WHOI-95-05
C.2

DOCUMENT
LIBRARY
Woods Hole Oceanographic
Institution

Woods Hole Oceanographic Institution

Monthly Atmospheric and Oceanographic Surface Fields for the Western North Atlantic: December, 1986 – April, 1989

by

Michael J. Caruso, Sandipa Singh, Kathryn A. Kelly and Bo Qiu

April 1995

Technical Report

Funding was provided by the National Oceanic and Atmospheric Administration under Contract No. NA16RC0468-01 and by the National Aeronautic Space Administration under Contract No. NAGW-1666.

Approved for public release; distribution unlimited.

WHOI-95-05

Monthly Atmospheric and Oceanographic Surface Fields for the Western North Atlantic: December, 1986 – April, 1989

by

Michael J. Caruso, Sandipa Singh, Kathryn A. Kelly and Bo Qiu

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

DOCUMENT
LIBRARY
Woods Hole Oceanographic
Institution

April 1995

Technical Report

Funding was provided by the National Oceanic and Atmospheric Administration under Contract No. NA16RC0468-01 and by the National Aeronautic Space Administration under Contract No. NAGW-1666.

Reproduction in whole or in part is permitted for any purpose of the United States Government. This report should be cited as Woods Hole Oceanog. Inst. Tech. Rept., WHOI-95-05.

Approved for public release; distribution unlimited.

Approved for Distribution:

Philip L. Richardson, Chair
Department of Physical Oceanography

Contents

1 Introduction 1

2 Atmospheric Fields 2

3 Oceanographic Fields 3

4 Comparison of ECMWF and Model Net Surface Heat Flux 4

Appendix: Monthly maps 9

1 Introduction

Atmospheric and oceanographic fields for the western North Atlantic Ocean from various sources were assembled to study the upper ocean heat budget in the vicinity of the Gulf Stream. Atmospheric fields include the surface heat fluxes and 1000 mb winds from the European Centre for Medium-range Weather Forecasting (ECMWF). Oceanographic fields included the sea surface height (SSH) from the Geosat radar altimeter and sea surface temperature (SST) from the AVHRR radiometer. The fields used in the heat budget analysis were averages over two-week periods, at intervals of one week. The same raw data set was used for the fields shown here, but the averages were computed over a month. All of the fields were interpolated to the model grid, which was 1/2-degree resolution in latitude by 1 degree in longitude.

Geostrophic velocities, derived from the SSH fields, and SST were assimilated into an oceanic mixed layer model forced by the wind stress to obtain estimates of the net surface heat flux as the residual of the upper ocean heat budget. The mixed layer model was forced by wind stress computed from the ECMWF winds. Assimilation was done using a Kalman filter on both the temperature tendency and the temperature of the mixed layer, as described by Kelly and Qiu (1995a). The error in temperature tendency was used to derive a new surface heat flux estimate. The agreement between the time series of spatially averaged surface flux and that obtained from the ECMWF atmospheric model was surprisingly good. The temporally averaged surface flux estimates from the mixed layer model were in good agreement with the Bunker climatological values, except in February and March, when the model mixed layer shoaled more rapidly than expected from climatology.

The heat budget of the mixed layer was analyzed to determine the importance of temperature advection relative to eddy diffusion and vertical entrainment, as de-

scribed by Kelly and Qiu (1995b).

The atmospheric fields are described in section 2 and the oceanographic fields are described in section 3. Section 4 contains a comparison of the heat fluxes and the monthly mean fields are presented in the appendix.

2 Atmospheric Fields

The mixed layer model was forced by wind stress and the surface heat flux. The surface wind data used to calculate the wind stress fields are the twice-daily 1000 mb wind vectors from ECMWF, with horizontal resolution of 2.5° × 2.5°. Wind vectors were converted to surface wind stress using the bulk aerodynamic formulae proposed by Trenberth et al. (1990), then averaged temporally and finally interpolated to the model grid.

The fluxes were available by component, short wave solar radiation, latent heat flux, sensible heat flux and outgoing longwave radiation, as cumulative values over two six-hour periods per day. To estimate the daily-averaged short wave solar radiation from the available values, we first estimated the clear-sky radiation values and inferred the (average) cloud cover from the 6-hour-accumulated data from ECMWF, as described in Qiu and Kelly (1993). The short wave radiation was the only ECMWF flux that was actually used in the mixed layer model; it was needed to estimate the vertical entrainment. The modified short wave radiation was combined with the other fluxes to obtain the net surface heat flux. The ECMWF estimates of net surface heat flux were used to test and tune the prognostic model, and for comparison with the surface flux estimates.

3 Oceanographic Fields

The sea surface height (SSH) data were derived from the Geosat altimeter, which had a repeat cycle of 17 days, using the new orbits and water vapor corrections (GEM-T2; Cheney et al., 1991). To eliminate the geoid, which dominates the altimetric height profiles, we computed and subtracted the mean altimetric sea surface from collinear profiles. Subtracting the temporal mean sea surface also removes the temporal mean topography due to ocean currents. Mean sea surface topography profiles relative to the geoid were then synthesized using the method of Kelly and Gille (1990), as modified by Qiu et al. (1991), and added back to the residual heights to obtain total SSH profiles. In this method, the Gulf Stream is modeled using a Gaussian velocity profile; the large SSH anomalies created by a narrow jet meandering far from its mean position are exploited to estimate the center position and magnitude of the Gaussian. The single jet model was revised to include recirculation as in Qiu (1992). Details of the computation of the mean SSH are contained in Qiu (1994), along with a comparison of the synthesized mean with the mean dynamic height from climatological data. The absolute surface height data were objectively mapped to the model grid.

To obtain the SST maps, we used AVHRR data and the optimal average method of Chelton and Schlax (1991), which is an extension of the usual optimal estimate to temporal averages of the data. The AVHRR data were weekly averages, which were initially processed by National Oceanic and Atmospheric Administration (NOAA) using the multichannel SST (MCSST) algorithm and then interpolated to an 18 km by 18 km grid at the Rosenstiel School of Marine and Atmospheric Science (RSMAS). The SST data were temporally averaged and then interpolated to the model grid. The optimal average method gives an error map, which was used in the data assimilation

of Kelly and Qiu (1995a), but it is not shown here to save space. The spatially averaged SST estimated errors (figure 1) show periods of extensive cloud cover (e.g., December 1987–January 1988), which gave errors that were nearly a factor of two larger than errors for times with clear skies (September 1988 and March 1989).

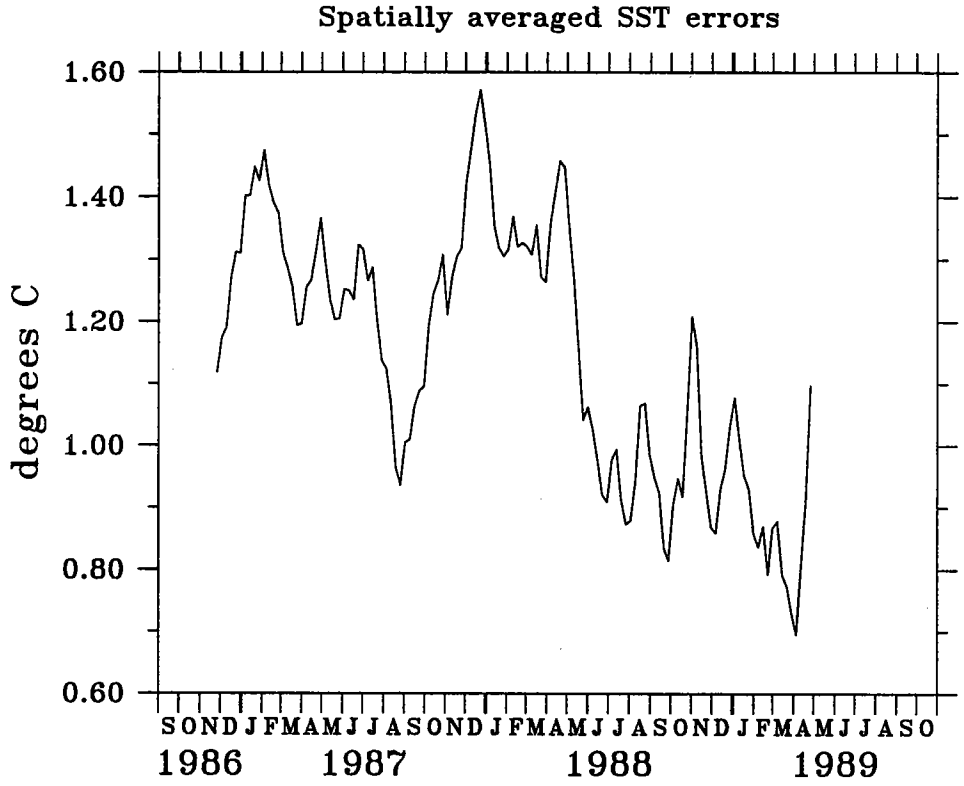


Figure 1: Spatially averaged SST errors from the optimal estimates. Weekly averages of AVHRR data were optimally averaged with an averaging interval of two weeks to reduce random errors and those from cloud cover gaps. The error estimates varied by nearly a factor of two, both temporally and spatially.

4 Comparison of ECMWF and Model Net Surface Heat Flux

Two estimates of the net surface heat flux are shown in this report: the ECMWF model estimates and the estimates derived from assimilating winds and satellite data into the mixed layer model. Spatially averaged values of these two quantities agree

rather well (figure 2, after Kelly and Qiu, 1995b); however, the details of these fields differ substantially. In part, this is due to the way in which the heat fluxes were estimated, as a linear combination of empirical modes derived from the weekly differences in ocean temperature (Kelly and Qiu, 1995a). In general, the mixed layer model fluxes tend to be more positive (atmosphere heating the ocean) than those from ECMWF. Also, the mixed layer model fluxes become positive earlier in the year (March, as opposed to April–May), relative to the ECMWF fluxes. This latter problem is associated with a tendency for the mixed layer depth to shoal too early in the year, relative to climatology.

Near the end of the time series (December 1988–March 1989), the two heat flux estimates differ substantially in spatial structure. During this period, winds are consistently strong, particularly the eastward winds in the northeast part of the region, where the temperature gradients from the Gulf Stream are also anomalously strong. This combination results in an unusually large cooling term (0.5 degree per day) from advection by the Ekman transport. The ocean temperature does not show a correspondingly large drop; thus, a large positive heat flux is inferred as the residual of the upper ocean heat balance near the Grand Banks. Although the magnitude of this positive flux clearly appears too large, particularly in the winter, the mean annual net surface flux from the Bunker climatology (Isemer and Hasse, 1987) is positive near the Grand Banks. In contrast, the ECMWF annual net flux is negative in this region.

That Ekman transport is responsible for this excessive cooling can be seen by examining the maps from December 1987, when winds were again strong, but the net flux estimate does not become positive. This is undoubtedly due to the weak ocean temperature gradients during that period, which did not produce the strong advection term. The temperature gradients were not the result of a weak Gulf Stream, but

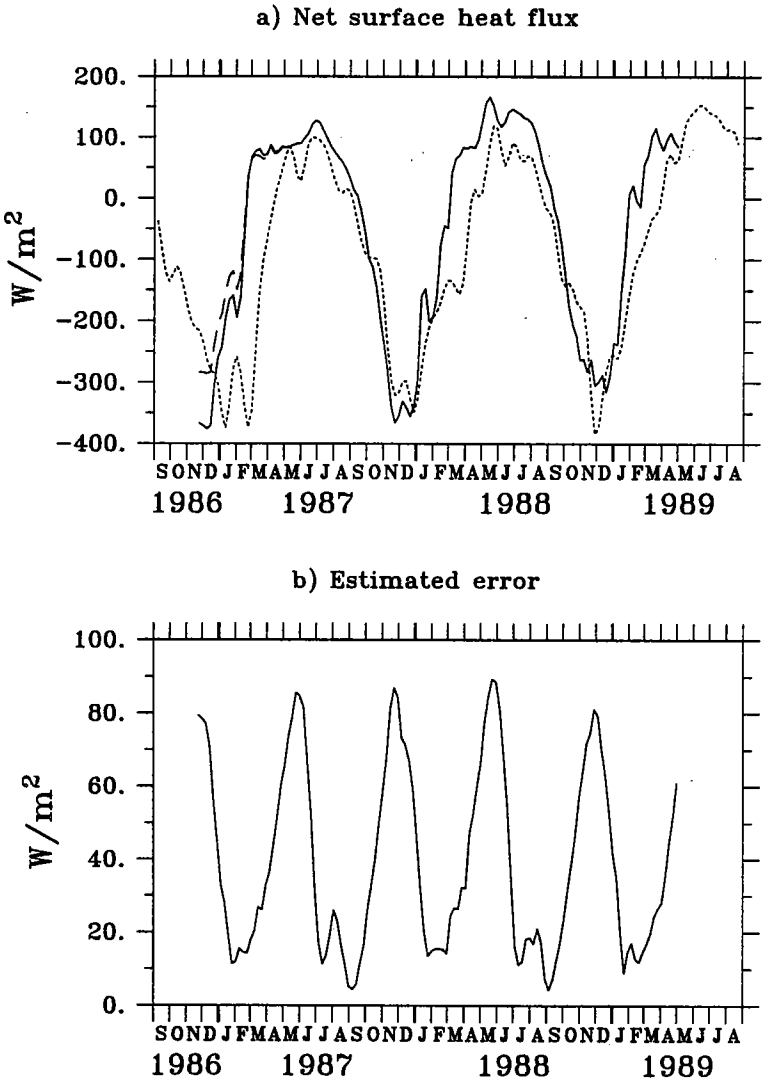


Figure 2: Net surface flux estimates from the mixed layer model and from ECMWF. (a) Spatially averaged estimates of the net surface flux from the Kalman filter (solid line), ECMWF (dotted line) and climatological (dashed line) and (b) an error estimate for the Kalman filter estimate. The larger (more negative) fluxes in the fall of 1986 resulted from initializing the model with the November 1987 mixed layer depth, rather than with a climatological estimate.

were due to the lack of available SST data, which forced the ocean temperature estimate to resemble the climatological mean. In addition, large values of the estimated temperature error (Figure 1) caused the Kalman filter to damp the adjustment to the flux estimate, resulting in a weaker response. These cooling episodes, as well as the tendency for the heat flux estimates to be too positive on average, suggest that the wind stress may be too large. Mestas-Nuñez et al. (1994) have suggested that using the 1000 mb winds, in place of 10-m winds, may produce wind stresses which are as much as 50% too large. A simple reduction in magnitude of the wind stress was attempted, but it did not eliminate the overall positive bias of the fluxes, and it underestimated the mixed layer depth.

Acknowledgments

Geosat altimeter data were obtained on CD-ROM from the NOAA National Oceanographic Data Center. AVHRR data were provided by the NASA Physical Oceanography Distributed Active Archive Center (PODAAC) at the Jet Propulsion Laboratory/California Institute of Technology. The wind fields and surface heat flux estimates were derived from ECMWF/WCRP Level III-A data from the Global Atmospheric Data Archive, supplied by the European Centre for Medium-range Weather Forecasting and the National Center for Atmospheric Research. This research was supported by the National Oceanic and Atmospheric Administration through the Atlantic Climate Change Program under contract NA16RC0468-01 and by the National Aeronautics and Space Administration under contract NAGW-1666.

References

Chelton, D.B., and M.G. Schlax, 1991. Estimation of time-averaged chlorophyll concentration from irregularly spaced satellite observations, *J. Geophys. Res.*, **96**, 14,669–14,692.

Cheney, R.E., W.J. Emery, B.J. Haines, and F. Wentz, 1991. Recent improvements in Geosat altimeter data, *EOS Trans. AGU*, **72**, 577.

Isemer, H.-J., and L. Hasse, 1987. The Bunker Climate Atlas of the North Atlantic Ocean, Vol. 2: Air-sea interactions. Springer-Verlag, 252 pp.

Kelly, K.A., and S.T. Gille, 1990. Gulf Stream surface transport and statistics at 69 W from the GEOSAT altimeter, *J. Geophys. Res.* **95**, 3149–3161.

Kelly, K. A., and B. Qiu, 1995a. Heat flux estimates for the North Atlantic, Part I: assimilation of satellite data into a mixed layer model, *J. Phys. Oceanogr.*, in press.

Kelly, K. A., and B. Qiu, 1995b. Heat flux estimates for the North Atlantic, Part II: the upper ocean heat budget, *J. Phys. Oceanogr.*, in press.

Mestas-Nuñez, A. M., D. B. Chelton, M. H. Freilich, and J. G. Richman, 1994. An evaluation of ECMWF-based climatological wind stress fields, *J. Phys. Oceanogr.*, **24**, 1532–1549.

Qiu, B., 1992. Recirculation and seasonal change of the Kuroshio from altimetry observations, *J. Geophys. Res.*, **97**, 17,801–17,811.

Qiu, B., 1994. Determining the mean Gulf Stream and its recirculations through combining hydrographic and altimetric data, *J. Geophys. Res.*, **99**, 951-962.

Qiu, B., and K.A. Kelly, 1993. Upper-ocean heat balance in the Kuroshio Extension region, *J. Phys. Oceanogr.*, **23**, 2027–2041.

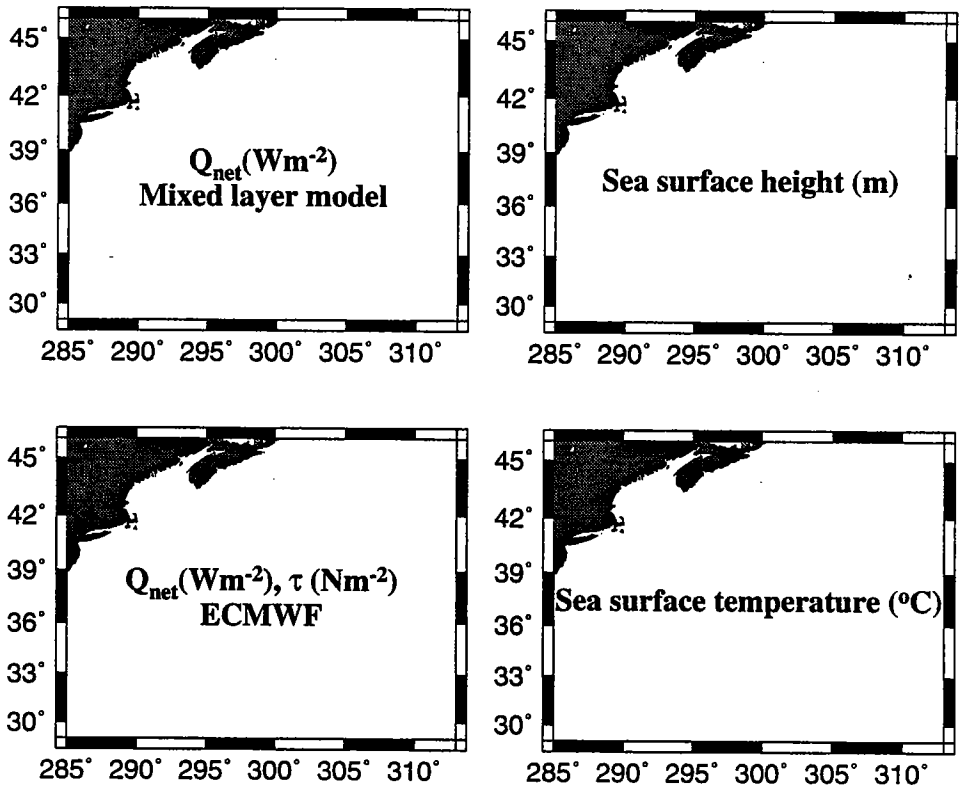
Qiu, B., K.A. Kelly and T.M. Joyce, 1991. Mean circulation and variability of the Kuroshio Extension from Geosat altimetry data. *J. Geophys. Res.*, **96**, 18,491–18,507.

Trenberth, K.E., W.G. Large, and J.G. Olson, 1990. The mean annual cycle in global wind stress, *J. Phys. Oceanogr.*, **20**, 1742–1760.

Wessel, P. and W.H.F. Smith, 1991. Free software helps map and display data, *EOS Trans. Amer. Geophys. U.*, **72**, 441,445-446.

Appendix: Monthly maps

Monthly means of heat flux Q_{net}, wind stress τ, sea surface height SSH and sea surface temperature SST are presented. The plots are positioned so that Q_{net} and τ are on the left hand page and SSH and SST are on the right hand page. The plots were generated using the GMT plotting package developed by Wessel and Smith (1991).



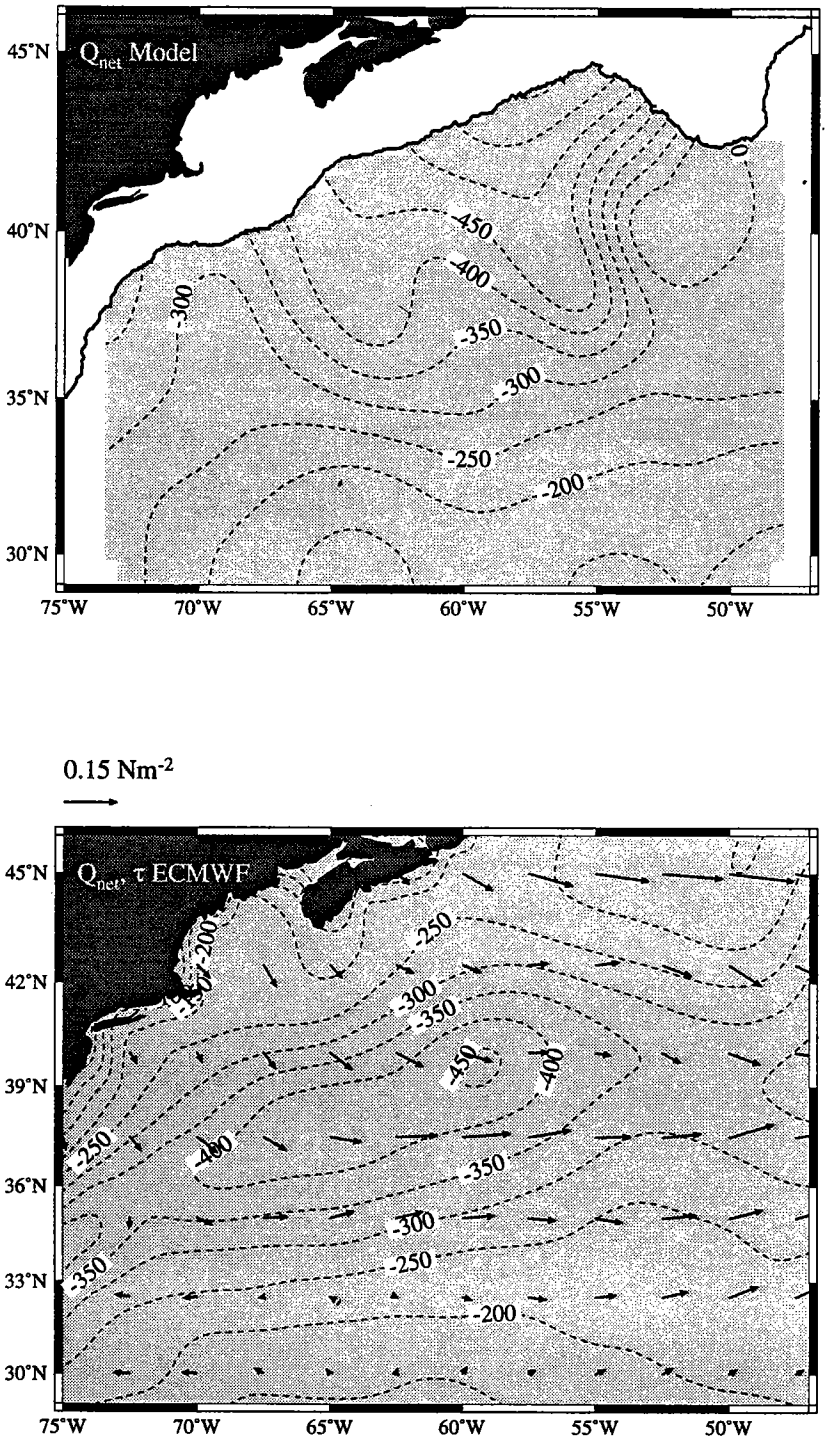
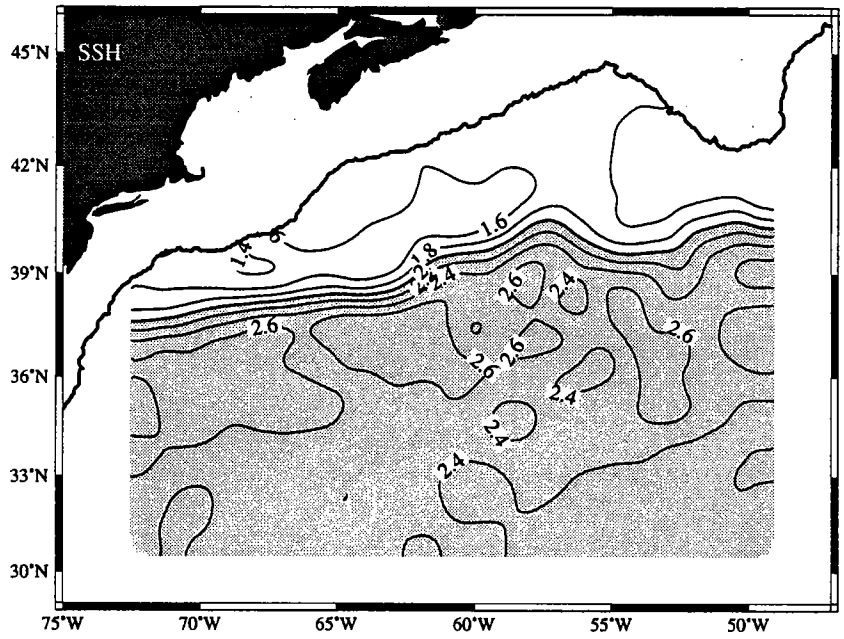


Figure 3: December 1986



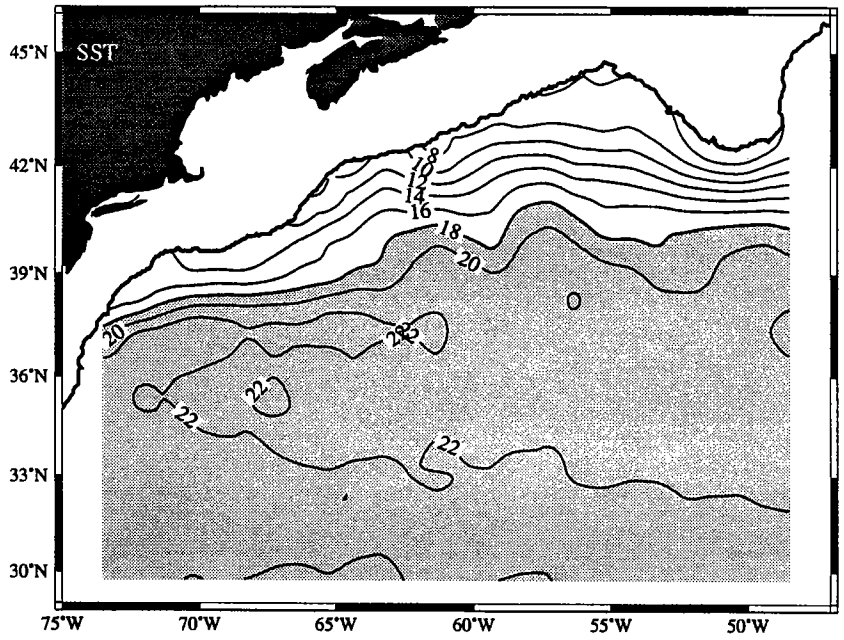
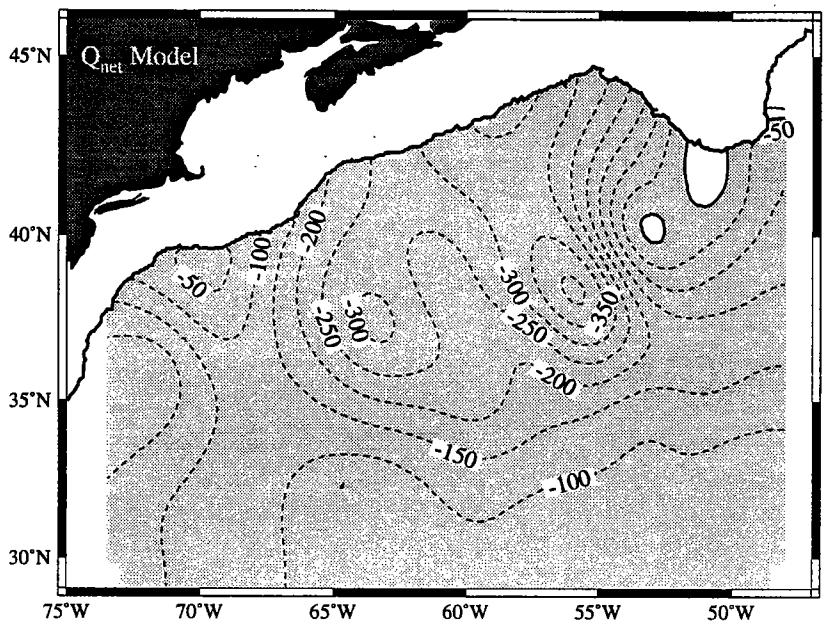


