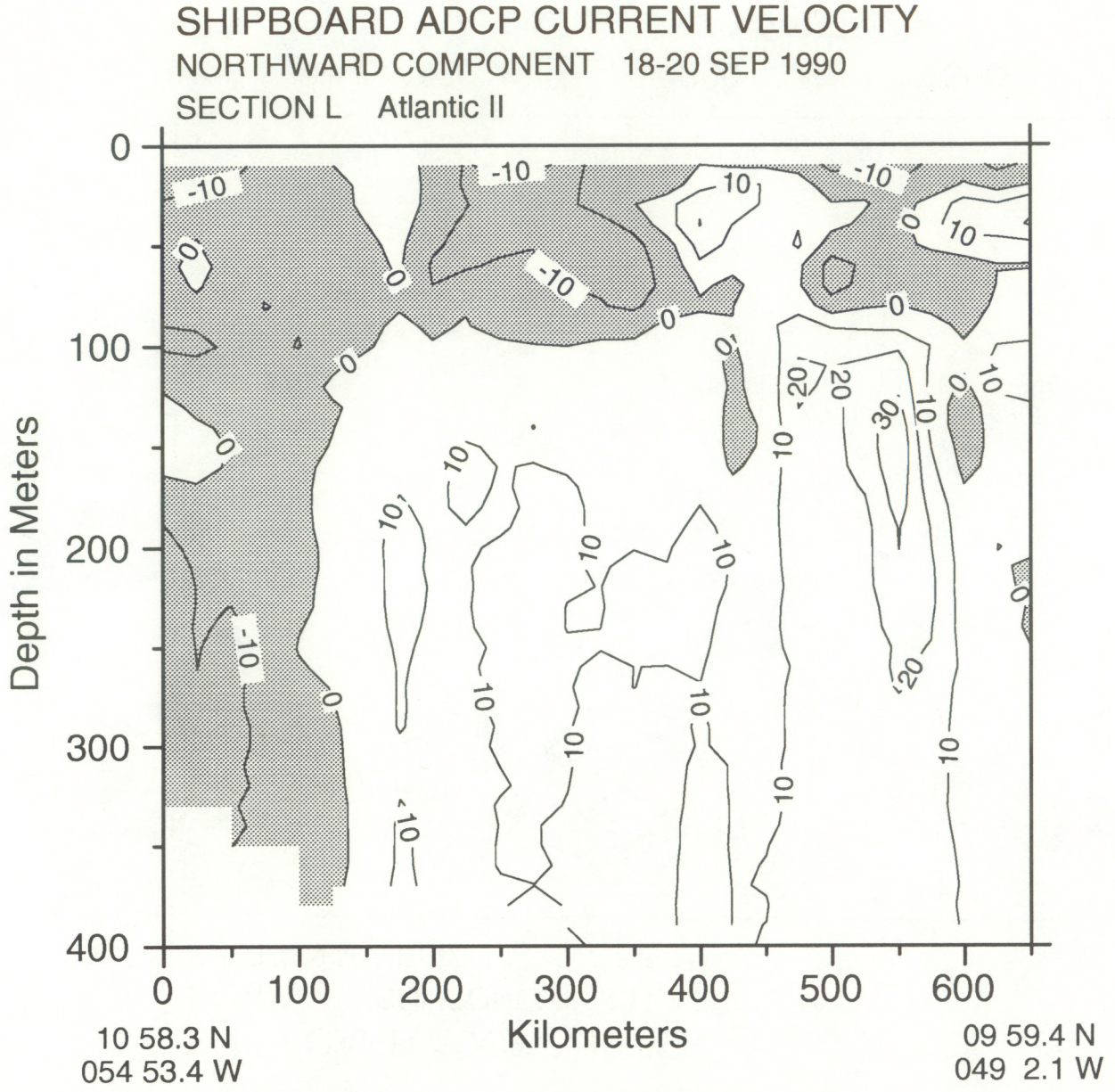
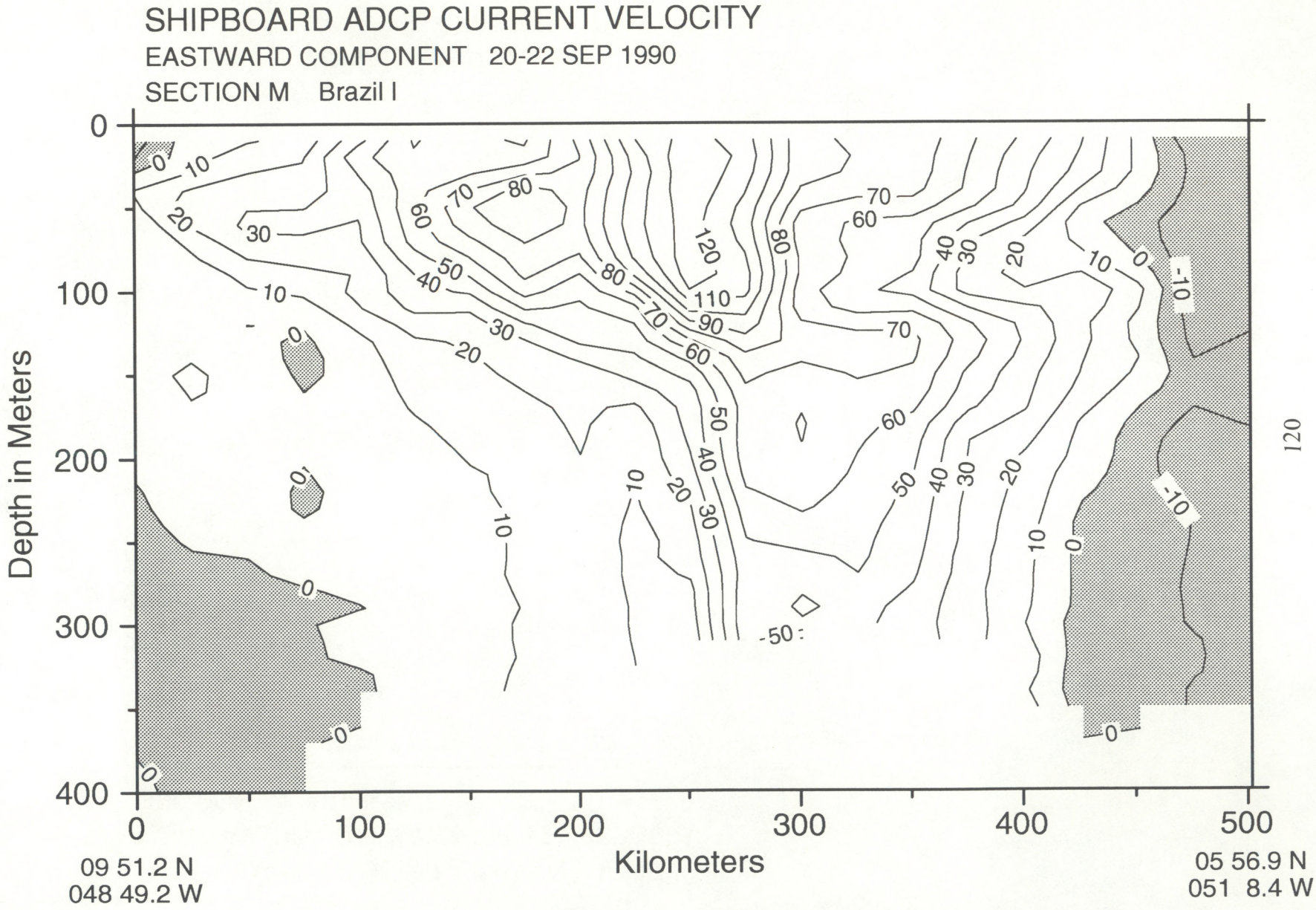


Figure C.24b 25 km Grid



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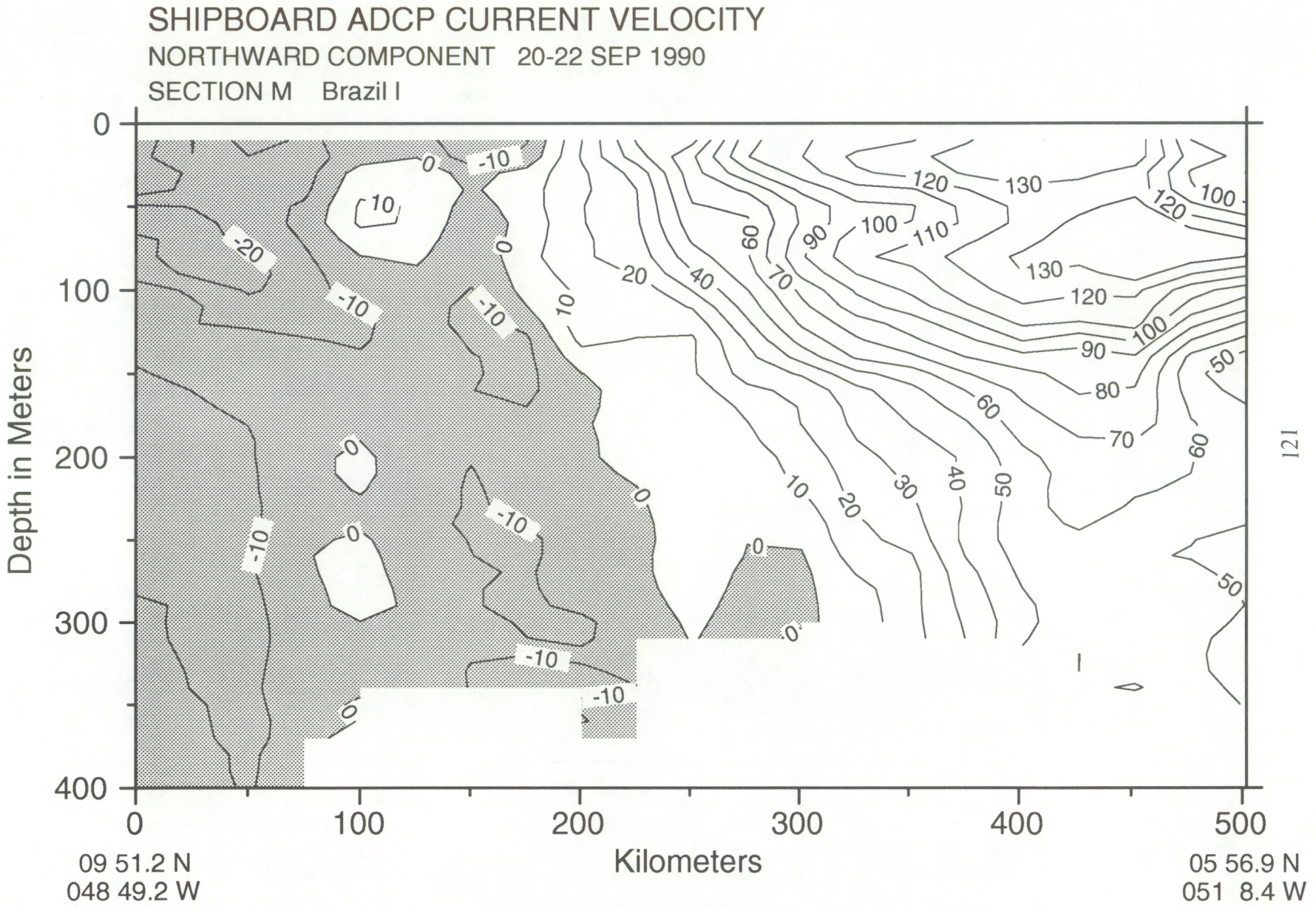


