A WESTERN TROPICAL ATLANTIC EXPERIMENT (WESTRAX)

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RECENTLY, a group of researchers from the U.S. and the broader international community have developed coordinated plans for observational and modeling work in the western tropical Atlantic. The overall research program is referred to as WESTRAX, for Western Tropical Atlantic Experiment. This article summarizes the research plans of the various participants and the scientific issues that have motivated the studies.

Background

Ocean heat flux is a significant component of the global energy balance. Vonder Haar and Oort (1973) found that, on a global average, the oceans between the equator and ~30°N transport more than half the heat required to balance the energy loss at more poleward latitudes. At subtropical latitudes in the North Atlantic (where the ocean heat flux is a maximum), western boundary currents represent an important component in the global heat budget (Bryden and Hall, 1980). Global-scale thermohaline circulation is believed to play a central role in the net northward interhemispheric transport of mass and heat in the Atlantic Ocean (Broecker *et al.,* 1985; Atlantic Climate Change Working Group, 1990). The notion of a global thermohaline "conveyor belt" involves warm upper-ocean transport from the Indian and Pacific Oceans moving northward through the Atlantic and a southward return of colder deep flow from the subpolar regions in the North Atlantic.

Important components of the global thermohaline conveyor belt are seen in the tropical Atlantic. The cross-equatorial transport of upper tropical Atlantic waters is comparable with the total rate of equatorial upwelling driven by the tropical wind systems. Thus, it appears that the deep and shallow parts of this meridional overturning system may be linked in the tropics. There is reason to believe that an improved understanding of these so-called conveyor-belt dynamics will help explain observed correlations between African and Brazilian drought cycles and ocean surface-temperature asymmetries in the Atlantic. It is hypothesized that changes in the meridional overturning rate induce climatically important changes in the surface ocean temperature anomalies.

What is the role of the tropical Atlantic in the northward interhemispheric heat transport in the Atlantic basin? To answer this question, it will be important to determine how much water is transported across the equator at different depths within the western-boundary current system and what fraction of this water is carried poleward into the subtropical basins of the North and South Atlantic. Answering this question requires a more complete understanding of the structure of western-boundary currents in the tropical Atlantic and their coupling to the interior circulation. A growing body of observations suggests that, at the surface, the northern-hemisphere summer and fall circulation in the western tropical Atlantic is dominated by the retroflection of an intense western-boundary current known as the north Brazil current (NBC). During this time, the upper layer of the NBC, which transports from 30 to 50 Sverdrups, feeds the north equatorial countercurrent (NECC). The lower layers of the NBC within and just below the thermocline also retroflect (Metcalf and Stalcup, 1967), but apparently at different locations, to feed the equatorial undercurrent and the subsurface branches of the NECC—more permanent features of the circulation. This layered structure of the NBC appears to be connected in some way to the presence of two quasipermanent eddies adjacent to the western boundary near 4°N and 8°N, commonly referred to as the Amazon and Demerara Eddies, respectively. These complex upper-level currents and underlying flows of

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minimum across 8°N. When the model NBC is continuous along the coast, northward heat flux is a maximum. Thus, the western tropical Atlantic Ocean appears to be a critical location for monitoring the net northward heat (and fresh-water) fluxes in the Atlantic basin. Several other numerical models have been applied to the region for somewhat different purposes (Schott and Böning, 1991; Thompson, McCreary, personal communications). All of these model results show an undercurrent flowing southward along the slope to join with either the equatorial undercurrent (EUC) or a subsurface branch of the NECC, depending on season. Although this flow has been detected in hydrographic sections, it has not been observed directly. Clearly, models will continue to play an essential role in estimating heat and mass transports and suggesting strategies for observing this complex region.

The observational and modeling studies of the western tropical Atlantic to date raise a host of important scientific questions concerning the dynamics of the various current components concentrated along the western boundary. In particular, it is unclear why the thermocline and subthermocline currents separate from the western boundary at different latitudes to feed the various zonal flows. Are separation latitudes dictated primarily by the structure of the wind-forced flow regime in the central basin or do local boundary-current dynamics prevail? What forces the subsurface currents? What is the dynamical role for the NW-SE orientation of the South American coastline?

