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Creation and Modification of 1/8° and 1/16° Subtropical Gyre Atlantic Topographies

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13. ABSTRACT *(Maximum 200 words)*

This report describes the development of the 1/16° Subtropical Gyre (STG) Atlantic topography used in the Naval Research Laboratory (NRL) Layered Ocean Model (NLOM). This topography is a version of the Earth Topography 5-minute (ETOP05) dataset that has been modified using maps from the National Imagery and Mapping Agency (NIMA), the Times (London) Atlas, and personal contacts. Comparisons are made between the pure ETOP05 dataset and the modified 1/8° and 1/16° versions of the STG Atlantic topographies. Actual and model coastlines (i.e., the 200-m isobath) from the final topography are more representative of this region, especially in the passages of the Lesser Antilles. Close examination of the coastlines at 1/16° resolution highlighted areas at 1/8° resolution that needed improvements. These were retrofitted into existing 1/8° topographies.

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CREATION AND MODIFICATION OF 1/8° AND 1/16° SUBTROPICAL GYRE ATLANTIC TOPOGRAPHIES

1.0 INTRODUCTION

The Subtropical Gyre (STG) Atlantic topography encompasses a region from 98° W to 8° W and 9° N to 47° N (Fig. 1). This domain includes the Sargasso Sea and the Intra-Americas Sea, which contains the Gulf of Mexico, the Caribbean Sea, and adjacent waters. A major western boundary current, which is part of the Gulf Stream system, passes through these marginal and semi-enclosed seas. In the tropical Atlantic, the western boundary current begins where the North Brazil Current (NBC) and the North Equatorial Current (NEC) enter the Caribbean Sea through the passages of the Lesser Antilles (Fig. 2a). Once in the Caribbean, the NBC and NEC merge and continue as the Caribbean Current, which becomes the Yucatan Current as it flows between the Yucatan peninsula and Cuba. As the Yucatan Current enters the Gulf of Mexico, it becomes the Loop Current and bends east, periodically shedding Loop Current eddies, as it feeds the Florida Current, which flows around the Florida peninsula to the south and then to the east. The Florida Current, continuing northward just off the east coast of the United States, separates from the coast at Cape Hatteras and becomes the Gulf Stream, and further downstream the Gulf Stream Extension.

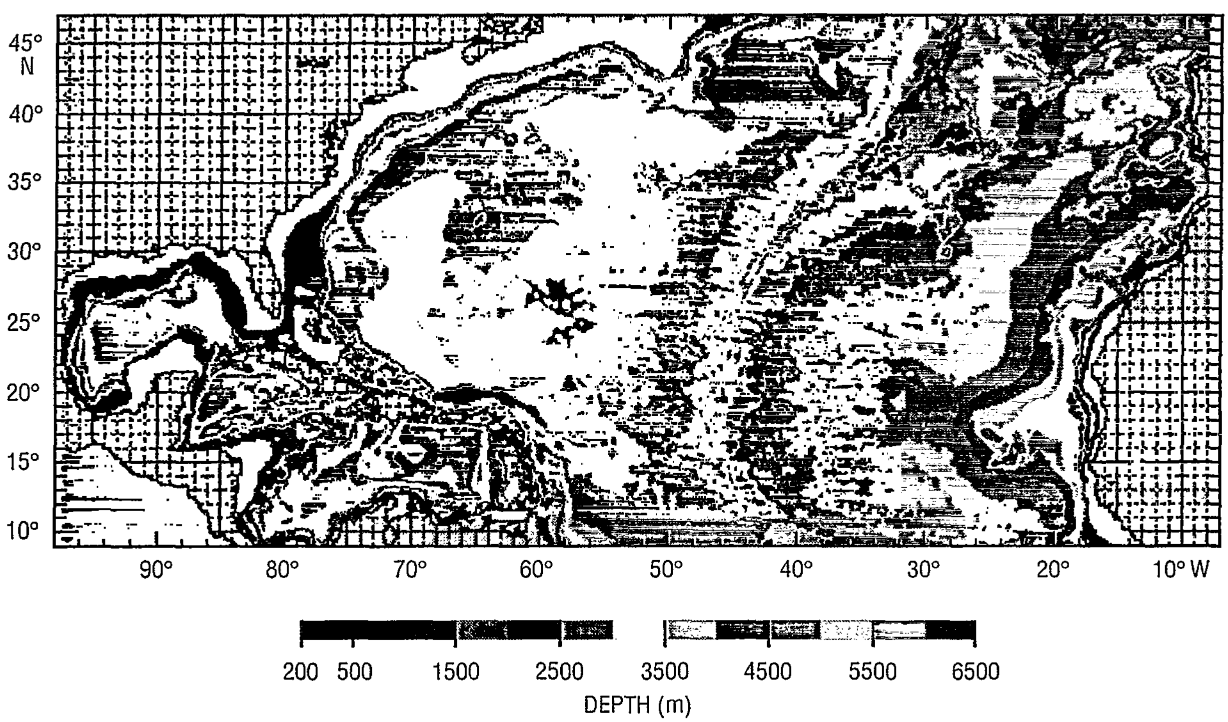

Fig. 1 — Current 1/16° STG Atlantic Ocean model topography that has been smoothed twice by a 9-point real smoother

Accurate coastline geometry and sill depths (Fig. 2, Table 1) are critical for successful modeling of flow through the Caribbean Sea and Bahama passages. This is well demonstrated in Hurlburt and Townsend (1994) where geometry changes in the Intra-Americas Sea region are shown to influence the strength of the transports through these passages in the 1/4° Naval Research Laboratory (NRL) Layered Ocean Model (NLOM) of the Atlantic north of 20° S, forced with the Hellerman-Rosenstein (1983) monthly mean wind stress climatology. Figure 3a shows that the model using an interpolated version of the Earth Topography 5-minute (ETOP05) dataset (National Oceanic and Atmospheric

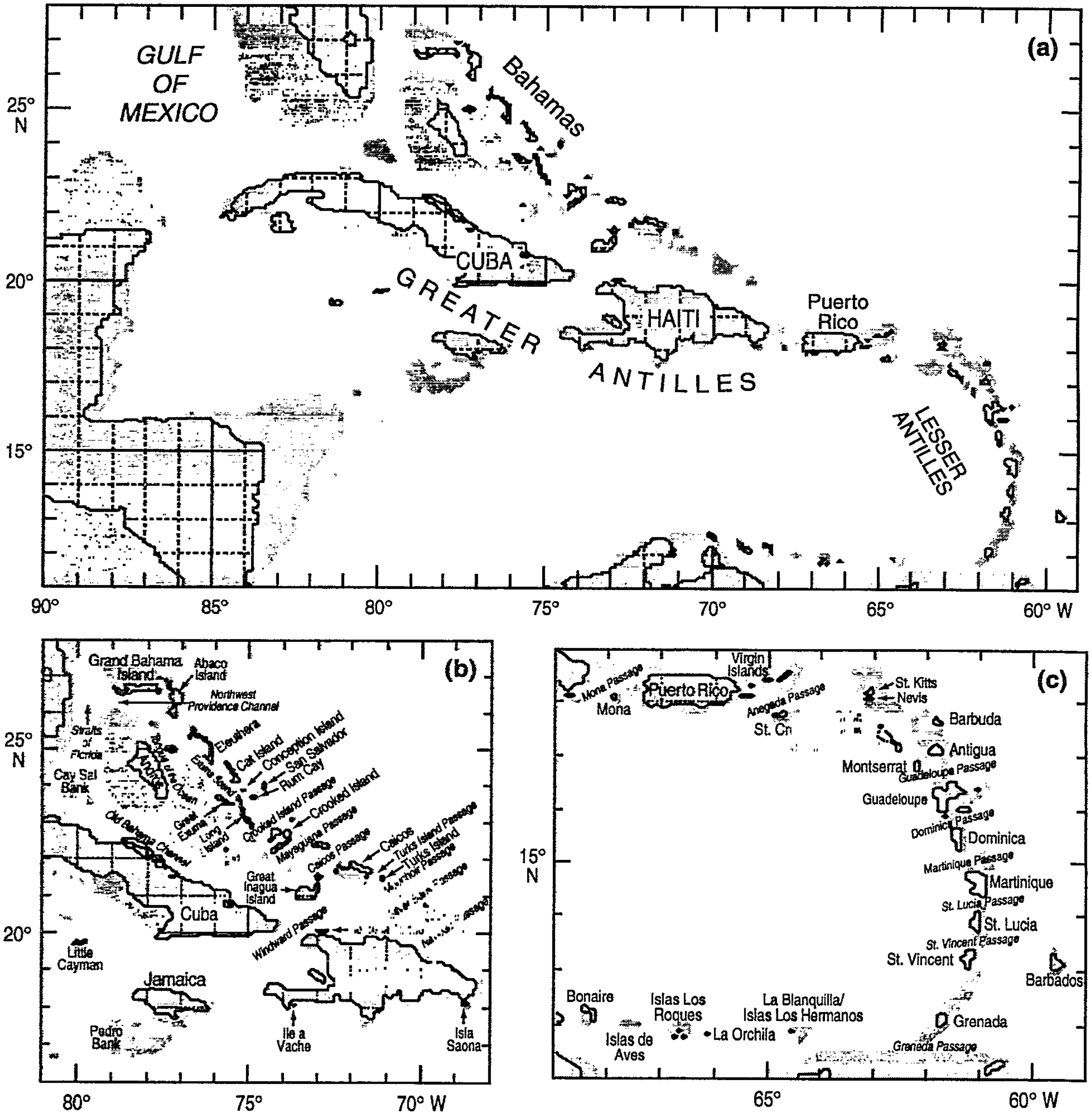

Fig. 2 — Geography of (a) a portion of the Intra-Americas Sea plotted on the 1/16° NLOM grid, (b) the Bahamas, and (c) the eastern Caribbean islands plotted on the 1/16° NLOM grid

Table 1 — Comparison of Sill Depths for the NA673E, NA673E2 (smoothed), ETOP05, and NIMA Chart Topographies for the Subtropical Atlantic

STRAIT	ETOP05	NIMA/OTHER	NA673E	NA673E2
Anegada Passage	1923	1910 Stalcup (1973)	1526	1452
Caicos Passage	2023	2219 NIMA #26260	2149	2143
Crooked Island Passage	1787	2200 NIMA #26240	1817	1728
Dominica Passage	580	1250 D. Wilson (1996) pers. comm.	505	522
Florida Straits	593	430 (at 27.6° N) NIMA #27005	565	545
Grenada Passage	511	740 Stalcup (1971)	444	455
Guadeloupe Passage	495	800 D. Wilson (1996) pers. comm	444	565
Mona Passage	545	370 NIMA #25700	503	492
Northwest Providence Channel	546	660 NIMA #26320	538	515
Old Bahama Channel	293	508 NIMA #27060	284	282
St. Lucia Channel	855	980 Stalcup (1971)	819	984
St. Vincent Passage	541	890 Stalcup (1971)	629	782
Silver Bank Passage	2564	3572 NIMA #25720	2719	2636
Windward Passage	2061	1560 Metcalf (1976)	2134	2142

Administration 1986) simulates an accurate Florida Current transport of 32.2 Sv (1 Sv = 10^6 m^3/s) at 27° N as compared to the 32.2 Sv mean transport determined from cable voltage measurements (Larsen and Sanford 1985). However, the ETOP05 dataset does not accurately represent the Bahamas geometry; most notably the 200-m isobath for the southern portion of the Tongue of the Ocean and Exuma Sound (compare Figs. 2b and 3a).