Figure C.25b 25 km Grid

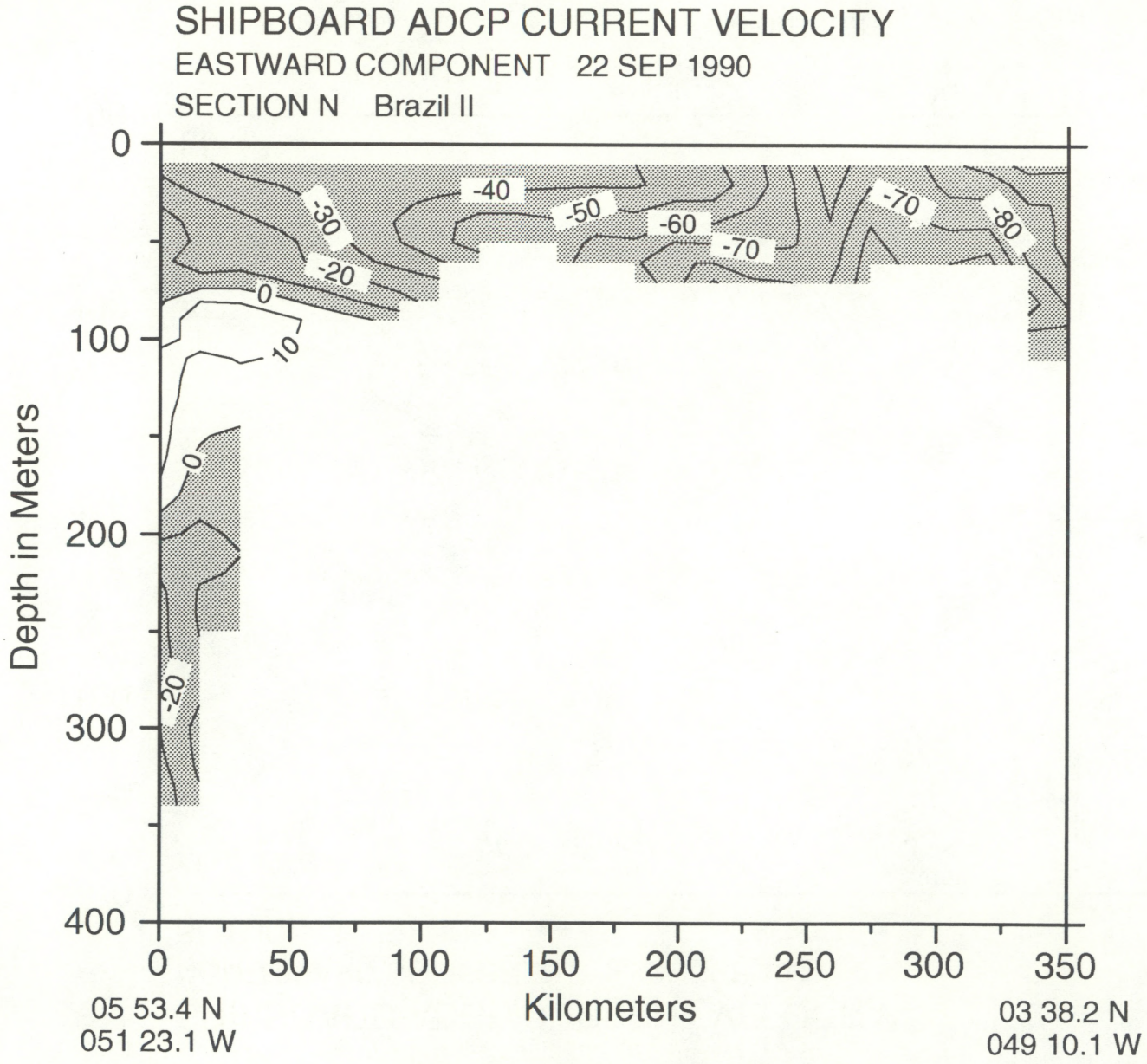


Figure C.26a 15 km Gird

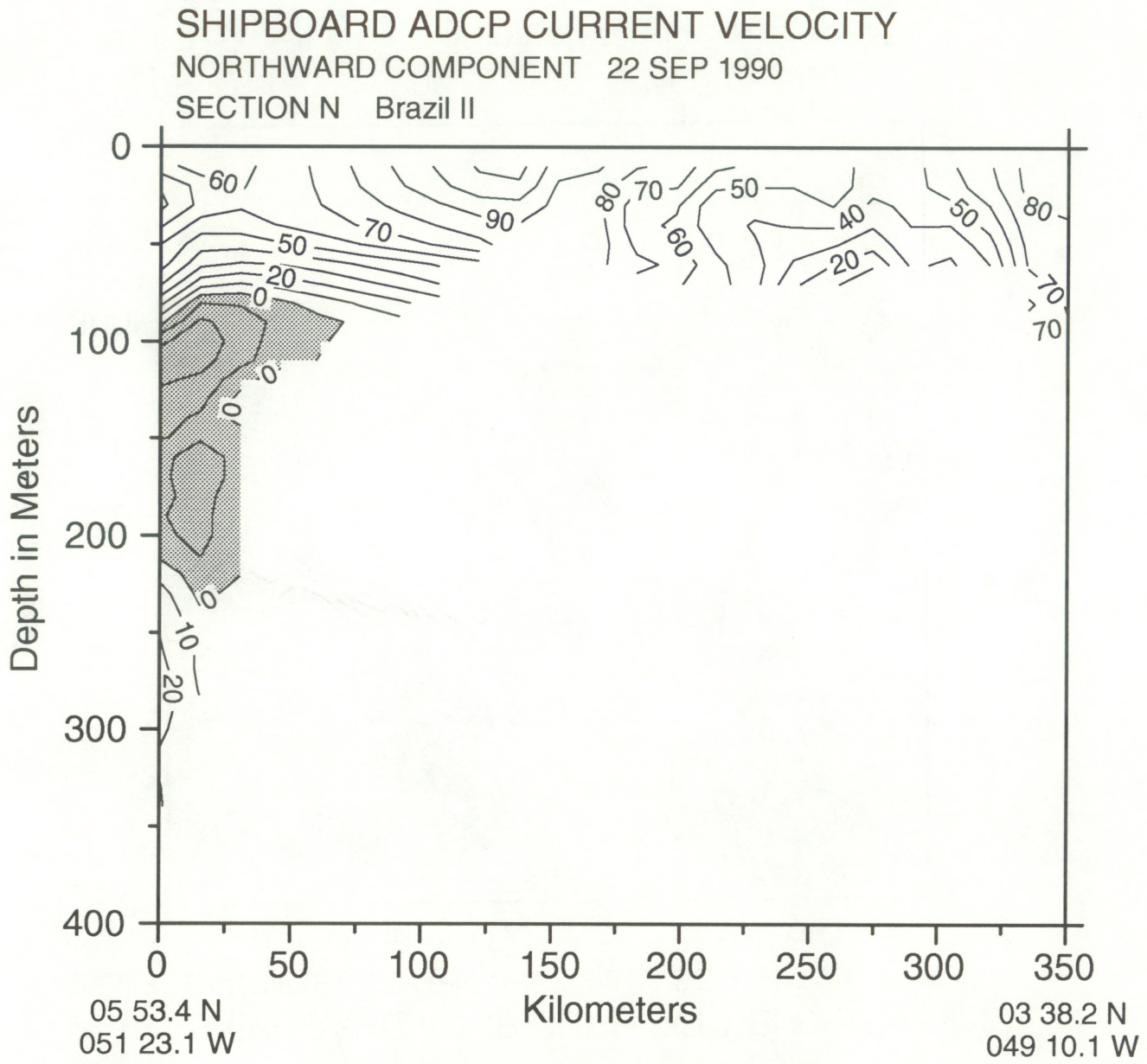


Figure C.26b 15 km Grid

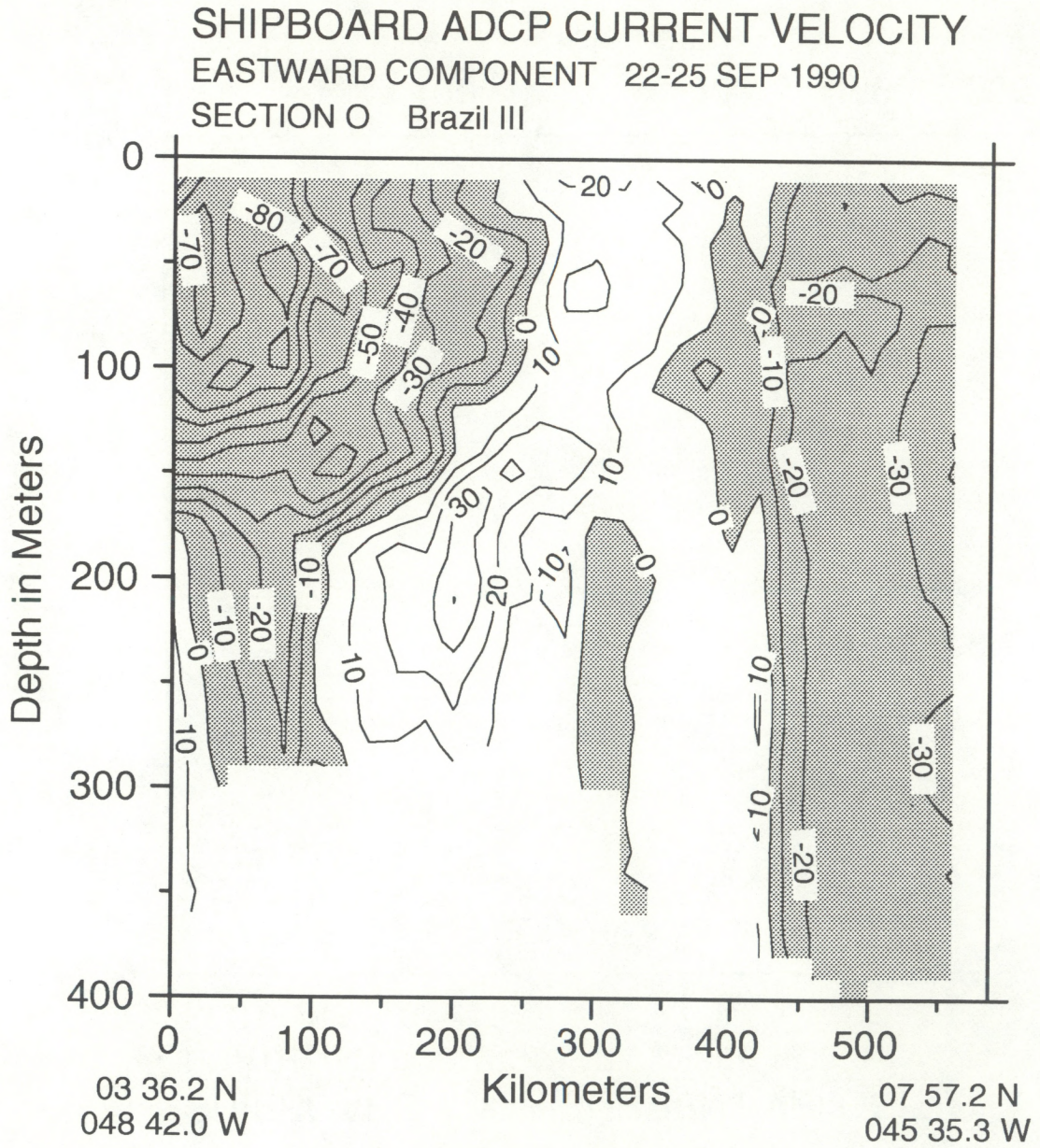


