The Atlantic Climate Change Program

Robert L. Molinari,* David Battisti,+
Kirk Bryan,** and John Walsh++

Abstract

The Atlantic Climate Change Program (ACCP) is a component of NOAA's Climate and Global Change Program. ACCP is directed at determining the role of the thermohaline circulation of the Atlantic Ocean on global atmospheric climate. Efforts and progress in four ACCP elements are described. Advances include 1) descriptions of decadal and longer-term variability in the coupled ocean–atmosphere–ice system of the North Atlantic; 2) development of tools needed to perform long-term model runs of coupled simulations of North Atlantic air–sea interaction; 3) definition of mean and time-dependent characteristics of the thermohaline circulation; and 4) development of monitoring strategies for various elements of the thermohaline circulation.

1. Introduction

The Atlantic Climate Change Program (ACCP) is a component of National Oceanic and Atmospheric Administration's (NOAA) Climate and Global Change Program. ACCP studies the effect of the thermohaline circulation of the Atlantic Ocean on global atmospheric climate. The scientific rationale for ACCP is given in Gordon et al. (1992). Briefly, analyses of the historical instrumental and proxy records, as well as numerical modeling studies, provide strong evidence for regional connections between Atlantic sea surface temperature (SST) patterns and atmospheric variability. On decadal and longer timescales, the historical data and models suggest that the SST anomalies are forced primarily by internal oceanic processes rather than by external surface flux variability, although the latter may be essential to exciting the former. On these timescales, the thermohaline circulation plays a role in establishing oceanic variability.

*National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida.
+Department of Atmospheric Sciences, University of Washington, Seattle, Washington.
**National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey.
++Department of Atmospheric Sciences, University of Illinois at Urbana–Champaign, Urbana–Champaign, Illinois.
Corresponding author address: Robert L. Molinari, National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149.
In final form 11 April 1994.

ACCP was initiated to begin the process of developing predictive capability for variability in the climate system on decadal and longer timescales. To meet this objective, the following initial goals were established for ACCP:

1) To determine the seasonal-to-decadal and multidecadal variability in the climate system due to interactions between the Atlantic Ocean, sea ice, and the global atmosphere using observed data, proxy data, and numerical models;
2) To develop and utilize coupled ocean–atmosphere models to examine seasonal-to-decadal climate variability in and around the Atlantic basin, and to determine the predictability of the Atlantic climate system on seasonal-to-decadal timescales;
3) To observe, describe, and model the space–time variability of the large-scale circulation of the Atlantic Ocean and determine its relation to the variability of the sea ice and sea surface temperature and salinity in the Atlantic Ocean on seasonal, decadal, and multidecadal timescales; and
4) To provide the necessary scientific background to design an observing system of the large-scale Atlantic Ocean circulation pattern, and develop a suitable Atlantic Ocean model in which the appropriate data can be assimilated to help define the mechanisms responsible for the fluctuations in Atlantic Ocean circulation.

These objectives are to be met in a joint undertaking of atmospheric and oceanographic scientists. The program manager for ACCP is David Goodrich of NOAA's Office of Global Programs (OGP). A Scientific Working Group (SWG) was established to provide scientific guidance to the program office. ACCP is a proposal-driven study. An important role of the SWG is to draft the ACCP portion of OGP's annual Program Announcement, which gives guidelines for proposers during a particular year.

2. Selected early results

ACCP has taken important strides toward meeting its objectives since the last program description appeared in Gordon et al. (1992). The following discussion is not inclusive, but is meant to provide a flavor of what ACCP has accomplished, its current status, and its future. Much of the discussion is taken from abstracts presented at the 1992 and 1993 ACCP principal investigator meetings. A list of ACCP principal investigators is given in Table 1.

a. Analysis of historical data

A key element of ACCP is to create a team of scientists working on studies of the interactions between the Atlantic Ocean and regional and global climate using both instrumental and proxy datasets, as well as building entirely new datasets where they are needed. Many of the studies combine data and models. For example, interhemispheric patterns of many variables, including SST, have substantial interannual-to-multidecadal variability in the tropical Atlantic. Analysis of these patterns, from both data and modeling representations, has been an area of interest to ACCP because of the observed relationship of SST to precipitation.

The mechanism by which changes in tropical SST distributions lead to changes in atmospheric circulation has recently been addressed by Hastenrath and Greischar (1993) through an analysis from European Centre for Medium-Range Weather Forecasts (ECMWF) and other observational sets. Their study suggests that shifts in the interhemispheric contrasts of temperature account for most of the changes in meridional pressure gradient and thus to near-surface winds. Earlier studies, in contrast, attributed the coupling to a dipole in SST anomaly patterns that straddled the equator (Moura and Shukla 1981, for instance). The mechanism that produces SST patterns is being examined by J. Carton in an ocean modeling study. His results suggest that the interhemispheric SST patterns result from weak changes in surface heat flux.