The first set of geometry changes include closing Exuma Sound and the Tongue of the Ocean and improving Puerto Rico's coastline and the passages of the Lesser Antilles. Exuma Sound and Tongue of the Ocean are closed because 1/4° resolution is not fine enough to properly resolve them.

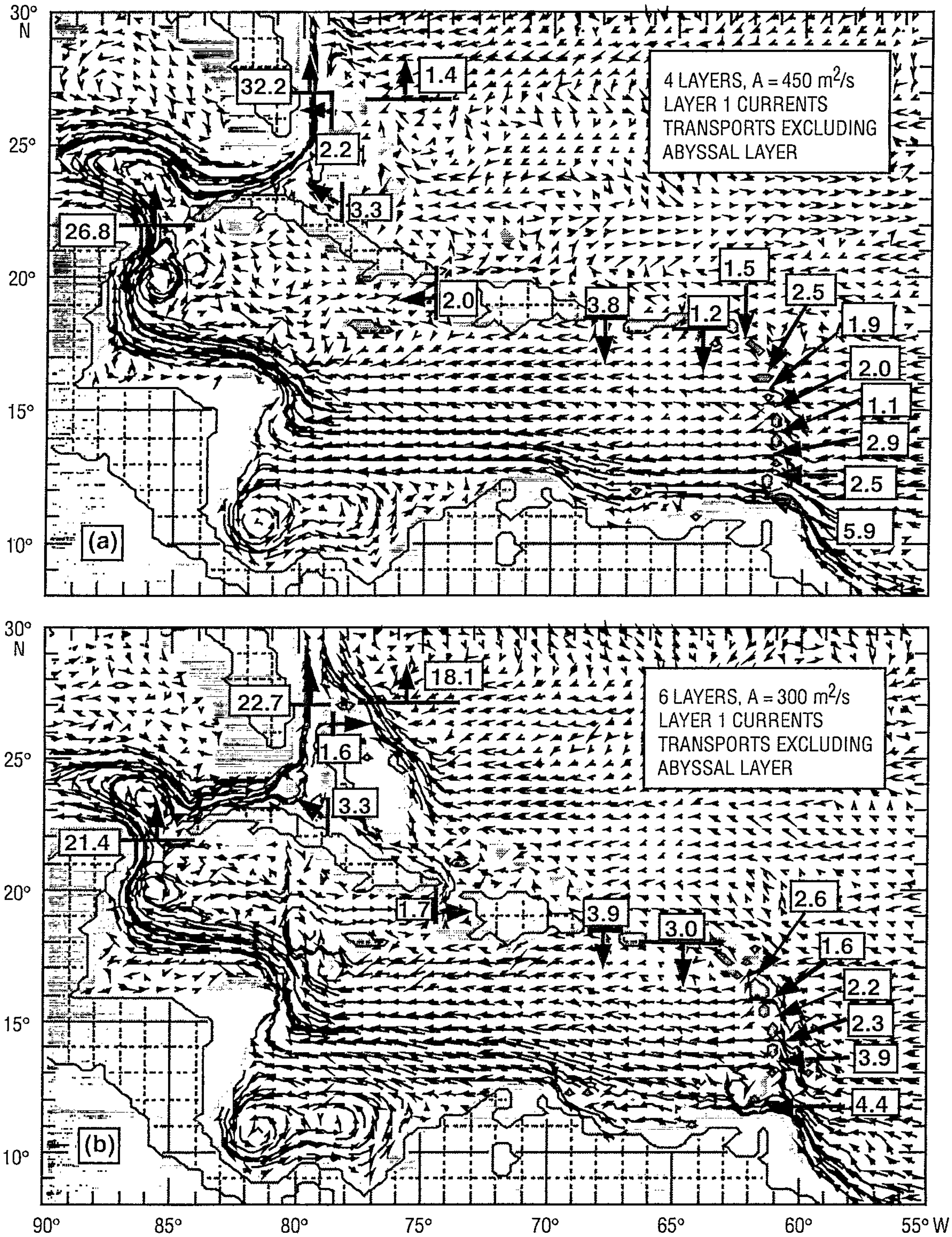

Fig. 3 — Mean currents and transports in the Intra-Americas Sea region from the 1/4° NLOM of the Atlantic, north of 20° S, with the model boundary that is (a) based purely on ETOP05 data and (b) same as in 3a with modifications to Exuma Sound, Tongue of the Ocean, and Puerto Rico

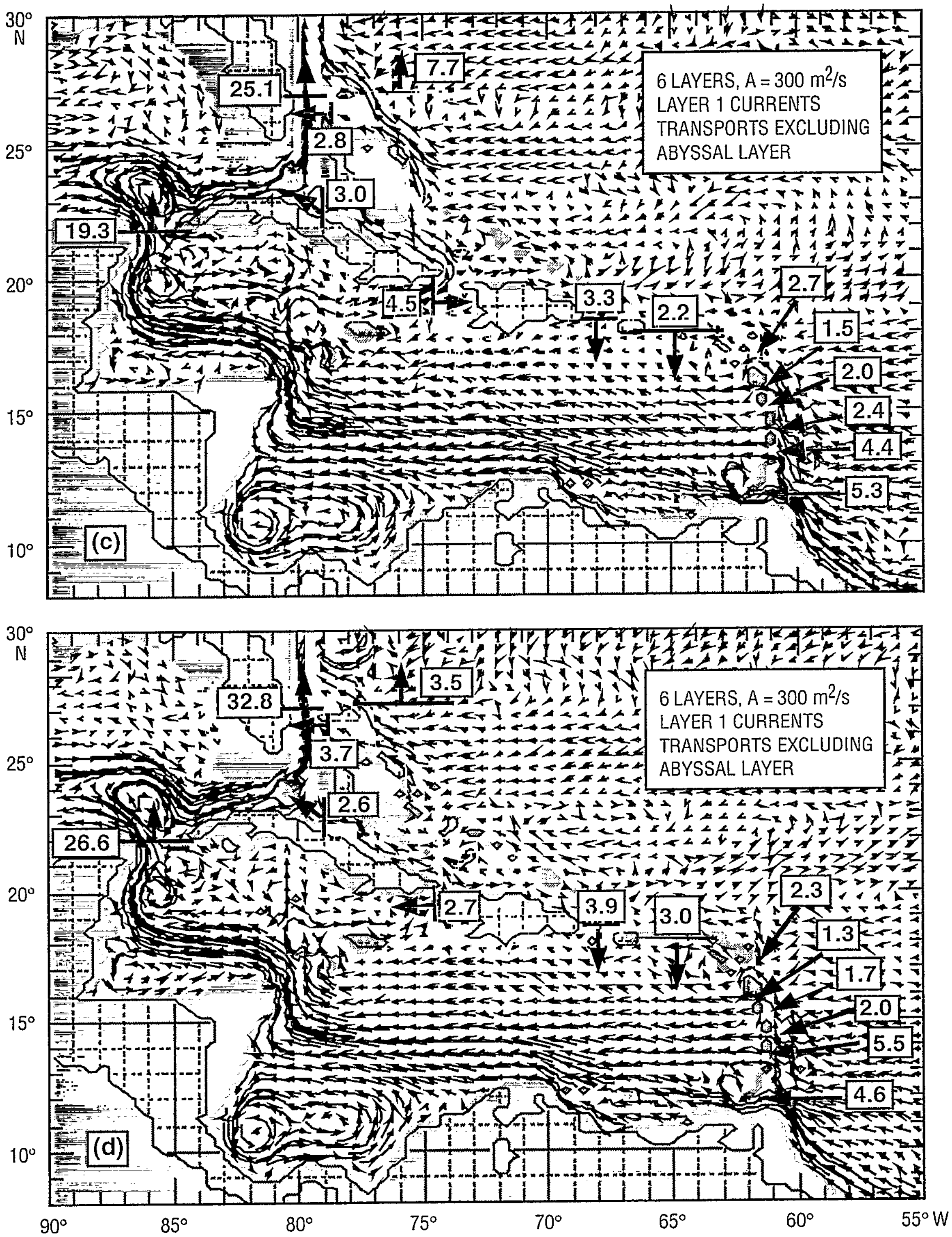

Fig. 3 — (cont.) (c) Same as in 3b with modifications to the eastern coast of Florida and (d) same as in 3c with modifications to area between Windward Passage and the Bahamas (from Hurlburt and Townsend 1994)

These topographic changes and a change in the NLOM's vertical mixing scheme result in a weaker Florida Current transport of 22.7 Sv (Fig. 3b). Part of this decrease is due to an unrealistic reversal of the flow through Northwest Providence Channel to the east at a rate of 1.6 Sv.

The next modification is an improvement to the gridded 200-m isobath along eastern Florida based on observational evidence (Johns, pers. comm.). This corrects the direction of the flow through Northwest Providence Channel so that it now travels westward at a rate of 2.8 Sv (Fig. 3c). The result of this correction is an increase in the Florida Current transport to 25.1 Sv, which is still low in comparison to the cable data. The same is true for the Yucatan Channel transport (19.3 Sv).

The last set of modifications are additional refinements to the area between Windward Passage and the Bahamas using National Imagery and Mapping Agency (NIMA, formerly Defense Mapping Agency) maps. These refinements include the addition of San Salvador, Rum Cay, Cat Island, and Mona Island and the improvement of the islands and banks north of Haiti and the islands of the Great and Little Bahama Banks. These changes to the 1/4° model geometry produce a more realistic Yucatan Channel transport (26.6 Sv) and Florida Current transport (32.8 Sv) (Fig. 3d).