Figure C.27a 20 km Grid

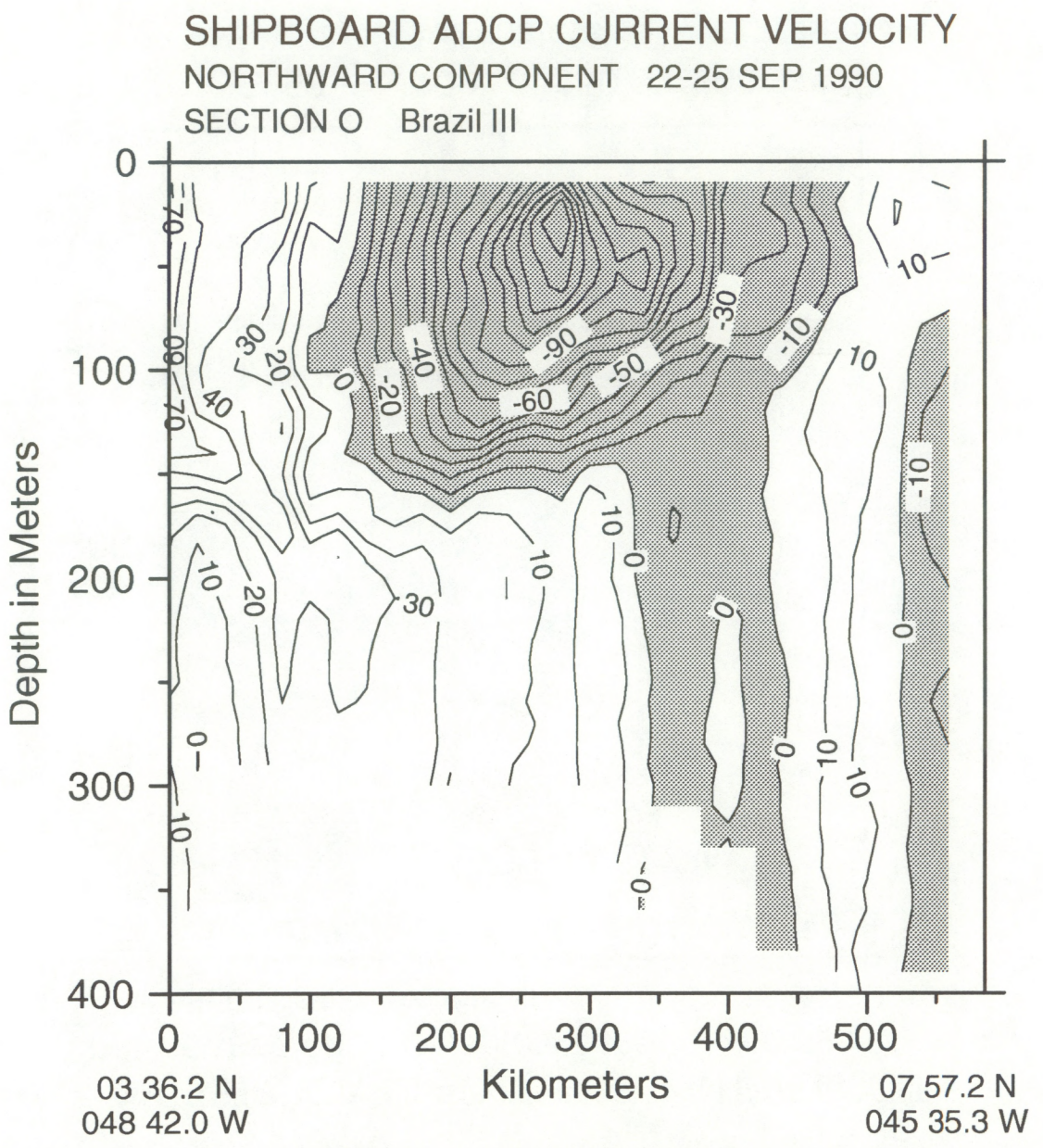


Figure C.27b 20 km Grid

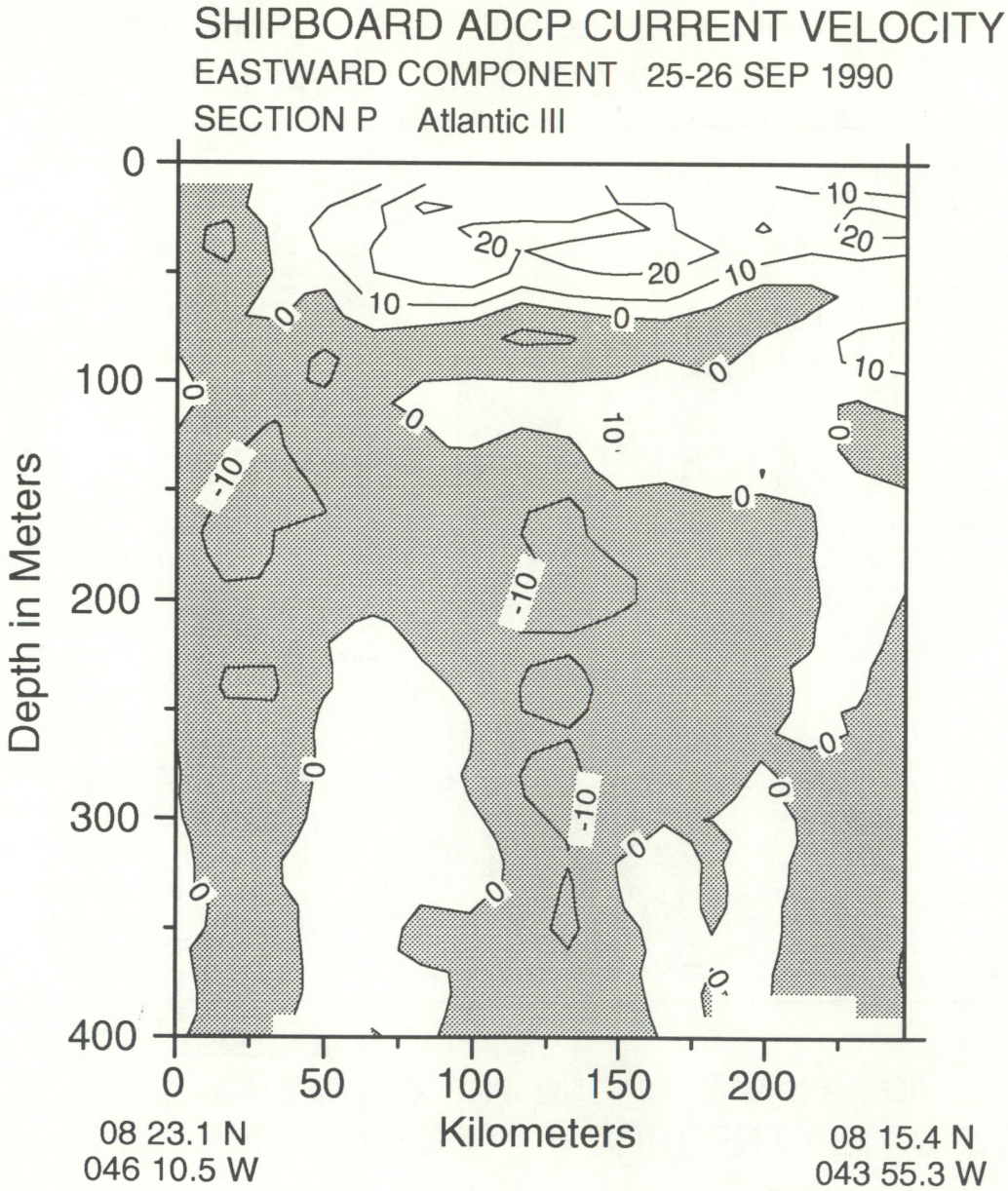


Figure C.28a 16 km Grid

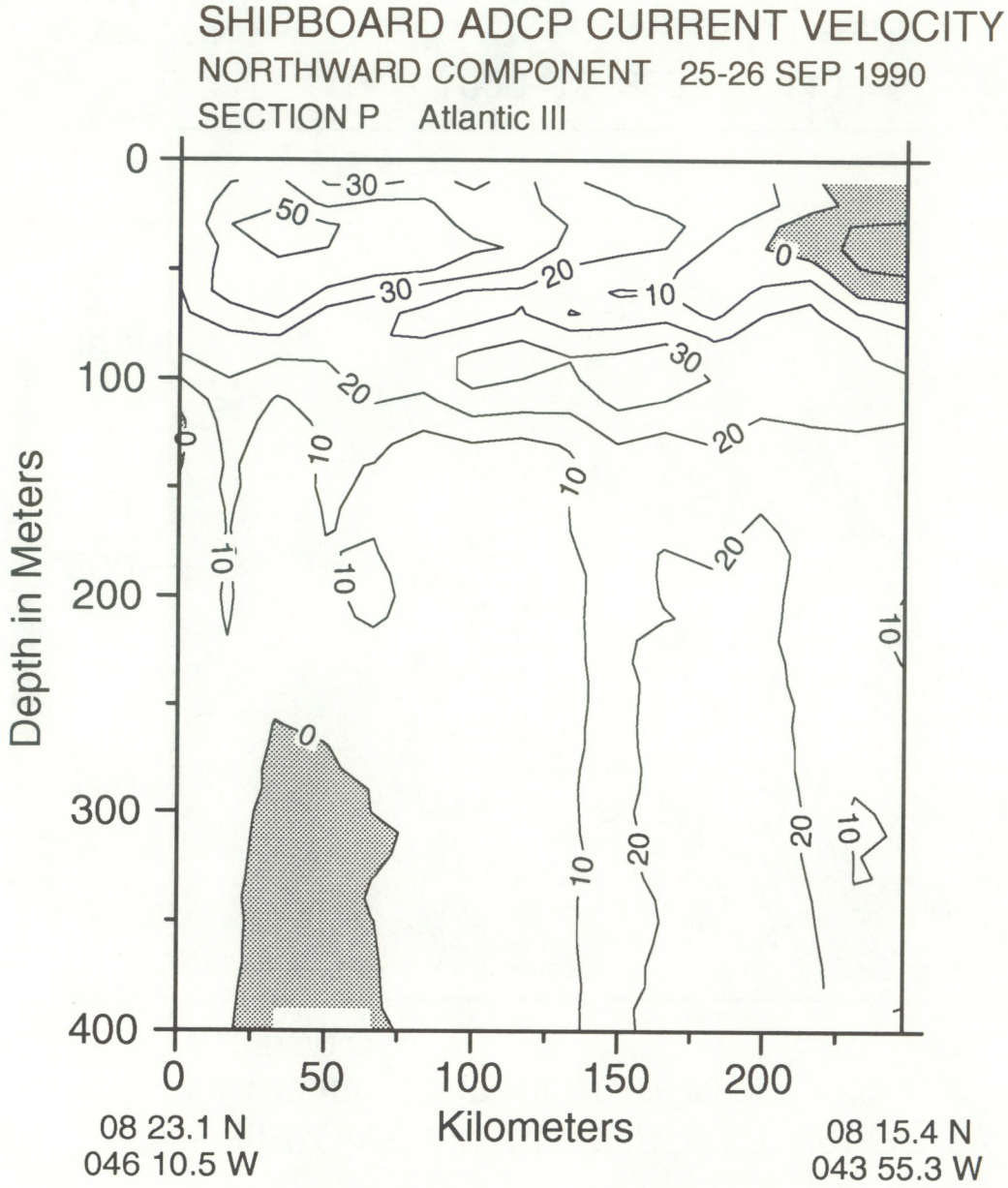