The possibility that the tropical Atlantic can support coupled modes, independent of other regions, has been addressed recently by Zebiak (1993). Through examination of the observational record, he has shown the existence of variability that has its highest amplitude in near-equatorial regions, and that shares many common features with the Pacific El Niño–Southern Oscillation (ENSO). In addition, he applied a coupled atmosphere–ocean model to the region and has provided evidence from the resulting simulations that the mode of variability shown in the observations results from unstable interactions between the tropical Atlantic Ocean and its overlying atmosphere.

The pioneering work of Bjerknes (1964) on air–sea interaction in the northwestern North Atlantic provided much of the historical rationale for ACCP. He speculated on a possible separation of timescales in the region, with interannual timescales characterized by atmospheric forcing of oceanic variability and decadal timescales characterized by oceanic forcing of atmospheric variability. Recent ACCP-supported studies have verified and quantified the essentially qualitative findings of Bjerknes (1964). For example, Kushnir (1994) studied interannual-to-interdecadal climate variability associated with mid- and high-latitude SST anomalies. His work verifies the timescale separation suggested by Bjerknes (1964).

Similarly, Deser and Blackmon (1993) describe quasi-decadal variability in SST and surface wind fields of the North Atlantic (Fig. 1). The SST variability is closely linked to decadal variations in sea ice extent in the Labrador Sea. Positive sea ice extent anomalies lead negative SST anomalies east of Newfoundland by two years (Fig. 2). They also describe recent surface warming in the subtropical and subpolar Atlantic and suggest that the warming may be caused by advective effects in the ocean. Deser and Blackmon also show that decadal variability can cause serious observational sampling problems when attempting to estimate long-term trends in North Atlantic temperature from a limited number of measurements at widely separated time intervals.

In another ACCP-supported project, Walsh (see Table 1) compiled a monthly sea ice database depicting sea ice conditions in the North Atlantic from 1901 to the present. This monthly database is an enhancement of a shorter (1953–1990) database described by Chapman and Walsh (1993). The charted variable is sea ice concentration for the years 1953 onward and the position of the ice edge for the pre-1953 period. Algorithms have also been developed for the inclusion of concentrations on the earlier grids. The spatial resolution of the grids is 110 km, permitting the depiction of interannual and interdecadal variations of sea ice at resolutions comparable with those of large-scale ice–ocean models of the North Atlantic. Thus, the data can be used in model verification studies.

Analyses of the data have shown that sea ice variations in the Greenland Sea sector have a multidecadal character (with heavy wintertime ice conditions in the 1905–1915 and the 1965–1975 decades), that ice coverage in the Baffin Bay/Labrador Sea sector has become more extensive in recent decades, and that the summertime ice extent in the North Atlantic waters east of 40°W has generally decreased during the twentieth century. Chapman et al. (1994), Hakkinen (1993), and Mysak (1993, personal communication) and colleagues at McGill University have used the database to verify sea ice model simulations spanning the period of the Great Salinity Anomaly. Finally, the dataset is providing the basis for sea ice boundary conditions in global climate model simulations at the Geophysical Fluid Dynamics Labo-