Figure 4: December 1986



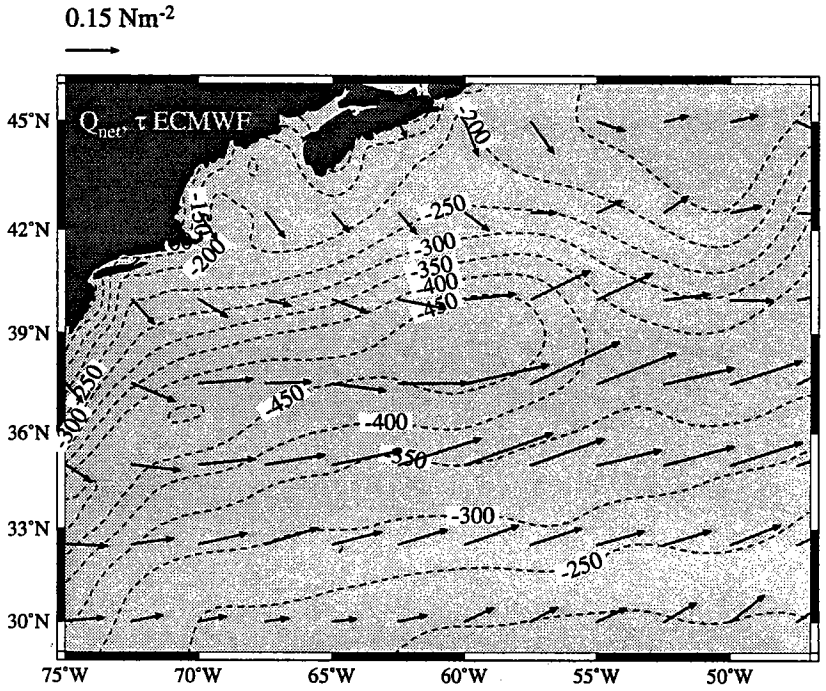
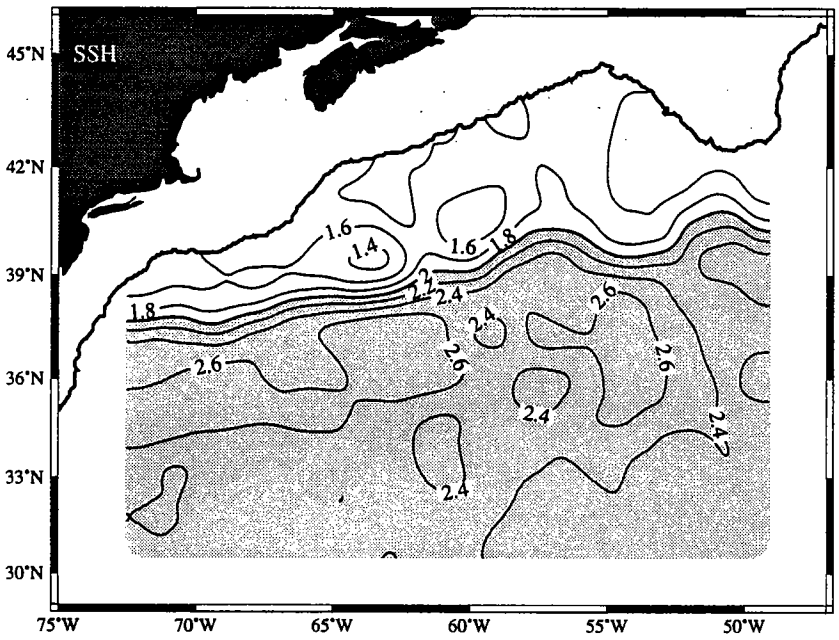


Figure 5: January 1987



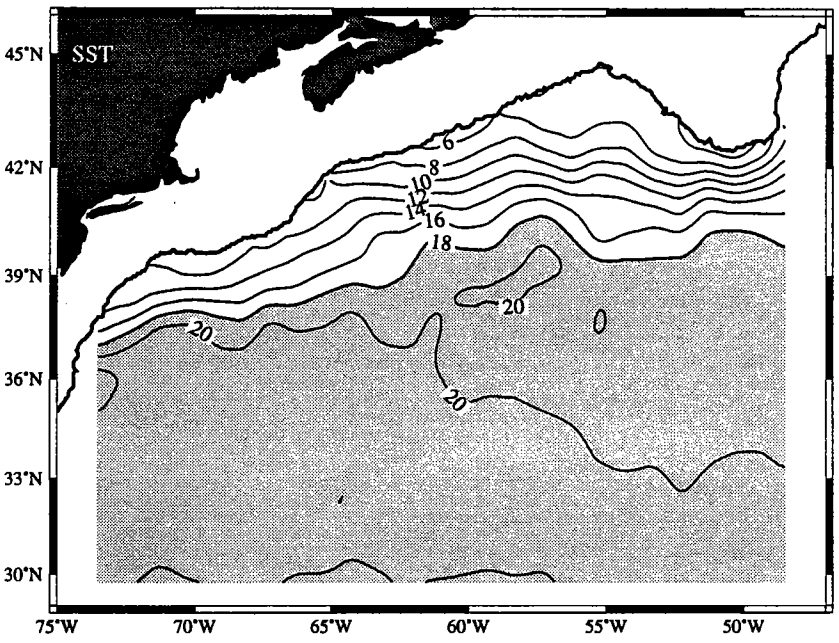
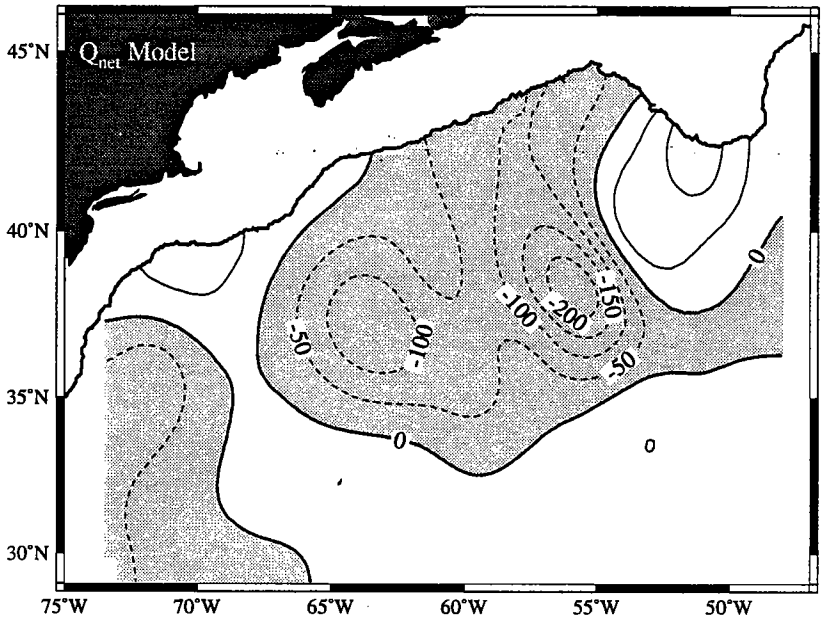


Figure 6: January 1987



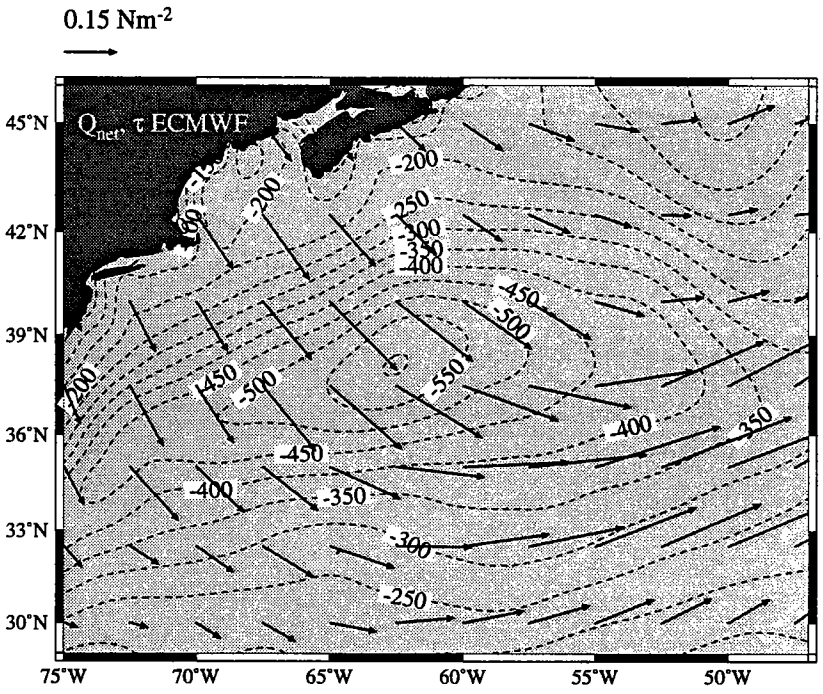
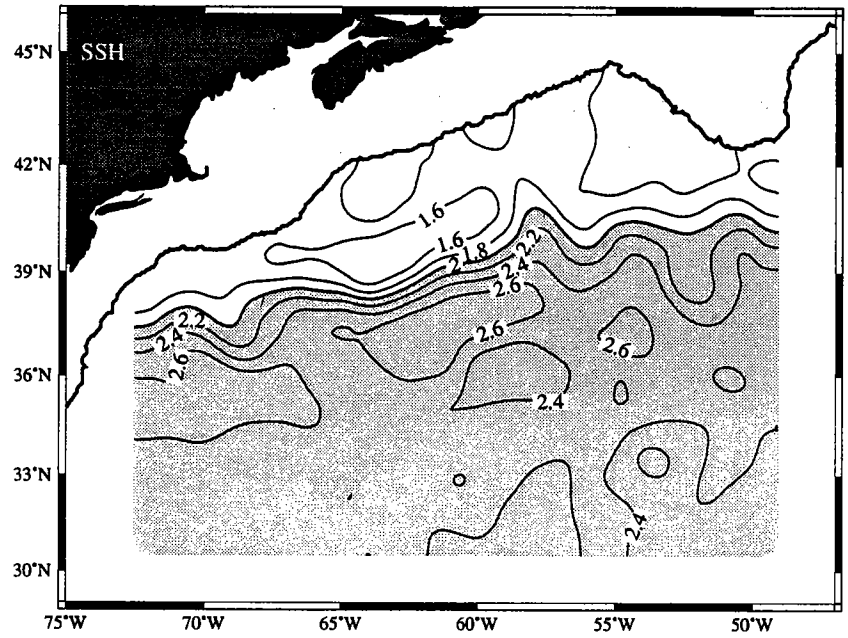


Figure 7: February 1987



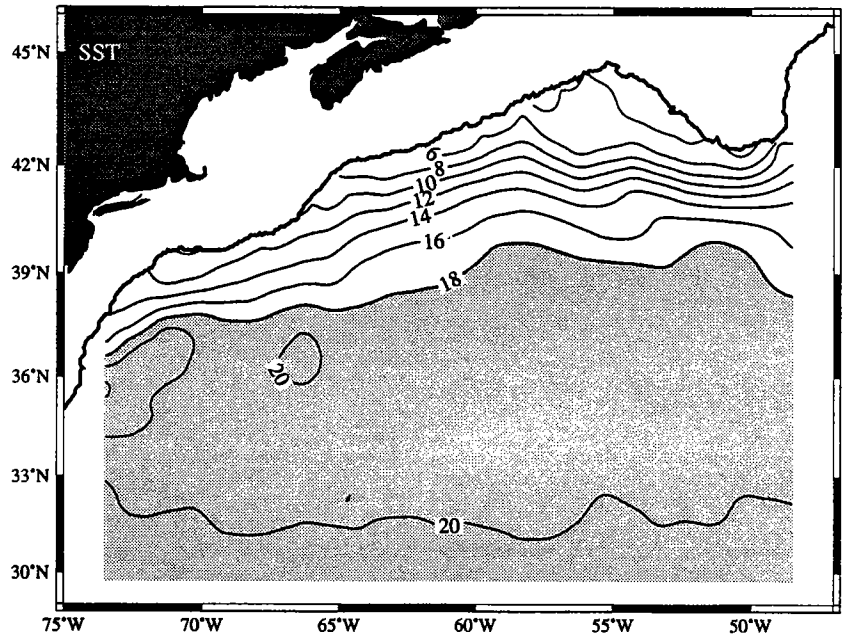
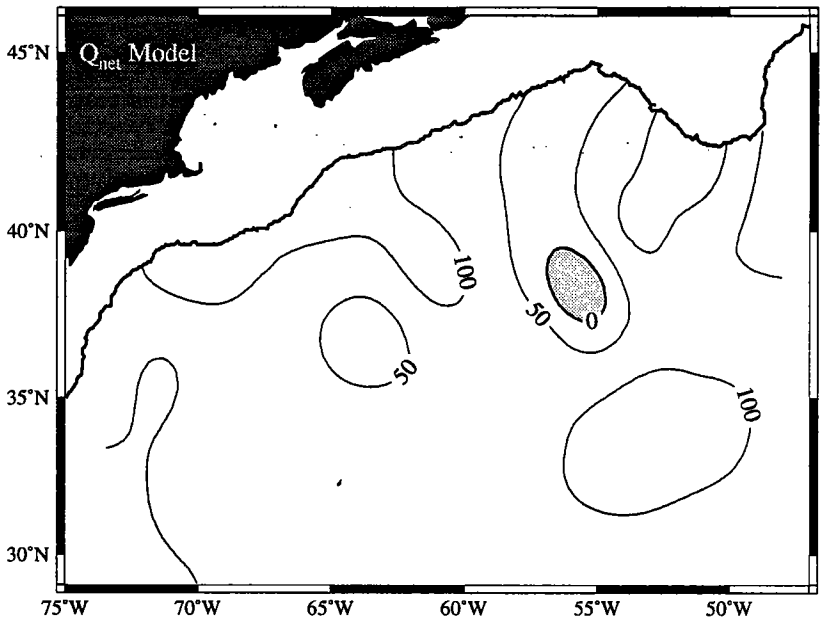


Figure 8: February 1987



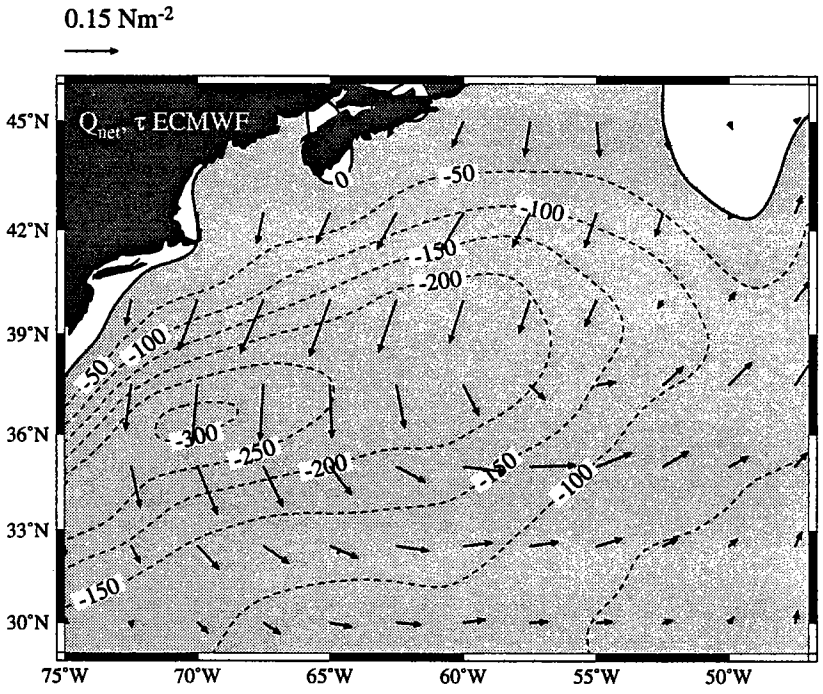
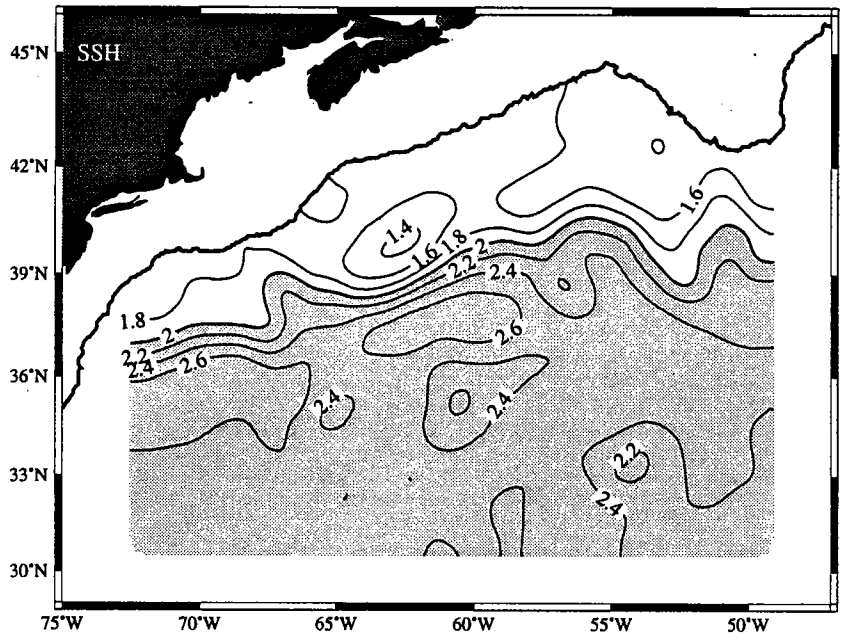


Figure 9: March 1987



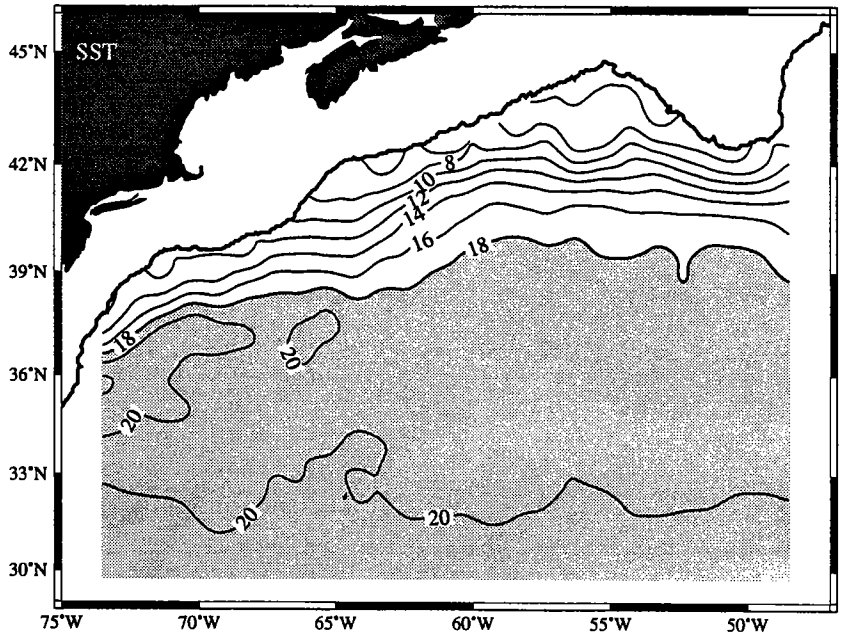
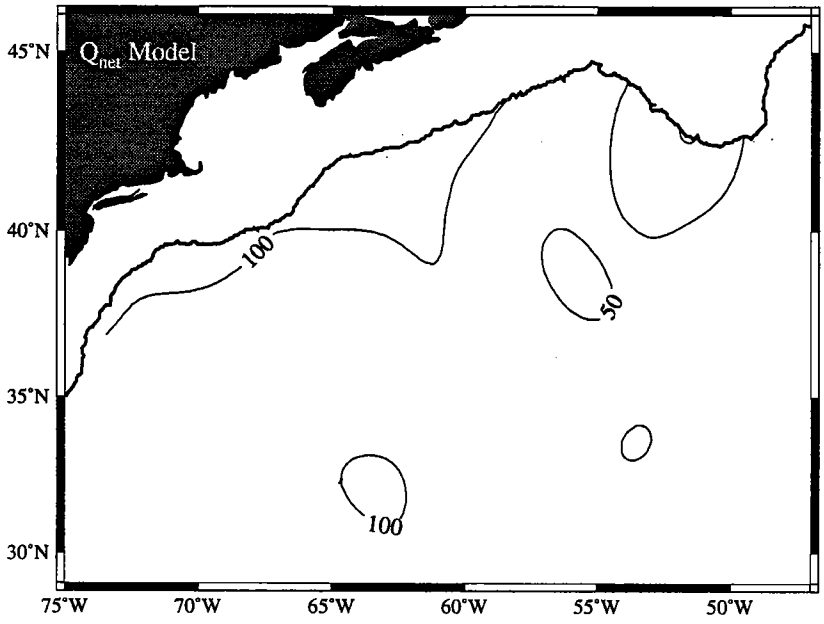


Figure 10: March 1987



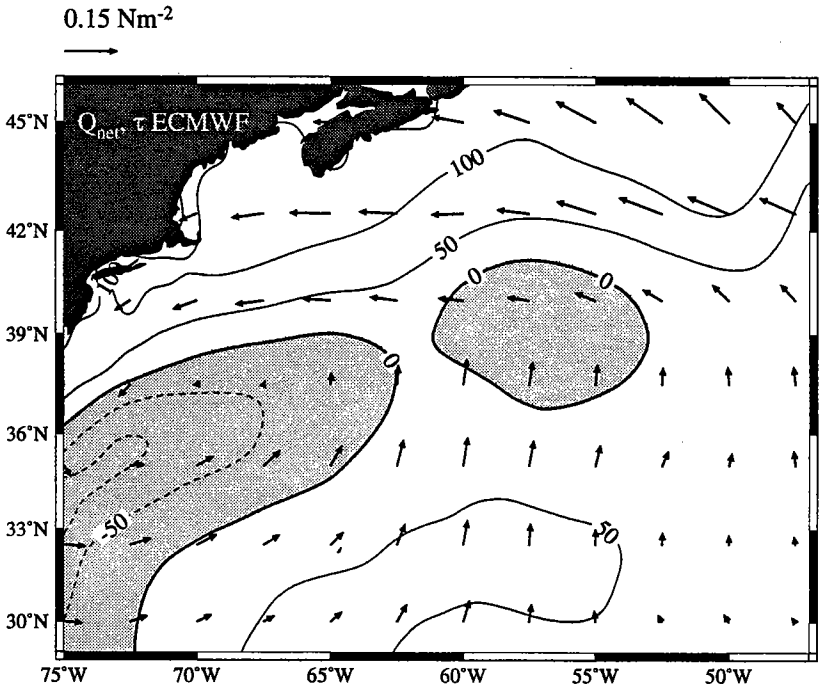
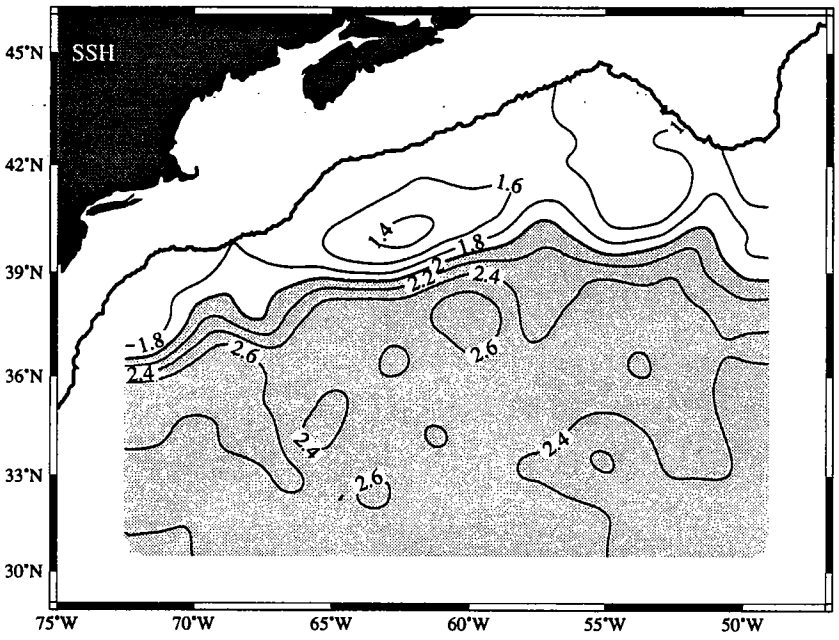


Figure 11: April 1987



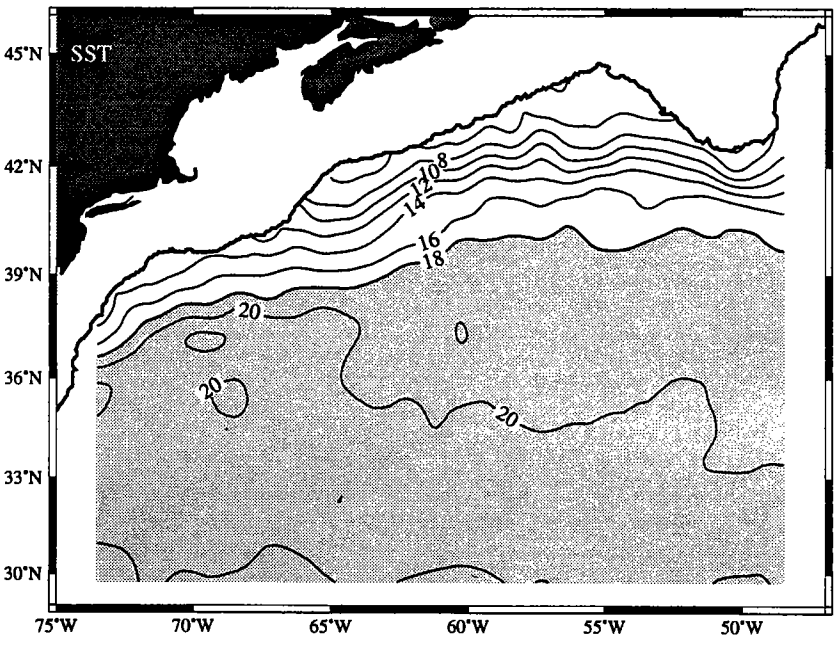
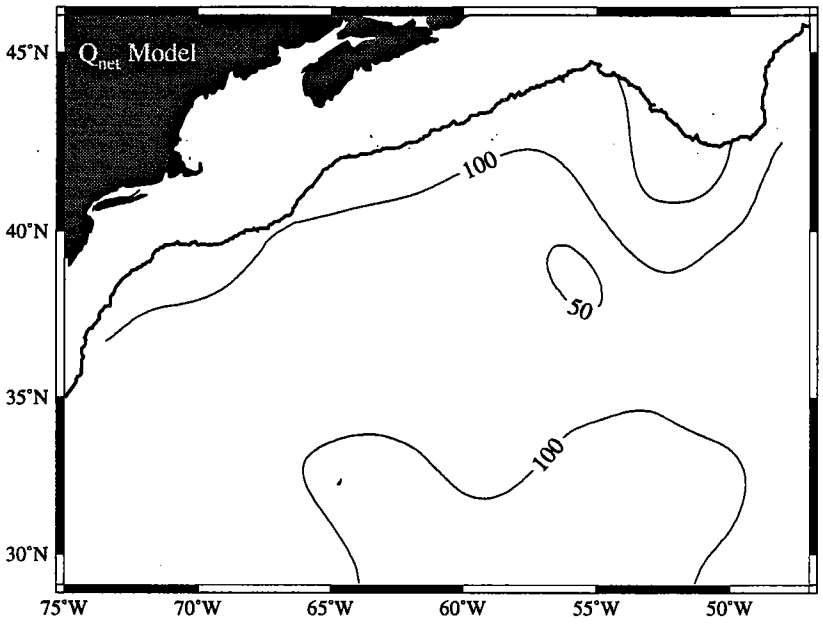