Other dynamical questions concern the role of the western tropical Atlantic in the dynamics of the thermohaline circulation of the Atlantic region. In particular, do the western tropics have a significant dynamic role in controlling the intensity of the meridional overturning cell in the Atlantic basin? There are also key questions concerning the deep-circulation components. In particular, do deep recirculation gyres, like those observed south of the Gulf Stream, exist in this region? If so, what is the offshore transport of the deep western-boundary current? What is the relationship between the thermohaline and eddy-driven transports? How is the deep eddy field related to the near-surface circulation field? What is the temporal variability of the deep circulation?

Many of these scientific issues are being addressed by WESTRAX.

The WESTRAX Study

One of the long-term goals of physical oceanographic research in the western tropical Atlantic is to estimate the cross-equatorial transport of water and heat. In order to detect long-term changes in the meridional mass and heat transport of the tropical Atlantic, a much better understanding of the seasonal variability in the current and property structure of the region must be obtained. Toward that end, an international group of scientists (Table 1) is cooperating in the context of WESTRAX to determine the first-order kinematics and dynamics of the flow in the western tropical Atlantic. During 1990 and 1991, the WESTRAX field program has obtained data that will be used to describe the annual cycle in the large-scale structure of the velocity and hydrographic properties over the full water column in the western tropical Atlantic Ocean between the equator and 15°N. Subsequently, the field data and model results will be compared in order to better understand the physics of the regional circulation in the broader context of Atlantic-basin thermohaline circulation.

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Scientific Objectives

The specific objectives of the WESTRAX studies are as follows:

1. to describe the annual evolution of the three-dimensional velocity field for the NBC, Guiana current, and the western parts of the NECC, south equatorial current, and EUC;
2. to determine the seasonal changes in the transport connecting the different components of the upper-level current system in the western tropical Atlantic;
3. to measure the temporal changes in the structure and transport of the intermediate and deep western-boundary currents in the region;
4. to determine the basic physical mechanism controlling the evolution of the NBC retroflection and associated eddy dynamics in the region; and
5. to estimate the proportion of the net meridional transport contained in the western boundary current system.

Experimental Plan

Observations. The WESTRAX observations include: ship surveys with Conductivity Temperature Depth and Oxygen probe (CTD/O_2), Expendable Bathythermograph (XBT), and Acoustic Doppler Current Profiler (ADCP) measurements;

Table 1
WESTRAX activities and associated principle investigators.

NOAA/NSF Large-Scale Ship Surveys, Pegasus/Doppler Velocity, $CTD/XBT/O_2$/Nutrient— W. Brown (UNH), E. Johns (NOAA), K. Leaman (RSMAS), R. Molinari (NOAA), D. Wilson (NOAA).
RSMAS Moored Currents—W. Johns, T. Lee
Kiel Modeling, Pegasus Velocity, CTD Ship Surveys, Moored Currents—F. Shott
Lamont Moored Inverted Echo Sounders—E. Katz
ORSTOM Small-Scale Ship Surveys, Moored Currents— C. Colin
Wood's Hole Oceanographic Institute Floats— P. Richardson, W. Schmitz
Maryland Modeling—J. Carton
Nova Modeling—J. McCreary, P. Kundu, P. Lu
NOARL Modeling—D. Thompson, J. Kindle, H. Hurlburt

Relation to other programs. WESTRAX benefits from other ongoing programs in the region. For example, the Tropical Ocean and Global Atmosphere Program (TOGA) supports some of the Lamont IES (E. Katz) and XBT ship-of-opportunity (R. Houghton) observations pertinent to WESTRAX objectives. The NSF-supported AmasSeds project (A Multidisciplinary Amazon Shelf SEDiment Study) in the region of the Amazon outflow includes a physical oceanographic component (R. Beardsley, WHOI; B. Castro, Instituto Oceanográfico, Universidade de São Paulo [IOUSP]) on the landward side of the WESTRAX region. Collaboration is also anticipated with the Soviets, who conducted three extensive hydrographic and current surveys of the region in 1990.

Although the observational phase of WESTRAX has ended, the WESTRAX Pegasus transponders should be useful through September 1992. The community is encouraged to take advantage of that opportunity to make further measurements, as well as to engage in other relevant collaborations with WESTRAX investigators.

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