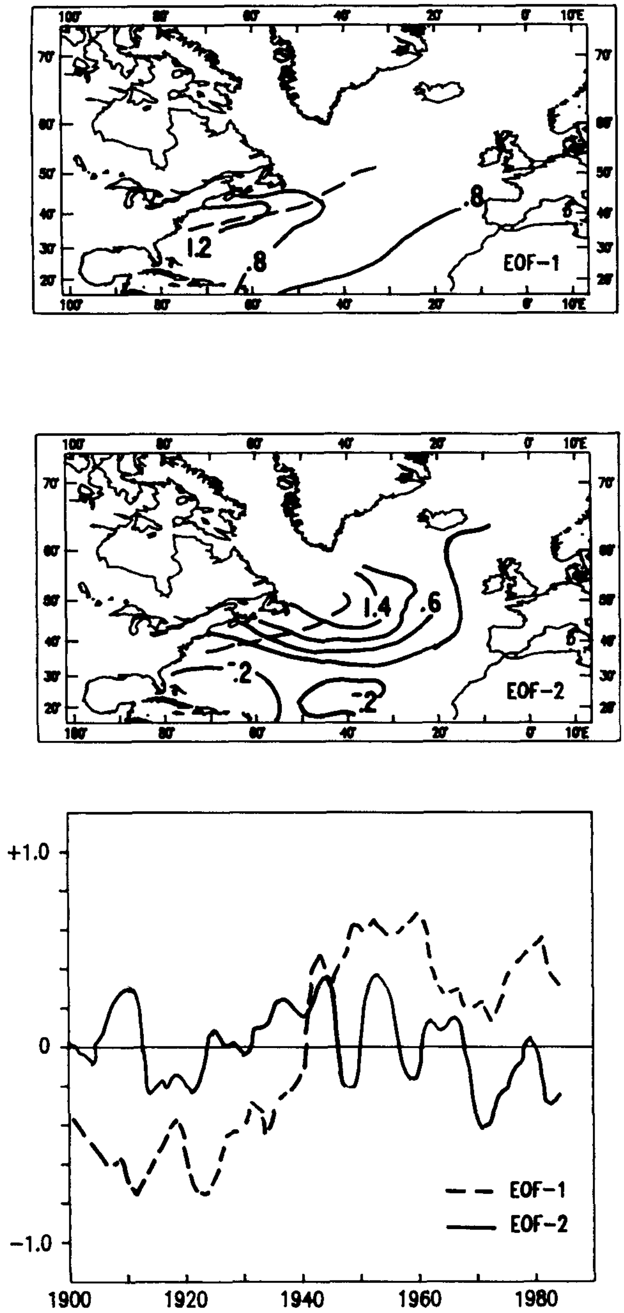

Fig. 1. EOF-1 (upper panel) and EOF-2 (middle panel) of North Atlantic SST anomalies based on unnormalized winter (November–March) means, 1900–1989. Time series of EOF-1 (dashed curve, lower panel) and EOF-2 (solid curve) smoothed with a five-point binomial from Deser and Blackmon (1993). The mean axis of the Gulf Stream as estimated from the average annual SST distribution is given as a dashed line.

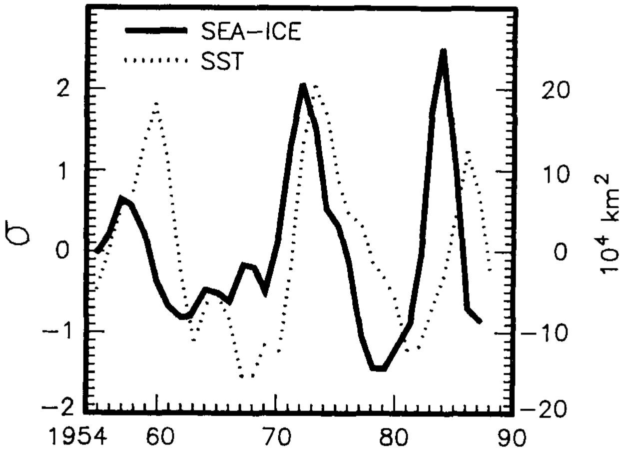

Fig. 2. Time series of winter sea ice anomalies (10^4 km^2) in the Davis Strait/Labrador Sea region superimposed on the time series of EOF-2 from Fig. 1 (from Deser and Blackmon 1993).

ratory (GFDL) and the Hadley Centre of the U.K. Meteorological Office. Deser and Blackmon (1993) have used this dataset in the study described above. In addition to oceanic and atmospheric forcing of SST variability east of Newfoundland, they suggest that "the quasi-decadal cycle in SSTs east of Newfoundland may result in part from low-frequency Arctic sea-ice variations."

b. Analysis of proxy data

The instrumental record extends only some 100 years into the past. Proxy data provide the longer time series of climate variability needed to study multidecadal variability. Much of the ACCP effort is directed at developing proxy datasets over large areas. For instance, D'Arrigo et al. (1994) employ tree ring data to reconstruct North Atlantic coastal land–sea temperatures. Much of their current effort is directed at calibrating recent tree ring records for current land temperatures and SSTs. Once verified, the tree ring record can be used to estimate climatic variables beyond the instrumental record. For example, D'Arrigo et al. (1994) have reconstructed land–sea temperatures for the North Atlantic near Labrador extending back to 1713.

Proxy data from ocean sediments are extensively used to increase the available temporal history of ocean variability. Bond, Broecker, McManus, and Lotti (1993, personal communication) are comparing North Atlantic sediment cores to records from Greenland ice cores to obtain a record of millennial- to century-scale climate changes. Similarly, Keigwin and Boyle (see Table 1) are using data from a Bermuda rise core to study changes in North Atlantic surface and deep waters during the past 80 000 years. Patzold (1993, personal communication) reported on proxy coral data at annual-to-decadal resolution for the last 800 years with prospects of records as far back as 4000 years. Both the land and sea time series provide important

TABLE 1. Climate and global change program titles.