Figure 12: April 1987



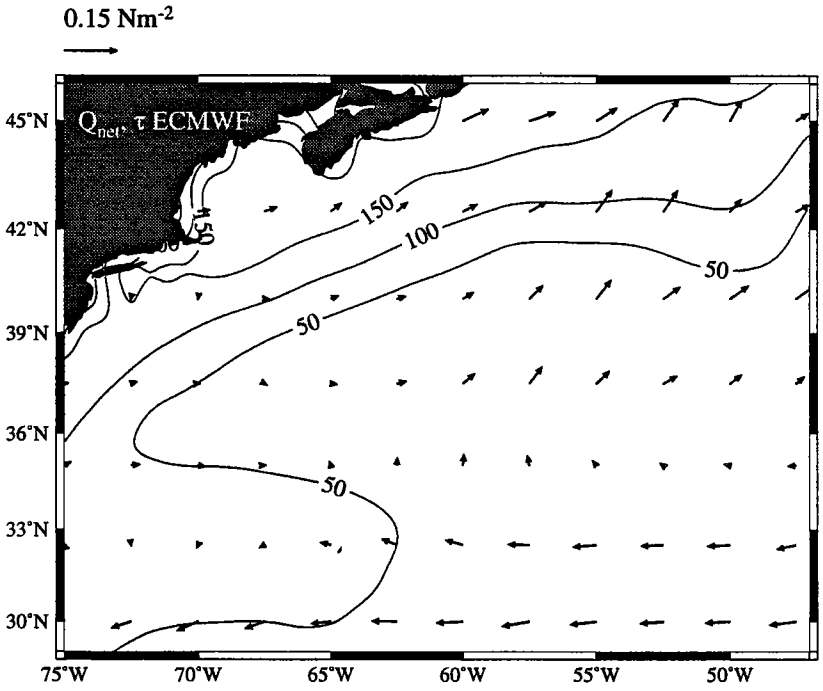
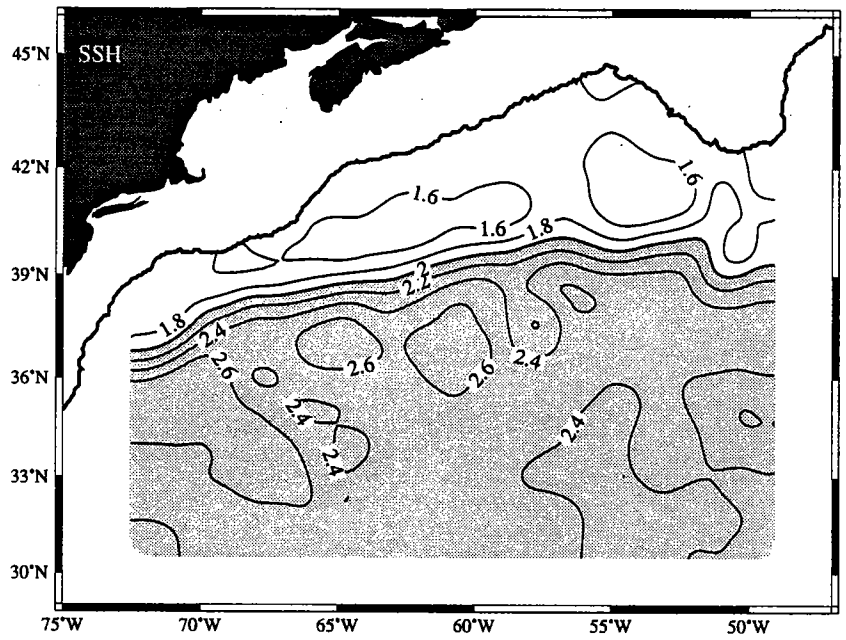


Figure 13: May 1987



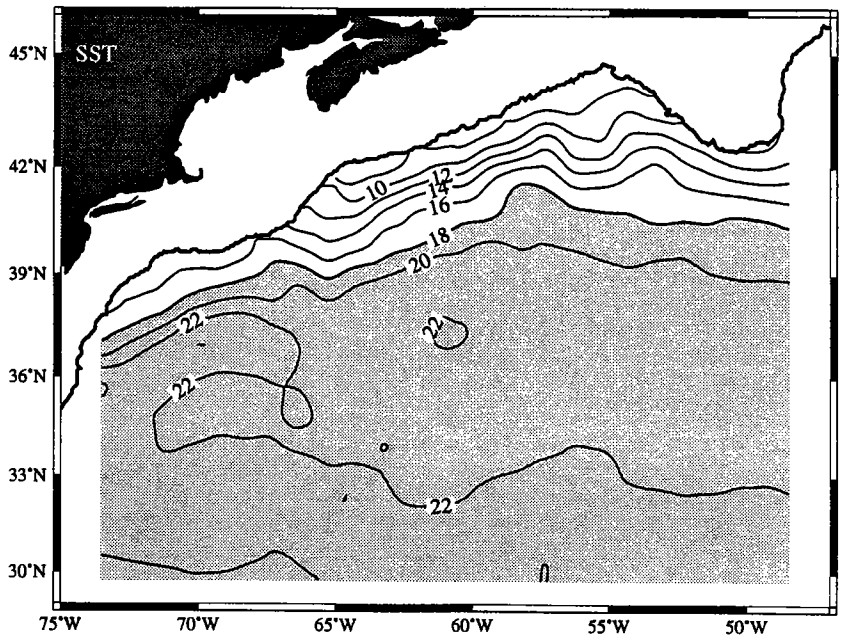
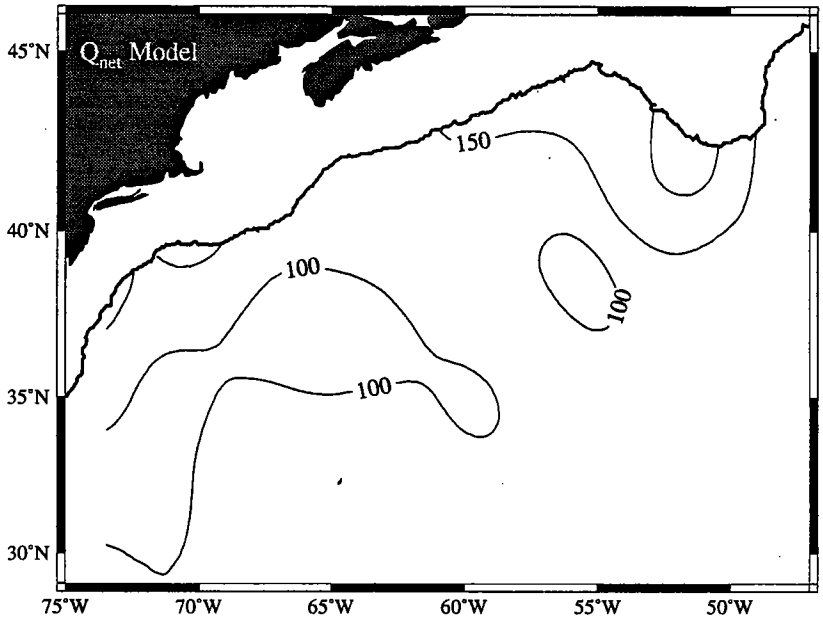


Figure 14: May 1987



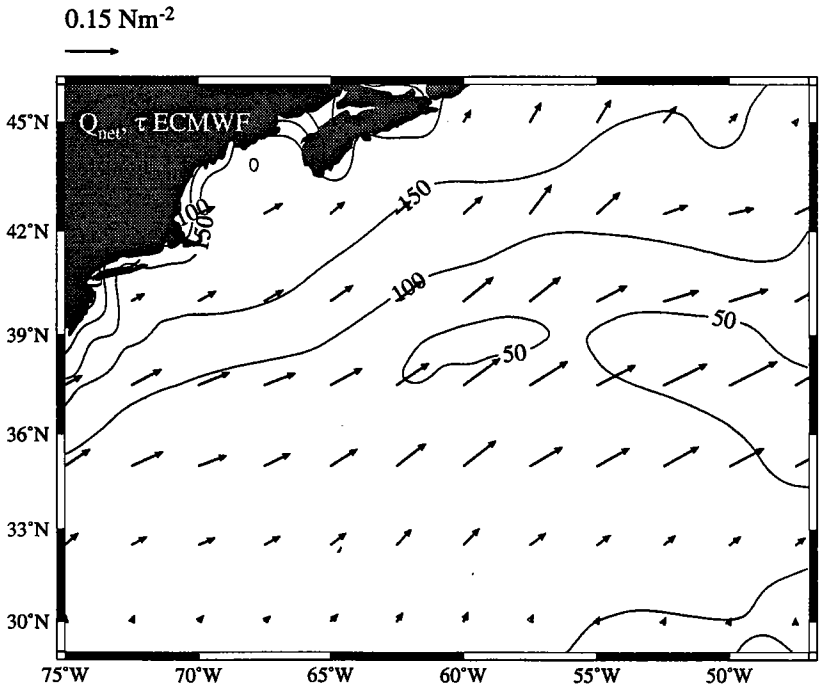
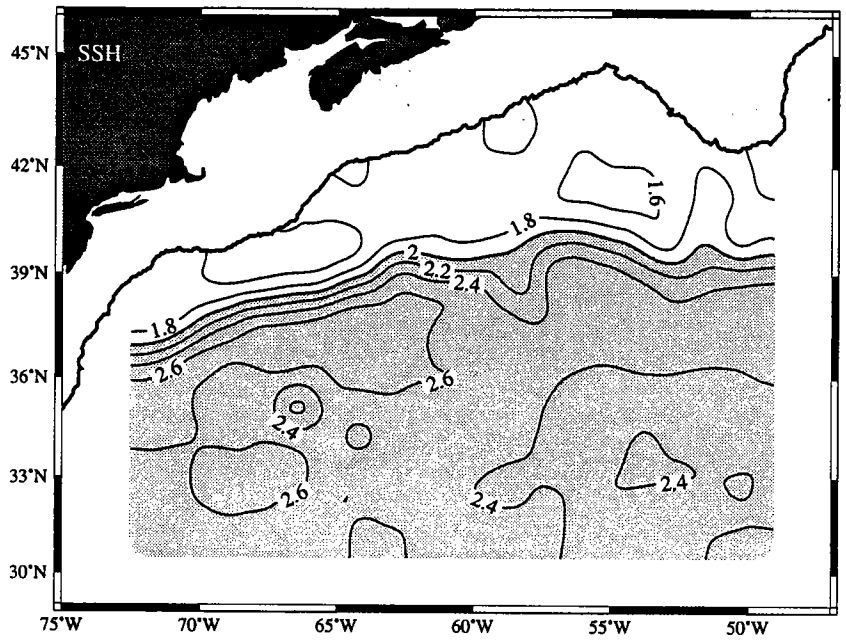


Figure 15: June 1987



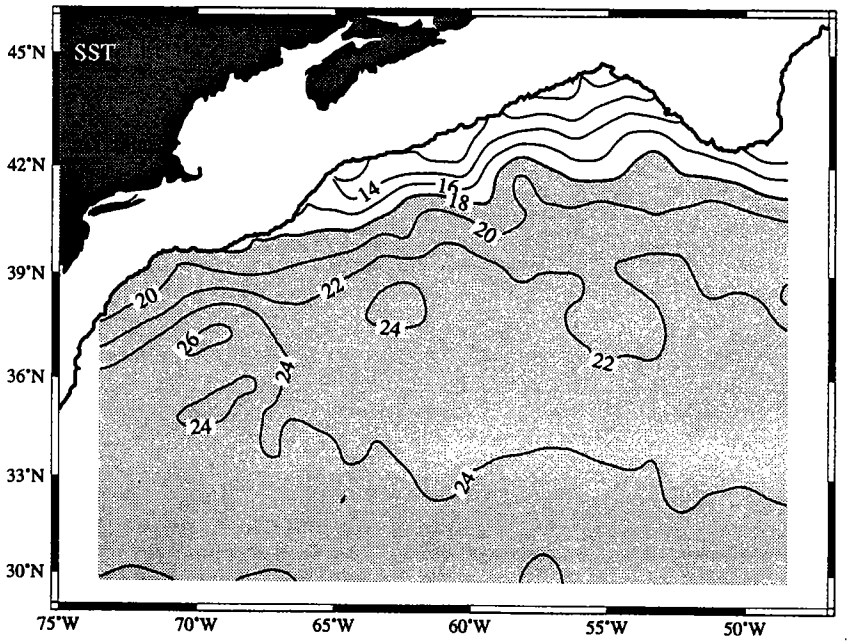
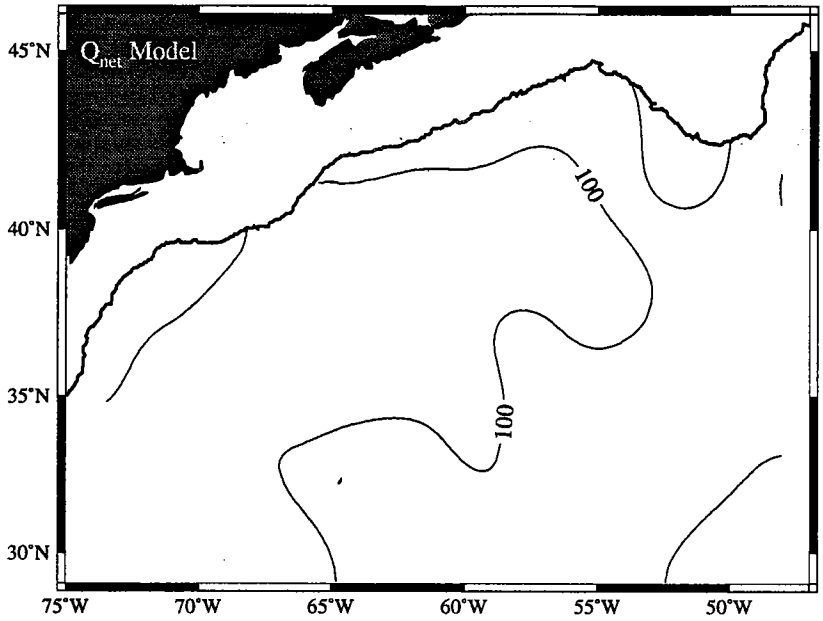


Figure 16: June 1987



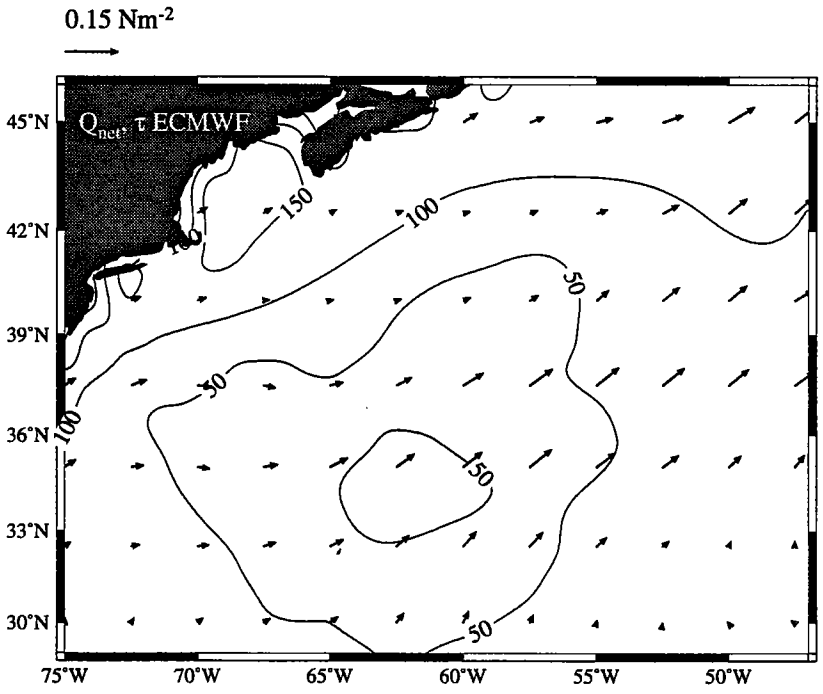
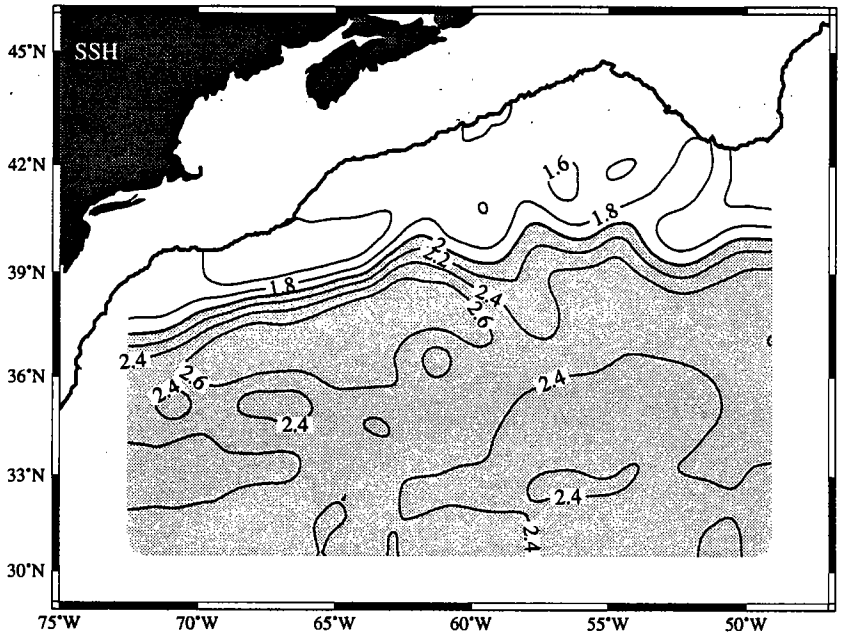


Figure 17: July 1987



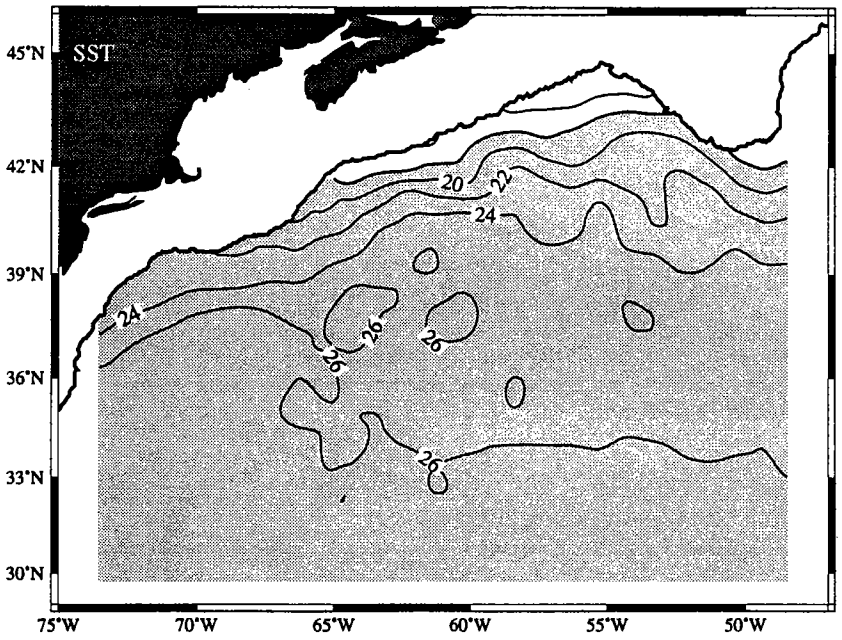


Figure 18: July 1987

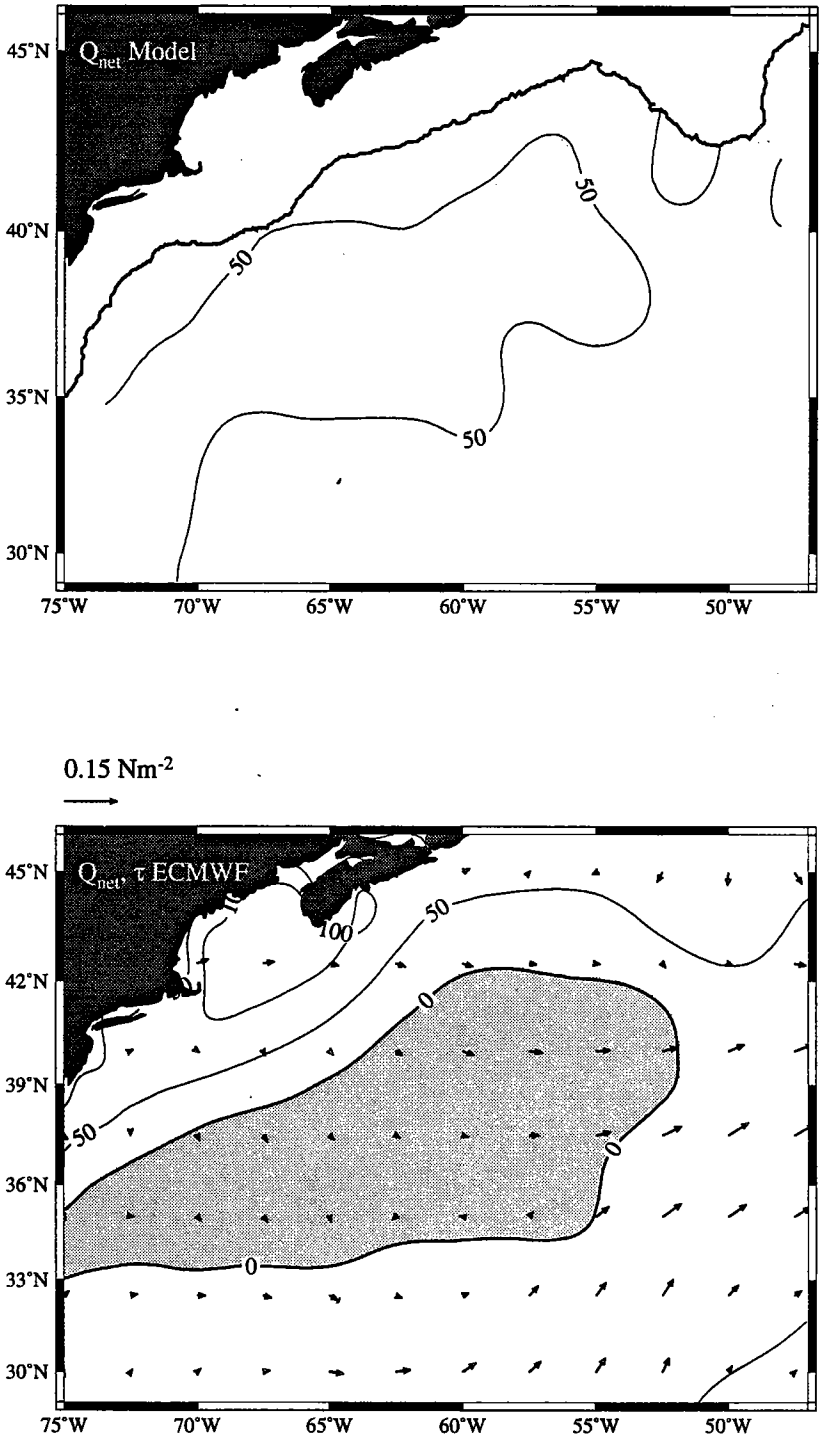
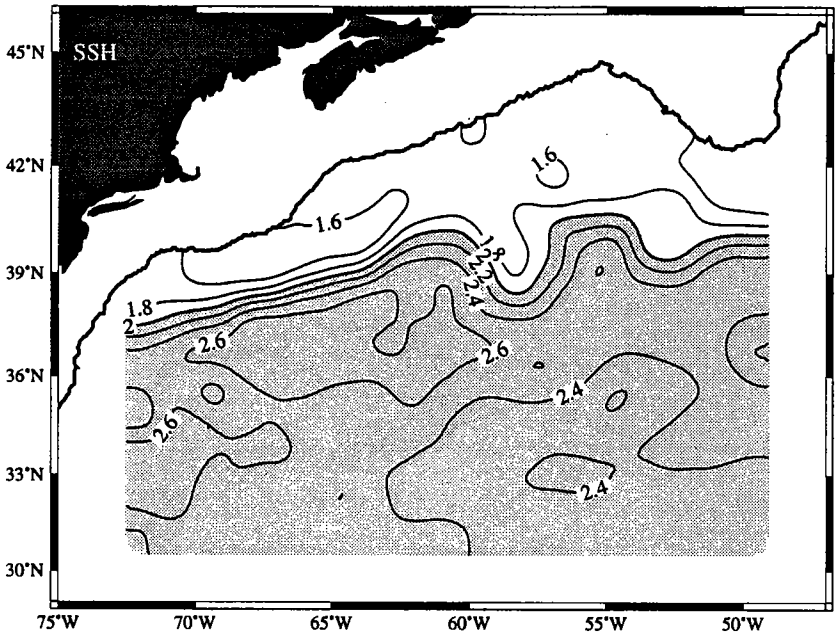


Figure 19: August 1987



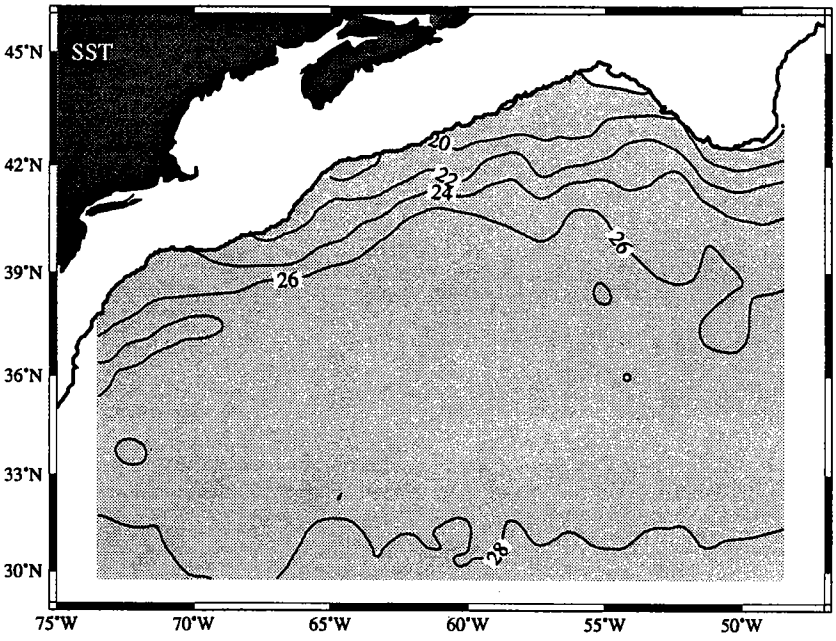
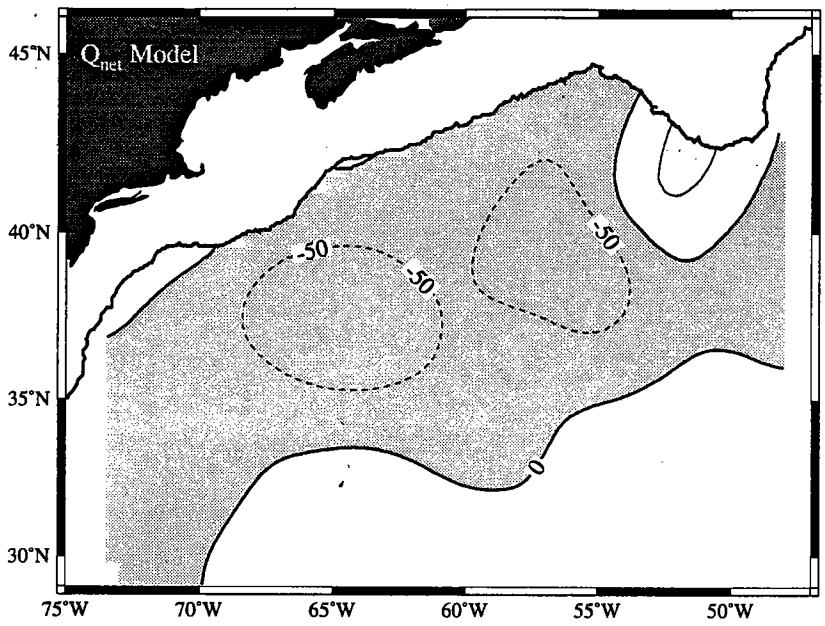