Figure C.28b 16 km Grid

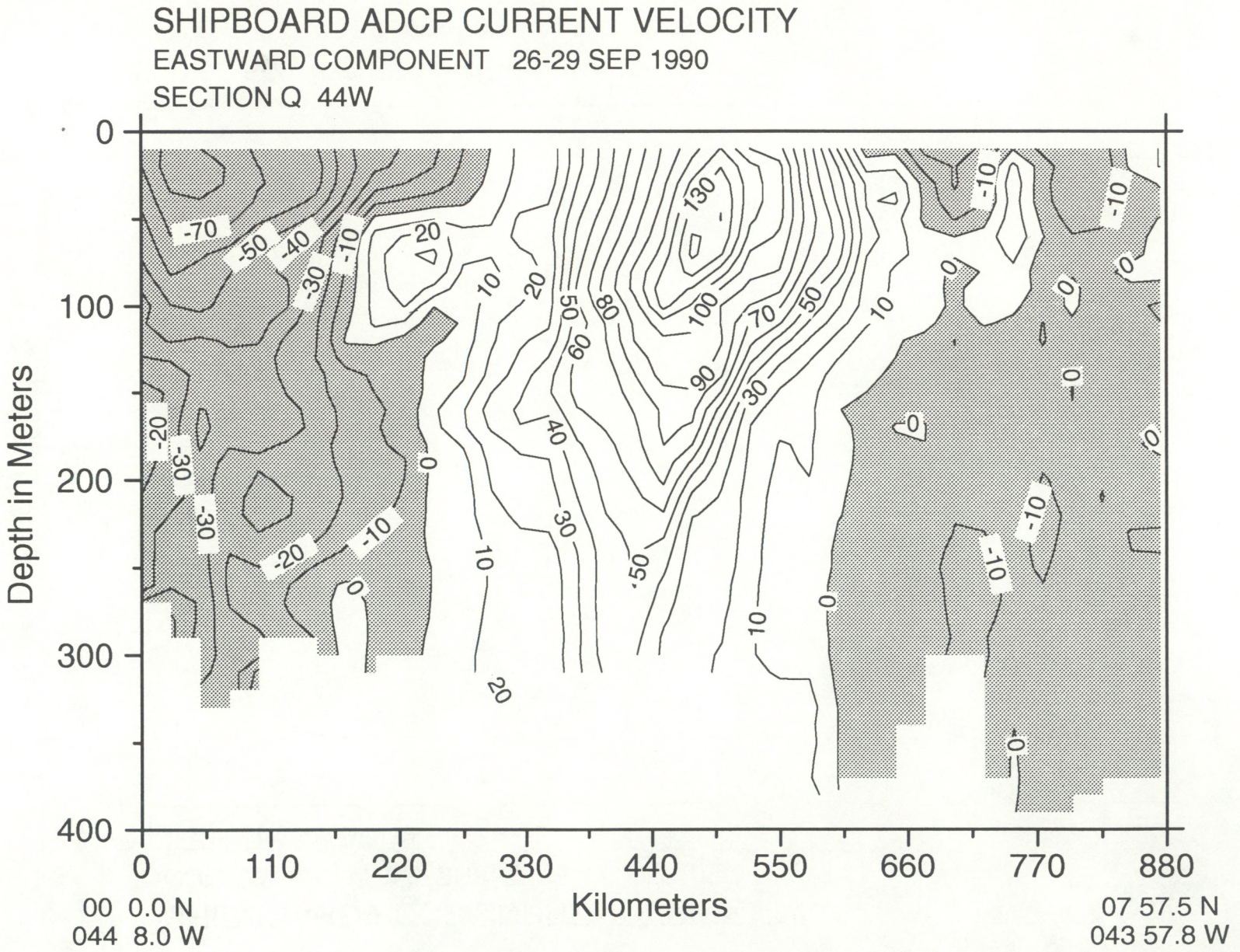


Figure C.29a 25 km Grid

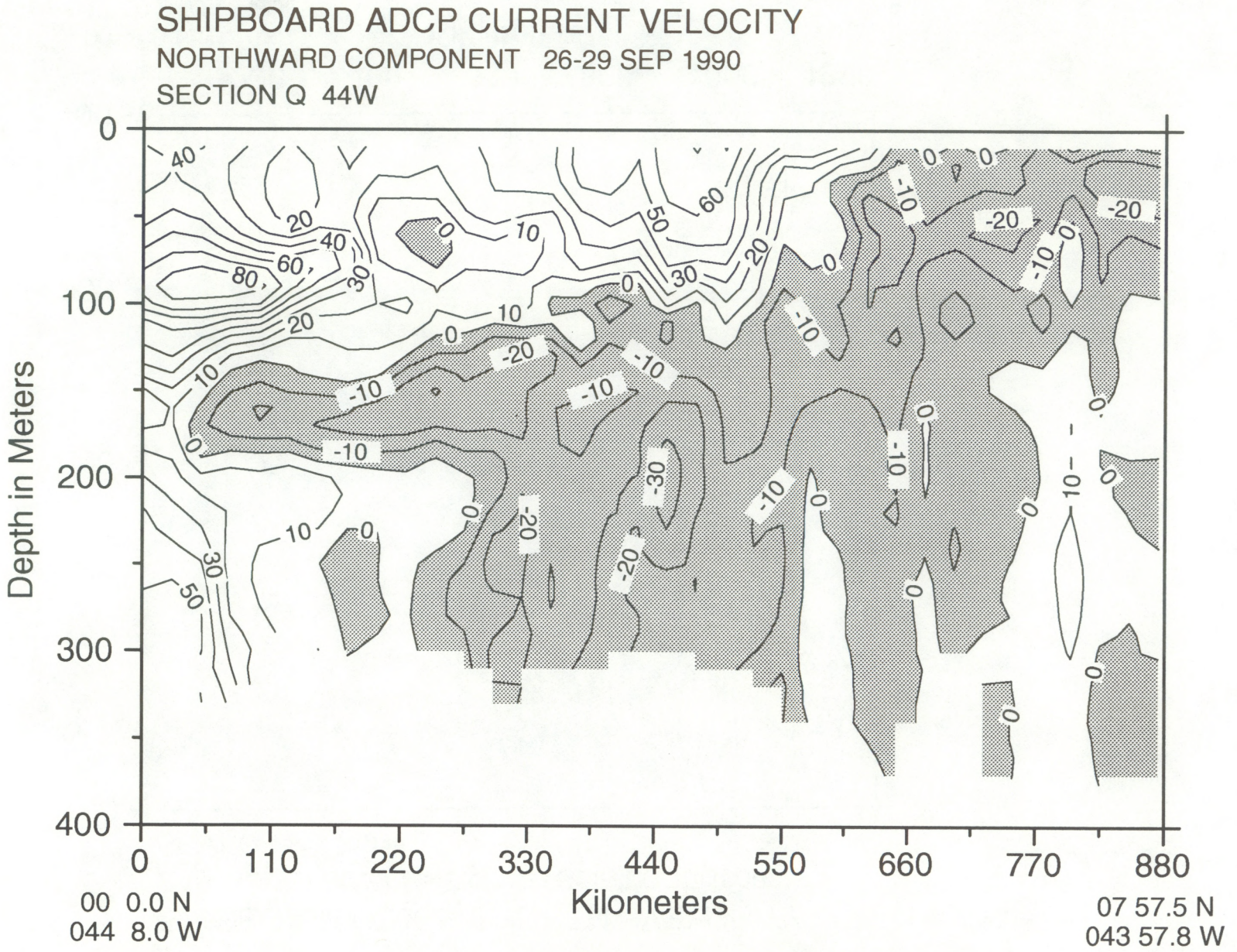


Figure C.29b 25 km Grid