Principal investigator	Institution*	Title
Knut Aagaard	UWA	The Fresh Water Flux through Fram Strait: A Variable Control on the Thermohaline Circulation
Michael Alexander	CIRES	Atmosphere–Ocean Interaction in the North Atlantic and Connections with Other Ocean Basins
David Battisti	UWA	Atmosphere–Ocean Interaction in the North Atlantic and Connections with Other Ocean Basins
Edward Boyle	MIT	High Resolution Deep and Surface Variability in the Latest Quaternary North Atlantic
Wendell Brown	UNH	The Role of the Western Tropical Atlantic Ocean in the Interhemispheric Transport of Mass and Heat
Kirk Bryan	NOAA/GFDL	Retrospective Modelling of the Atlantic Ocean
Harry Bryden	WHOI	A New Trans-Atlantic Hydrographic Section Across 24°N in 1992
John Bullister	NOAA/PMEL	Long-Term Tracer Observations in the Greenland, Norwegian, and Labrador Seas
James Carton	UMD	The Role of the Western Tropical Atlantic Ocean in the Interhemispheric Transport of Mass and Heat
Daniel Cayan	SIO	Variability of Surface Salinity over the North Atlantic Ocean
Gabriel Csanady	ODU	Air–Sea Coupling in the North Atlantic
Rosanne D'Arrigo	LDEO	Modelling Seasonal to Decadal-Scale Climate Variability for the North Atlantic Sector Based on Dendroclimatic Evidence from Adjacent Land Areas
Clara Deser	UCO	Decadal Climate Cycles over the North Atlantic
Rana Fine	RSMAS	TRIDENT: Heat Flux and Water Mass Ventilation within the Subtropical North Atlantic
		A Synthesis of Western North Atlantic Ocean CFC Data
Charles Flagg	BNL	Monitoring Annual and Subannual Mass and Heat Fluxes in the Western North Atlantic: The Shelf, Gulf Stream, and Western Sargasso Sea
Arnold Gordon	LDEO	TRIDENT 1992—CTD Data Analysis Phase
Louis Gordon	ORSU	TRIDENT: Heat Flux and Water Mass Ventilation within the Subtropical North Atlantic: Processes and Variability Deduced from Simultaneous Use of Biogeochemical and Physical Data
Sirpa Hakkinen	NASA/GSFC	A Numerical Model Study of the North Atlantic and the Arctic Ocean
Stefan Hastenrath	UWI	Climate Dynamics of the Tropical Atlantic (formerly "Diagnostics of Climate Anomalies in the Tropical Atlantic Sector")
William Holland	NCAR	Continuing Studies on the Interaction of the Atlantic Ocean and the Global Atmosphere on Subseasonal to Decadal Time Scales
Robert Houghton	LDEO	Atlantic Atmosphere–Upper Ocean Climate Diagnostic Studies
Rui Xin Huang	WHOI	Thermohaline Circulation in the Atlantic and Its Variability
William Johns	RSMAS	A Continuation of Funding for Windward Island Passages Monitoring Program: Measurement of Transport and Water Mass Properties
Lloyd Keigwin	WHOI	High Resolution Deep and Surface Variability in the Latest Quaternary North Atlantic
Peter Lamb	UOK	Diagnostics of Climate Anomalies in the Tropical Atlantic Sector
James Larsen	NOAA/PMEL	Monitoring of Ocean Volume Transport by Cross-Stream Voltage Measurements
Thomas Lee	RSMAS	Monitoring Thermohaline Circulation and Meridional Heat Flux in the Subtropical Western Atlantic at 26.5°N: 1993–1994

TABLE 1. Continued.

Sydney Levitus	NOAA/NODC	Analysis of Atlantic Ocean Hydrographic Time Series
M. Susan Lozier	DU	The Climatology of the Atlantic Basins
John Marshall	MIT	Studies of Deep Convection and Its Parameterization
Michael McCartney	WHOI	Deep Water Circulation in the Atlantic Ocean
Vikram Mehta	NASA	Modelling of Atlantic Regional Decadal Climate Variabilities with Coupled Ocean–Atmosphere Models
George Mellor	PRINC	A Numerical Model Study of the North Atlantic and the Arctic Ocean
Robert Molinari	NOAA/AOML	Direct Velocity Observations in Support of Operational Monitoring in the Straits of Florida
		Production of ACCP newsletter
W. Brechner Owens	WHOI	Upper Ocean and Sea-Ice Modelling of Intra-Decadal Climate Variations
		The Climatology of the Atlantic Basins
Peter Rhines	UWA	Site Studies in the Labrador Sea
Jeffrey Rogers	OHST	Atmospheric Circulation, Sea Ice and Climate Variability around the Northern Atlantic
Thomas Rossby	URI	Monitoring Annual and Subannual Mass and Heat Fluxes in the Western North Atlantic: The Shelf, Gulf Stream, and Western Sargasso Sea
Thomas Sanford	UWA	Gulf Stream Climate Studies: Near Surface and Depth Averaged Currents between New York and Bermuda
Edward Sarachik	UWA	Thermohaline Circulation and Variability in Climate
Peter Schlosser	LDEO	Long-Term Tracer Observations in the Greenland, Norwegian, and Labrador Seas
Frederick Semazzi	NCSU	A Modelling Study of the Relationship between the Atlantic SST Anomalies and the Sahelian Droughts
William Smethie	LDEO	CFC Measurements along 24°N in the Atlantic Ocean
		Investigation of Formation of High CFC 4–5°C Water along the Labrador and North Atlantic Currents
		A Synthesis of Western North Atlantic Ocean CFC Data
Carlisle Thacker	NOAA/AOML	A Dynamically Balanced Three-Dimensional Climatological Analysis Providing Estimates of Salinity, Temperature, Currents, Transport Parameters and Surface Fluxes for the North Atlantic Ocean
Zafer Top	RSMAS	A Tritium and Noble Gas Sections Study Along 24°N during Spanish–WOCE North Atlantic Expedition
Douglas Wallace	BNL	Long-Term Tracer Observations in the Greenland, Norwegian, and Labrador Seas
John Walsh	UIL	Hydrologic Contribution to North Atlantic Salinity Anomalies
W. Douglas Wilson	NOAA/AOML	Windward Island Passages Monitoring Program: Measurements of Transport and Water Mass Properties
Stephen Zebiak	LDEO	Mechanisms of Atlantic Climate Variability