Figure 20: August 1987



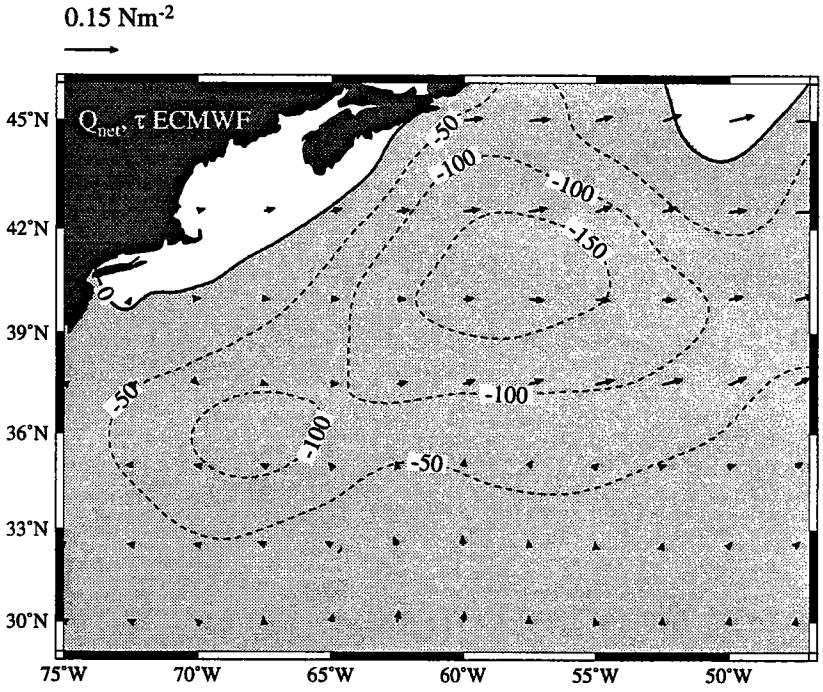
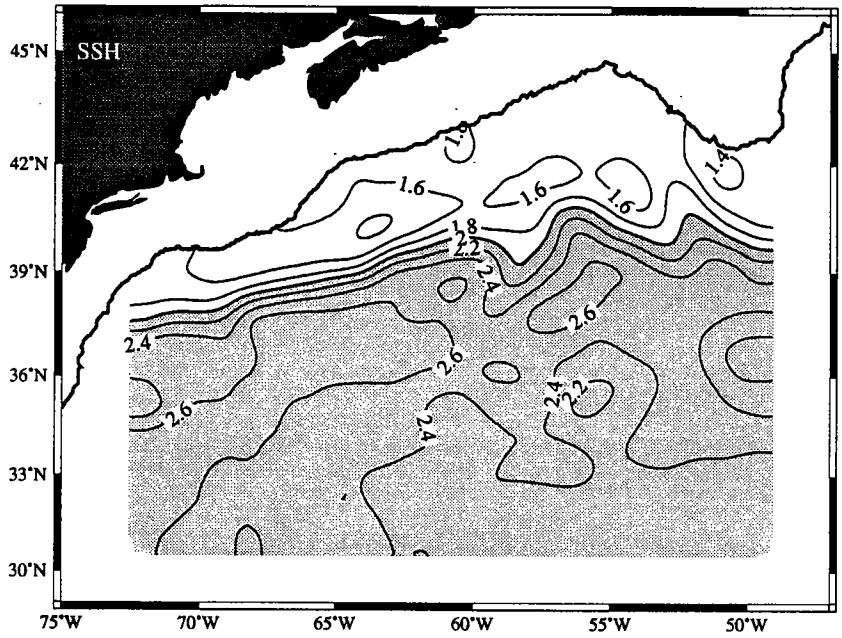


Figure 21: September 1987



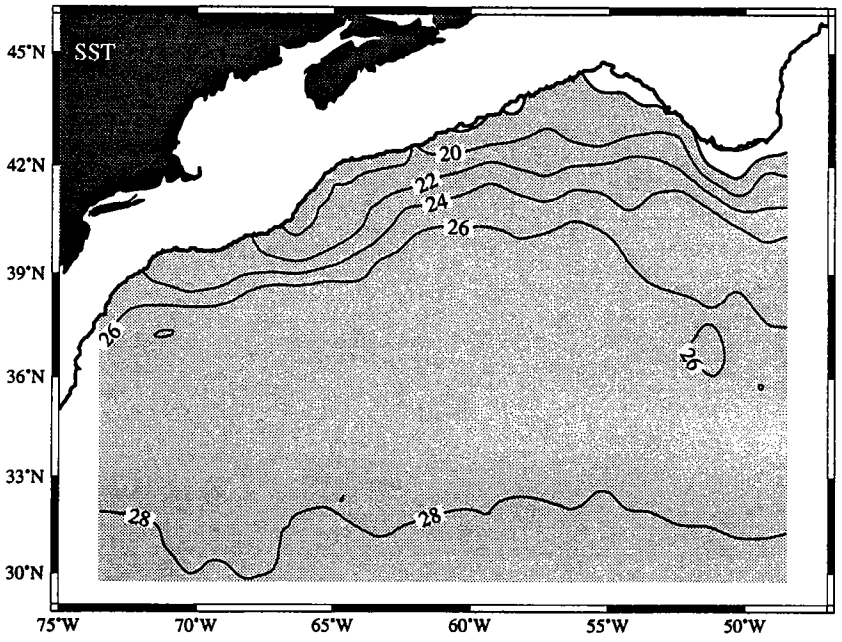
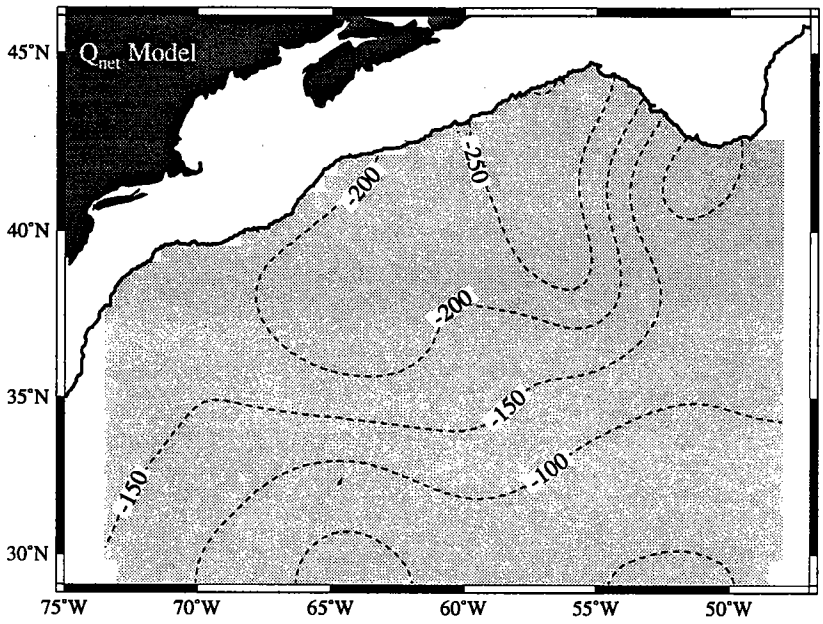


Figure 22: September 1987



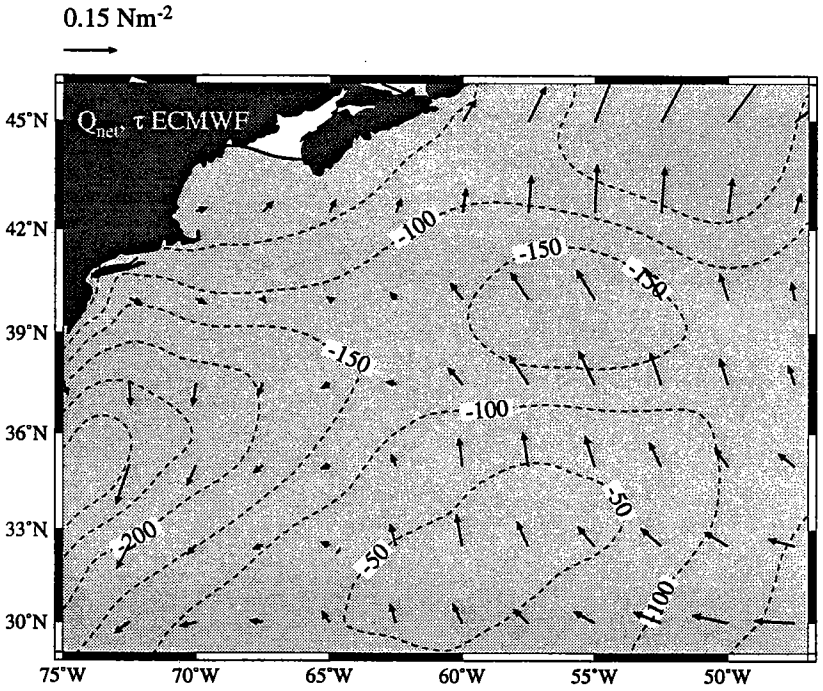
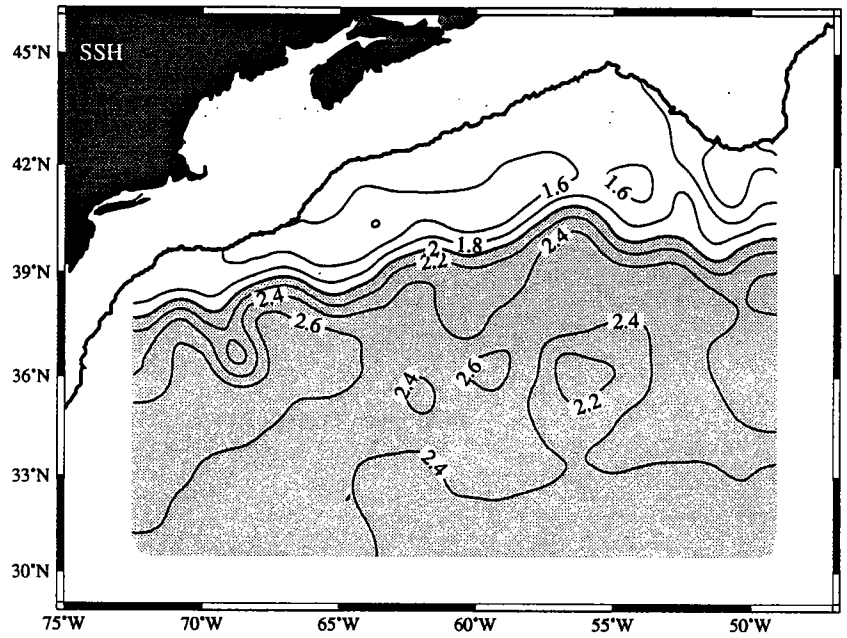


Figure 23: October 1987



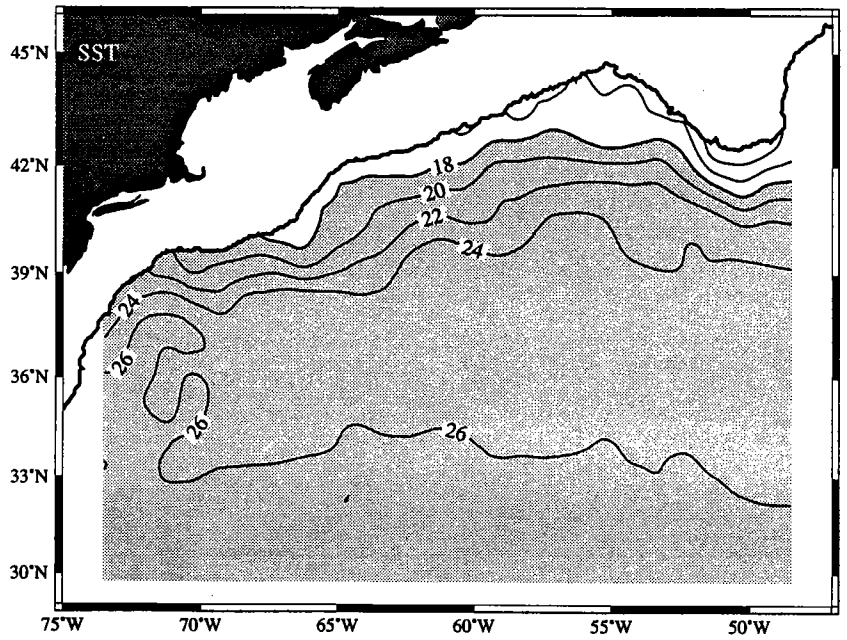
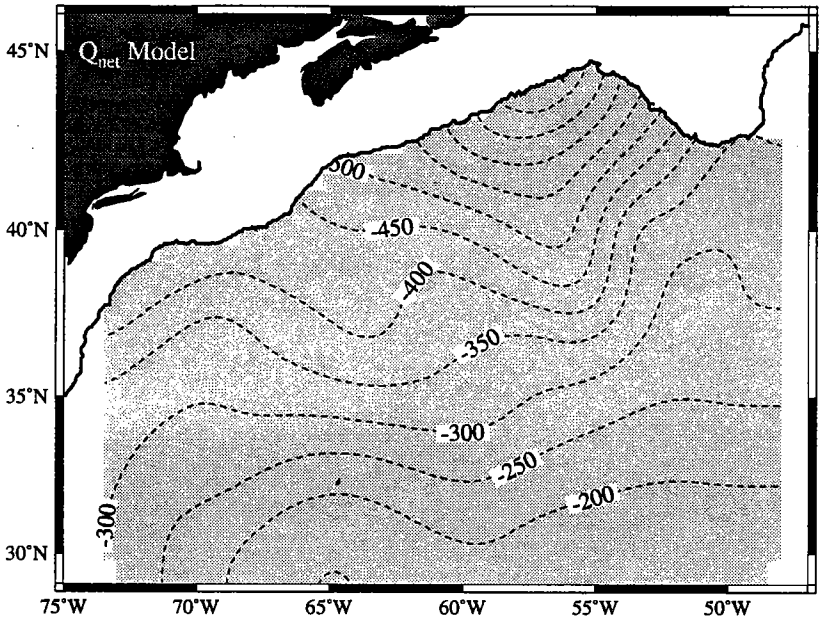


Figure 24: October 1987



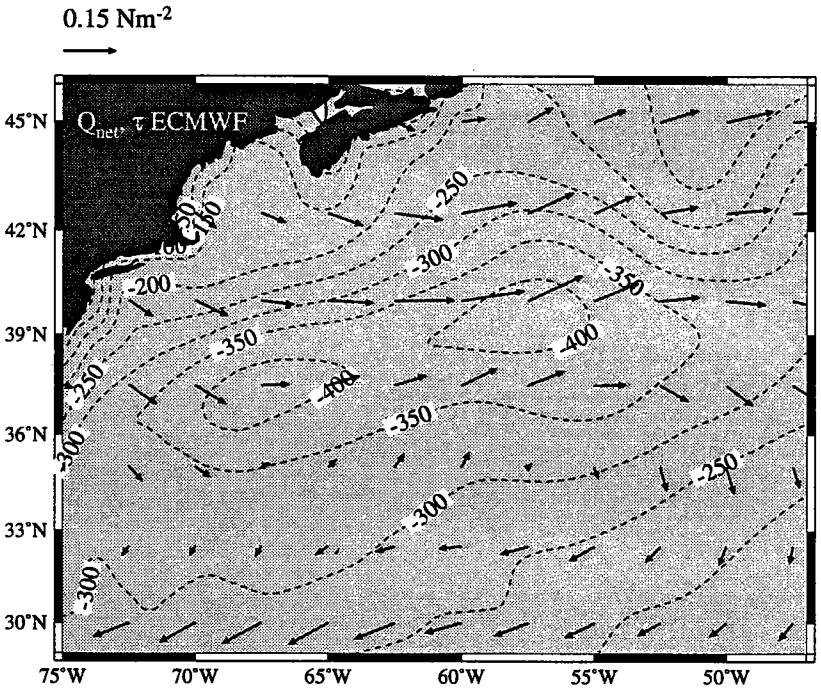
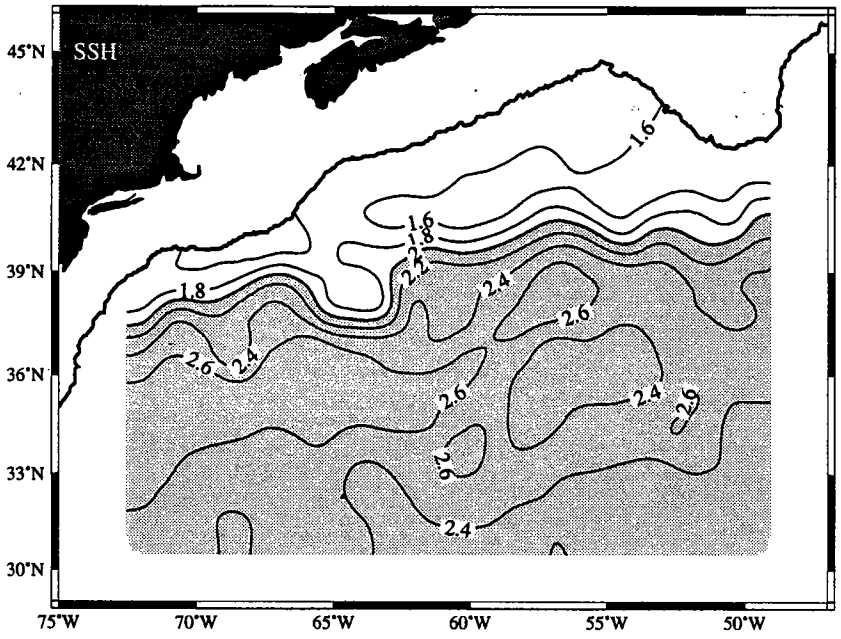


Figure 25: November 1987



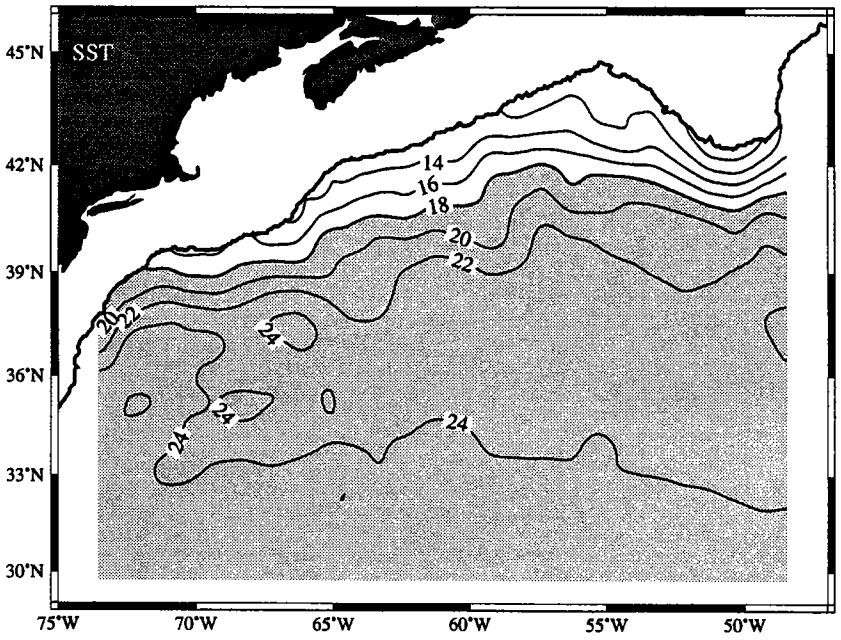
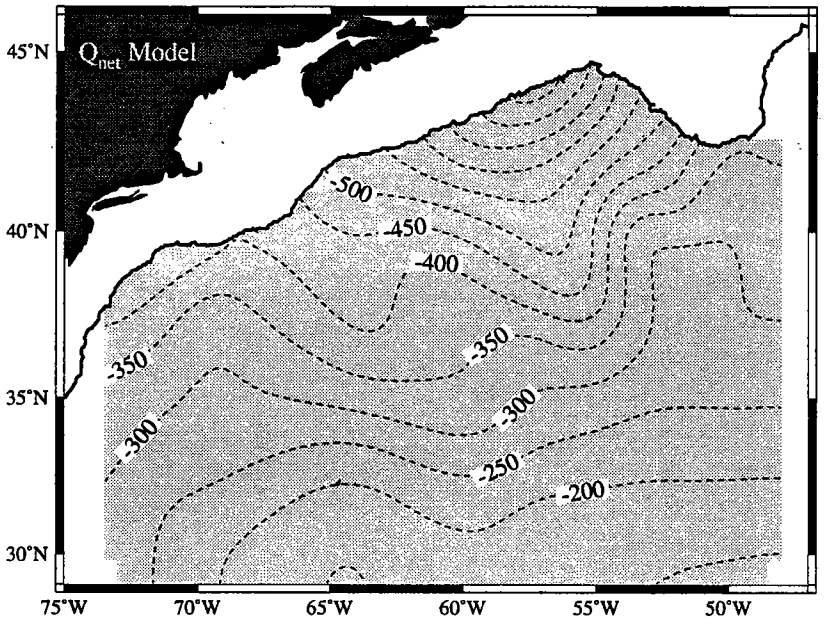


Figure 26: November 1987



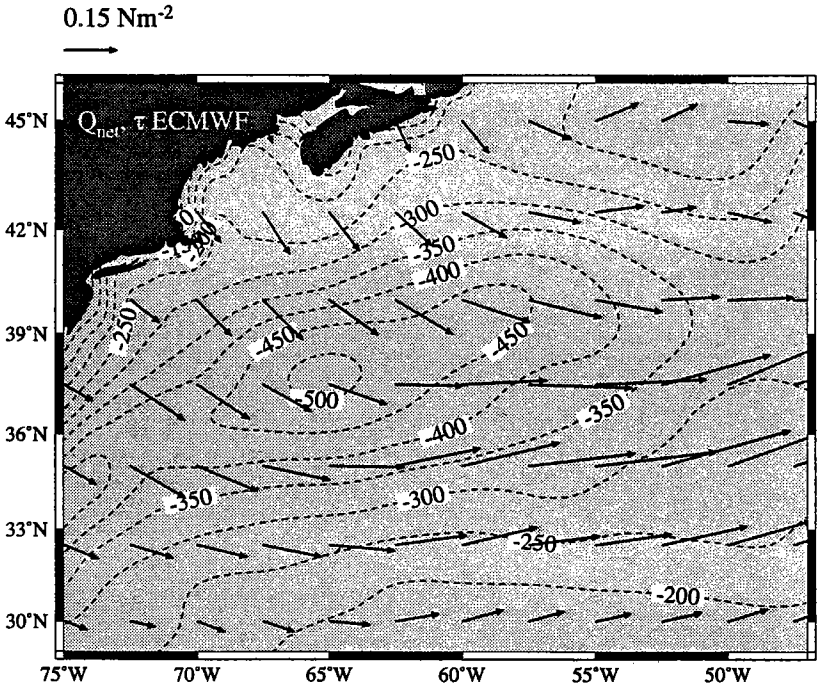
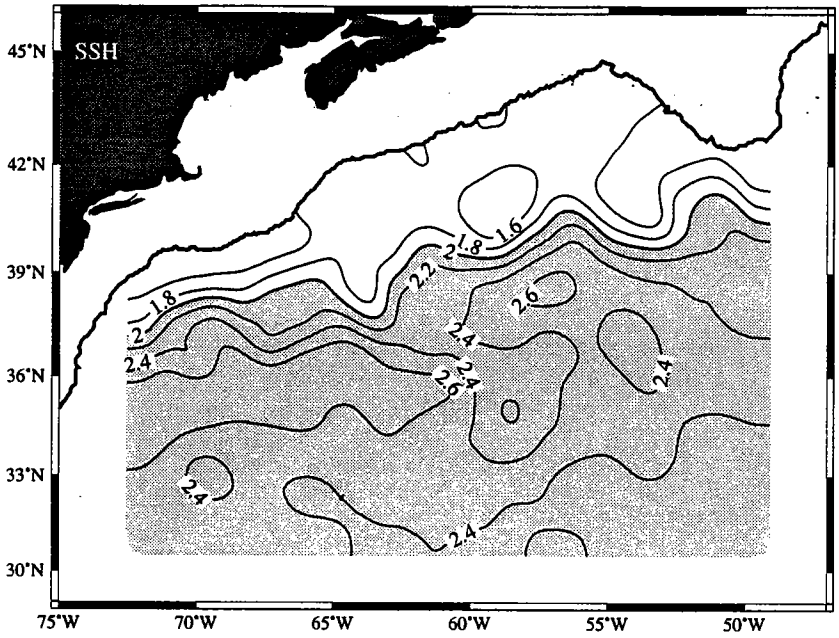


Figure 27: December 1987



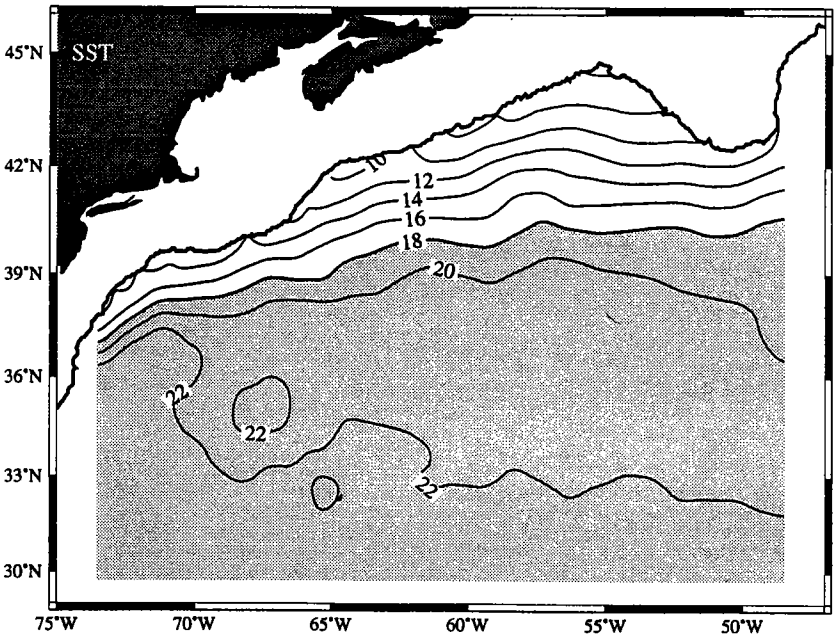


Figure 28: December 1987

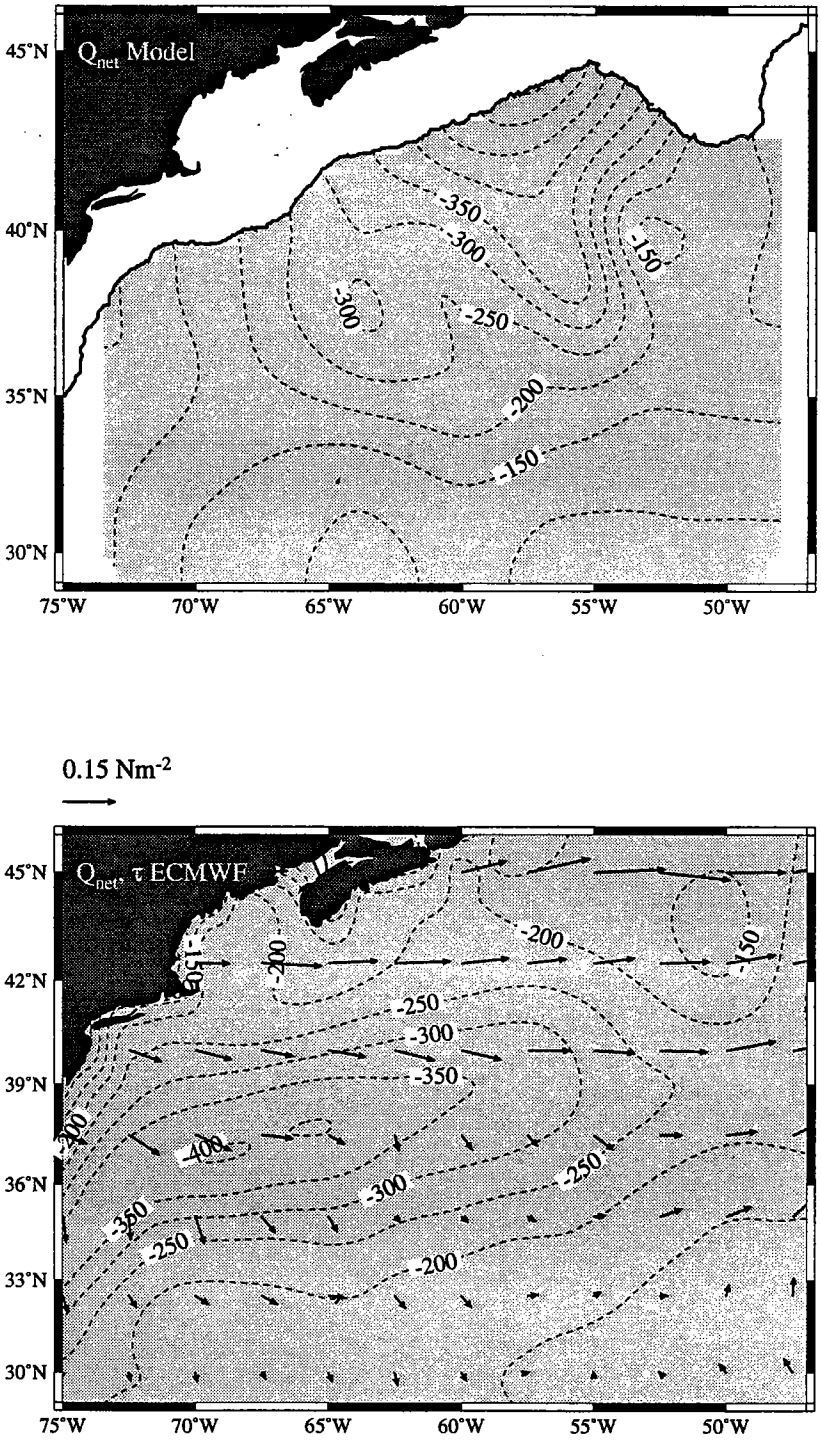
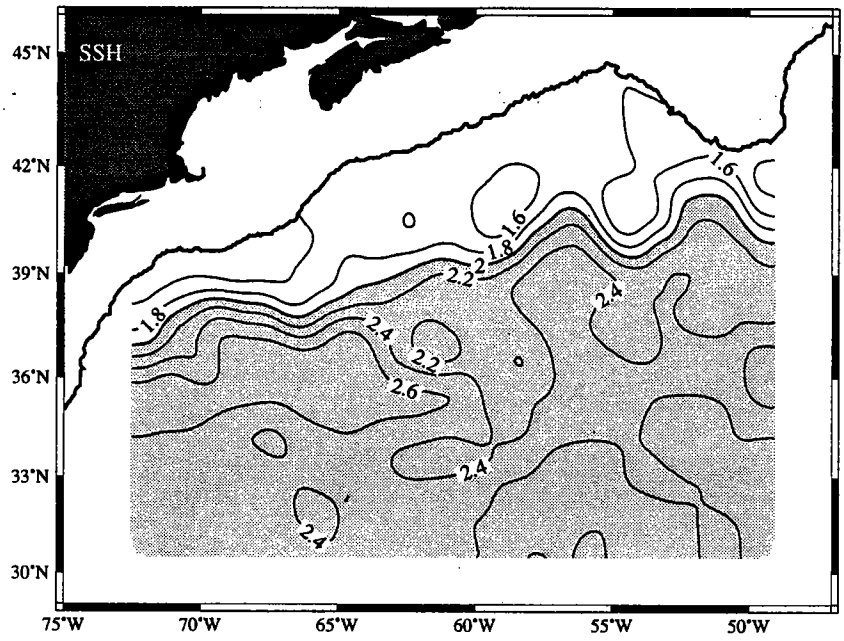