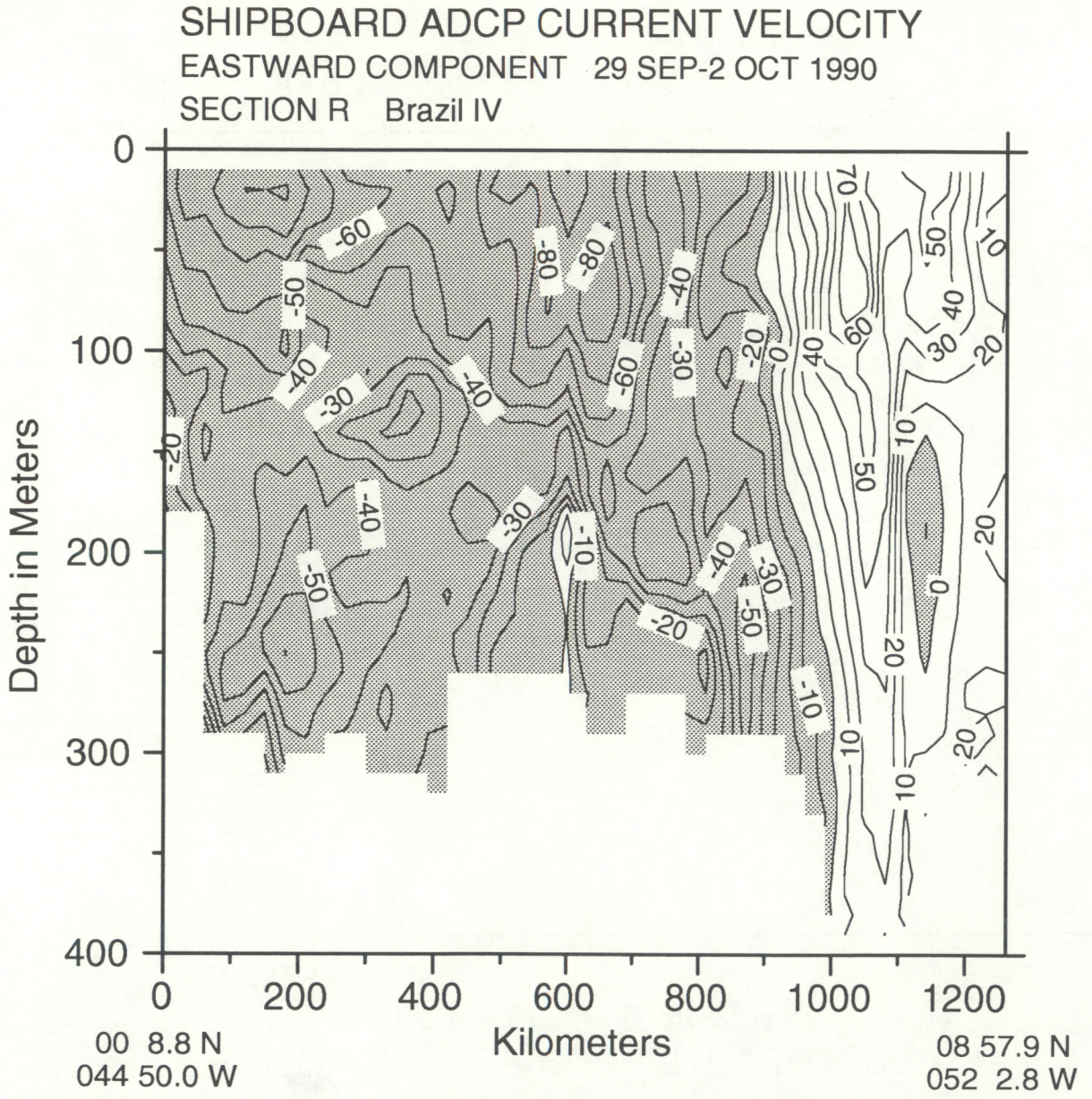


Figure C.30a 30 km Grid

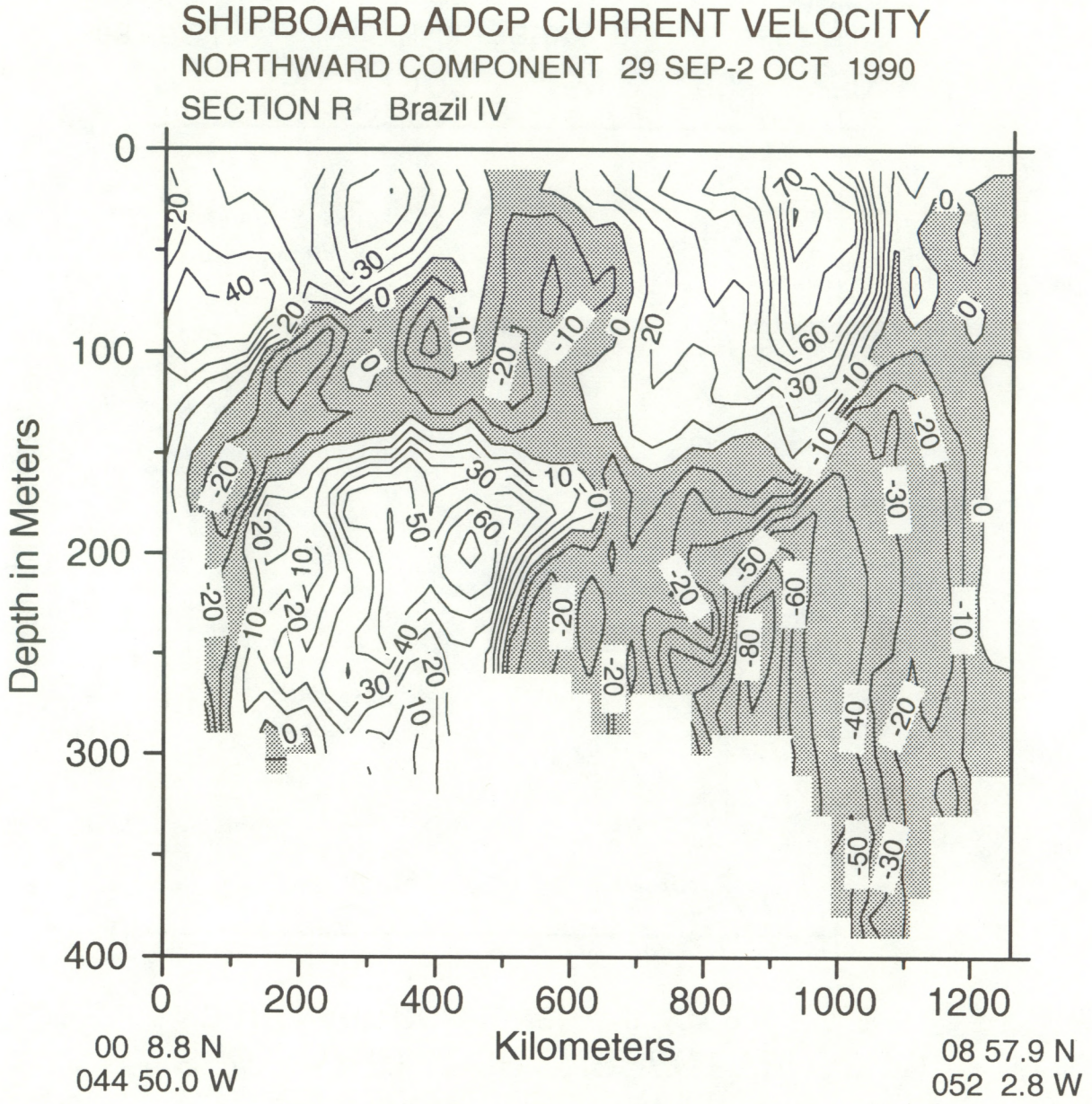


Figure C.30b 30 km Grid

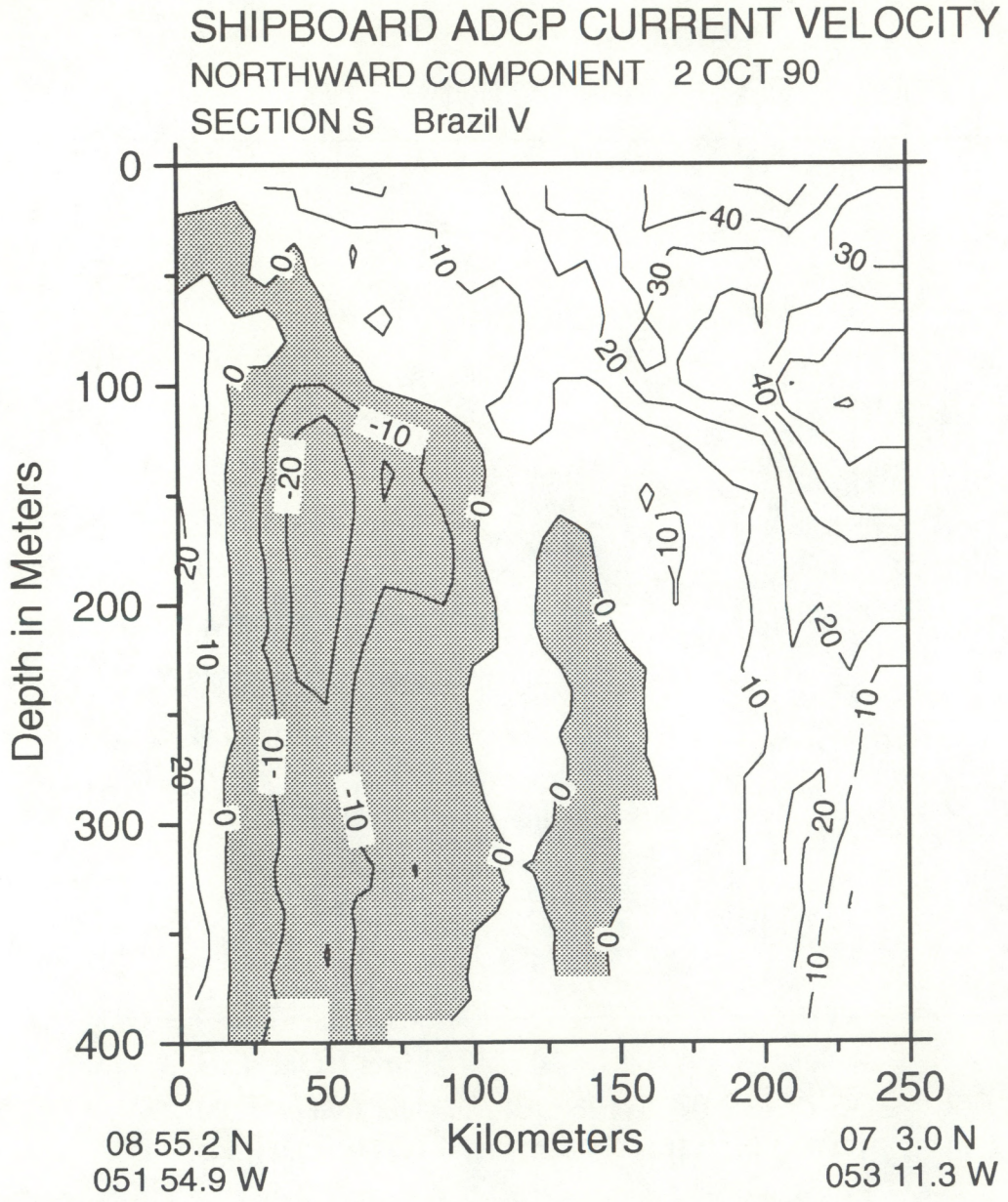


Figure C.31a 10 km Grid