2.0 HISTORY OF THE 1/8° GLOBAL TOPOGRAPHY

For topographic consistency between various models of the same resolution, all basin-scale model topographies are subsets of the global model topography. The history of the STG Atlantic topography, therefore, starts with the 1/8° latitude by 45/256° longitude global topography. (After the first reference, each topography will be referred by its latitudinal resolution only.) Youtsey (1993) documents the history of the modifications to the first 1/8° global topography used in the NLOM. The topography in Youtsey (1993) is based on ETOP05 data (National Oceanic and Atmospheric Administration 1986) and the model land/sea boundary is at the 200-m isobath with a few exceptions; specifically, in the Gulf of Mexico where the 50-m isobath is used, except along Campeche Bank where the 100-m isobath is used. Hurlburt and Thompson (1980) show that these modifications to the model land/sea boundary result in observed northward penetration of the Loop Current and shedding of Loop Current eddies in the NLOM.

Since Youtsey (1993), several regions in the 1/8° global topography have been modified based on NIMA maps, the Times (London) Atlas (1991), and personal contacts. In particular, the areas in STG Atlantic and the Sea of Japan inflow/outflow passages have had significant modifications. These changes include:

STG Atlantic:

- added features:
  - Brown Bank
  - Cayman Islands
  - Conception Island
  - Diana Bank
  - Grand Cayman
  - Hogsty Reef
  - Little Inagua Island
  - San Salvador
- improved features:
  - area around Haiti
  - Campeche Bank
  - Crooked Island
  - Great Inagua Island
  - Mona Passage
  - Navidad Bank

— east Florida coastline
— entrance to Tongue of the Ocean
— Great Bahama Bank
– St. Vincent Passage
– Silver Bank

Sea of Japan:

• improved features:

— Soya Strait
— Tsugaru Strait
– Tsushima Strait

The 1/8° global topography from which the development of the 1/16° STG Atlantic topography begins is known as top117d.

3.0 HISTORY OF THE 1/16° STG ATLANTIC TOPOGRAPHY

The creation of the 1/16° latitude by 45/512° longitude STG Atlantic topography begins with the extraction of a 1/8° version from the most up-to-date global topography. Figures 6d–11d show the original 1/8° STG Atlantic topography extracted from the global topography. Figures 6–15 provide a comparison of model coastlines (200-m isobath) and depths between the topographic versions discussed here.

To preserve the coastline, the next step is to create a 1/16° STG Atlantic topography (top673a) from the 1/8° version (top672a) with software that exactly doubles the resolution of a topographic dataset. This software determines whether an interpolated point is land or sea by the four surrounding points. If two or more of the surrounding points are ocean, the interpolated value will be an ocean point, thus maximizing ocean points by favoring ocean over land. The interpolation code has two side-effects: (1) "stair-stepping," which occurs when the original diagonal coastline is interpolated into a jagged diagonal coastline (compare Eleuthera Island at 76.5° W, 25.2° N or Great Exuma Island at 76.3° W, 23.7° N in Figs. 4 and 7d) and (2) the translation of a diagonal strip of land into two or more sections of land with artificial passages between them (compare Figs. 5 and 9d in the area near 17.4° N, 63° W). Because of these two problems with the software and the fact that additional topographic features can be resolved at higher resolutions, hand-editing is necessary. Even though the side effects are important to correct, these occurrences are few and do not diminish the benefits of this software.

Next, a second 1/16° topography (top673b) covering the same region is extracted from ETOP05 using the bathymetric extraction software described in Youtsey and Woodyard (1993). A topography based purely on ETOP05 is not used because of serious discrepancies in the ETOP05 dataset, especially in shallow regions (see Tongue of the Ocean, Fig. 7b). Figures 6b–15b are based exclusively on ETOP05.

The 1/16° topography interpolated from the 1/8° version (top673a) and the 1/16° topography interpolated from ETOP05 (top673b) are then merged (top673c). To preserve the hand-edited coastlines from the 1/8° version, ETOP05 depths are used only at points that are considered ocean in both 1/16° topographies.

Finally, the merged topography (top673c) is hand-edited further using the Times Atlas and the NIMA maps listed in Table 2. Two major additions to the topography are the Tongue of the Ocean and Exuma Sound (Fig. 2); it is only at 1/16° resolution that these two features are sufficiently

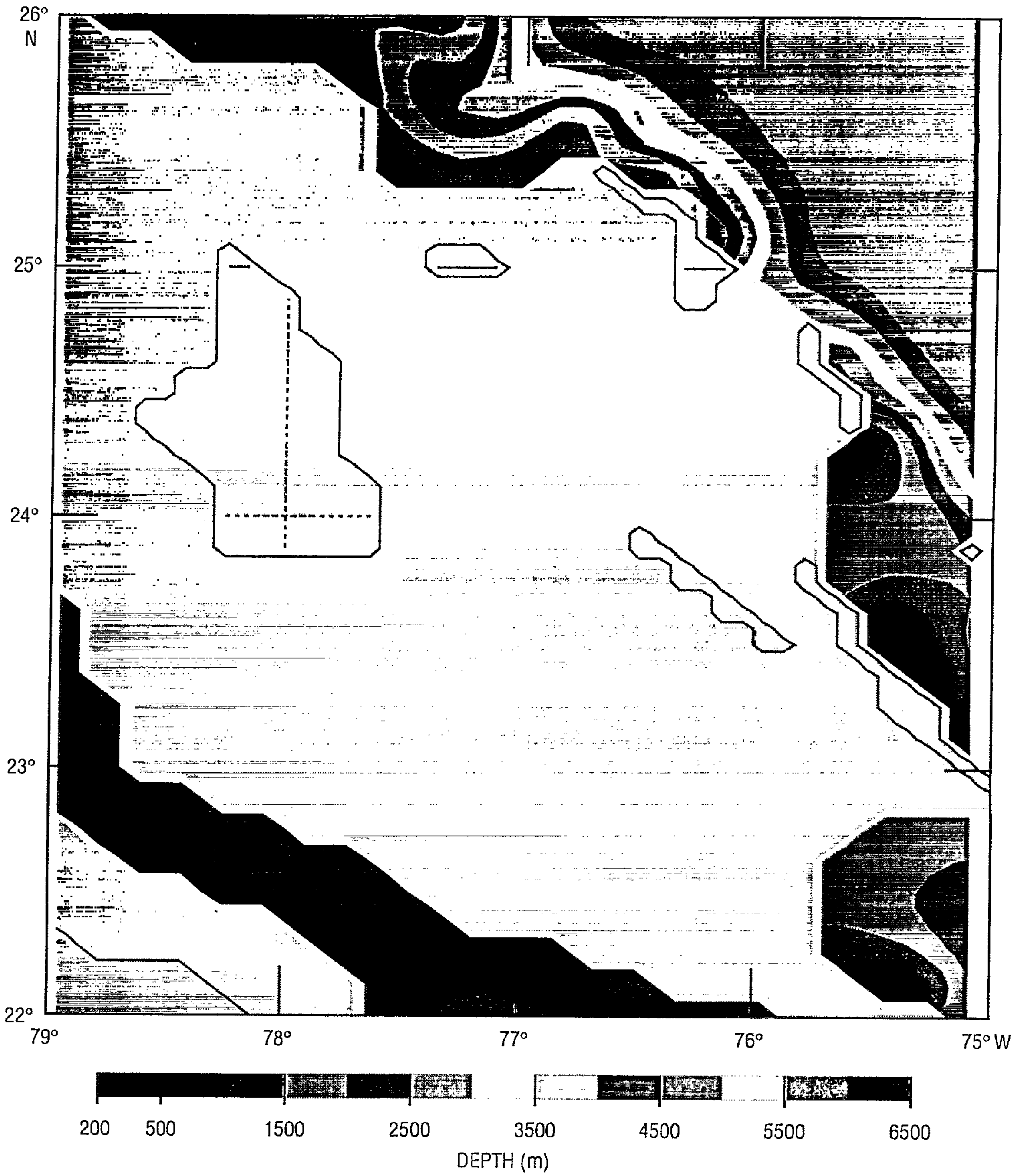

Fig. 4 — Bahamas region from the 1/16° STG Atlantic topography that was interpolated from 1/8° STG Atlantic topography before it was hand-edited. This topography was smoothed with two passes by a 9-point smoother. The west coast of Great Exuma Island (76.3° W, 23.7° N) shows the "stair-stepping" artifact of the interpolation code.

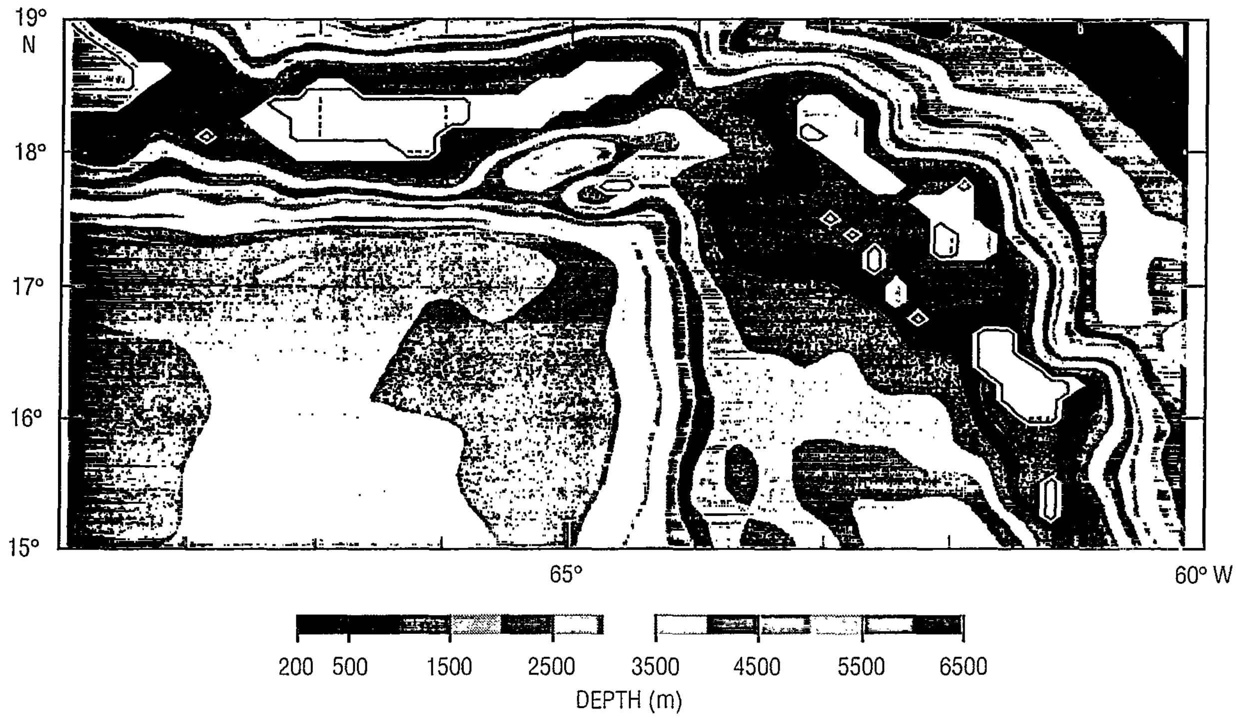

Fig. 5 — The northeastern portion of the Caribbean Sea from the 1/16° STG Atlantic topography that was interpolated from 1/8° STG Atlantic topography before it was hand-edited. This topography was smoothed with two passes by a 9-point smoother. The area west of Antigua and Barbuda (63° W, 17.4° N) is an example of the problem in which two or more islands result when interpolating a diagonal strip of land.

