Study of Mass and Heat Transport of the Tropical Atlantic Ocean Using Models and Altimeter Data

Principal Investigator:

J. Merle
Laboratoire Océanographie Dynamique et Climatologie
Université Paris VI
Paris, France

Co-Investigators:

S. Arnault, A. Morliere, and J. M. Verstraete
Laboratoire Océanographie Dynamique et Climatologie
Université Paris VI
Paris, France

Y. Menard and L. Gourdeau
Groupement de Recherche en Géodésie Spatiale
Toulouse, France

I. Scientific Background

There is recent interest in studies of tropical ocean climates because (1) the changes of sea surface temperature (SST) in the tropics have an influence on the circulation of the global atmosphere; (2) the tropical oceans play a major role in meridional heat transport (Oort and Vonder Haar, 1976) and have an additional important influence on climate at time scales of the order of a decade; (3) in the vicinity of the equator, the vanishing of the Coriollis parameter implies that a stratified ocean can respond strongly and rapidly to basinwide wind fluctuations and adjust its thermal structure on seasonal and interannual time scales.

The Atlantic Ocean contributes enormously to the heat budget of the Northern Hemisphere (Stommel, 1980), and the tropical region plays a key role in the meridional transport of heat. The annual mean meridional heat flux in the Atlantic is northward in both hemispheres and reaches a high maximum in the tropics (Oort and Vonder Haar, 1976; Hastenrath, 1977). However, little is known about the pathways and rates of these interhemispheric exchanges and their seasonal and interannual variations. This is a major objective of the World Ocean Circulation Experiment (WOCE) program.

Important progress has been achieved during the last decade in modeling the tropical oceans, which suggests that models can be used as tools for understanding and possibly forecasting the upper-ocean changes in the tropics. One ultimate goal of the Tropical Ocean and Global Atmosphere (TOGA) program, achieved before demonstrating the possibility of a complete simulation of the coupled air–sea interaction system, is to implement an operating monitoring and modeling of the tropical oceans with the assimilation of data. Such a now-casting/ forecasting operational simulation of the three-dimensional tropical Altantic Ocean is now in development.

Altimeter observations have particular importance in the tropics because the structure of the ocean could be considered a two-layer system. A sharp and thin thermocline separates a warm and well-mixed superficial layer from deeper cold waters. In such a simplified system, sea level, dynamic height, and heat content are directly related to the thermocline depth. With such a system, it is possible to derive the depth of the thermocline and the heat content changes from sea level observations. Nevertheless, to determine more accurately these budgets and to compute the global mass and heat transport with the full dynamic and thermodynamic constraints, three-dimensional model simulations are necessary, as clearly shown recently by Philander and Pacanowsli (1986).

The validity of the model simulations, however, should be checked by comparison with observed data. And the model simulations will be greatly improved if controlled by assimilation of both conventional in situ data and altimeter data. The TOPEX/POSEIDON project is a unique opportunity to provide on a large-scale basin a global and long-term coverage of the sea level, a coverage that could allow constraint of these models for a realistic simulation of the circulation fields and computation of the heat transport and depth of the thermocline over a 3- to 5-year period.

II. Objectives

The specific objectives of this proposal are

(1) To assess the quality of the TOPEX/POSEIDON surface altimeter data in regard to its use for a large, low-frequency monitoring of the surface topography of the tropical Atlantic Ocean (from 25°N to 25°S).

(2) To develop a method, on a demonstration basis, to derive from the tropical Atlantic the depth of the

thermocline and the heat content changes from the surface altimeter data field.

(3) To develop a method of assimilation of altimeter data into Oceanic General Circulation Models (OGCMs) for the purpose of preparing an operational, permanent, three-dimensional now casting of the tropical Atlantic Ocean (a TOGA objective).

(4) To derive from these models global circulation fields and a time series of mass and meridional heat transports across the tropical Atlantic region (a WOCE objective).

III. Approach

These objectives will be approached with a strategy that intimately combines conventional in situ observation, altimeter observation, and models.

The altimeter data and other conventional oceanographic data will first allow us to derive a two-layered tropical-ocean concept, the depth of the thermocline change, the heat content change, and the heat divergence. The assimilation of these altimeter data with the other oceanographic data in an OGCM will then allow us to perform a three-dimensional now casting of the thermal structure and current fields (a TOGA objective). From these simulations, more complete and accurate computations of heat-budget parameters will be performed. The model simulations will be used for the computation of global mass and heat transports (a WOCE objective).

The following sequence of operations is proposed:

(1) Acquisition and analysis of altimeter TOPEX/POSEIDON data on the tropical Atlantic Ocean (from 20°N to 20°S), with a possible extension to 35°S. A repetitive orbit of 7 to 10 days is required.

(2) Acquisition and analysis of conventional in situ oceanic data, including expendable bathythermograph (XBT), tide gauge, and conductivity/temperature/depth (CTD) data.

(3) Long-term calibration of the satellite sea level data in reference to the in situ conventional data.

(4) A run of the three-dimensional primitive-equation model on an operational basis, forced by surface wind and thermodynamic air–sea fluxes.

(5) Assimilation of altimeter data and in situ ocean data in the model.

(6) Analyses of the model simulations and computations of time series of global mass and heat transports over the whole tropical Atlantic basin for the total life of the satellite (3 to 5 years).

IV. Anticipated Results

The main anticipated result of this investigation is an improved understanding of altimeter measurements and a demonstration of their usefulness for climate studies in tropical oceanography. Large-scale, low-frequency, sea level changes in the tropics are intimately associated with climatological events like the El Niño Southern Oscillation (ENSO) in the Pacific Ocean and similar warm events in the Atlantic. The mean sea surface dynamic topography in the tropical Atlantic is characterized by the superposition of an east-to-west rise and a series of zonal ridges and troughs. The total variability of the altimeter signal is maximum and reaches 10 cm in an area situated along the equator and between 10°W and west of 30°W. This is consistent with what has been observed with hydrographic observations (Figures 1 and 2). Furthermore, it has been recently demonstrated that altimeter observations are able to restitute the main aspects of the sea level seasonal-variability data from the tropical Atlantic (Menard, 1988; Arnault et al., 1989). Sea level in the tropics is the most pertinent indicator of the baroclinic response of the ocean to atmospheric forcing. This is due to the near two-layer structure of the upper tropical ocean that places heat content, depth of the thermocline, and dynamic height in close relationships with sea level. Such monitoring of the thermal and dynamic variability of the upper tropical oceans is a central objective of the TOGA program.

Another anticipated result of this investigation is the demonstration of the feasibility of a permanent three-dimensional model simulation using assimilation for altimeter sea level observations. The operational assimilation of the altimeter data will be made tentatively in real time if the ephemerides of TOPEX/POSEIDON are available in real time. Up to now, Ocean General Circulation Models (OGCM) have been used primarily in idealized studies to improve our understanding of the oceanic response to different wind and thermal forcings. This will change very soon when OGCM are run operationally to provide real-time and synoptic descriptions of phenomena, such as El Niño in the Pacific Ocean and similar warm events in the Atlantic. These models will assimilate the available data and, in particular, satellite altimeter data, and will provide coherent pictures of large-scale conditions in tropical oceans—the analogs of weather maps. The gridded data sets produced by the models will make possible computation of the oceanic mass and heat transports, a computation that cannot be obtained from the measurements only. These heat and mass transports in the Atlantic Ocean are of crucial importance and represent one of the central objectives of WOCE.