*AOML = Atlantic Oceanographic and Meteorological Laboratory; BNL = Brookhaven National Laboratory; CIRES = Cooperative Institute for Research in Environmental Sciences; DU = Delaware University; GFDL = Geophysical Fluid Dynamics Laboratory; GSFC = Goddard Space Flight Center; LDEO = Lamont-Doherty Earth Observatory; MIT = Massachusetts Institute of Technology; NCAR = National Center for Atmospheric Research; NCSU = North Carolina State University; NODC = National Oceanic Data Center; ODU = Old Dominion University; OHST = Ohio State University; ORSU = Oregon State University; PMEL = Pacific Marine Environmental Laboratory; PRINC = Princeton; RSMAS = Rosenstiel School of Marine and Atmospheric Science; SIO = Scripps Institution of Oceanography; UCO = University of Colorado; UIL = University of Illinois; UMD = University of Maryland; UNH = University of New Hampshire; UOK = University of Oklahoma; URI = University of Rhode Island; UWA = University of Washington; UWI = University of Wisconsin; WHOI = Woods Hole Oceanographic Institution.

datasets for verification of long-term model runs (see below).

c. Model results

A variety of models for the ocean, the atmosphere, and the coupled ocean–atmosphere system are being utilized to meet the second ACCP objective listed above. Particular attention is being directed at developing models that perform the long time integrations needed in decadal and longer timescale studies. At the process level, studies are being supported to improve the parameterizations used in GCMs to perform long-term integrations. For example, Marshall and Klinger (see Table 1) are studying oceanic convection. They included rotation in their model of these elements and developed scaling laws for use in GCMs. Their numerical results reproduce laboratory results in several flow regimes. Large (1993, personal communication) is testing a mixed layer model based on similar ideas with the aim of reducing vertical resolution requirements as compared to earlier schemes.

Other modeling and empirical studies are directed at regional climate questions and atmospheric effects on both SST and deeper temperature structure. For example, Mehta and Delworth (1994) examined the variability in the tropical Atlantic sector of a sophisticated coupled ocean–atmosphere model that reveals pronounced decadal and multidecadal variability. Semazzi (see Table 1) has used a coupled GCM, including land processes developed at the National Center for Atmospheric Research (NCAR), to study the effect of tropical SST anomalies on Sahelian rainfall. Using an atmospheric GCM, Kushnir (1994) is examining the hypothesis that atmospheric anomalies are forced by oceanic anomalies. With a simple upper ocean model of the North Atlantic, Battisti et al. (1994) have demonstrated that the variability in the SST over the past 35 years is consistent with the observed surface fluxes. Alexander and Deser (1994) have performed a hindcast of the upper ocean variability at four weather ships, providing support for an earlier hypothesis concerning the persistence of wintertime upper ocean anomalies. Bryan and Dixon (1994) used a GCM of the World Ocean and the SST dataset of the British Meteorological Office to reconstruct the changes in deep Atlantic water temperatures that have taken place over the last century.

Recognizing that only coupled models will be capable of long-term forecasts, coupling of atmospheric and oceanic GCMs is another important area of study for ACCP. F. Bryan (1993, personal communication) is studying approaches to coupling the World Ocean Circulation Experiment (WOCE) Community Model of the North Atlantic to the NCAR Community Climate Model. Of particular concern is how to match atmospheric and oceanic flux fields during the coupling process. Blumenthal (1993, personal communication) is testing a simplified model of atmospheric moisture balance for possible coupling with ocean GCMs.