resolved to warrant inclusion. Another significant modification is made off the southwest coast of Florida. Sirkes and Anantharaj (pers. comm.) provided National Oceanic Service (NOS) data (National Oceanic Service 1994), which shows a different 200-m shelf break near 83° W, 25° N compared to ETOP05 (compare Figs. 7a and b). Because of possible effects on the Loop Current eddy shedding in the Gulf of Mexico, the more accurate NOS data are used.

The following is a complete list of modifications to the 1/16° STG Atlantic topography:

• added features:

— banks south of Cuba
— Exuma Sound
— Ile a Vache
— Ile de la Gonave
— Isla de la Tortue
— Isla Saona
— Islas Las Aves
– Little Cayman
– Little Inagua Island
– La Orchila Island
– Mira Por Vos Passage
– Saba Bank
– Tongue of the Ocean
– Virgin Islands – Walton Bank

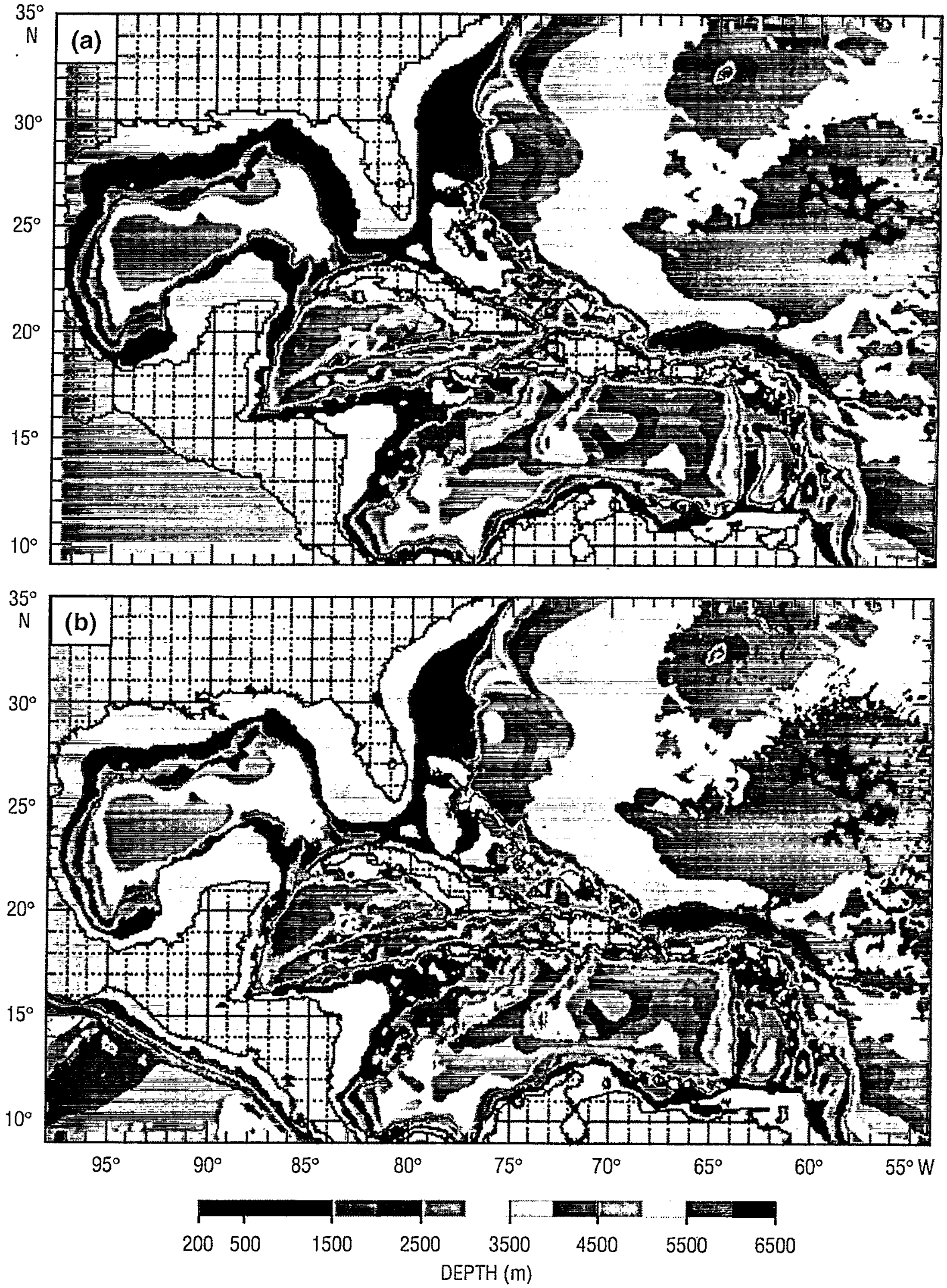

Fig. 6 — Intra-Americas Sea region from (a) the current 1/16° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (b) from 1/12° ETOP05 topography

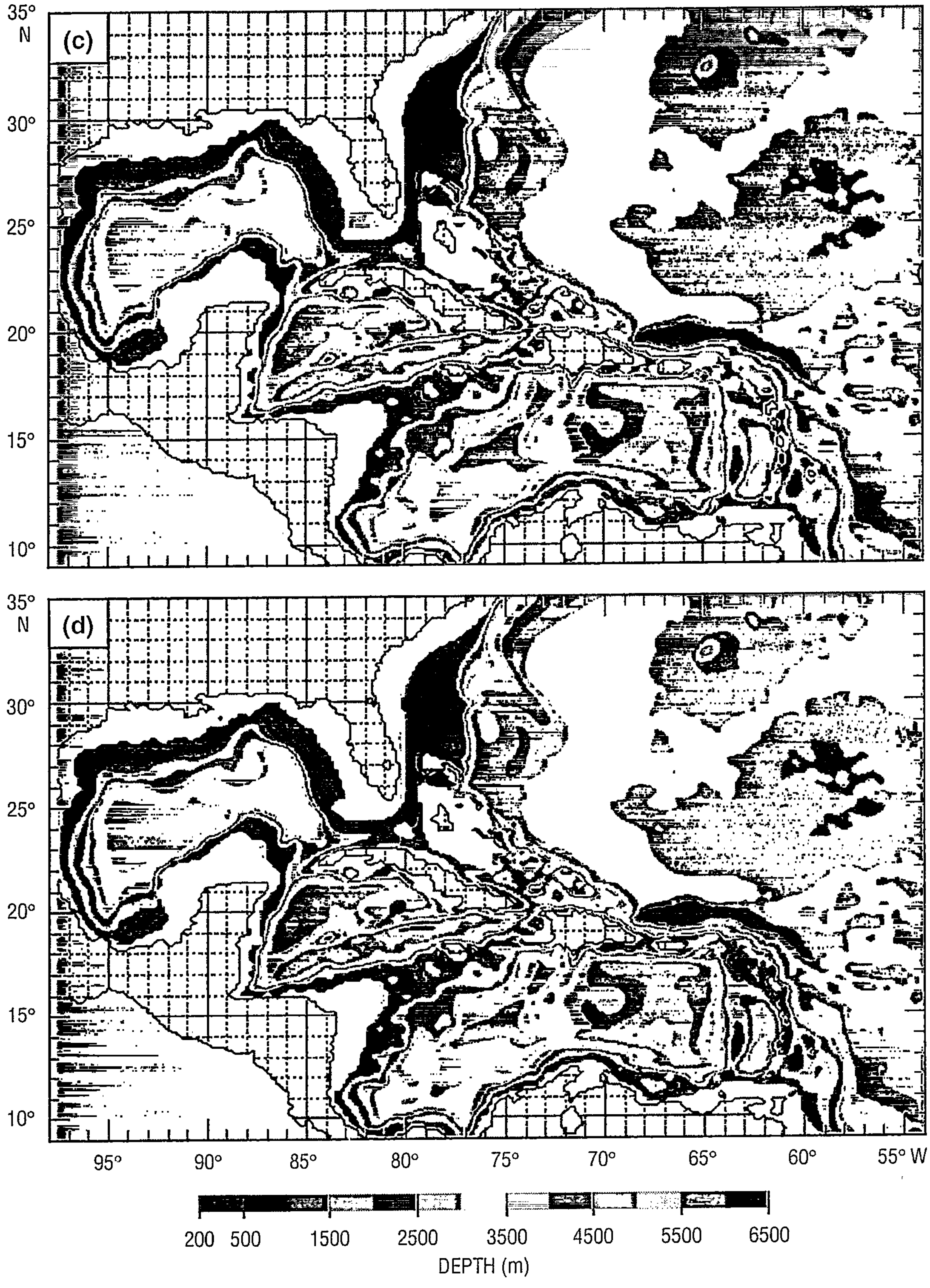

Fig. 6 — (cont.) (c) Intra-Americas Sea region from final version of 1/8° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (d) from the original 1/8° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother

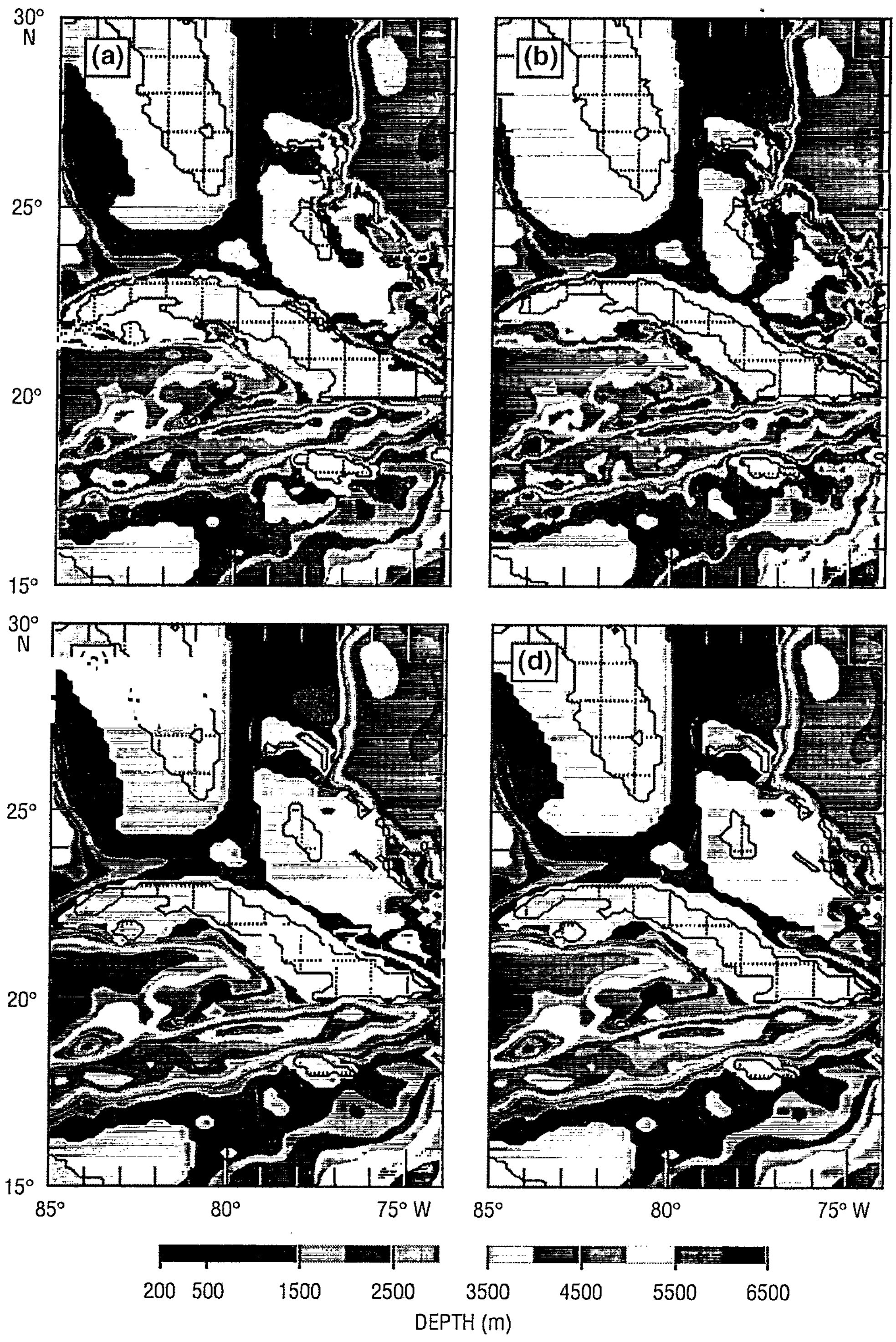

Fig. 7 — Northwest section of Intra-Americas Sea from (a) current 1/16° STG Atlantic topography, (b) original 1/12° ETOP05 topography, (c) current 1/8° STG Atlantic topography, and (d) original 1/8° STG Atlantic topography. (a), (c), and (d) were smoothed by two passes of a 9-point smoother.

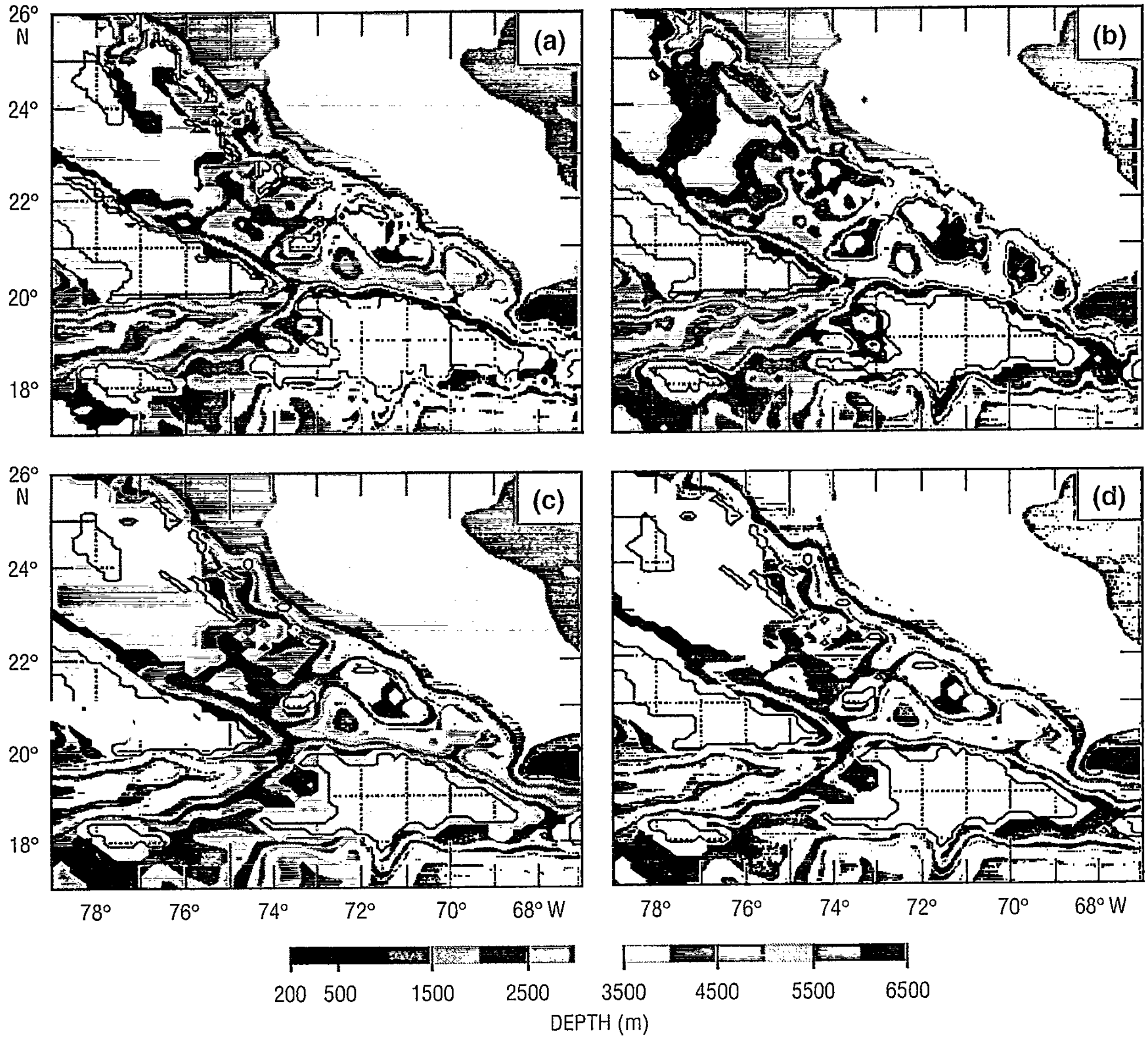

Fig. 8 — Northern section of Intra-Americas Sea from (a) current 1/16° STG Atlantic topography, (b) 1/12° ETOP05 topography, (c) current 1/8° STG Atlantic topography, and (d) original 1/8° STG Atlantic topography. A two-pass, 9-point smoother has been applied to (a), (c), and (d).