Figure 29: January 1988



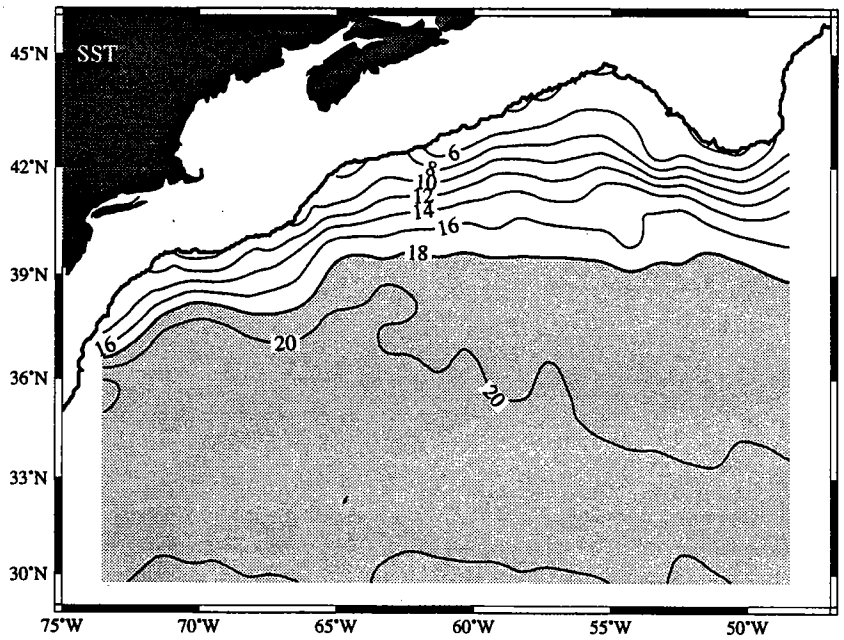
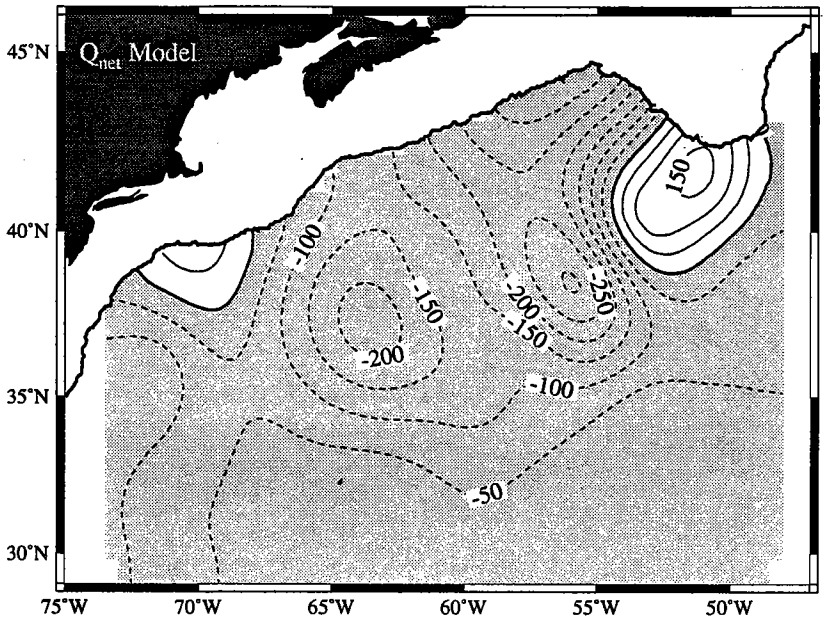


Figure 30: January 1988



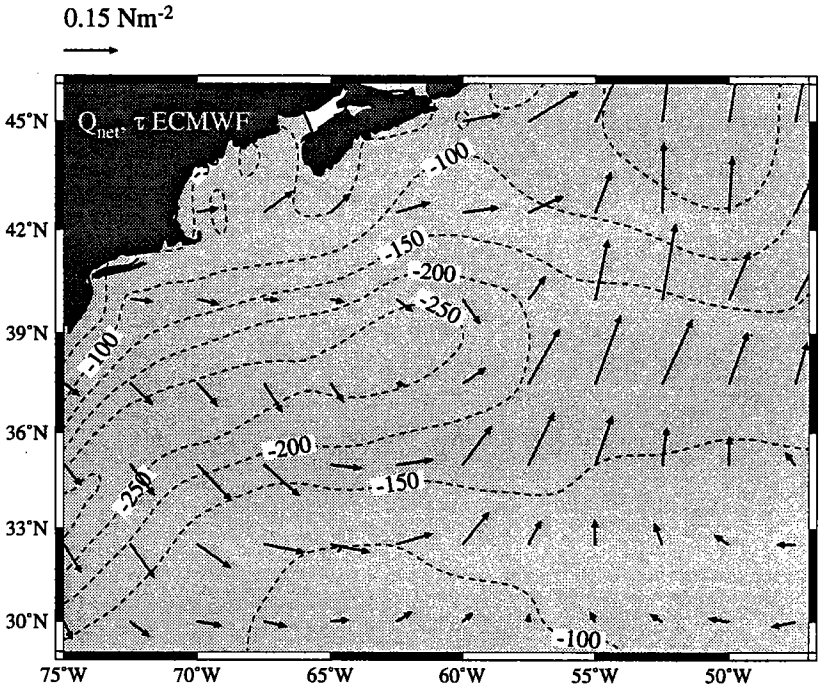
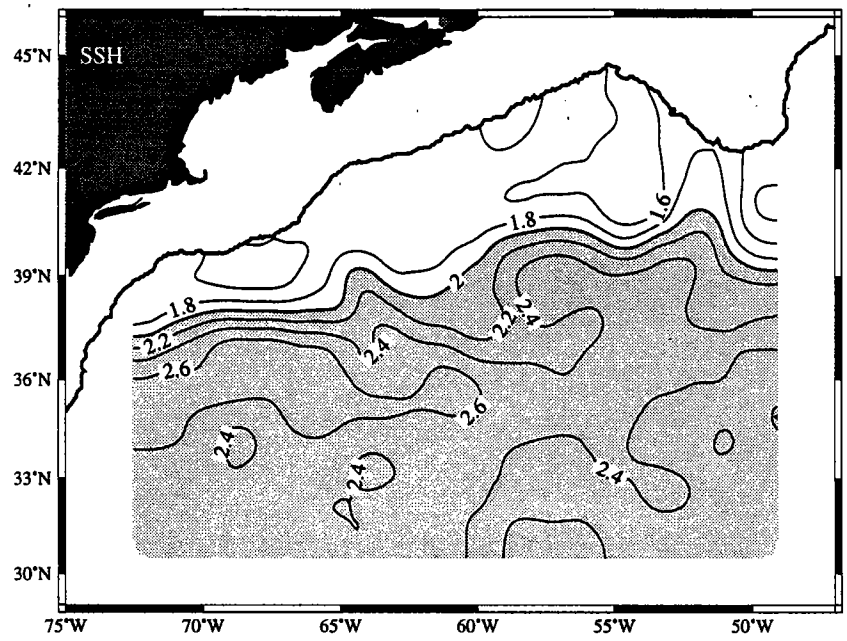


Figure 31: February 1988



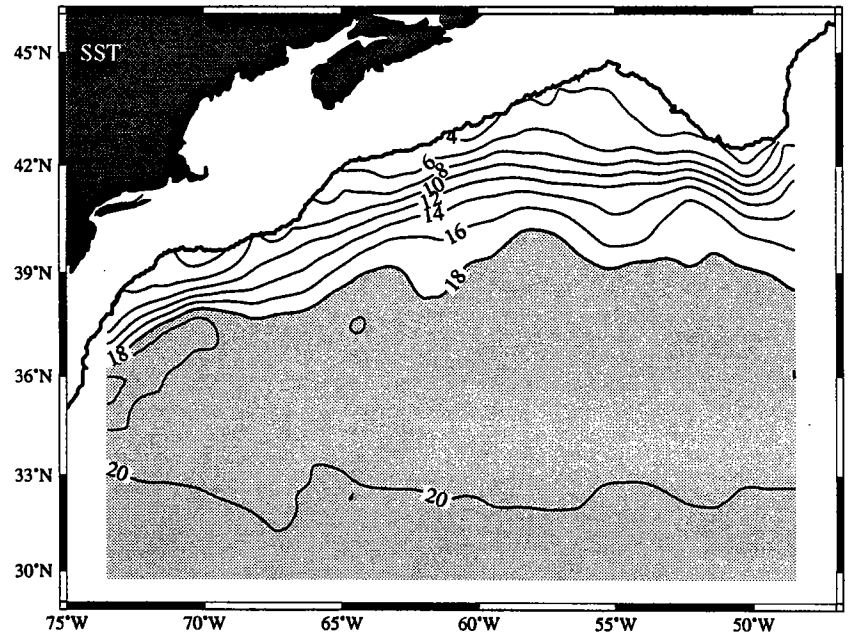
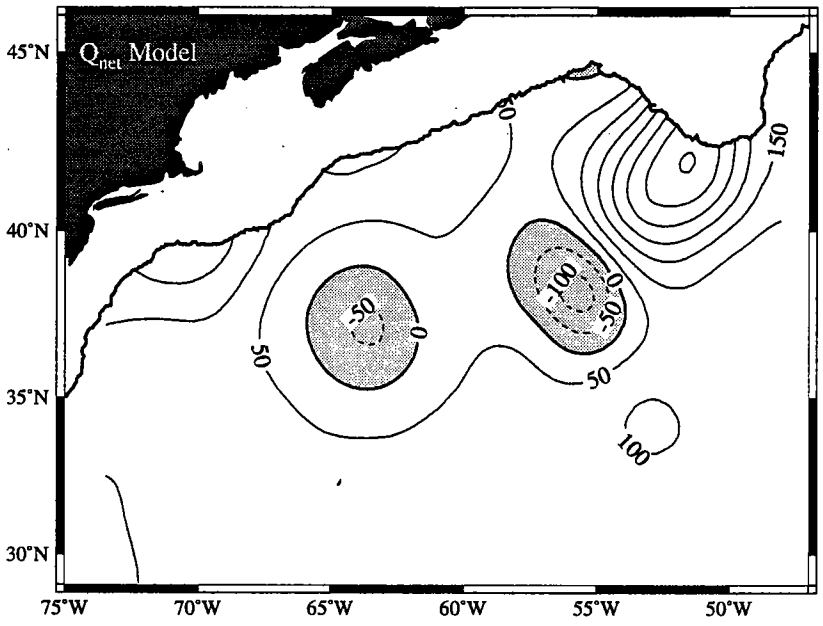


Figure 32: February 1988



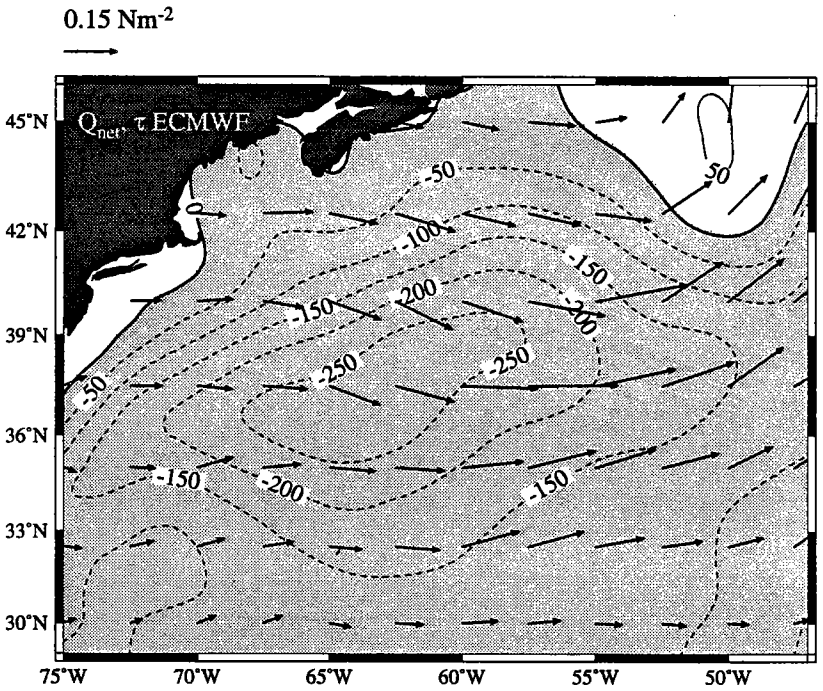


Figure 33: March 1988

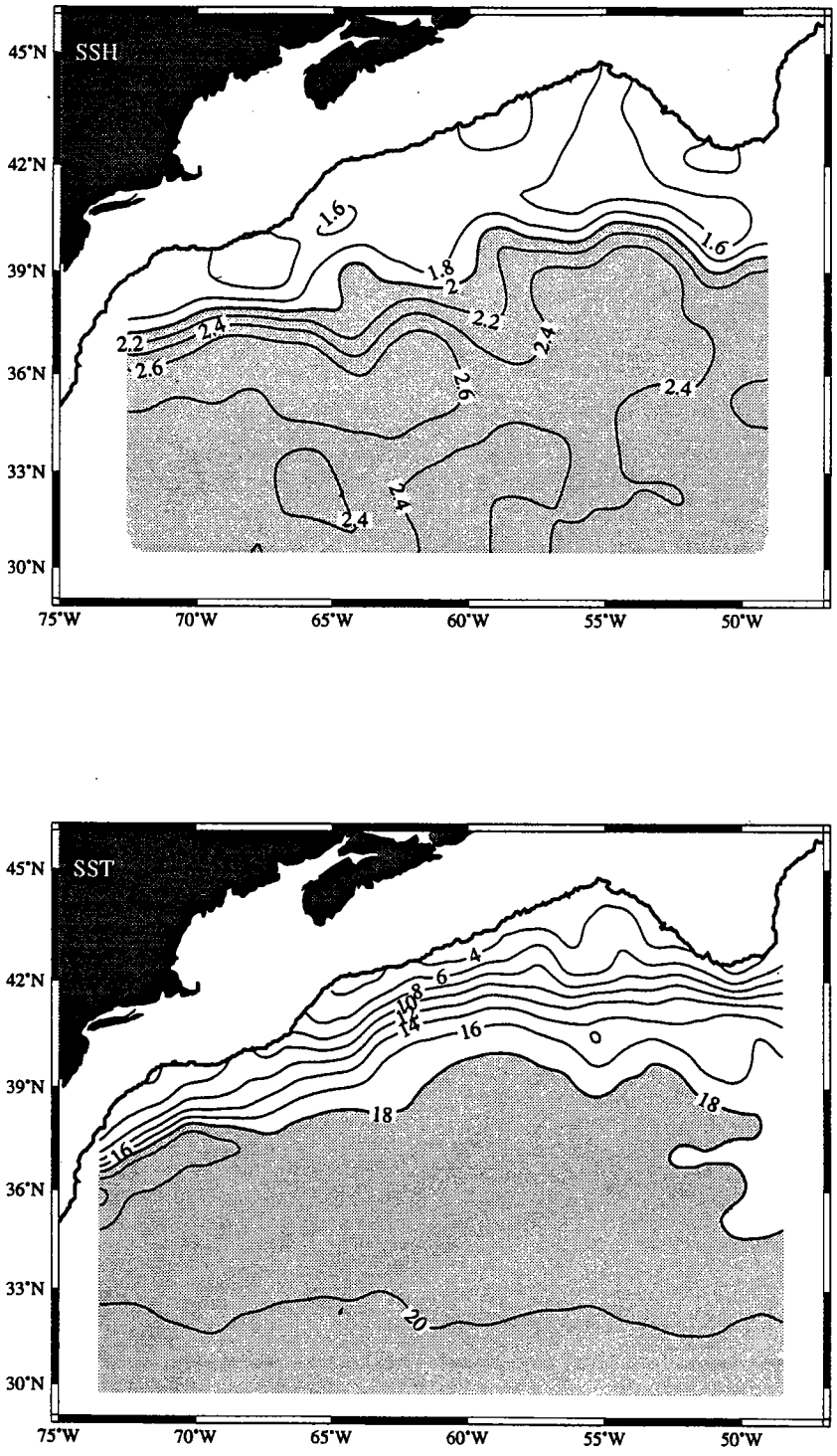


Figure 34: March 1988

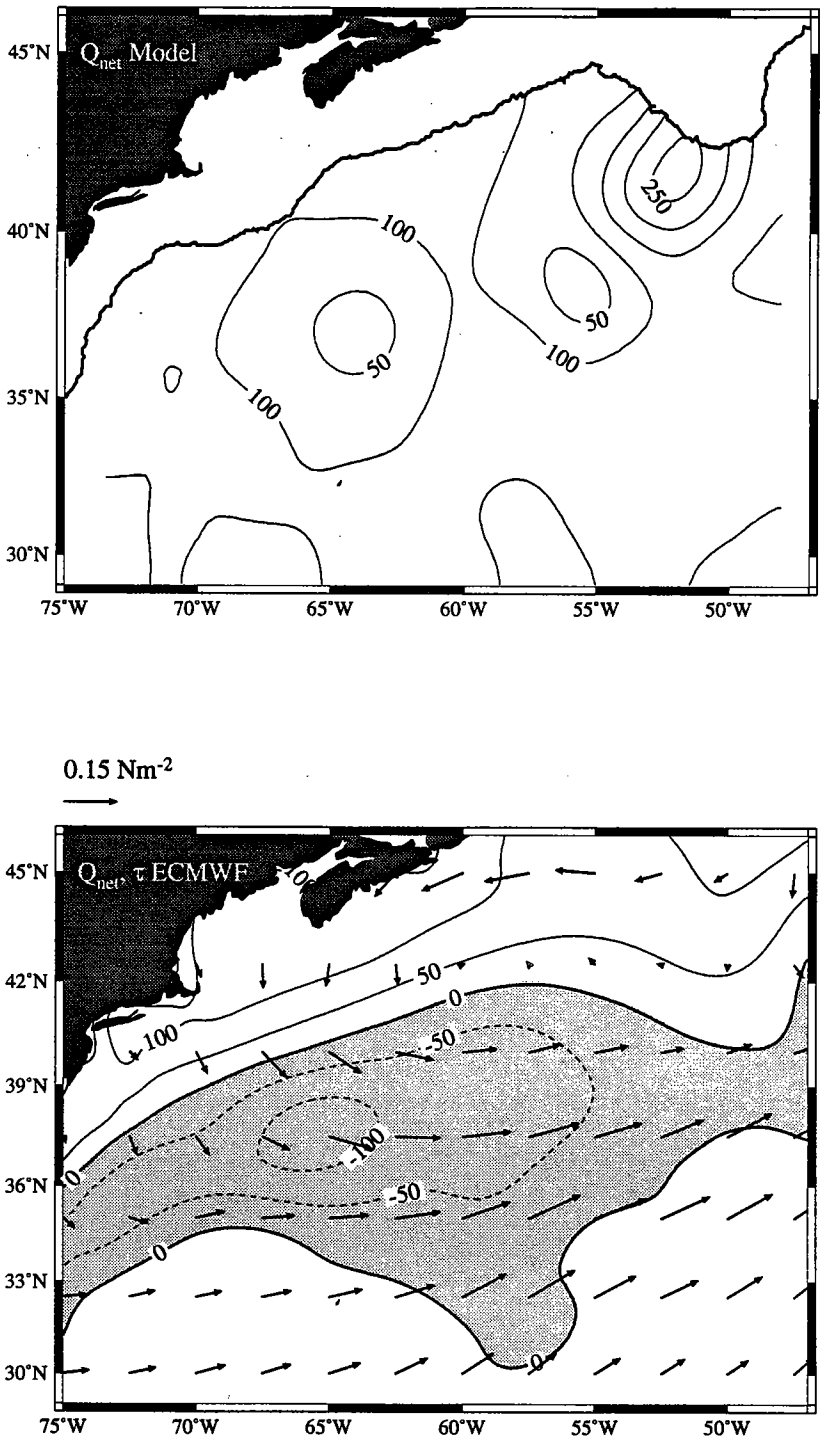
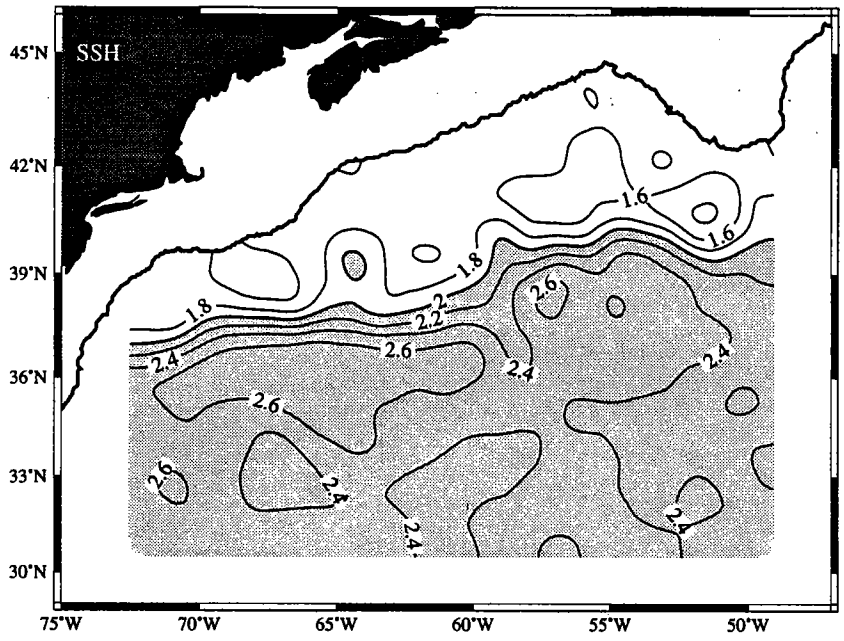


Figure 35: April 1988



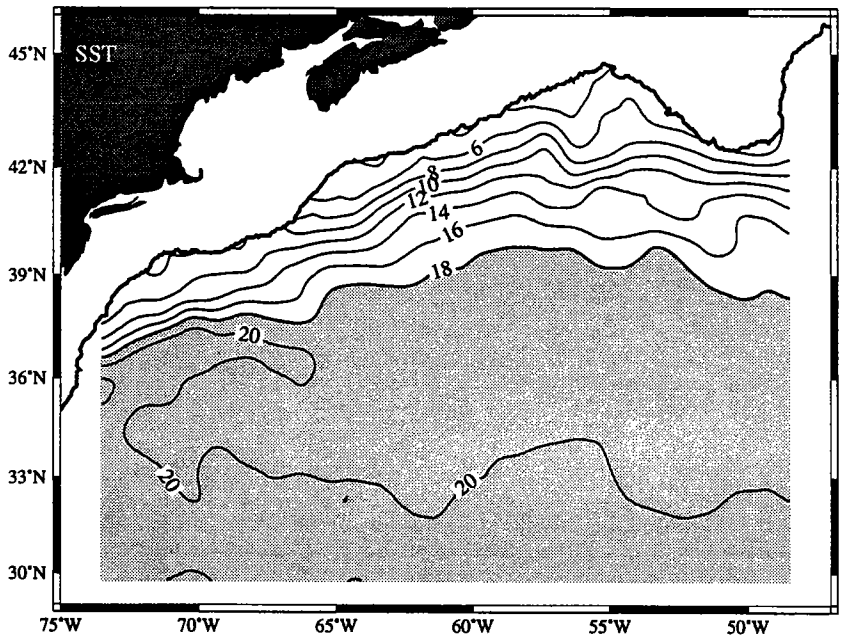
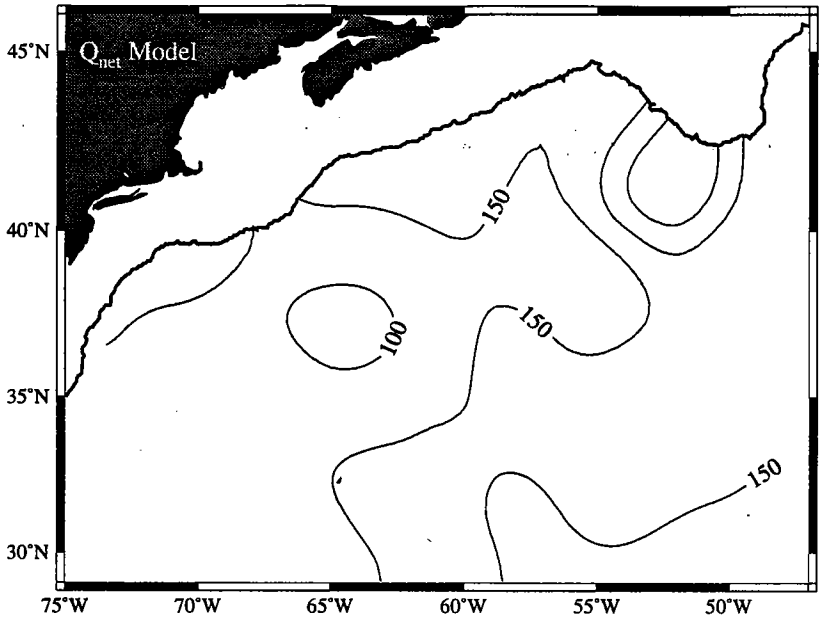