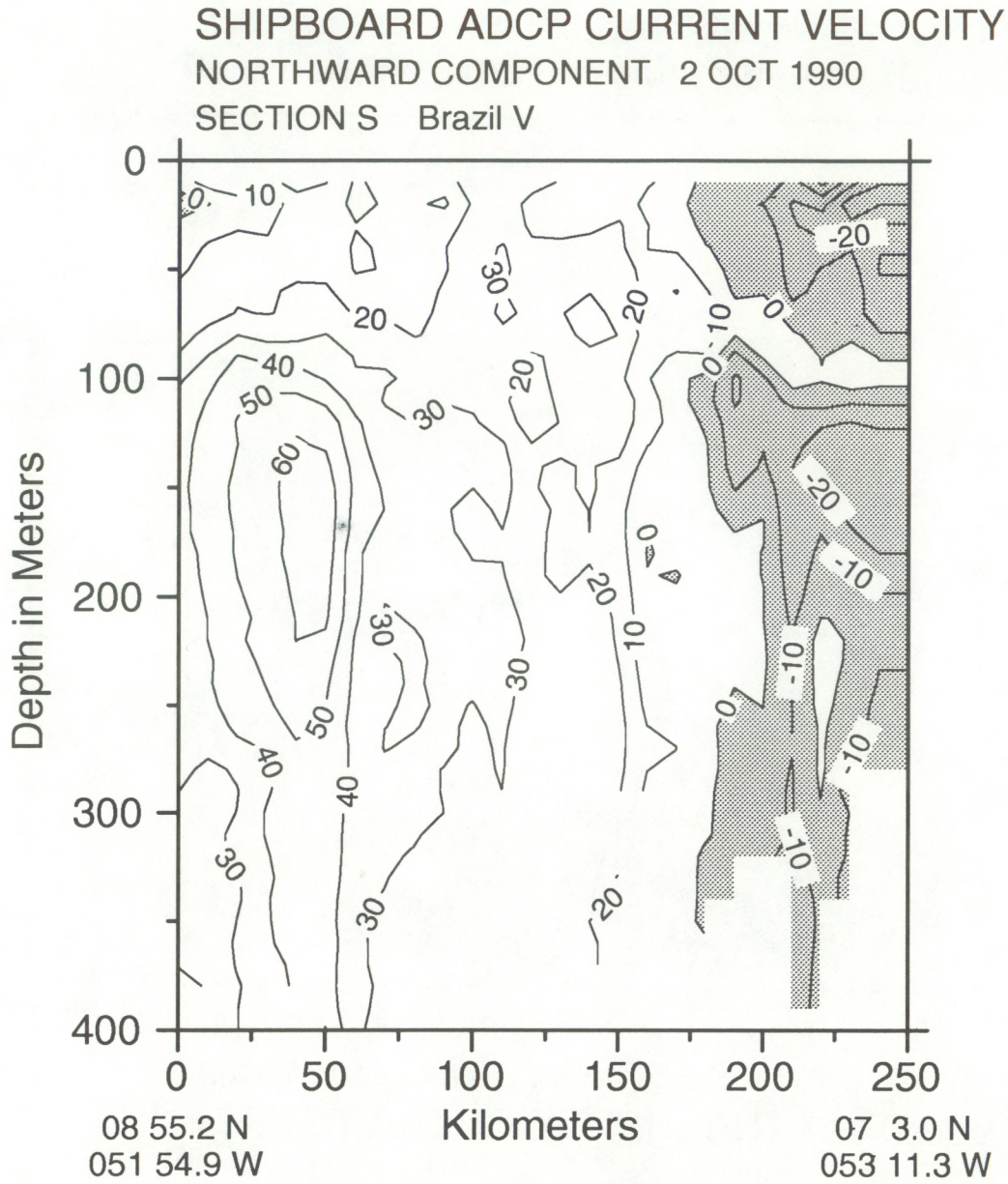
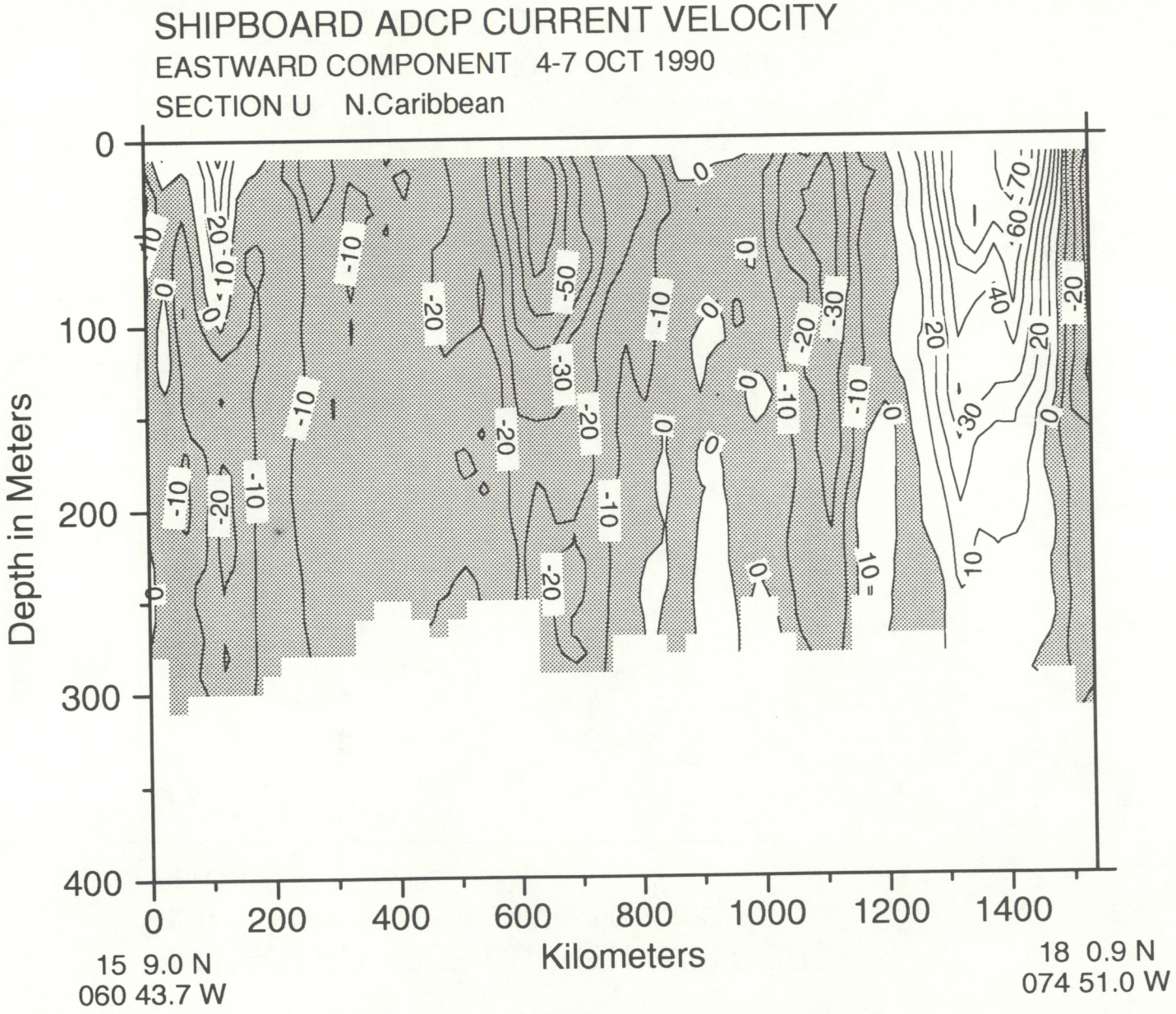


Figure C.31b 10 km Grid



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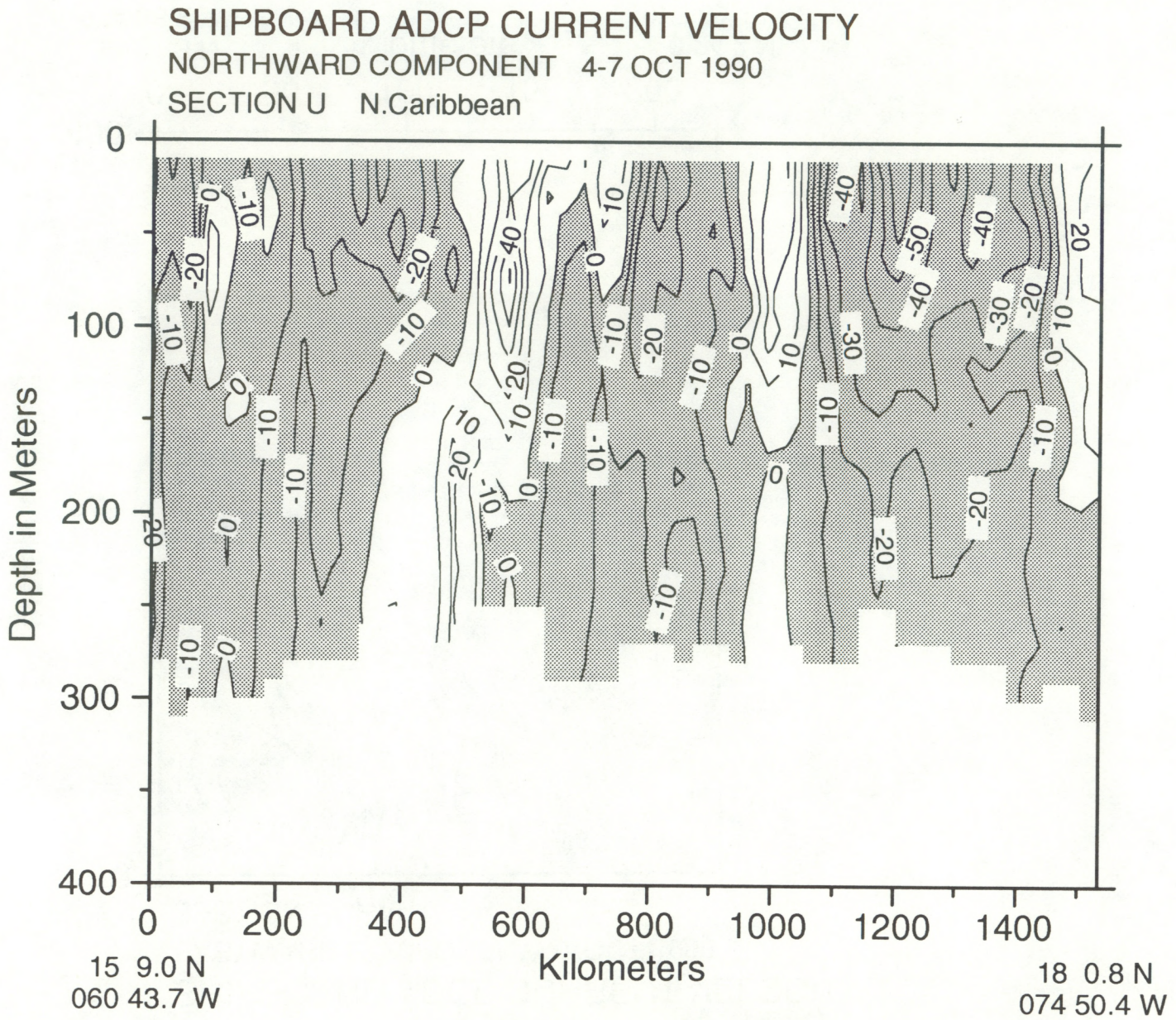