Fully coupled GCMs are being run to study various aspects of ACCP interest. Delworth et al. (1993) have run one such model, examining a 1000-year time span, to demonstrate the effects of thermohaline circulation variability on climate. This model is able to simulate 40–70-year climate variability that is clearly associated with the Atlantic thermohaline circulation. This is the first time that Bjerknes's (1964) hypothesis for multidecadal climate variability in the North Atlantic has been demonstrated in a physically consistent model. Using the same model, Manabe et al. (1992) have examined the effect of greenhouse warming on the thermohaline circulation.

d. Ocean observations

Historical and proxy data, modeling, and recent observations are being used to describe and explain the mean state and space–time variability of the Atlantic Ocean (objective 3 above). In terms of long-term average conditions in the Tropics, Molinari et al. (1992) have described the Deep Western Boundary Current, a major component of the Atlantic's thermohaline circulation. They show that chloroflourocarbon concentrations clearly delineate the deep water masses present in the region and that these tracers can provide information on timescales of the deep circulation. McCartney (see Table 1) uses water mass distributions to map the deep circulation of the Atlantic with particular emphasis on the major recirculations found in deeper layers.

Levitus (see Table 1) is building an expanded dataset of time series of ocean temperature and salinity to study the variability of the subtropical and subpolar gyres of the North Atlantic. Particular emphasis is placed on data "rescue" from former Soviet Union archives in an attempt to increase the available information base. Lozier, Owens, and Curry (see Table 1) are generating climatologies for the North Atlantic temperature and salinity fields averaging on potential density rather than depth surfaces. These studies represent contributions to the ACCP objective of creating new datasets for the study of the North Atlantic climate variability.

Earlier studies (Manabe and Stouffer 1988, for instance) suggest climatically important variability in the thermohaline circulation is concentrated on the western boundary of the North Atlantic. Thus, ACCP efforts to develop monitoring strategies are positioned primarily on this boundary (Fig. 3) to meet objective 4 above. The preliminary data resulting from these studies will also be used to increase understanding of

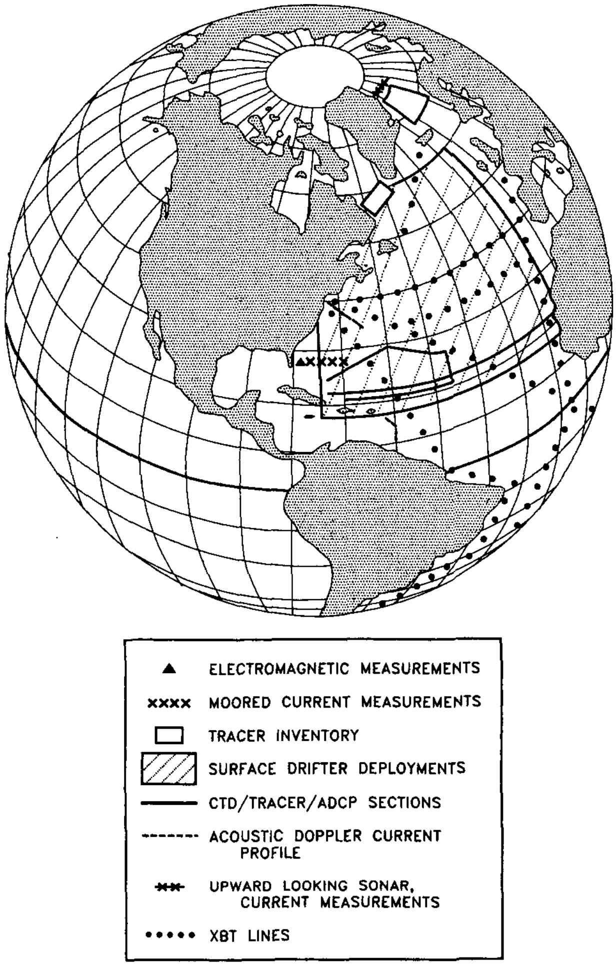

FIG. 3. The recent past and present ACCP observation system includes continuous shipboard monitoring of the southern passages of the Lesser Antilles and a section between the U.S. mainland and Bermuda; a single transatlantic section and shorter sections along the western boundary; communications cable and sea level monitoring of the Florida Current; current meter monitoring of the flow east of the Bahamas and through the Fram Strait, tracer inventory cruises in the North Atlantic; satellite-tracked surface drifters; and XBT transects from merchant ships.

the dynamics of North Atlantic circulation and in model verification efforts.

Cross-equatorial fluxes of upper-layer heat, mass, and momentum are an important component of the thermohaline circulation. Wilson and Johns (see Table 1) have established a monitoring program within the passages of the Lesser Antilles to track this exchange (Fig. 3). A long-term objective of this effort is to transfer the monitoring task to regional organizations for continued operations. Proceeding poleward, ACCP supports monitoring efforts in the Straits of Florida and east of the Bahamas, at the approximate latitude of maximum oceanic heat flux. Larsen (1992) utilized an inactive submarine communications cable to monitor Florida Current transport (Fig. 4). Although the annual signal varies from year to year, interannual variability is only about 10% of the mean annual signal. These data are being used extensively to verify models of the North Atlantic. Currently, an active communications cable and coastal tide gauge stations are being used to monitor this transport.