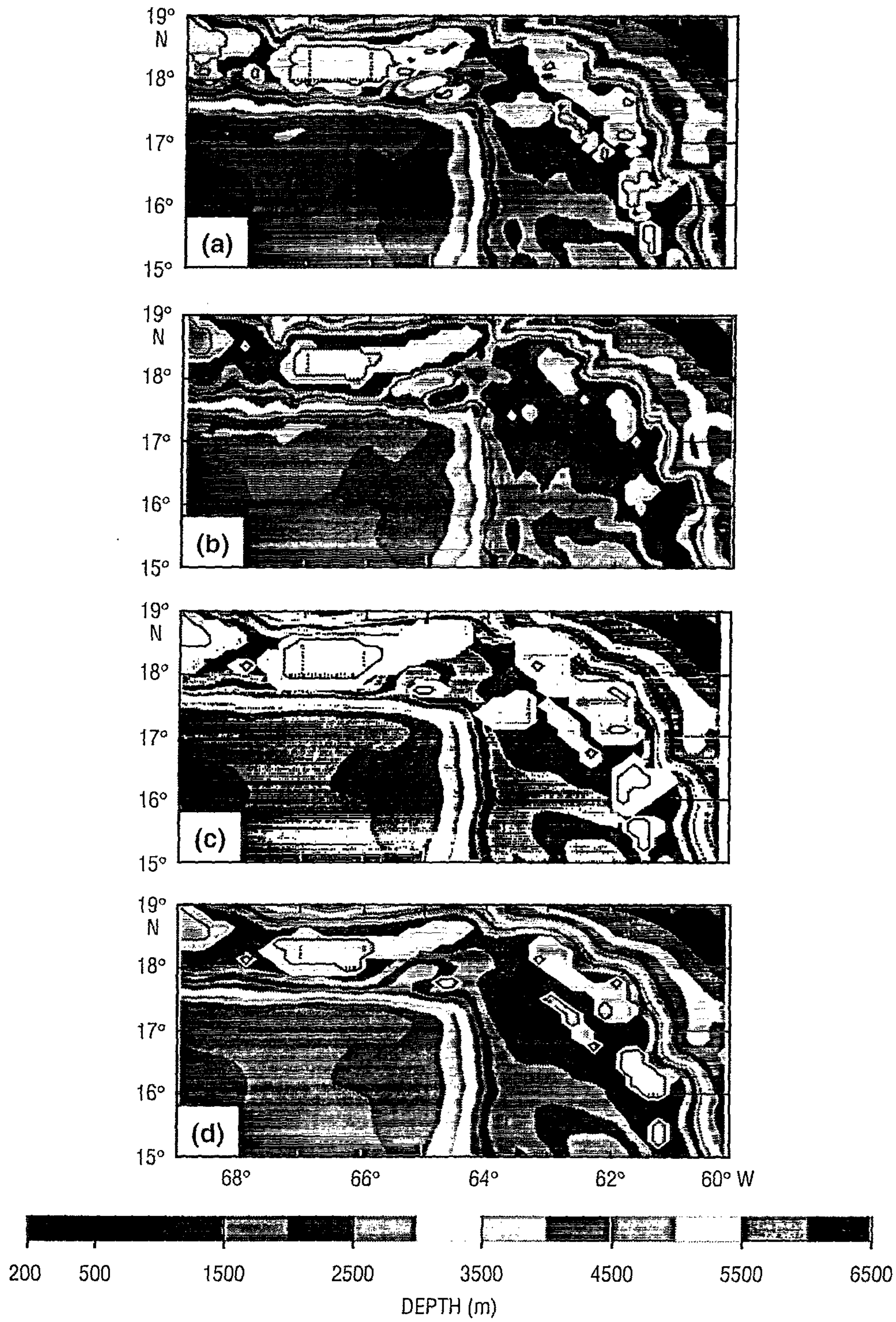

Fig. 9 — Northeast section of Intra-Americas Sea from (a) current 1/16° STG Atlantic topography, (b) 1/12° ETOP05 topography, (c) current 1/8° STG Atlantic topography, and (d) original 1/8° STG Atlantic topography. A two-pass, 9-point smoother has been applied to (a), (c), and (d).

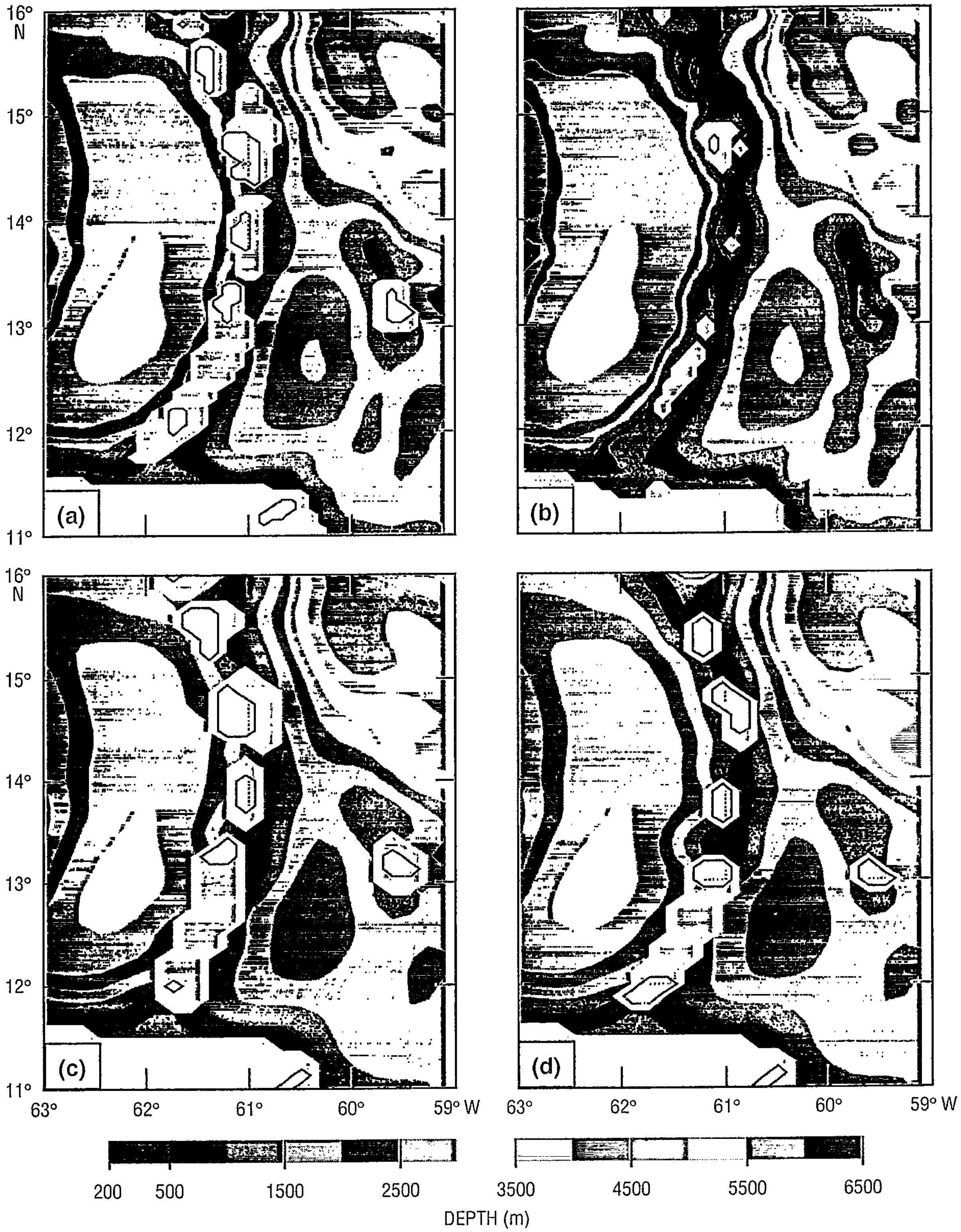

Fig. 10 — Southeast section of Intra-Americas Sea from (a) current 1/16° STG Atlantic topography, (b) 1/12° ETOP05 topography, (c) current 1/8° STG Atlantic topography, and (d) original 1/8° STG Atlantic topography. A two-pass, 9-point smoother has been applied to (a), (c), and (d).

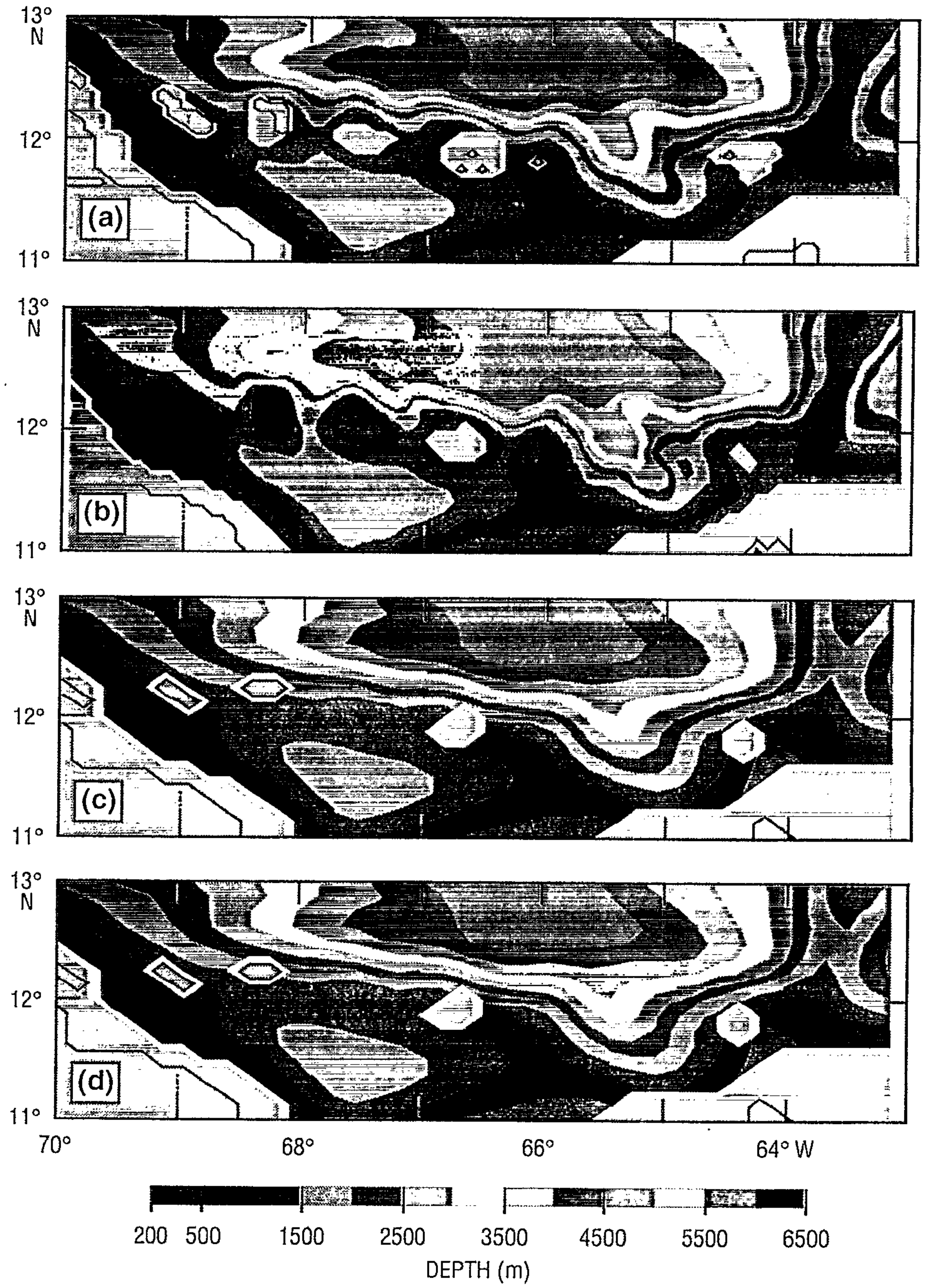

Fig. 11 — Region north of Venezuela from (a) current 1/16° STG Atlantic topography, (b) 1/12° ETOP05 topography, (c) current 1/8° STG Atlantic topography, and (d) original 1/8° STG Atlantic topography. A two-pass, 9-point smoother has been applied to (a), (c), and (d).