Figure C.33b 30 km Grid

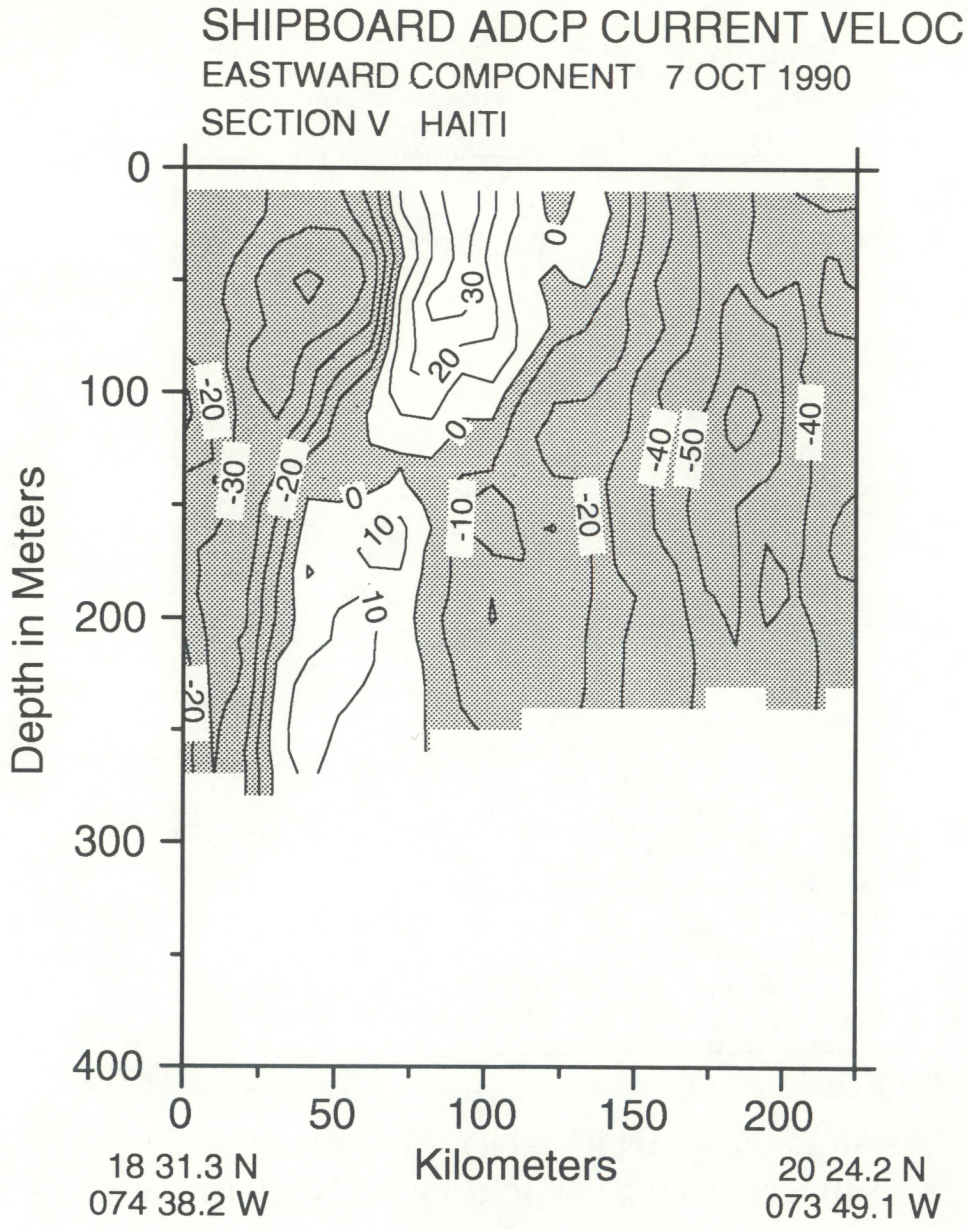

Figure C.34a 10 km Grid

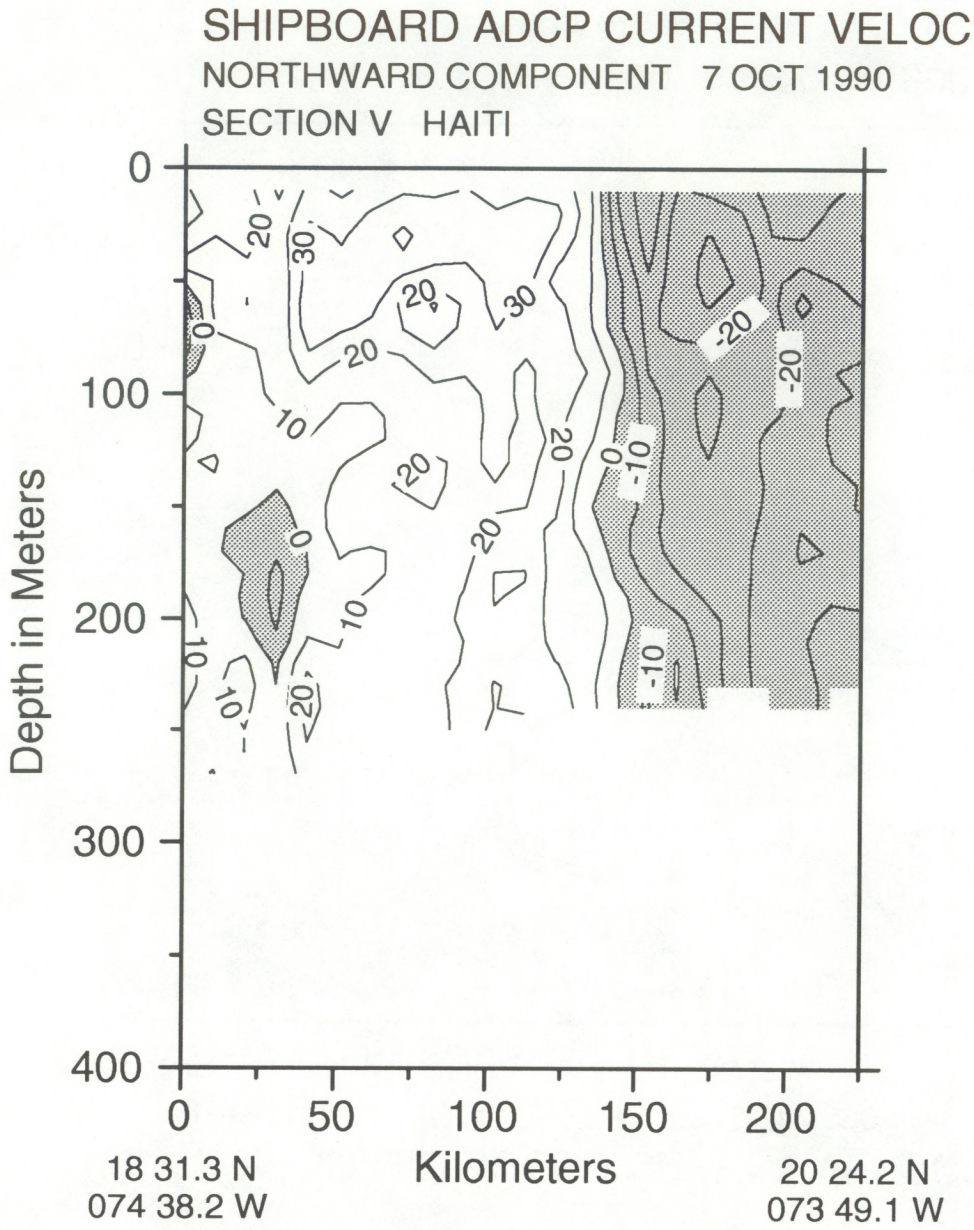

Figure C.34b 10 km Grid

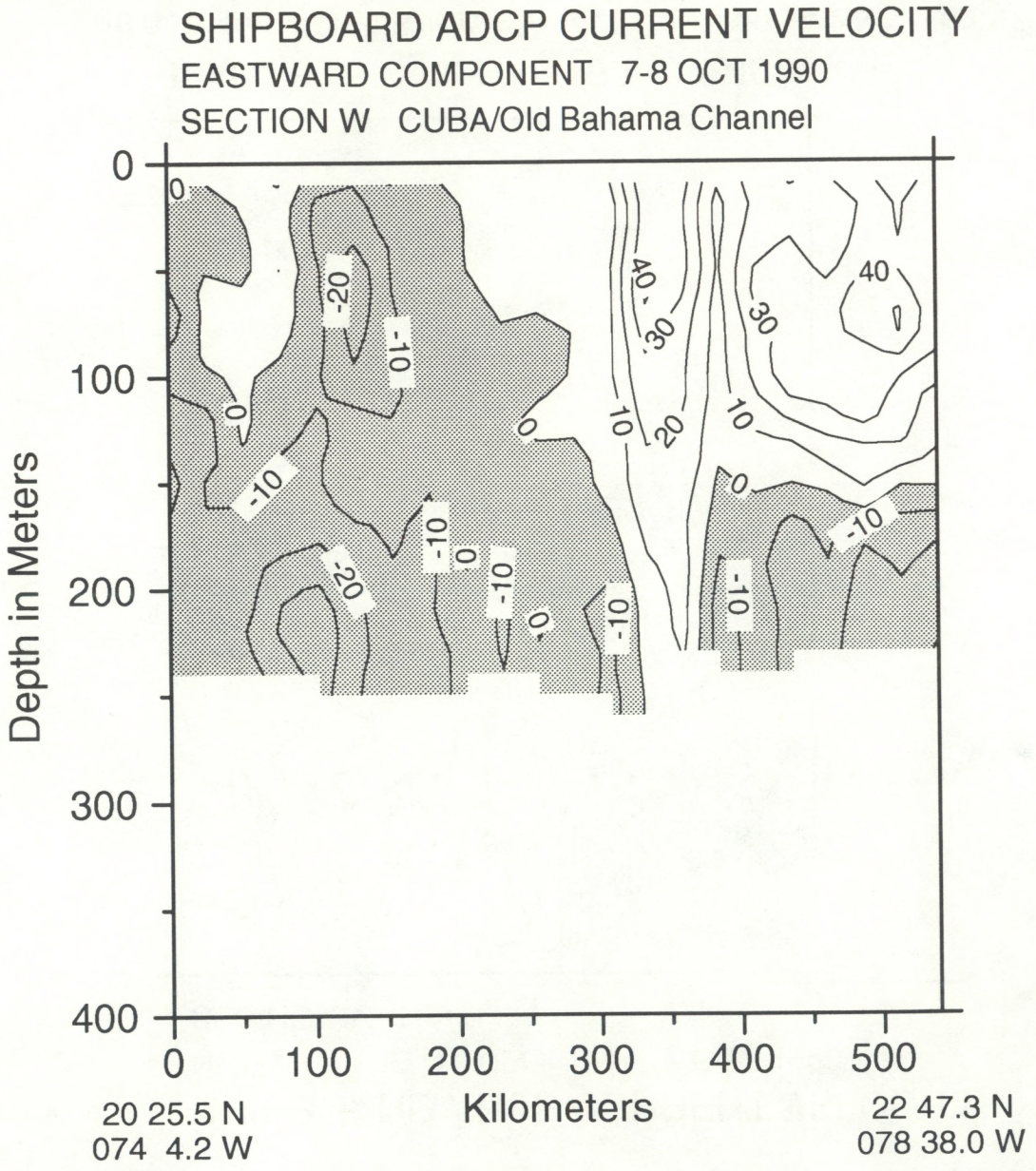

Figure C.35a 25 km Grid