Figure 36: April 1988



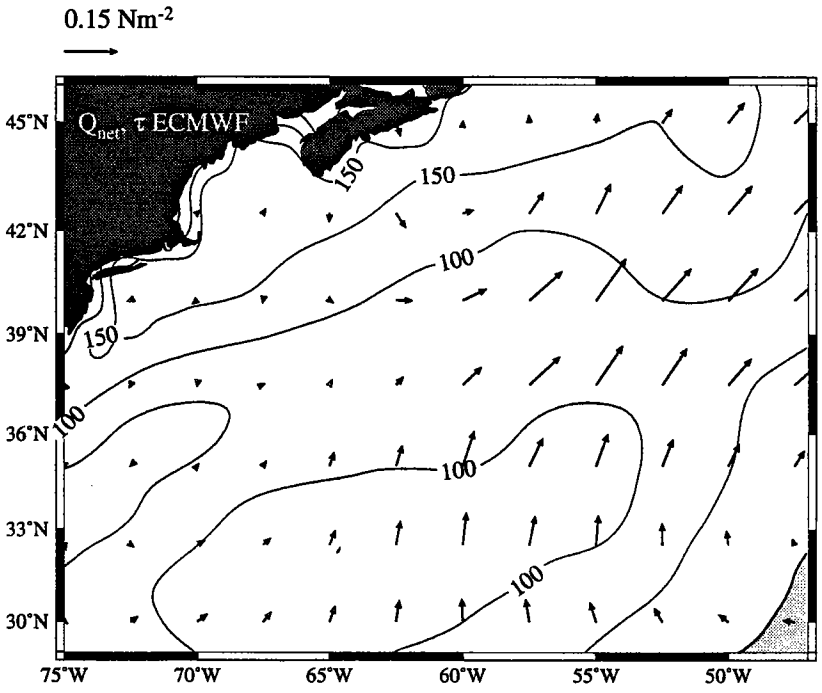
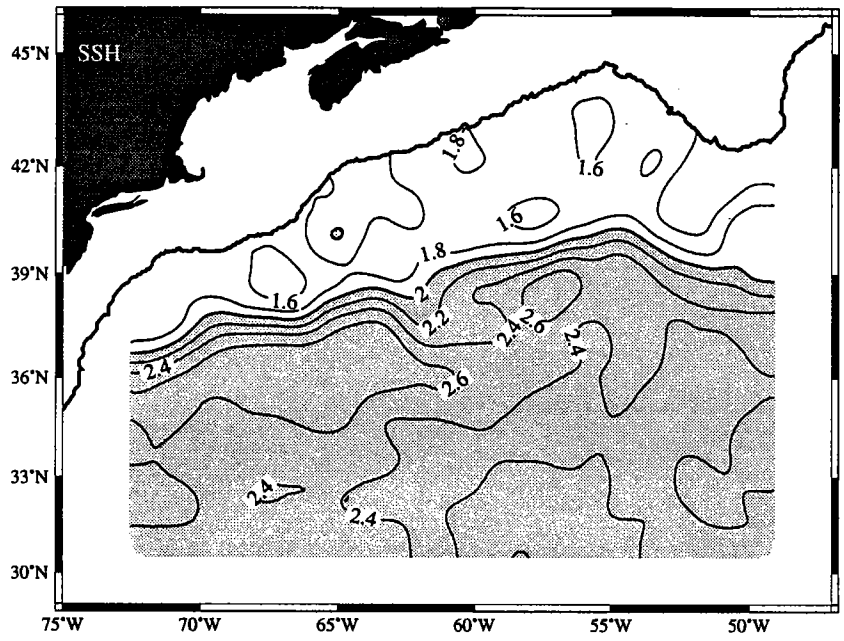


Figure 37: May 1988



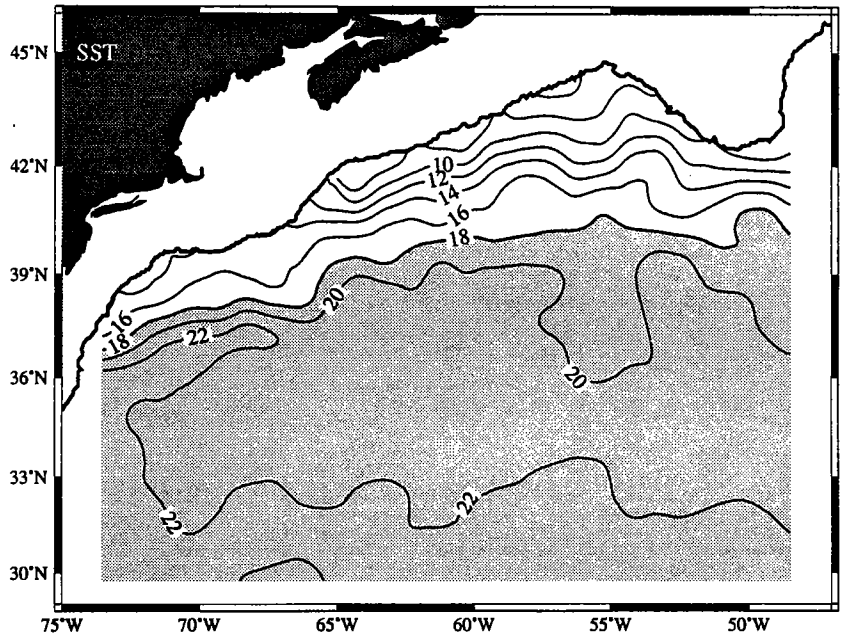


Figure 38: May 1988

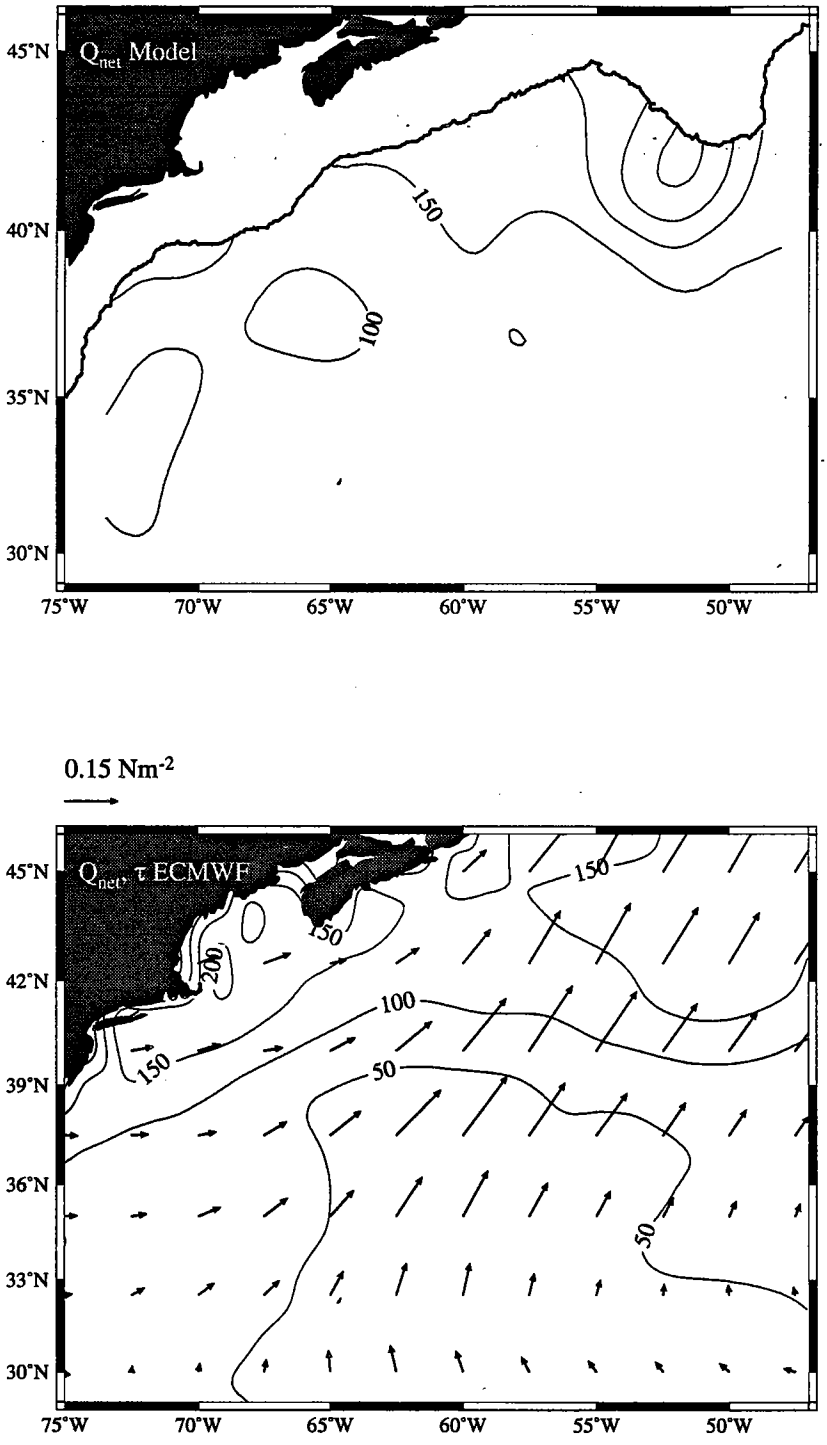
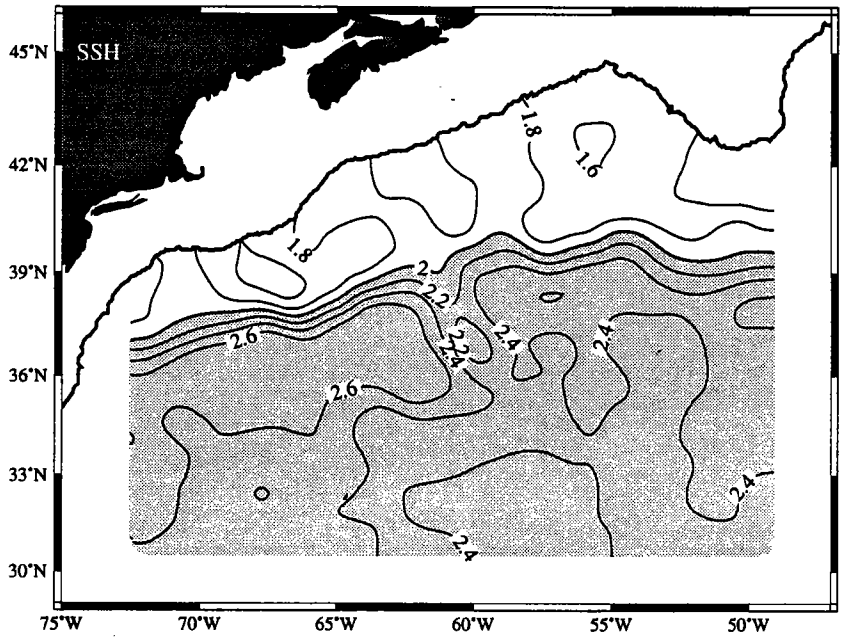


Figure 39: June 1988



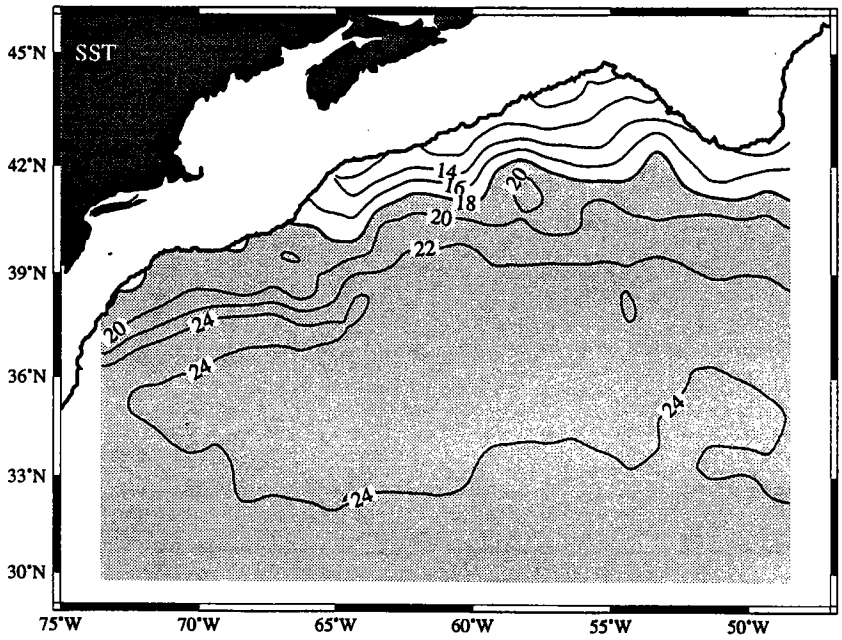
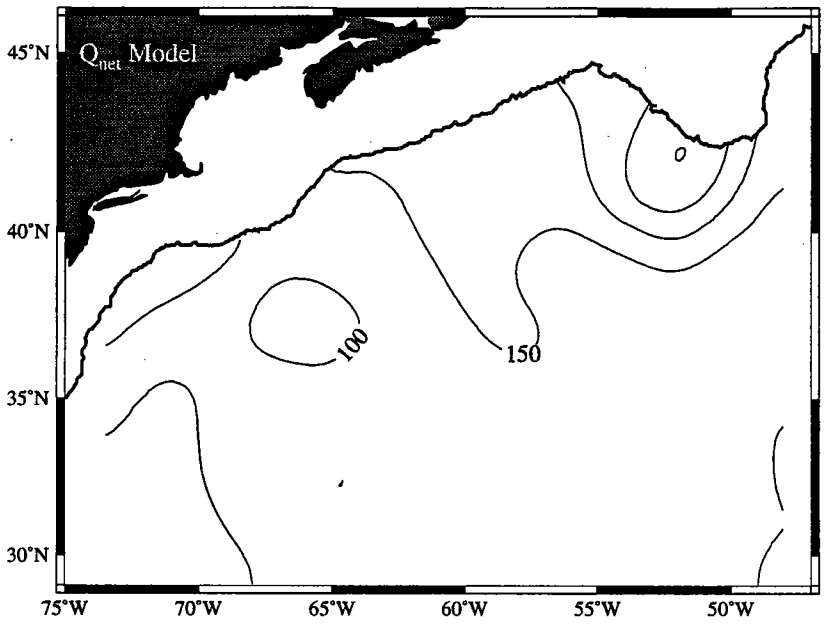


Figure 40: June 1988



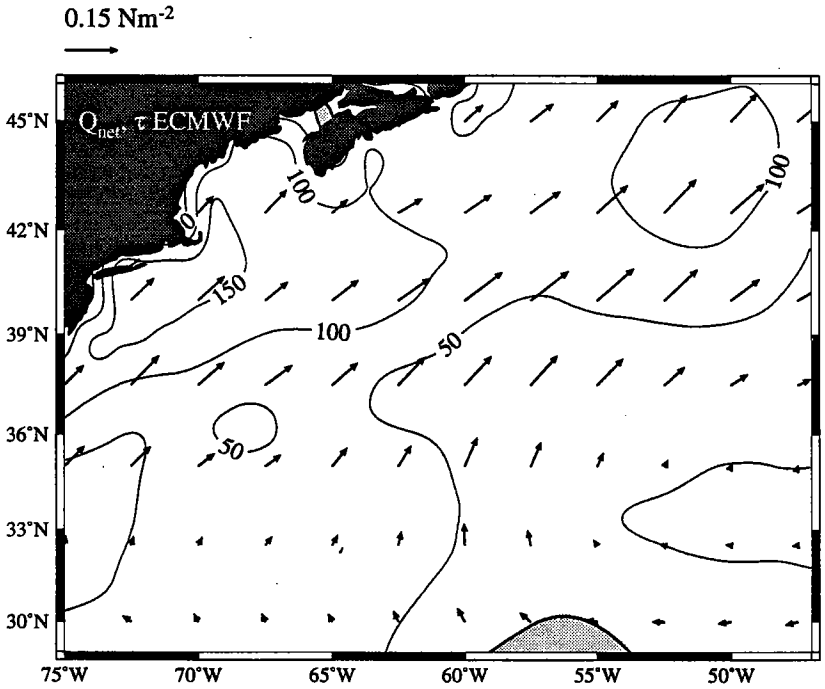
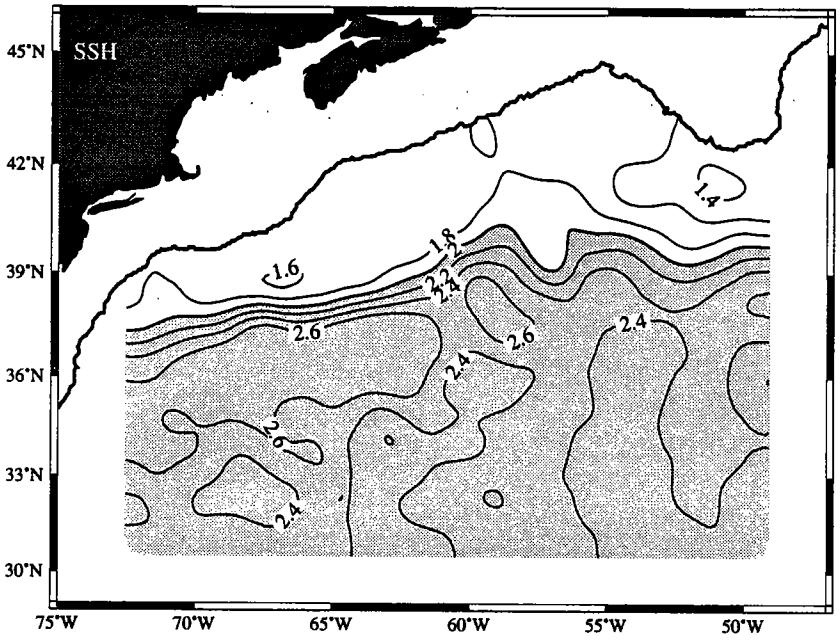


Figure 41: July 1988



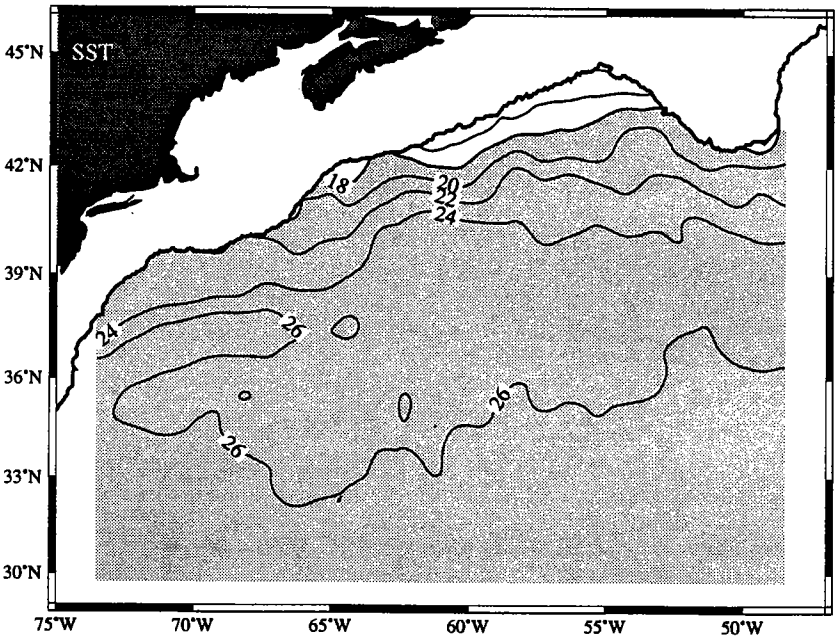
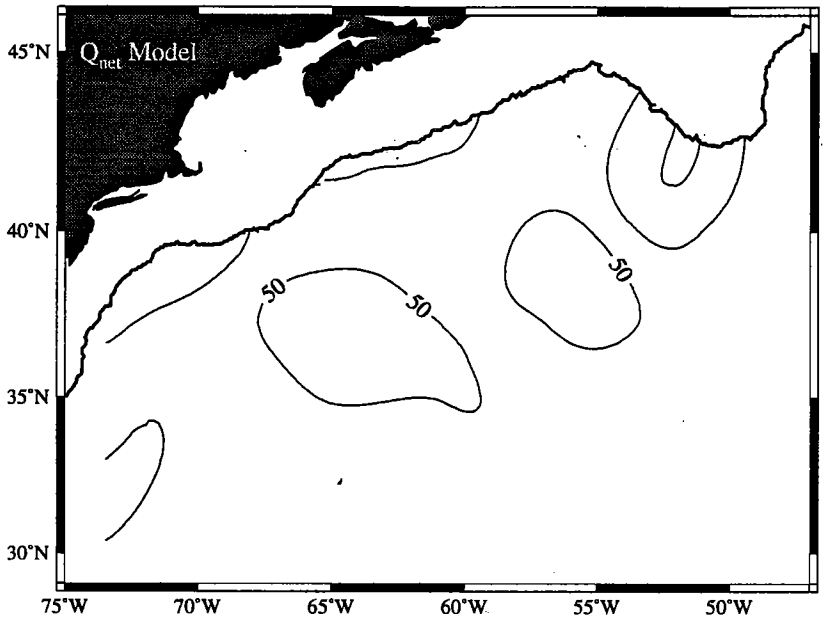


Figure 42: July 1988



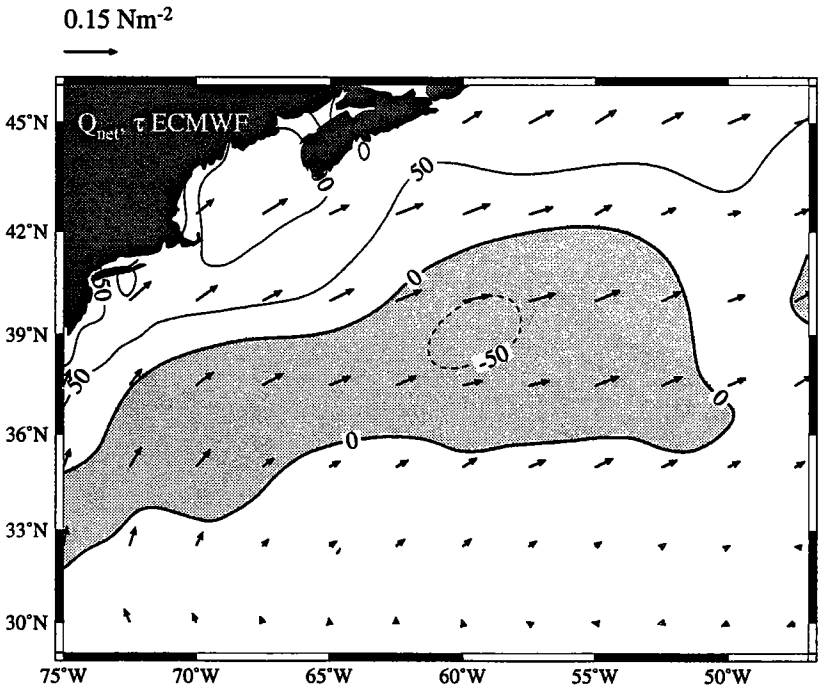
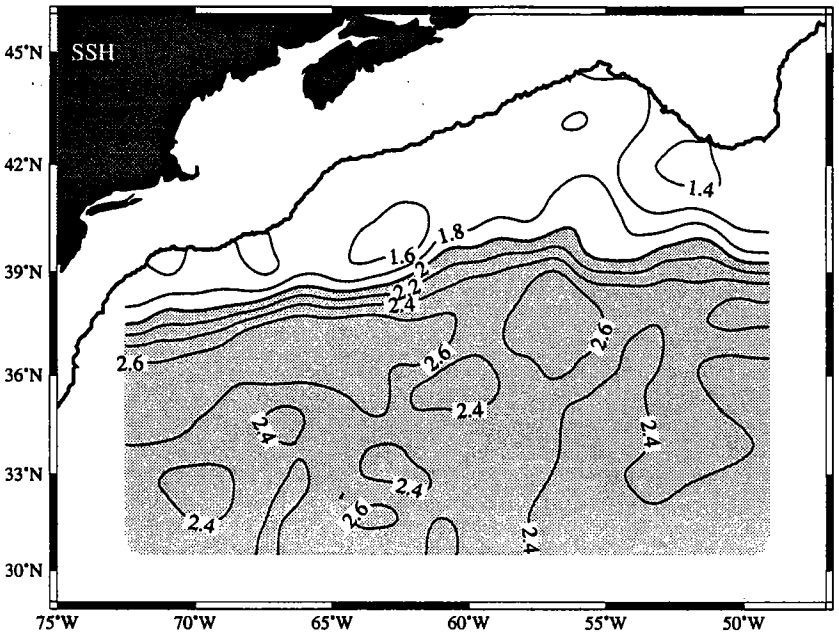


Figure 43: August 1988



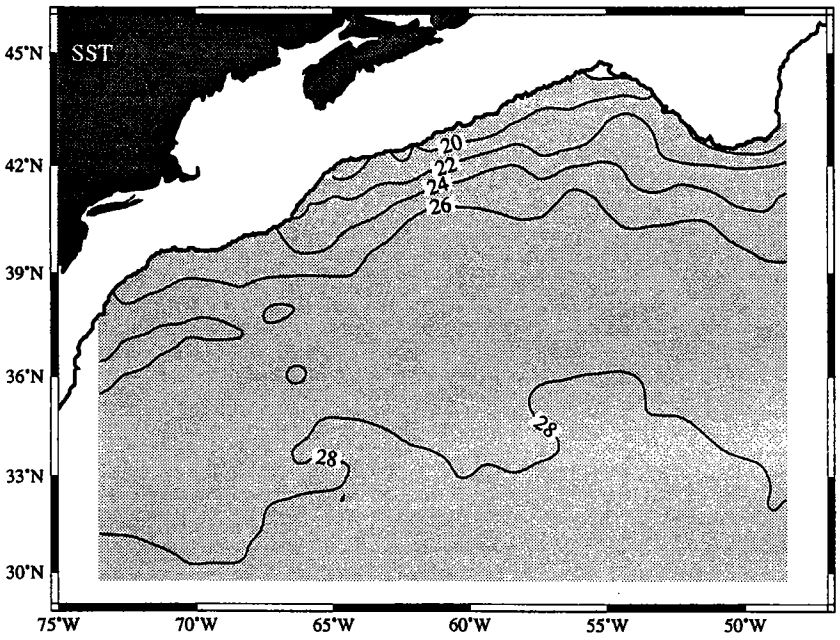


Figure 44: August 1988

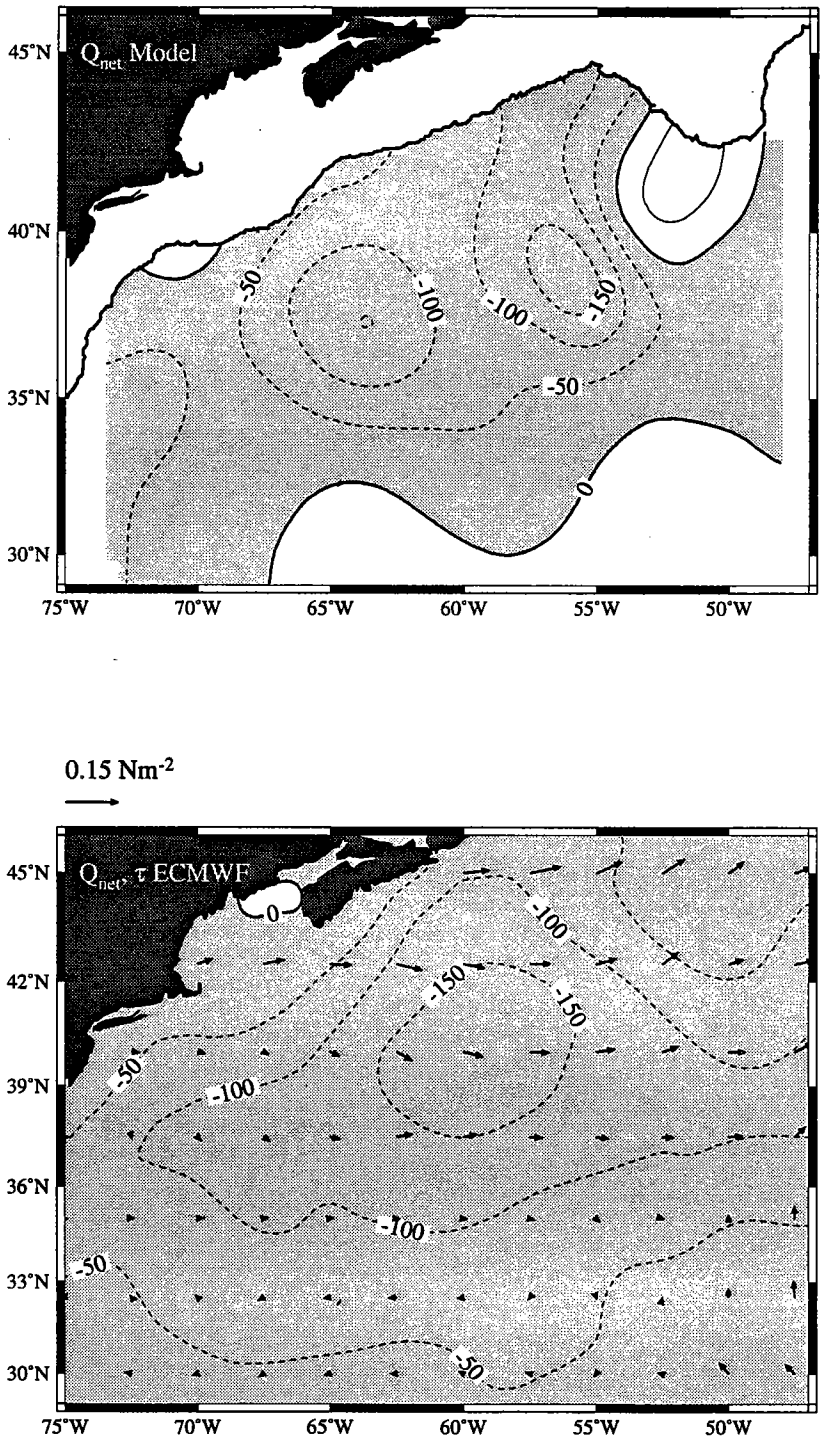
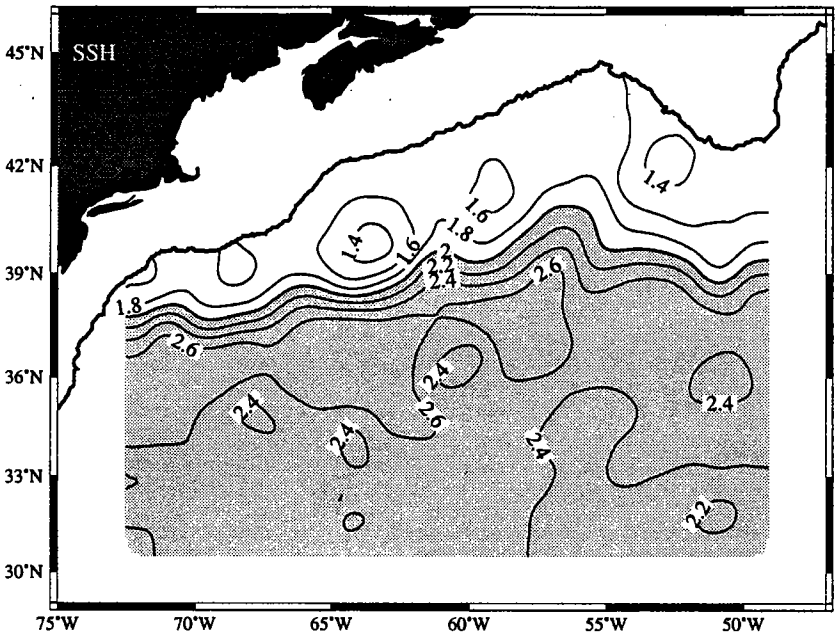