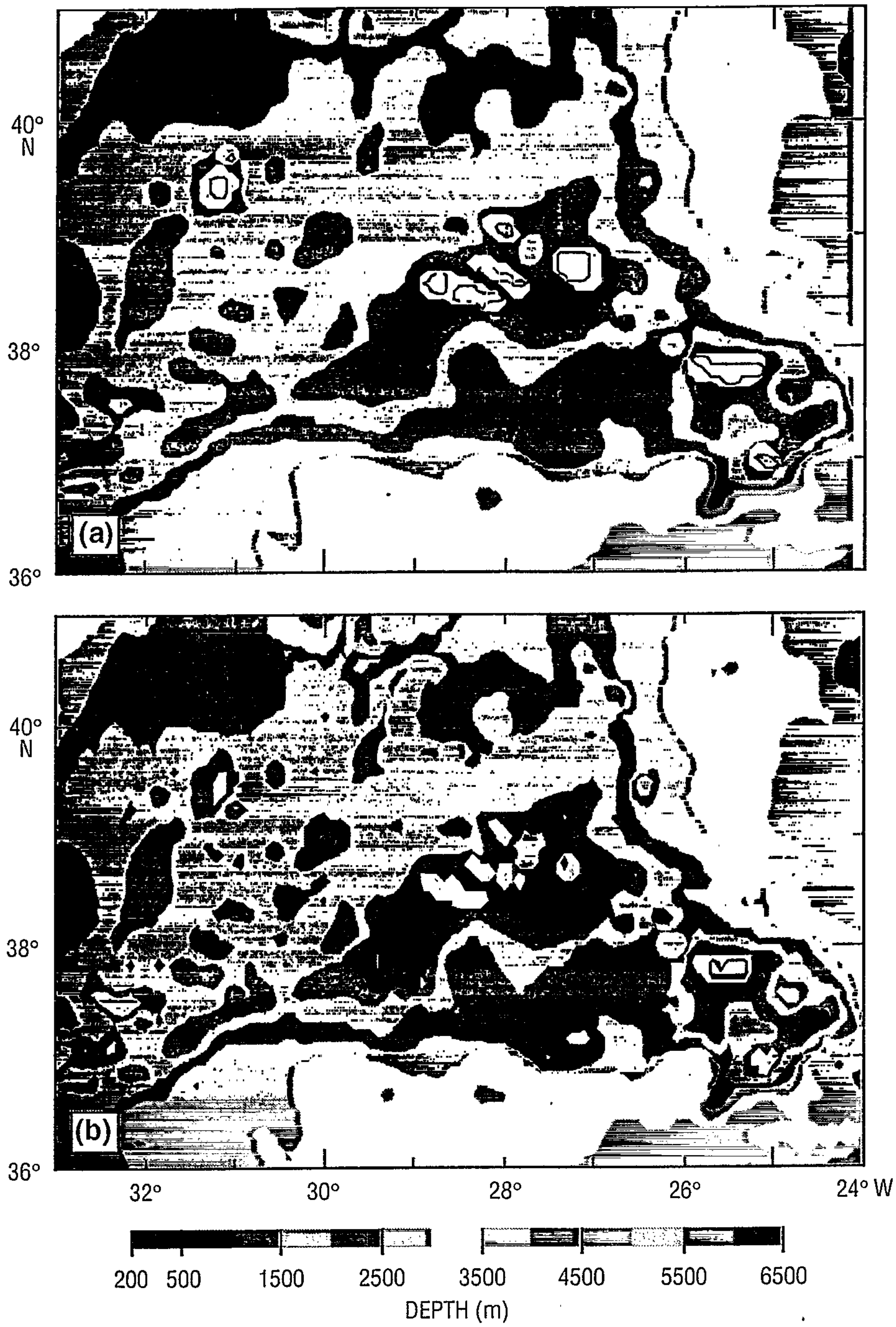

Fig. 12 — Area around the Azores from (a) current 1/16° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (b) 1/12° ETOP05 topography

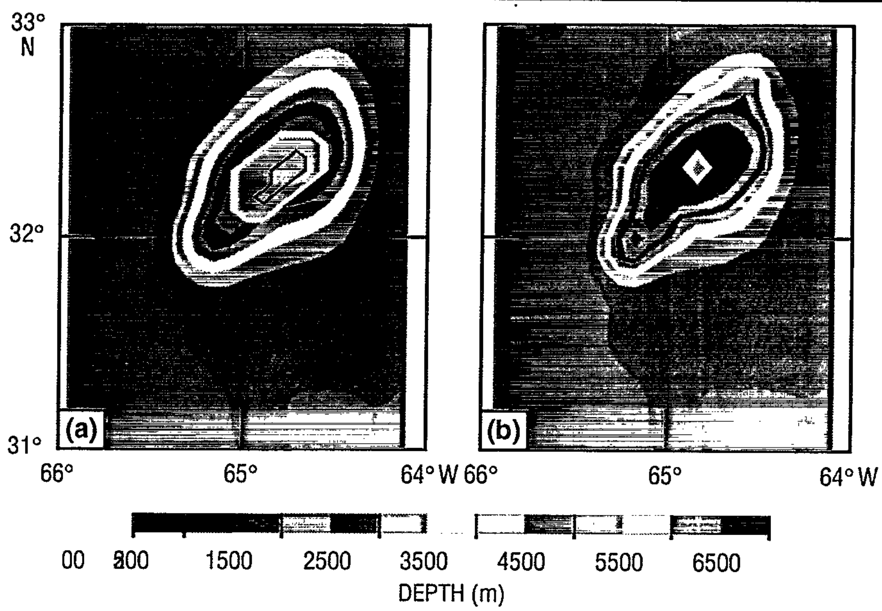

Fig. 13 — Area around Bermuda from (a) current 1/16° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (b) 1/12° ETOP05 topography

- improved features:
  - Abaco Island
  - Andros Island
  - Azores
  - Barbados
  - Bonaire Island
  - Caicos Island and Bank
  - Canary Islands
  - Cape Verde Islands
  - Cat Island
  - Cay Sal Bank
  - Conception Island
  - Crooked Island
  - Cuba
  - Curacao Island
  - Dominica Island and Passage
  - Eleuthera Islands
  - Grand Bahamas Island
  - Grand Cayman
  - Great Exuma Island
  - Grenada Island and Passage
  - Guadeloupe Island and Passage
  - Haiti
  - Isla de Pinos
  - Isla de Margarita
  - Islas Los Hermanoes
  - Islas Los Roques
  - Jamaica
  - La Blaquilla
  - Long Island
  - Mira Por Vos Cays
  - Mona Island and Passage
  - Montserrat Island
  - Mouchoir Bank
  - Old Bahama Channel
  - Pedro Bank
  - Plana Cays
  - Puerto Rico
  - Rum Cay
  - San Salvador Island
  - St. Croix
  - St. Lucia Passage
  - southwest Florida shelf
  - St. Vincent Passage
  - Turks Islands and Passage

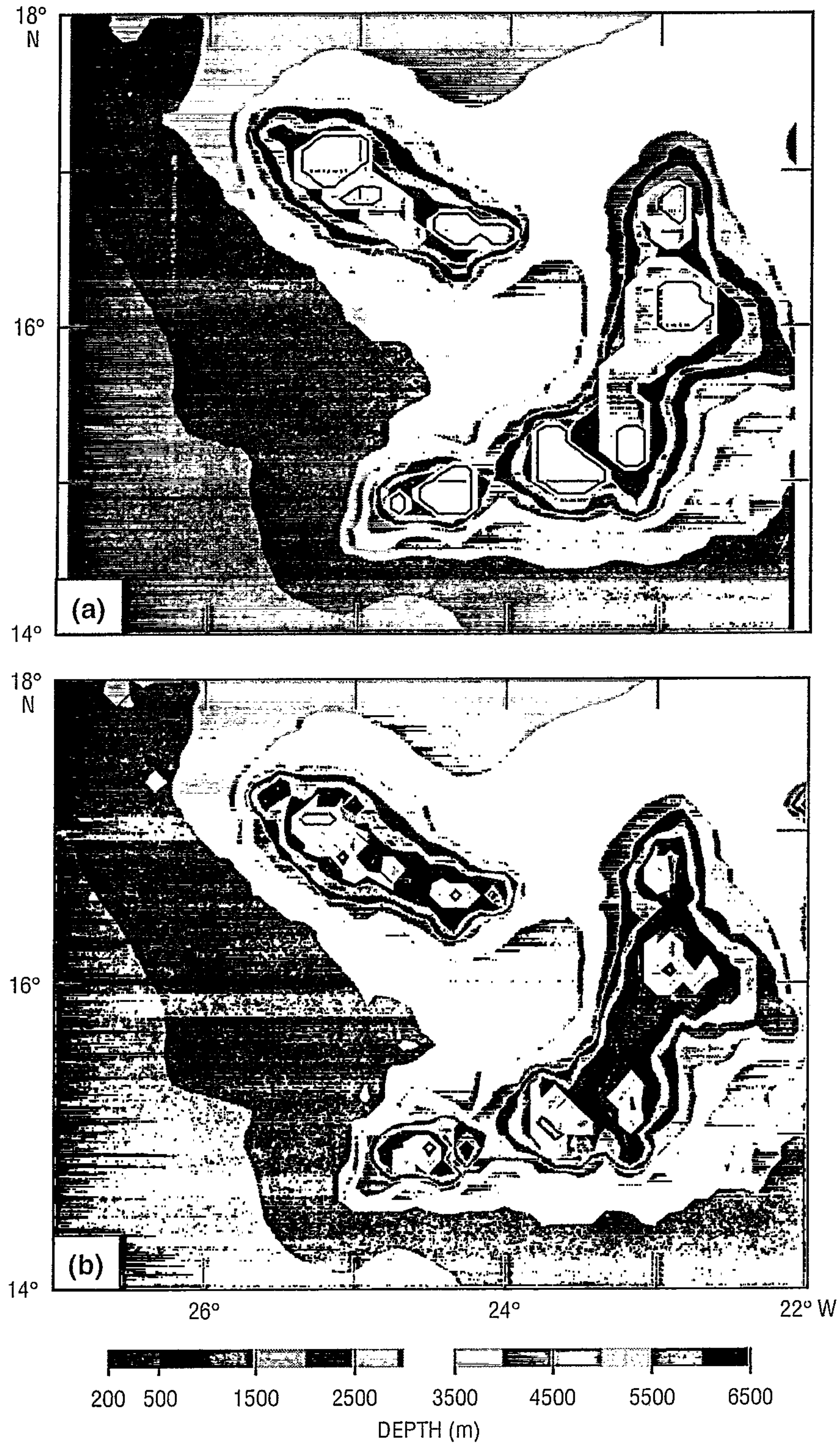

Fig. 14 — Area around the Cape Verde Islands from (a) current 1/16° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (b) 1/12° ETOPO5 topography