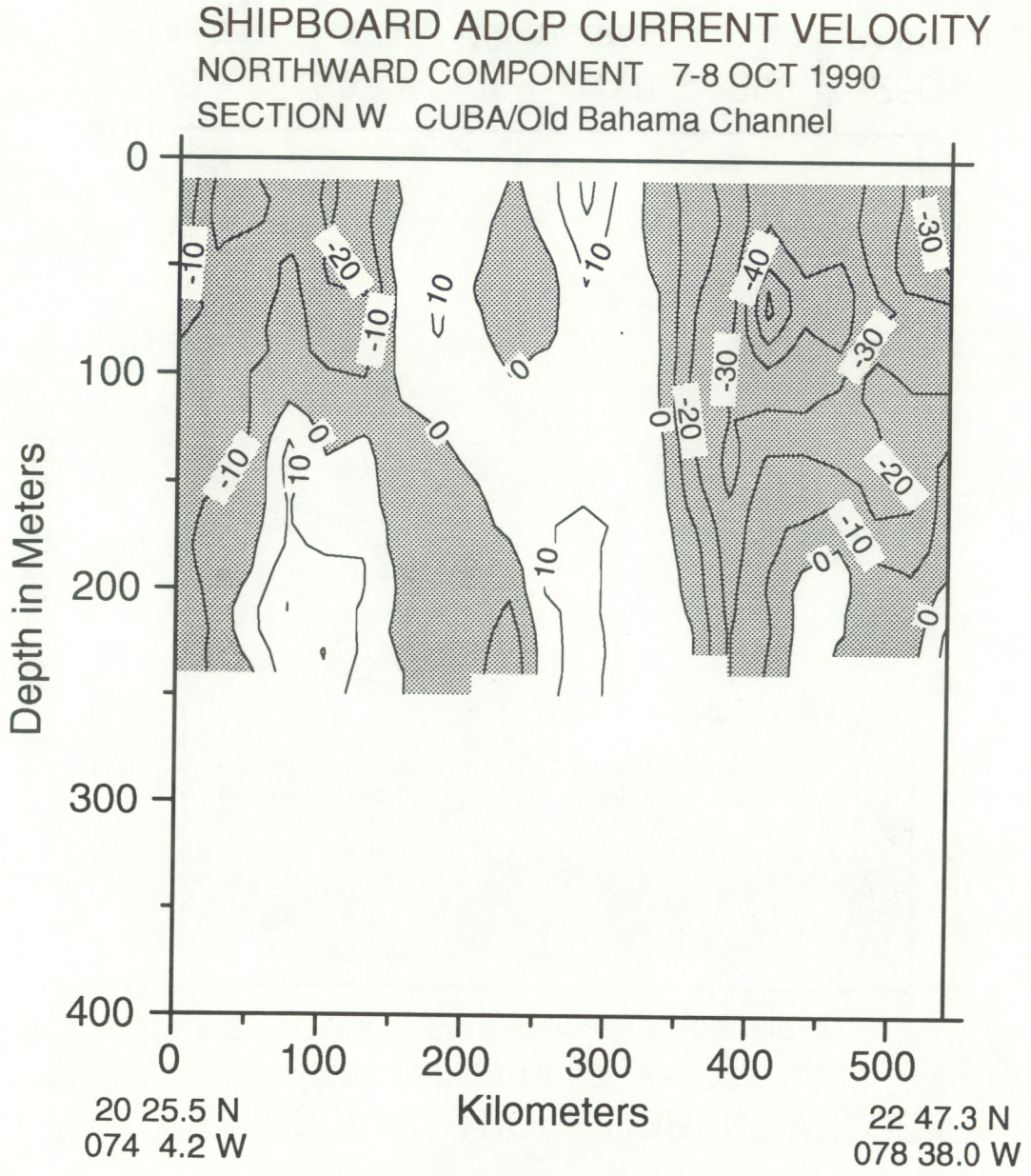

Figure C.35b 25 km Grid

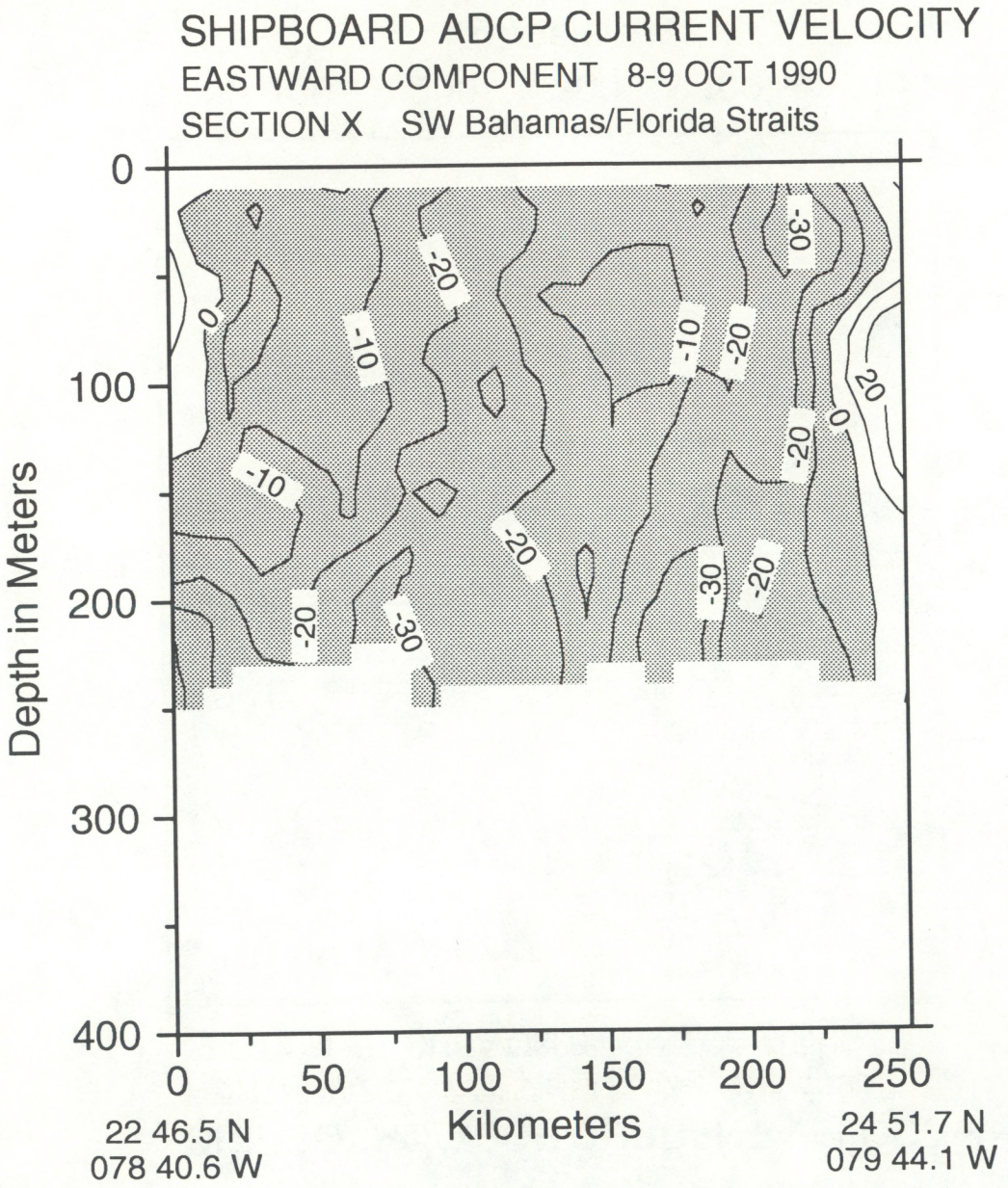

Figure C.36a 10 km Grid

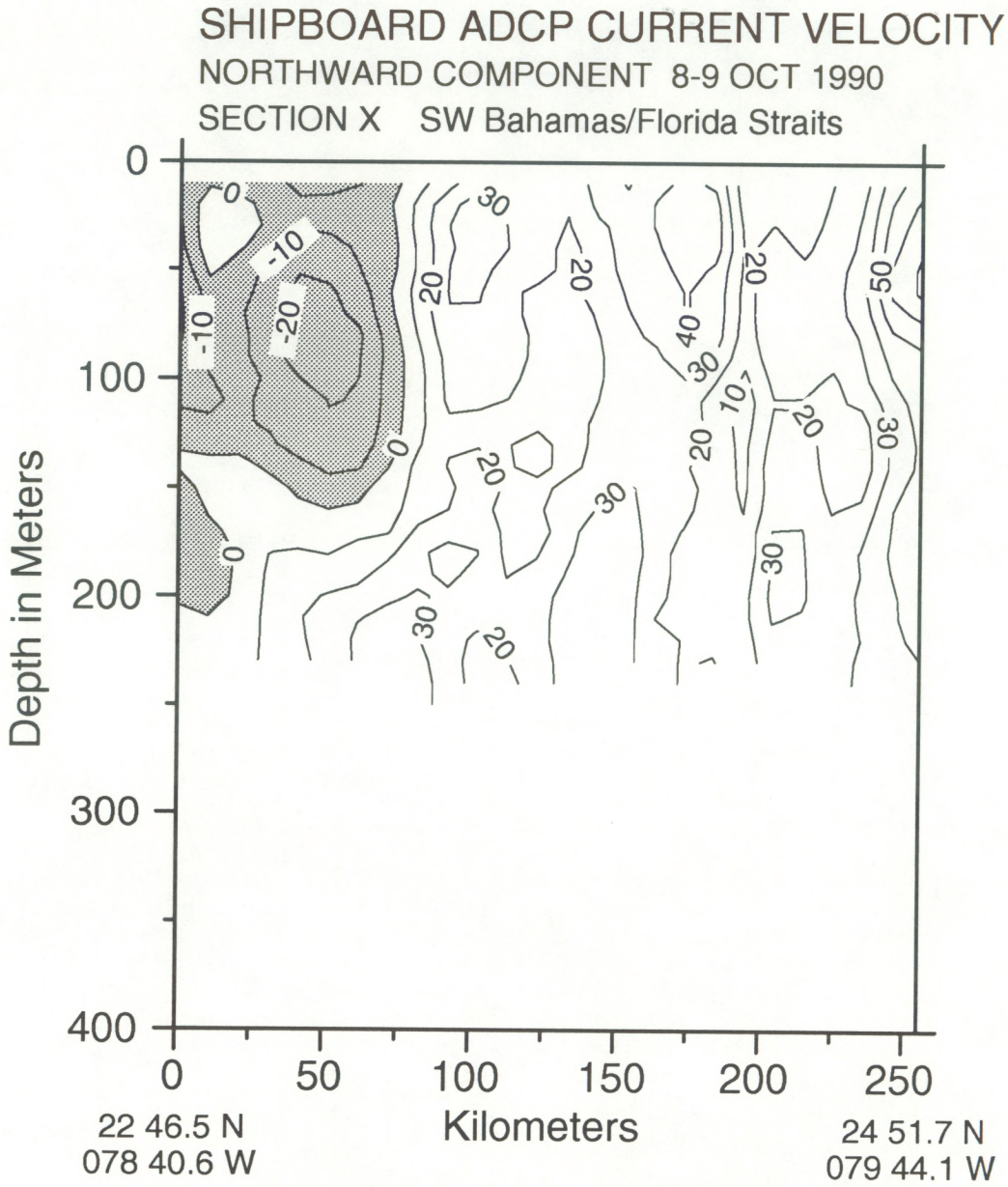

Figure C.36b 10 km Grid

*U.S. GOVERNMENT PRINTING OFFICE: 1992-673-025/69023