Figure 45: September 1988



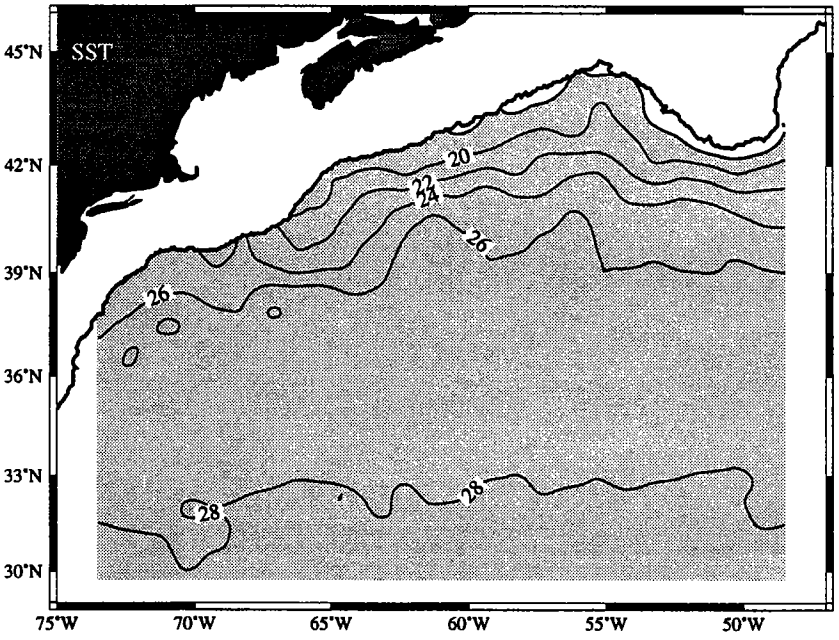


Figure 46: September 1988

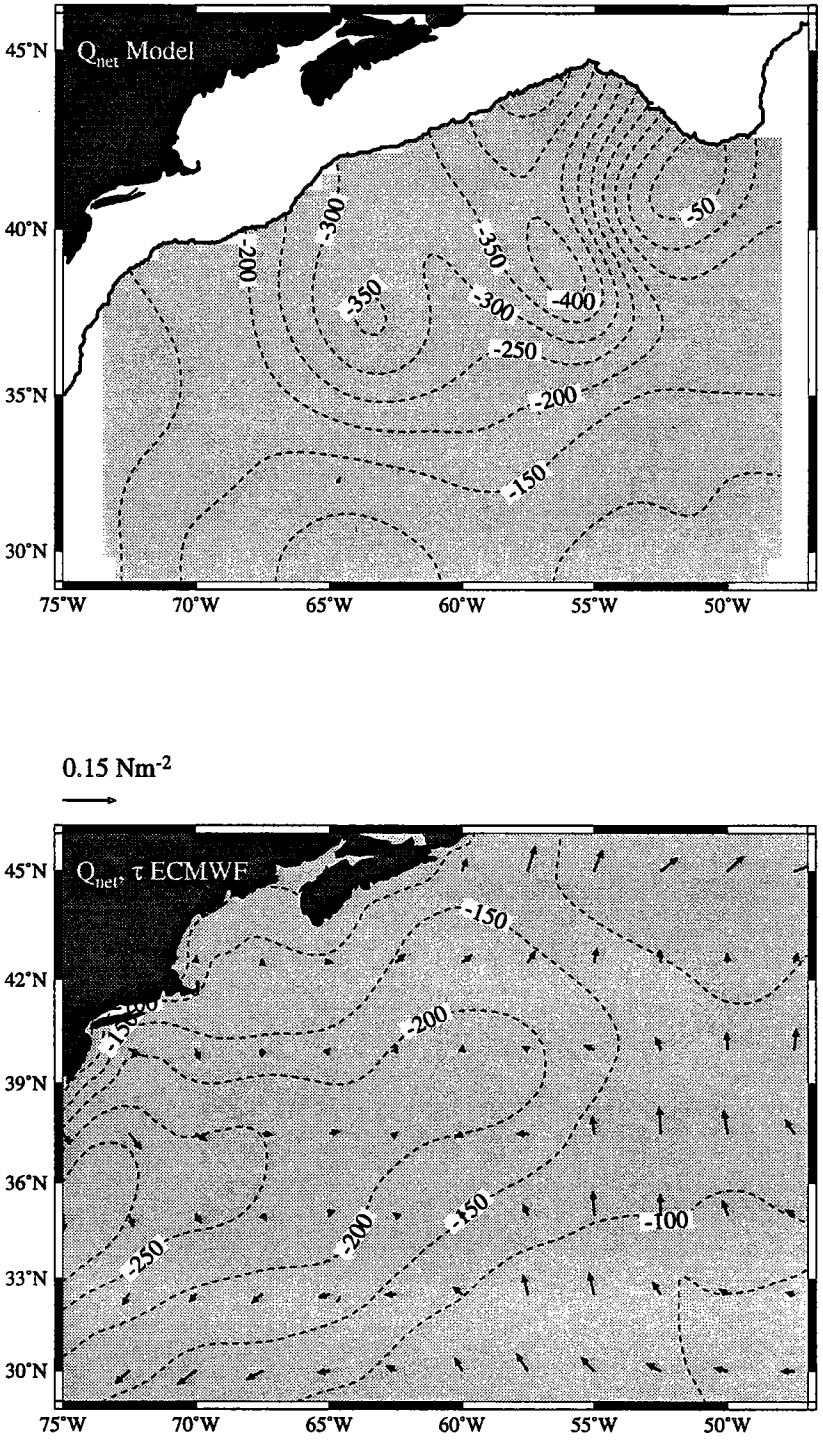
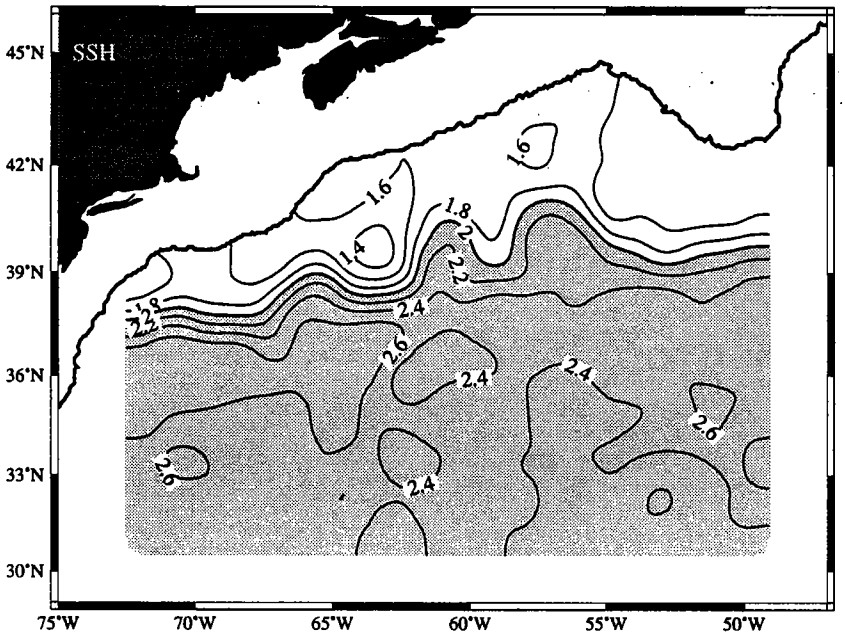


Figure 47: October 1988



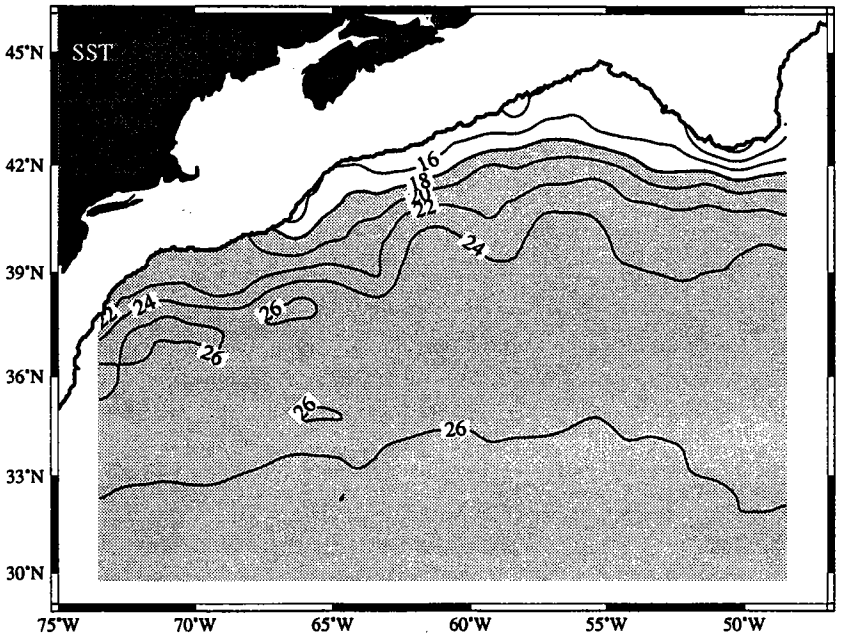


Figure 48: October 1988

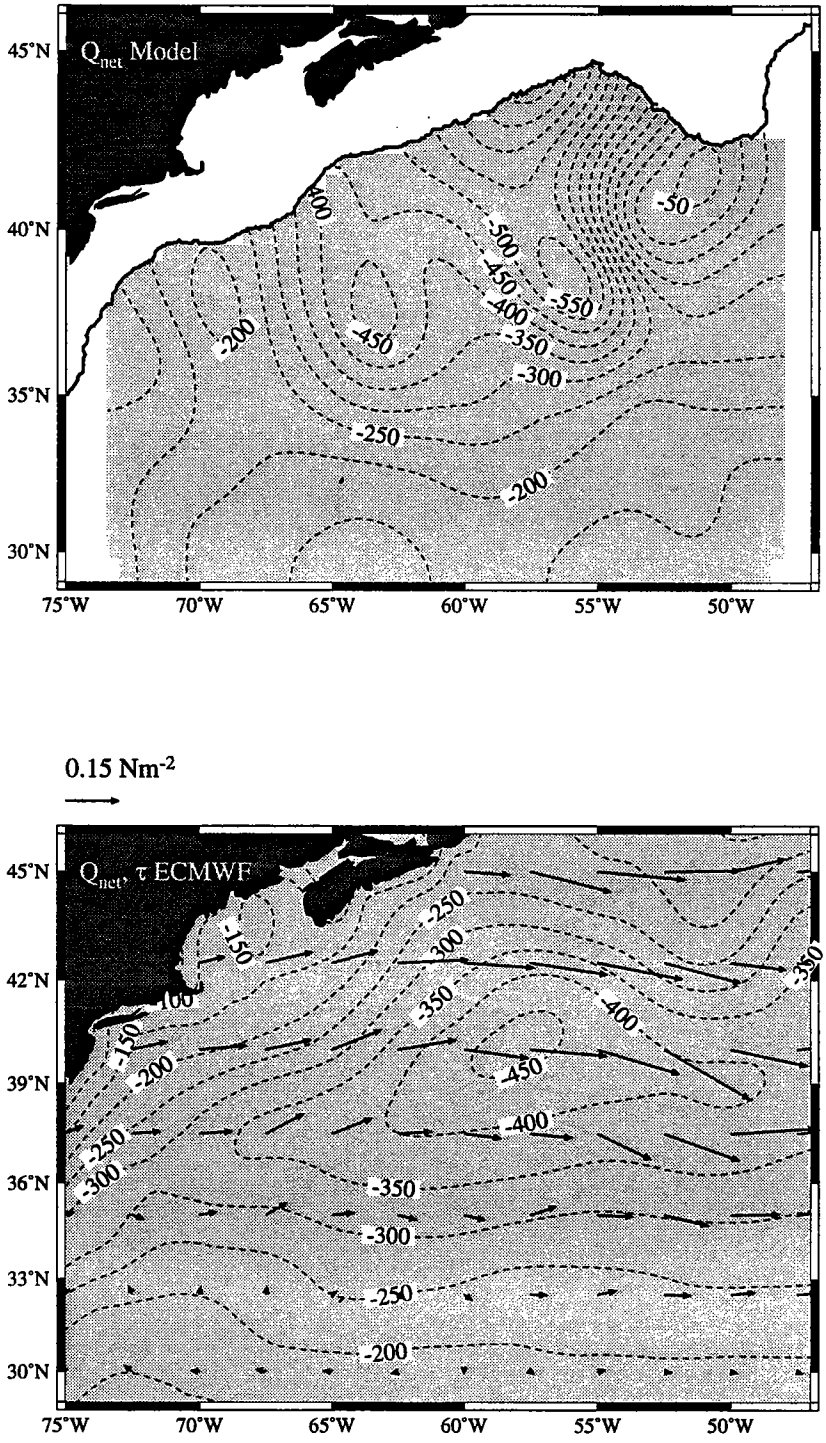
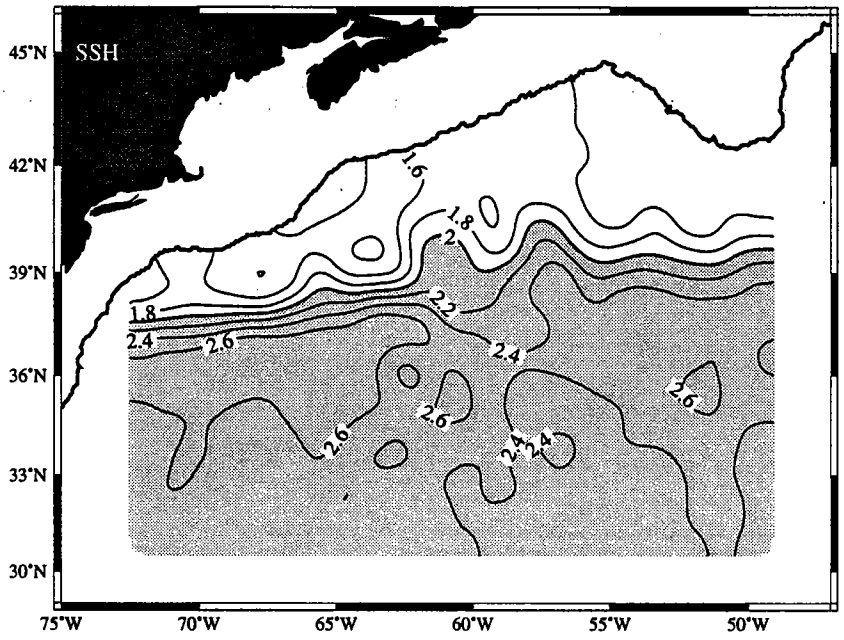


Figure 49: November 1988



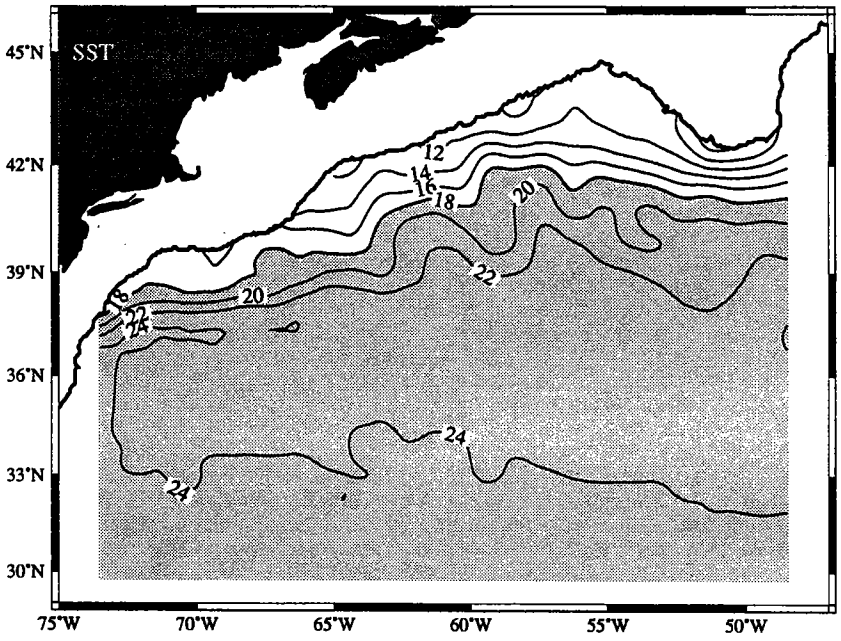
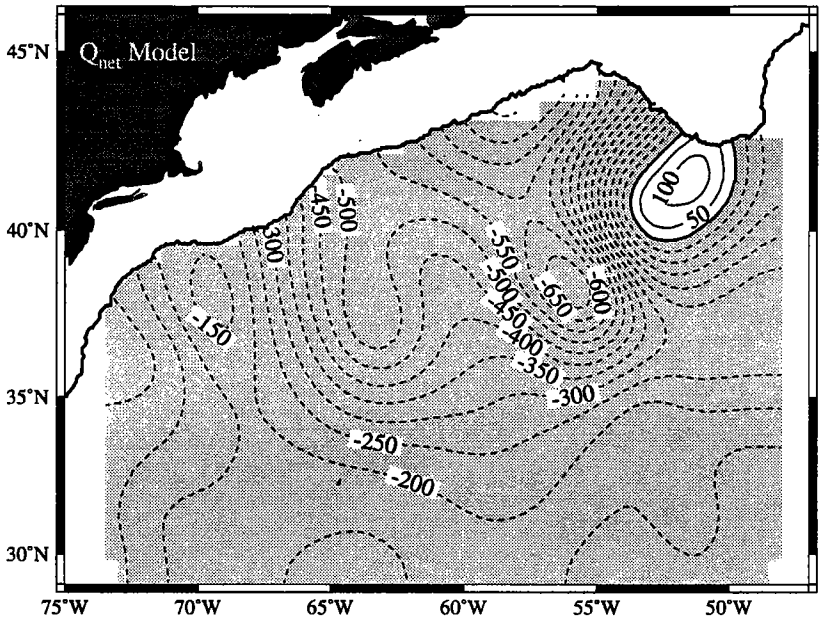


Figure 50: November 1988



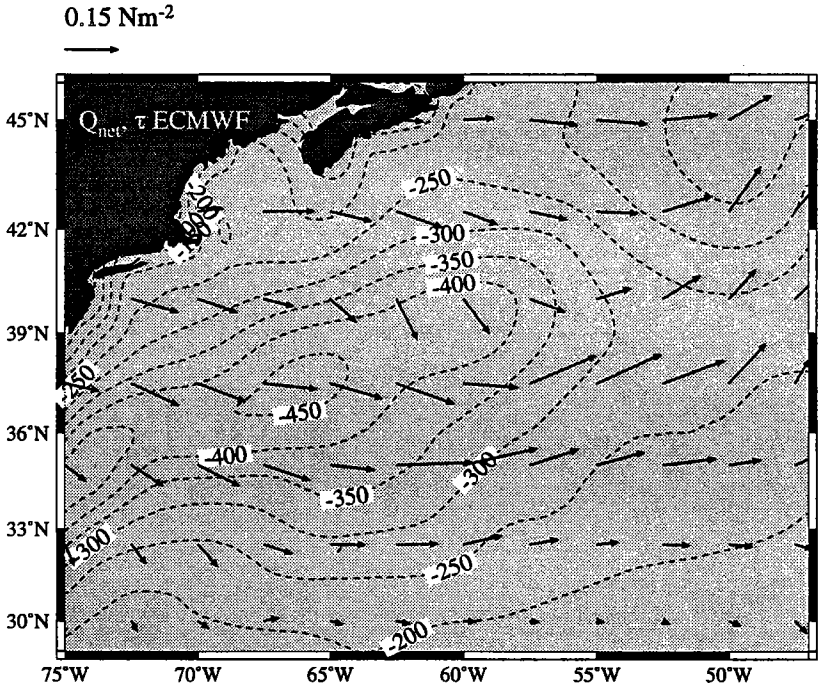
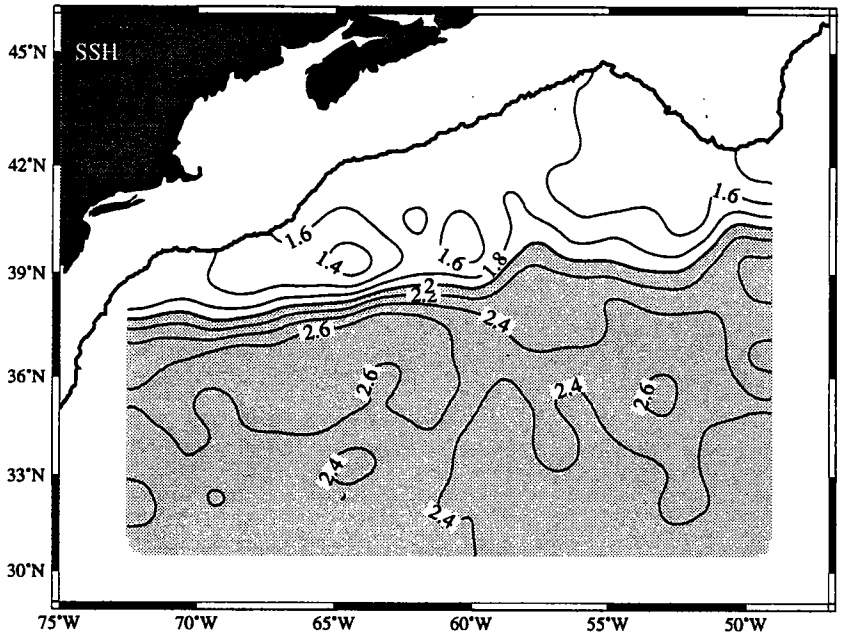


Figure 51: December 1988



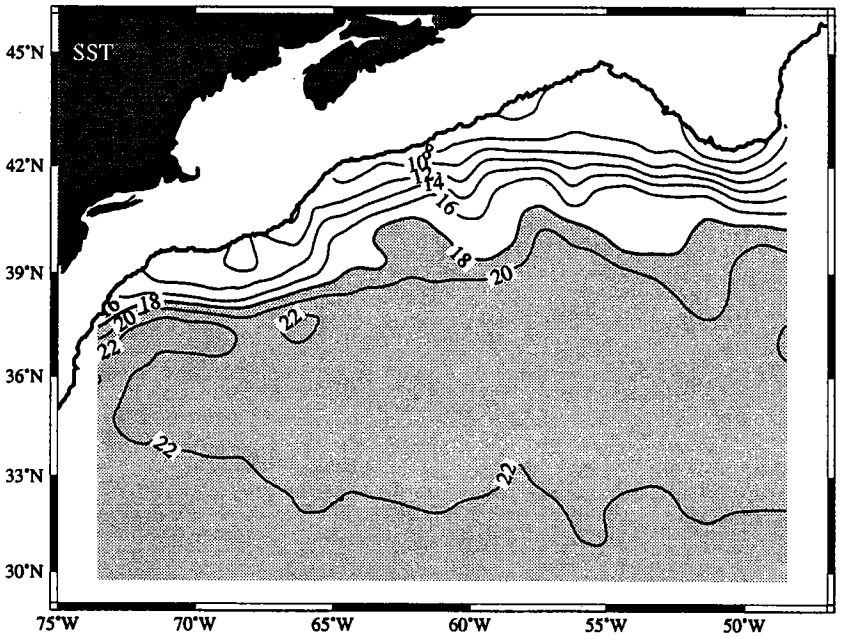
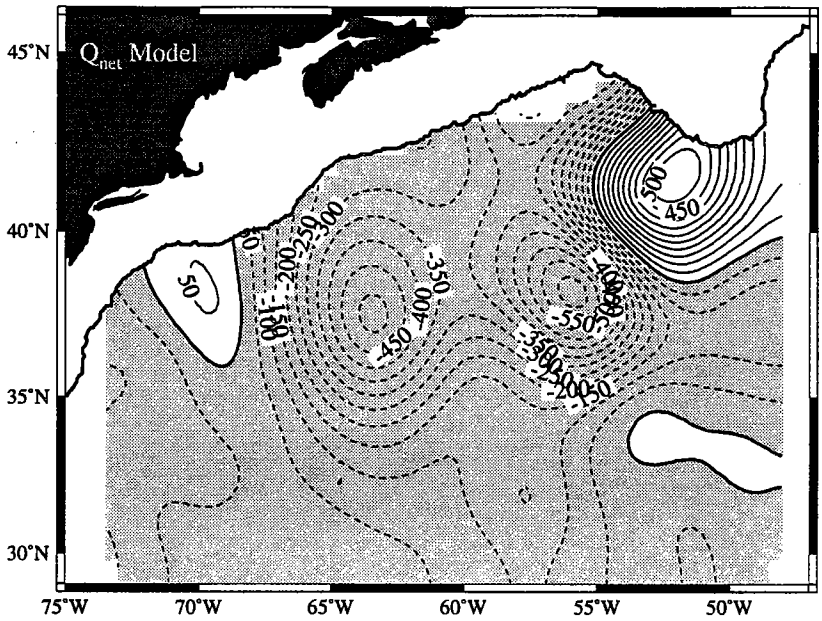