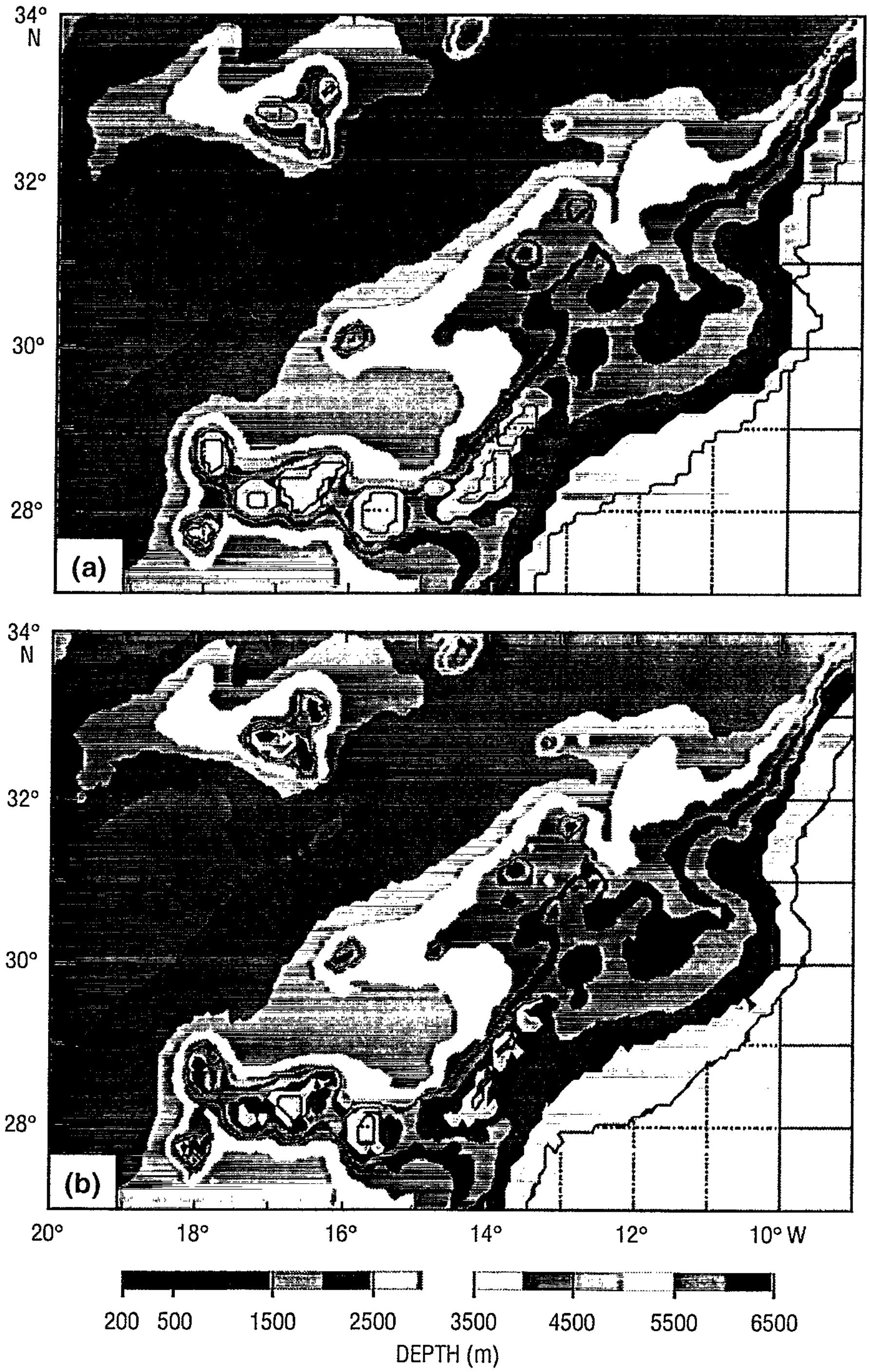

Fig. 15 — Area around the Canary Islands from (a) current 1/16° STG Atlantic topography that has been smoothed by two passes of a 9-point smoother and (b) 1/12° ETOP05 topography

Table 2 — Maps from NIMA Used in Topography Modifications and Sill Depth Comparisons

NIMA STOCK NUMBER	MAP TITLE	REGION
11ACO11013	Straits of Florida and Approaches	Including Cuba and Bahamas
25XCO25001	Caribbean Sea – Eastern Part	Southeastern Haiti, Puerto Rico, Virgin Islands, Leeward Islands, Windward Islands, Northern part of South America
25ACO25700	Mona Passage	Between Dominican Republic and Puerto Rico
25ACO25720	Monte Cristi to Cabo Frances Viejo	Caicos Islands, Turk Islands, Turks Island Passage, Mouchoir Passage, Silver Bank Passage
26ACO26000	Caribbean Sea – Central Part	Southern Cuba, Jamaica, Panama, Western Haiti, Little Inagua Island to Northern Part of South America
26ACO26240	Crooked Island Passage to Cabo Maisi	
26XCO26260	Passages between Acklins Island, Haiti, and Caicos Islands	
26XCO26320	Northern Florida Straits and Northwest Providence Channel	East Coast of Florida, Cuba, Jamaica to Western Puerto Rico
27XCO27005	Key West to San Juan	Southern Florida, Cuba, Jamaica to Western Puerto Rico
27ACO27060	Cayo Lavela to Cayo Verde (OBC)	Santaren Channel, Old Bahama Channel and Andros Island

NIMA Address: National Imagery and Mapping Agency, 4600 Sangamore Road (D-17), Bethesda, MD 20816-5003

In the final 1/16° STG Atlantic topography (top673e), the Lesser Antilles passages are much more narrow than in past 1/8° topographies (compare Figs. 10a, 10d, 11a, and 11d). The orientations of St. Vincent and Martinique passages have also changed significantly. Windward and Mona Passages have become more realistic, and Old Bahama Channel is narrower also. Figures 6a–15a show the final 1/16° STG Atlantic topography. Comparisons of sill depths between ETOP05, NIMA maps and other sources, and the 1/16° STG Atlantic topographies (smoothed and unsmoothed) are shown in Table 1.

3.1 1/8° STG Atlantic Topography Modifications

Closer examination of the 1/8° STG Atlantic topography (top672a) indicated additional improvements could be made based on the 1/16° modifications. Areas of improvements to the 1/8° STG Atlantic topography include the Bahamas, Old Bahama Channel, and the Lesser Antilles.

As in the current version of the 1/16° STG Atlantic topography, the Lesser Antilles passages in the current version of the 1/8° STG Atlantic topography are narrower than they are in the original version. All of these changes are in the final 1/8° global topography consistent with this report (top117e). The final version of the 1/8° STG Atlantic topography for this report is top672b. Figures 6c–11c are from the final 1/8° STG Atlantic topography that has been modified based on the 1/16° version.

4.0 SUMMARY AND CONCLUSIONS

This report documents the creation of a 1/16° STG Atlantic topography for use in the NLOM. This topography is based on a combination of these topographic datasets: 1/8° global topography used by the NLOM and a 1/16° STG Atlantic topography derived primarily from the ETOP05 dataset. The merging of these datasets and modifications based on maps from NIMA, the Times Atlas, and personal contacts produce model coastlines (i.e., the 200-m isobath) that are more representative of the region than any single data source.

In the final 1/16° STG Atlantic topography (top673e), the Lesser Antilles passages are narrower than in past 1/8° topographies. Windward and Mona Passages and the area off the southwest coast of Florida have been made more realistic, and Old Bahama Channel is narrower as well. These improvements to the 1/16° topography could possibly impact the flow through the Lesser Antilles into the Caribbean Sea in the NLOM. A comparison of the existing 1/8° STG Atlantic topography with the final 1/16° topography indicated that improvements to Old Bahama Channel, the Lesser Antilles, and the Bahamas could result in more accurate simulation of the observed flow in these areas. Additional model experimentation with the new 1/16° and 1/8° topographies will provide the answers.

5.0 ACKNOWLEDGMENTS

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6.0 REFERENCES

Hellerman, S. and M. Rosenstein, "Normal Monthly Wind Stress over the World Ocean with Error Estimates," *J. Phys. Oceanogr.* **13**, 1093–1104 (1983).

Hurlburt, H. E. and J. D. Thompson, "A Numerical Study of Loop Current Intrusions and Eddy Shedding," *J. Phys. Oceanogr.* **10**, 1611–1651 (1980).

Hurlburt, H. E. and T. L. Townsend, "NRL Effort in the North Atlantic," Data Assimilation and Model Evaluation Experiment Preliminary Experiment Plan, p. 30 (1994).

Johns, W., pers. comm., 1993.

Larsen, J. C. and T. B. Sanford, "Florida Current Volume Transports from Voltage Measurements," *Science* **227**, 302–304 (1985).

Metcalf, W. G. and M. C. Stalcup, "A New Bathymetric Chart of the Windward Passage Sill," *Deep Sea Res.* **23**, 1209–1212 (1976).

National Oceanic and Atmospheric Administration, "ETOP05 Digital Relief of the Surface of the Earth," Data Announcement 86-MGG-07, Nat. Geophys. Data Center, Washington, D.C. (1986).

National Oceanic Service, "NOS Hydrographic Data Base – Expanded, Digital Bathymetric Data for U.S. Coastal Waters," Data Announcement 87-MGG-12, Nat. Geophys. Data Center, Boulder, CO (1994).

Sirkes, Z. and V. Anantharaj, pers. comm., 1995.

Stalcup, M. C. and W. G. Metcalf, "Bathymetry of the Sills for the Venezuelan and Virgin Island Basins," *Deep Sea Res.* **20**(8), 739–742 (1973).

Stalcup, M. C., W. G. Metcalf, and M. Zemanovic, "Current Measurements in the Lesser Antilles," Woods Hole Oceanographic Institution, Ref. 71-51, Tech. Report (unpub. manuscript), 1971.

The Times (London) Atlas of the World, 8th ed., 1991.

Wilson, D., pers. comm., 1996.

Youtsey, W. J., "Report Detailing Modifications to the 1/8 Degree Bathymetry," NRL Memorandum Report 7023, Naval Research Laboratory, Stennis Space Center, MS, 1993.

Youtsey, W. J. and R. L. Woodyard, "Users Guide to Bathymetric Data Set Extraction Program," NRL Formal Report 9431, Naval Research Laboratory, Stennis Space Center, MS, 1993.