East of the Bahamas, Lee and Johns (see Table 1) have monitored Deep Western Boundary Current (DWBC) transport for seven years. They are beginning to provide estimates of both average and time-dependent properties of this flow, the first long-term observations in this important component of the thermohaline circulation. To take advantage of these western boundary observations, a heat flux section was conducted by Bryden (see Table 1) during the summer of 1992. Concurrently, Fine, Gordon, Gordon, and Molinari (see Table 1) took concentrated observations at several latitudes along the western boundary to assess the representativeness of single heat flux sections.

East of Cape Hatteras, Rossby (see Table 1) established an upper ocean monitoring section for the Gulf Stream. A merchant ship that operates between Bermuda and Newark, New Jersey, is equipped with a suite of oceanographic sensors to track upper ocean currents, temperature, and salinity. Aagaard (see Table 1) has been monitoring the freshwater flux through the Fram Strait, an important contribution to the thermohaline circulation. Bullister, Wallace, and Smethie (see Table 1) are determining the utility and feasibility of monitoring transient tracers in the Greenland, Norwegian, and Labrador Seas as a strategy for tracking the intensity of the thermohaline circulation.

Although not funded directly by ACCP, another component of Climate and Global Change (Long-term Ocean Observations) supports several large-scale observing systems in the Atlantic Ocean. Niiler (1993, personal communication) has deployed a suite of satellite-tracked surface drifters at the positions shown in Fig. 3. Molinari, Szabados, and Hamilton (1993, personal communication) have implemented volunteer observing ship track lines in the Atlantic to obtain upper ocean temperature data (Fig. 3). Both studies also include a component to quality control the resulting data to ensure a high-quality data stream for ACCP and other investigators.

3. Relationship to other programs

Air–sea interaction on timescales longer than the three- to four-year El Niño timescale has been recognized as an important topic for international cooperation in research. The World Climate Research Programme, under the International Council of Scientific Unions and the World Meteorological Organization, included the study of decadal variability as Focus II of the Climate Variability and Predictability (CLIVAR) program. The Global Climate Observing System and the Global Ocean Observing System are international groups organized to study the technical aspects of ocean monitoring, making use of the results of the World Ocean Circulation Experiment and other recent studies. ACCP is one of NOAA's contributions to the study of the decade-to-century climate problem, and to the establishment of requirements for a future ocean observing system from the standpoint of air–sea interaction and climate variability. ACCP has begun interaction with many of the national and international programs addressing these issues and will continue to coordinate with these studies.

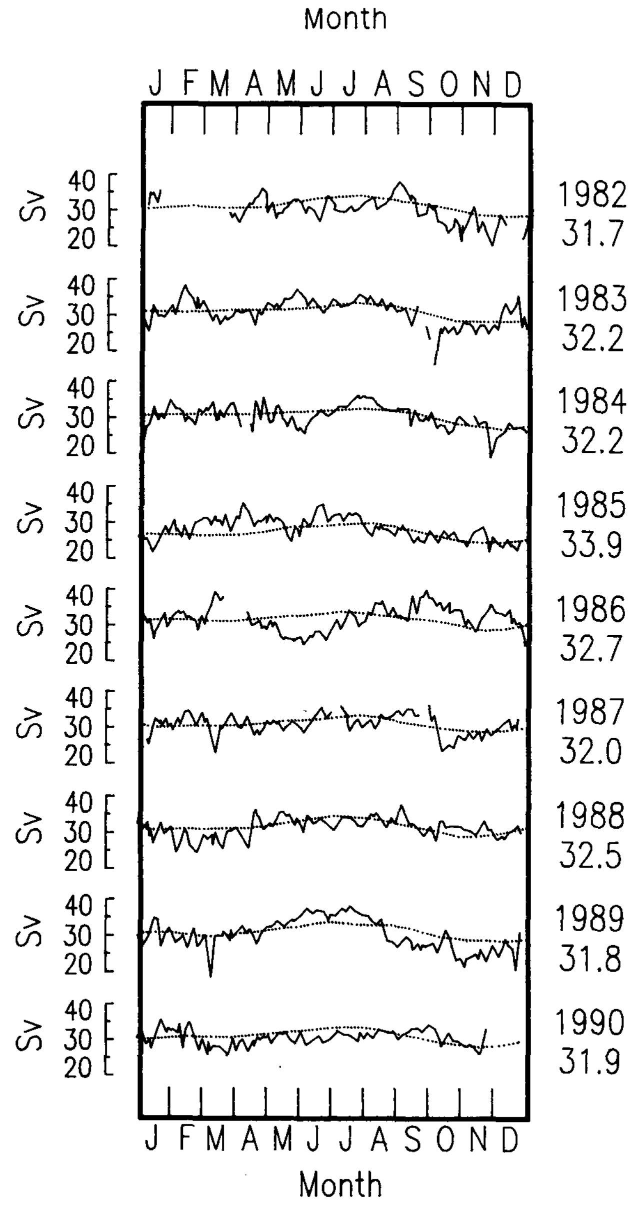

FIG. 4. Time series of Florida Current transport (solid line) derived from abandoned communications cable. The dotted line represents the mean annual cycle. Also given is the mean annual transport (from Larsen 1992).

4. Future direction

Based on the results presented above, ACCP has refocused the earlier objectives of the program.

Focus 1: What determines decadal variability in the Atlantic and subsequent feedbacks to the atmosphere?

Specific issues:

a. What processes determine the buoyancy flux into the North Atlantic subpolar gyre? Particular emphasis is on advection of heat and salt, advection of ice, air–sea fluxes, and the Great Salinity Anomaly.
b. What processes determine SST in the Tropics and subsequent feedback to the atmosphere on decadal timescales? Particular emphasis is on dipole versus gradient SST effects.

Focus 2: What determines variability in the thermohaline circulation on decadal and longer timescales, and how does this variability feed back to the atmosphere?

Specific issues:

What processes effected the warming observed in the Atlantic over the past decades?

Acknowledgments. The contributions of ACCP Scientific Working Group members, in particular, J. Carton, T. Delworth, and W. Ruddiman, are gratefully acknowledged.

References

Alexander, M., and C. Deser, 1994: A mechanism for the recurrence of wintertime midlatitude SST anomalies. *J. Climate,* submitted.

Battisti, D., U. Bhatt, and M. Alexander, 1994: A modeling study of the interannual variability in sea surface temperature in wintertime in the North Atlantic. *J. Climate,* submitted.

Bjerknes, J., 1964: Atlantic air–sea interaction. *Adv. Geophys.,* **10** (1), 1–82.

Bryan, K., and K. Dixon, 1994: Deep ocean temperature changes in the World Ocean, 1888–1988. A model study. *J. Climate,* submitted.

Chapman, W. L., and J. E. Walsh, 1993: Recent variations of sea ice and air temperature in high latitudes. *Bull. Amer. Meteor. Soc.,* **74,** 33–47.

——, W. J. Welch, K. P. Bowman, J. Sacks, and J. E. Walsh, 1994: Arctic sea ice variability: Model sensitivities and a multidecadal simulation. *J. Geophys. Res.*, in press.

D'Arrigo, R. D., E. R. Cook, G. C. Jacoby, and K. R. Buffa, 1994: North Atlantic oscillation and sea surface temperature signatures in tree-ring records from the North Atlantic sector. *Quart. Sci. Rev.*, submitted.

Delworth, T., S. Manabe, and R. J. Stouffer, 1993: Interdecadal variations of the thermohaline circulation in a coupled ocean–atmosphere model. *J. Climate*, **6**, 1993–2011.

Deser, C., and M. Blackmon, 1993: Surface climate variations over the North Atlantic during winter, 1900–1989. *J. Climate*, **6**, 1743–1753.

Gordon, A. L., S. E. Zebiak, and K. Bryan, 1992: Climate variability and the Atlantic Ocean. *Eos*, **73**, 161, 164–165.

Hakkinen, S., 1993: An Arctic source for the Great Salinity Anomaly: A simulation of the Arctic ice–ocean system for 1955–1975. *J. Geophys. Res.*, **98**, 16 397–16 410.

Hastenrath, S., and L. Greischar, 1993: Circulation mechanisms related to northeast Brazil rainfall anomalies. *J. Geophys. Res.*, **98**, 5093–5102.

Kushnir, Y., 1994: Interdecadal variations in North Atlantic sea surface temperature and associated atmospheric conditions. *J. Climate*, **7**, 141–157.

Larsen, J. C., 1992: Transport and heat flux of the Florida Current at 27°N derived from cross-stream voltages and profiling data theory and observations. *Phil. Trans. Roy. Soc. London*, **A338**, 169–236.

Manabe, S., and R. J. Stouffer, 1988: Two stable equilibria of a coupled ocean–atmosphere model. *J. Climate*, **1**, 841–866.

——, M. J. Spelman, and R. J. Stouffer, 1992: Transient response of a coupled ocean–atmosphere model to gradual changes of atmospheric CO_2. Part II: Seasonal response. *J. Climate*, **5**, 105–126.

Mehta, U. M., and T. Delworth, 1994: Decadal variability in the tropical Atlantic Ocean surface temperature in shipboard measurements and a global ocean–atmosphere model. *J. Climate*, in press.

Molinari, R. L., R. A. Fine, and E. Johns, 1992: The Deep Western Boundary Current in the tropical North Atlantic Ocean. *Deep-Sea Res.*, **39**, 1967–1984.

Moura, A. D., and J. Shukla, 1981: On the dynamics of drought in northeast Brazil: Observations, theory, and numerical experiments with a general circulation model. *J. Atmos. Sci.*, **38**, 2653–2675.

Zebiak, S. E., 1993: Air–sea interaction in the equatorial Atlantic region. *J. Climate*, **6**, 1567–1586.