Figure 52: December 1988



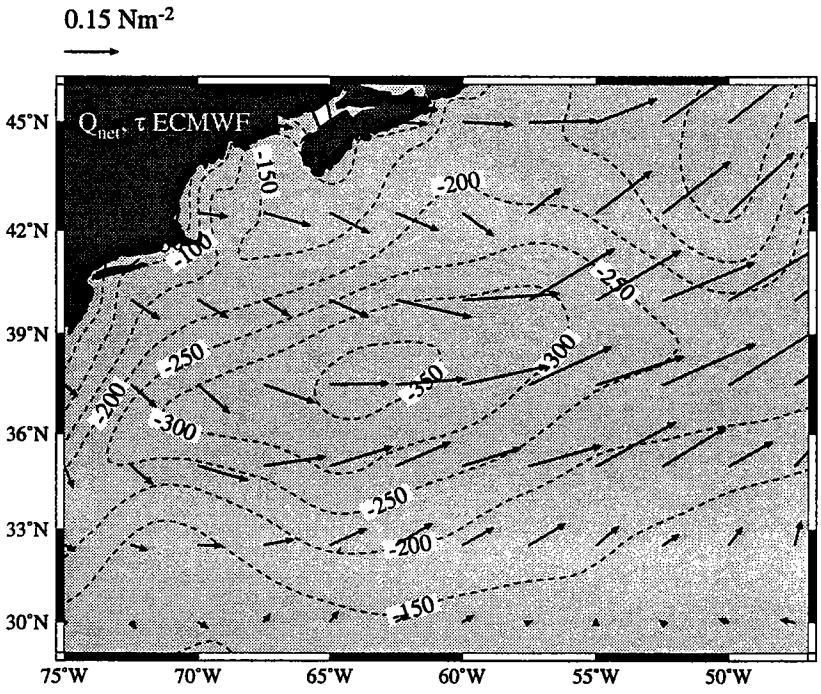
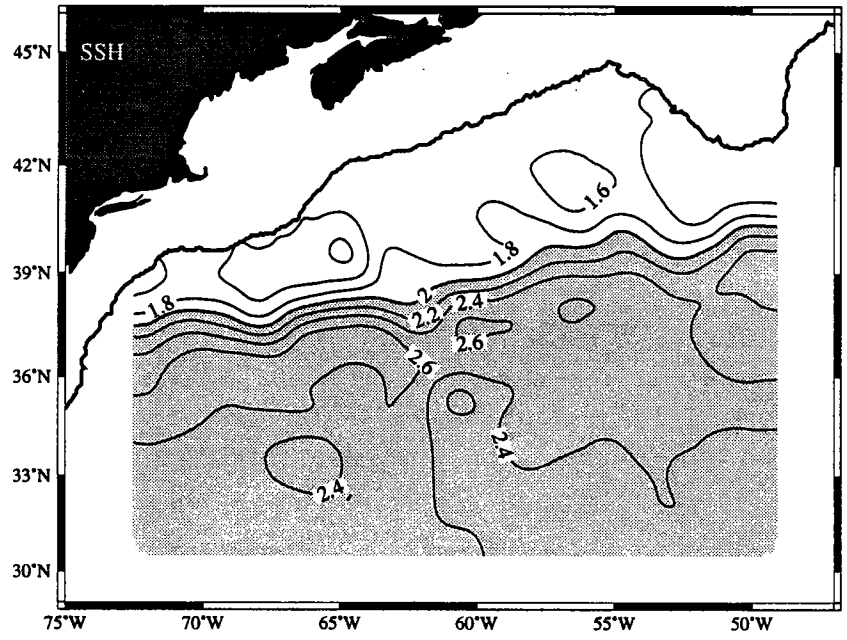


Figure 53: January 1989



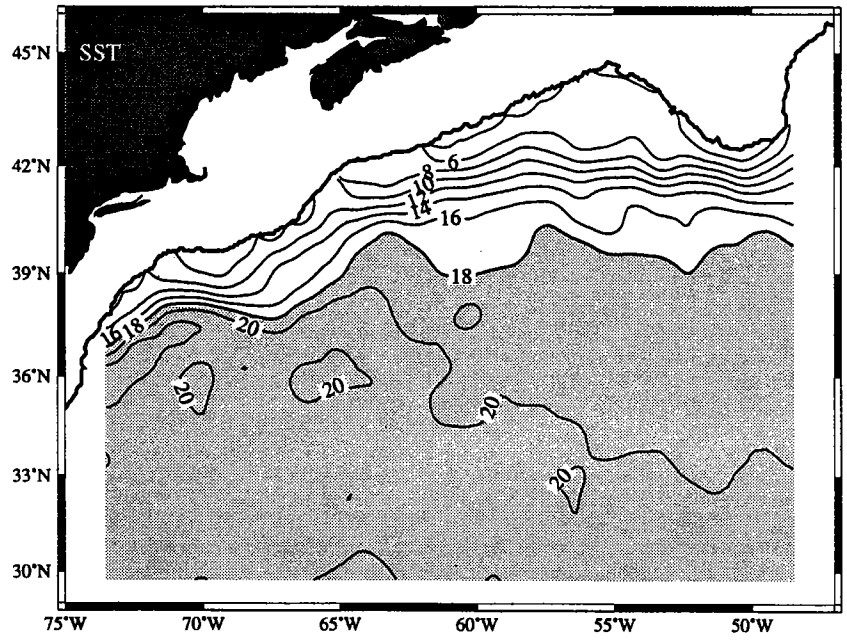


Figure 54: January 1989

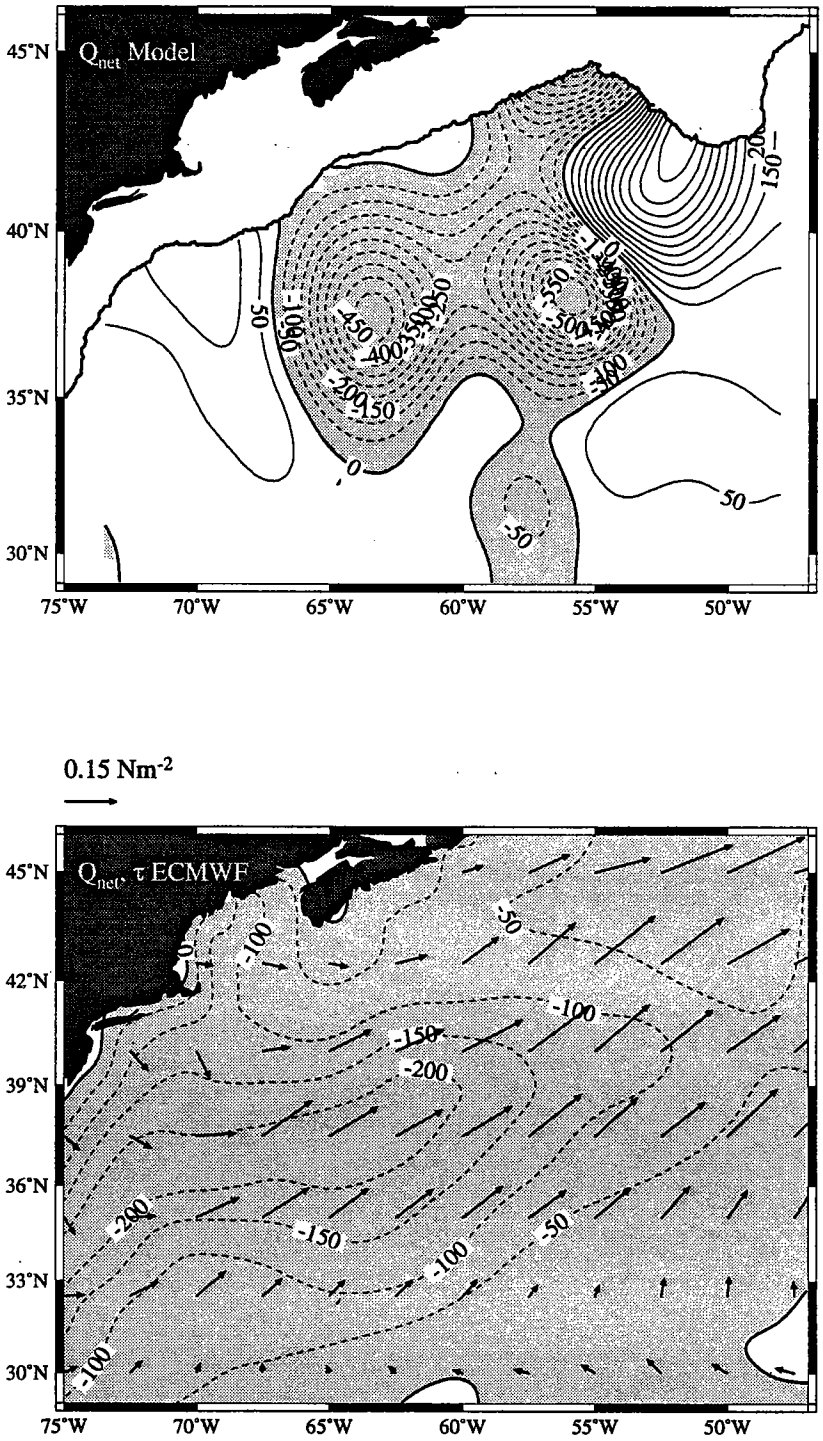
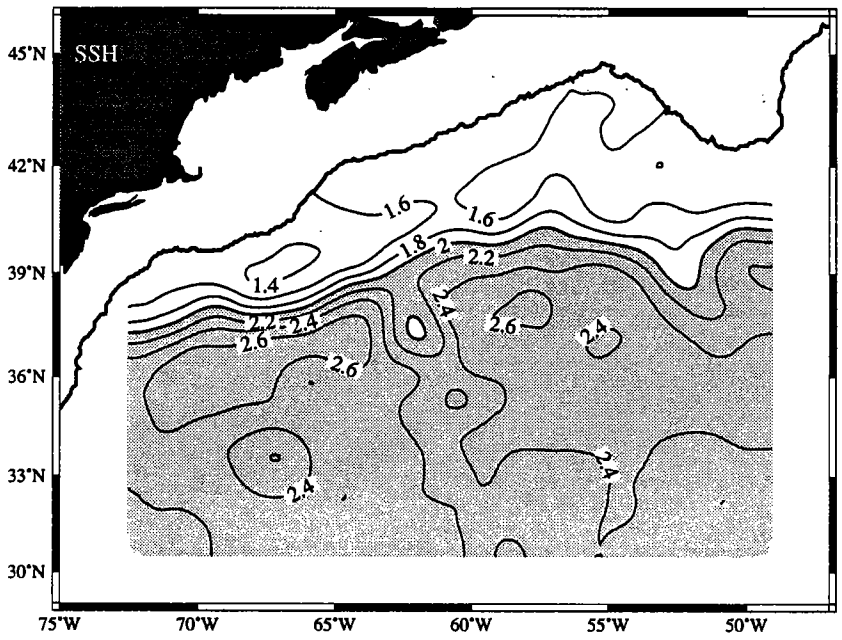


Figure 55: February 1989



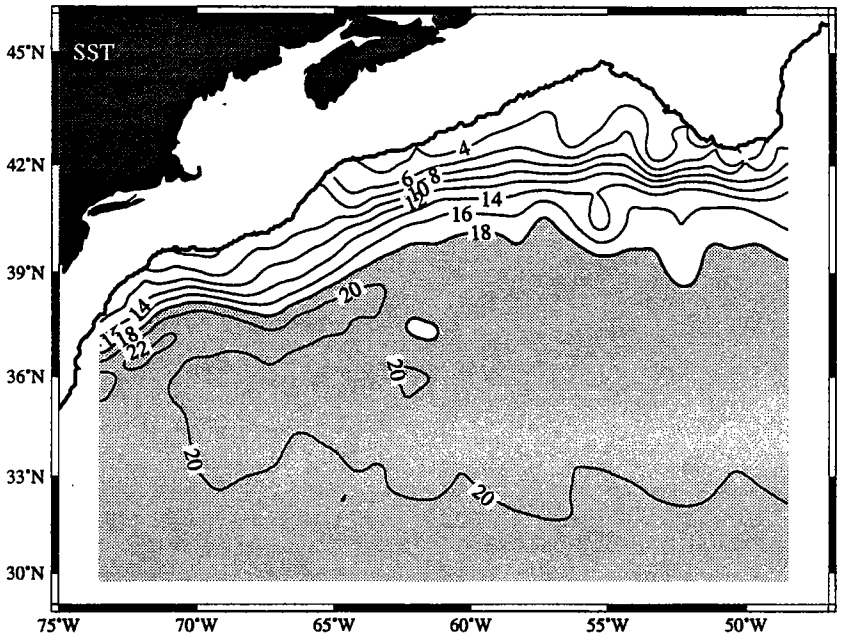


Figure 56: February 1989

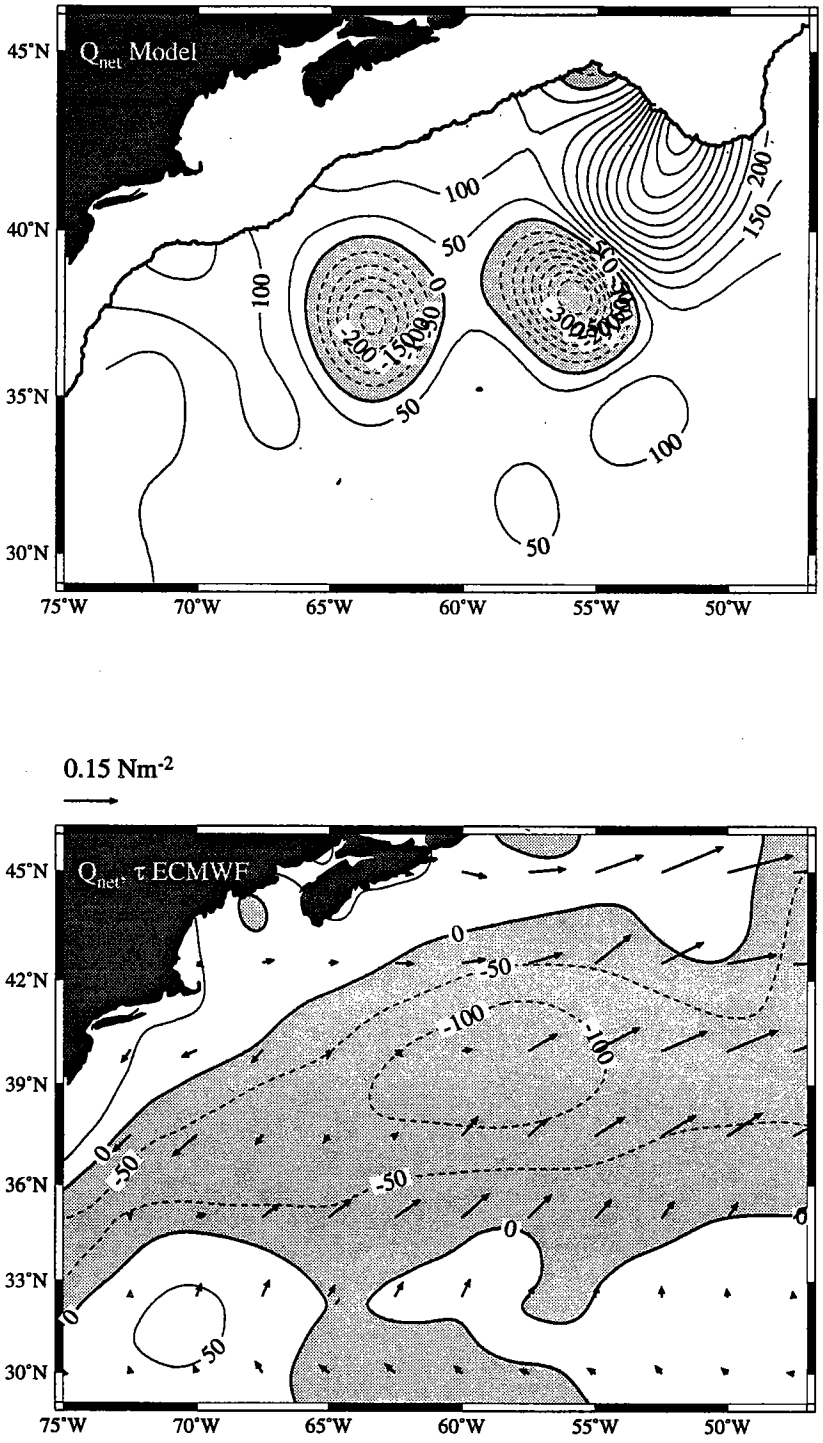
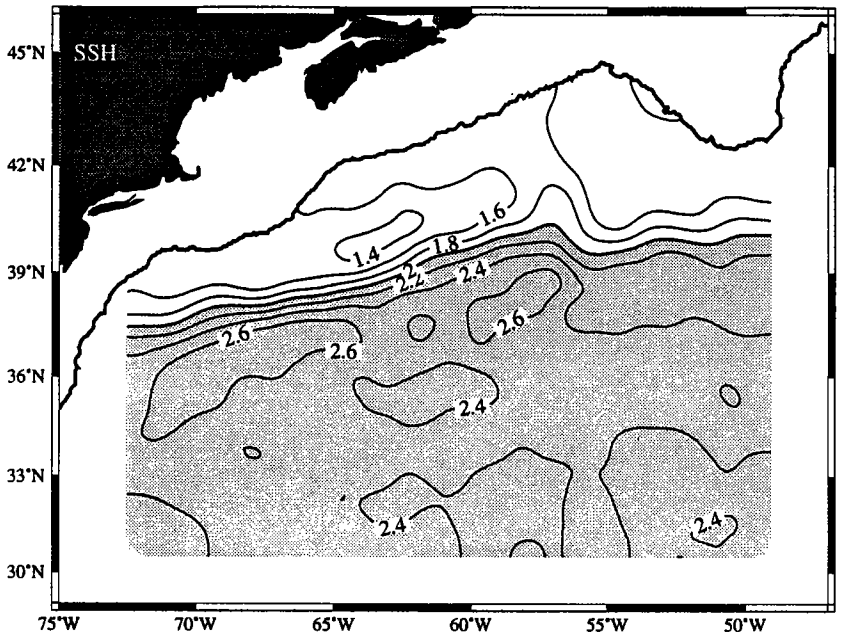


Figure 57: March 1989



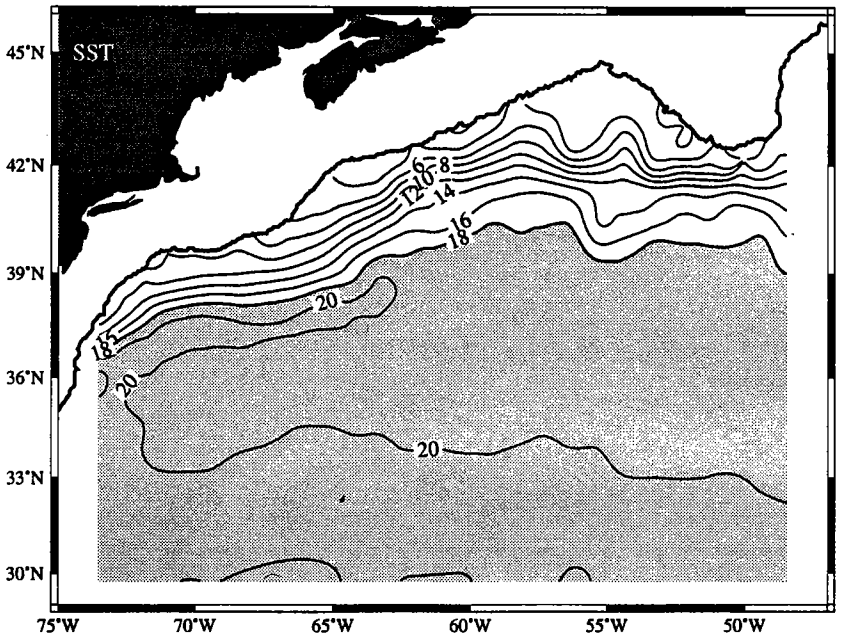


Figure 58: March 1989

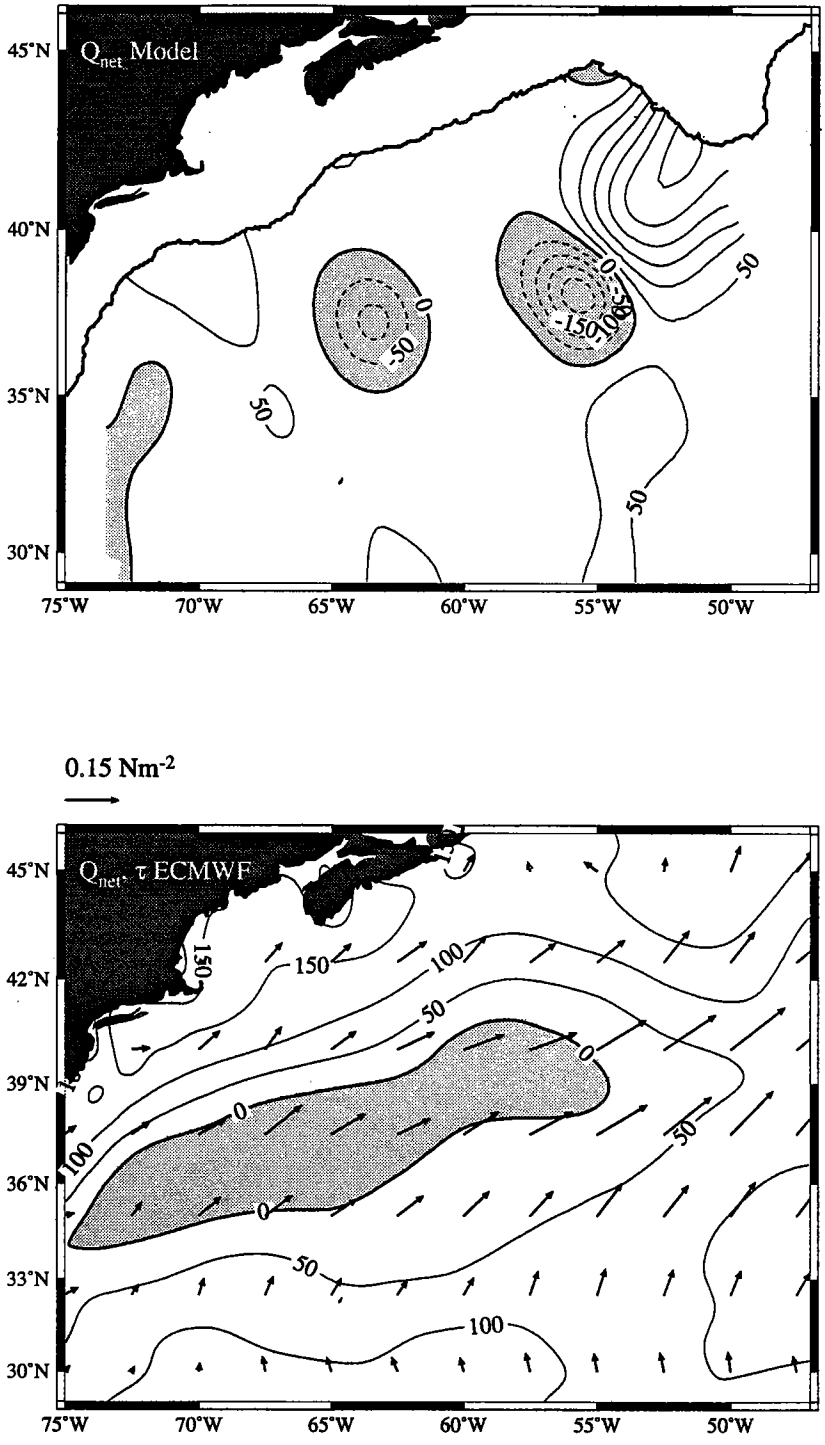
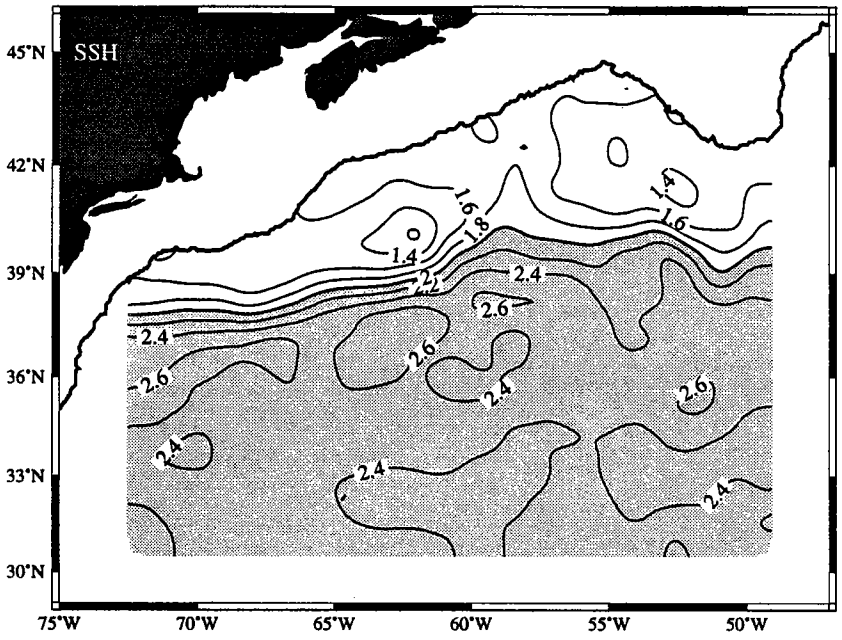


Figure 59: April 1989



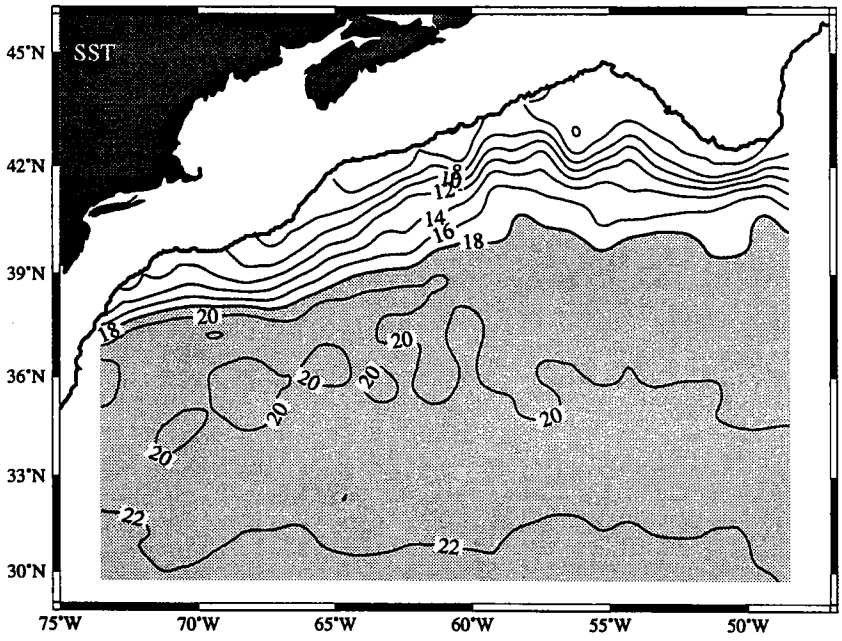


Figure 60: April 1989

DOCUMENT LIBRARY

Distribution List for Technical Report Exchange – May 1995

University of California, San Diego
SIO Library 0175C
9500 Gilman Drive
La Jolla, CA 92093-0175

Hancock Library of Biology & Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

Commander
International Ice Patrol
1082 Shennecossett Road
Groton, CT 06340-6095

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Research Library
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Institute of Geophysics
University of Hawaii
Library Room 252
2525 Correa Road
Honolulu, HI 96822

Marine Resources Information Center
Building E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological Observatory
Columbia University
Palisades, NY z10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Maury Oceanographic Library
Naval Oceanographic Office
Building 1003 South
1002 Balch Blvd.
Stennis Space Center, MS, 39522-5001

Library
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. V8L 4B2
CANADA

Library
Institute of Oceanographic Sciences
Deacon Laboratory
Wormley, Godalming
Surrey GU8 5UB
UNITED KINGDOM

The Librarian
CSIRO Marine Laboratories
G.P.O. Box 1538
Hobart, Tasmania
AUSTRALIA 7001

Library
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7 RA
UNITED KINGDOM

IFREMER
Centre de Brest
Service Documentation - Publications
BP 70 29280 PLOUZANE
FRANCE

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-95-05	2.	3. Recipient's Accession No.

4. Title and Subtitle
Monthly Atmospheric and Oceanographic Surface Fields for the Western North Atlantic: December, 1986 – April, 1989

5. Report Date
April 1995

6.

7. Author(s) Michael J. Caruso, Sandipa Singh, Kathryn A. Kelly and Bo Qiu

8. Performing Organization Rept. No.
WHOI-95-05

9. Performing Organization Name and Address

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) NA16RC0468-01 (NOAA)
(G) NAGW-1666

12. Sponsoring Organization Name and Address

The National Oceanic and Atmospheric Administration and the National Aeronautic Space Administration

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes
This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-95-05.

16. Abstract (Limit: 200 words)

Monthly atmospheric and oceanographic variables for the western North Atlantic Ocean from various sources are presented as contour or vector maps. These fields were assembled for a study of the upper ocean heat budget. Atmospheric fields include the net surface heat fluxes and wind stress derived from the 1000 mb winds from the European Centre for Medium-range Weather Forecasting (ECMWF). Oceanographic fields include the sea surface height from the Geosat radar altimeter and sea surface temperature from the Advanced Very High Resolution Radiometer (AVHRR). An additional estimate of net surface heat flux is shown; this estimate was derived by assimilating winds, currents and ocean temperatures into a mixed layer model. The maps show a complex interplay of fluctuations in the winds and heat fluxes, and in the structure and temperature gradients of the Gulf Stream system. Some comments are offered on a comparison of the two heat flux estimates.

17. Document Analysis a. Descriptors
heat flux
sea surface height
wind stress

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Approved for public release; distribution unlimited.	UNCLASSIFIED	75
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce