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TOWARD AN OPERATIONAL 3 DIMENSIONAL SIMULATION OF THE TROPICAL ATLANTIC OCEAN

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Abstract. Simulations obtained with a three dimensional primitive equation model in the tropical Atlantic ocean are compared with observations made during the FOCAL and SEQUAL experiments in 1984. In many respects the results are encouraging; notably, the most characteristic aspects of the 1984 warm event are correctly represented by the simulations. As part of the TOGA program, it is planned to run such a model operationally in the tropical Atlantic ocean. An improvement in the simulation is expected from a regular reinitialization of the model using observations. The quality of the forcing functions, especially the wind stress, will be improved by using a high frequency wind field provided operationally by the European Center for Medium range Weather Forecasting (ECMWF).

Introduction

Important progress has been achieved during the last decade in modelling tropical oceans, which suggests that models can be used as tools for understanding and possibly forecasting upper ocean changes in the tropics. Observed climatological winds and surface thermodynamic fluxes have been used to force sophisticated three-dimensional models both in the Pacific [Philander et al., 1987] and in the Atlantic [Philander and Pacanowski, 1986].

One of the ultimate objectives of the Tropical Ocean and Global Atmosphere international program (TOGA) is to operate a coupled tropical ocean-atmosphere model that will possibly predict the evolution of the ocean-atmosphere climate system at low latitudes on an operational basis. An intermediate important goal could be reached before the existence of these coupled models; namely, the development of an operational tropical ocean model. It is planned, as part of the TOGA program, to run operationally such models in the three oceans. In the Pacific, Leetmaa (1987) has achieved an operational, near real time simulation of the ocean upper layers that is in some aspects quite realistic. He used the model of Philander et al., (1987). More recently a French group [P. Delecluse, personal communication, 1988], also developed a general circulation model (OGCM) that correctly simulated the evolution of upper layers of the Atlantic ocean during the FOCAL/SEQUAL experiments (1982-1984).

The purpose of this note is to briefly overview the first results obtained at the Laboratoire d'Océanographie DYnamique et de Climatologie (LODYC) using this new OGCM to simulate the 1984 year in the tropical Atlantic ocean. We also present plans for the development of a permanent nowcasting of the tropical Atlantic ocean.

The model

The model is a multilayer primitive equation Ocean General Circulation Model (OGCM) with the usual Boussinesq, hydrostatic and rigid lid approximations. The primitive equations are solved numerically by means of finite differencing methods. The parametrization of vertical diffusivity is the one used by Pacanowski and Philander (1981). The coefficient of horizontal eddy viscosity is constant and equal to 2.10^7 cm^2/s. Vertical instabilities are eliminated instantaneously by vertical mixing to a depth that ensures stable density gradient. The model extends from 20°S to 20°N and from the American coast to the African coast with a grid point distribution variable in longitude. The latitudinal reso-lution varies continuously from 1/3 of a degree at the Equator to 1.5 degree at 20° latitude. The longitudinal resolution varies also continuously from 0.5 degree near the coasts to 1 degree at the center of the basin. There are 16 levels in the vertical from 0 to 3,750 meters, no topography and no islands. A no slip condition is used at the 20°N-20°S boundaries. The time step used is 40 minutes.

The Short Wave and Long Wave components of the surface heating are taken to be constant (respectively 203 Wm^{-2} and 56 Wm^{-2}). Sensible and latent heat fluxes are computed from the usual bulk formula with a drag coefficient equal to $1.4\ 10^{-3}$ The air temperature is a climatology given by Esbensen and Kushnir (1981). The wind field used to force the model has been prepared by Servain et al. (1987) from ship observations. It is given in the form of a monthly mean of pseudo-stress gridded by squares of 2 degrees in latitude by 2 degrees in longitude. In addition, the wind stress has now been corrected for stability, which substantially increases the stress in light wind conditions.

The initial conditions for the model are zero currents and a uniform thermal stratification given by Philander and Pacanowski (1980). The equilibrium for the seasonal cycle is reached after four years of integration of the model forced by the climatological winds [Hellerman and Rosenstein, 1983]. The model was then run again for two more years (1982-1983) using a wind field produced for the FOCAL/SEQUAL experiments [V. Cardone and Y. Tourre personnal communication, 1987] derived from output of the predictive model of the European Center for Medium range Weather Forecasting (ECMWF). The simulations presented here start the first of January 1984 using initial conditions which are the model situation on December 31, 1983.

The 1984 tropical Atlantic simulation

The model has been tested for the 1984 year during which the two intensive observing programs, FOCAL and SEQUAL (1982-1984) provided the most complete data set ever collected at a basin scale for two seasonal cycles in the tropics. Most of these observations have been described in a set of 24 papers collected in a special issue of Geophysical Research Letters referenced hereafter as SEQUAL/FOCAL (1984).

From these data, unusual warm conditions in 1984 have been described that are, in many respects similar to oceanic conditions observed during an EL NINO in the Pacific ocean [Philander, 1986; Hisard et al., 1986]. During the first three months of 1984 the upper ocean was unusually warm in the eastern part of the basin, with substantial deepening of the thermocline. The Intertropical Convergence Zone (ITCZ) was displaced southward about 400 kilometers from its normal near equatorial position. As a consequence light winds were preponderant with a strong southward component in the west indicating an extension of the northern trade winds in the southern hemisphere. The South Equatorial Current (SEC), which usually flows westward with an average speed of 80 cm/s, almost disappeared in Ja-

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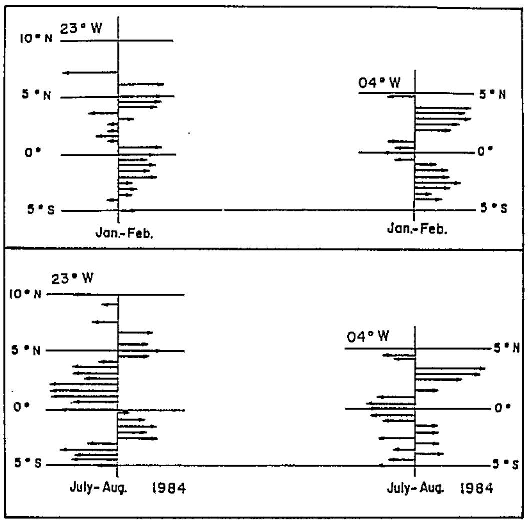

Fig. 1. The zonal component of the 0-20 surface currents (arrows to the right are eastward) as measured along 23°W and 4°W in January-February and July-August 1984 during FOCAL cruises. (From Hisard et al., 1986).

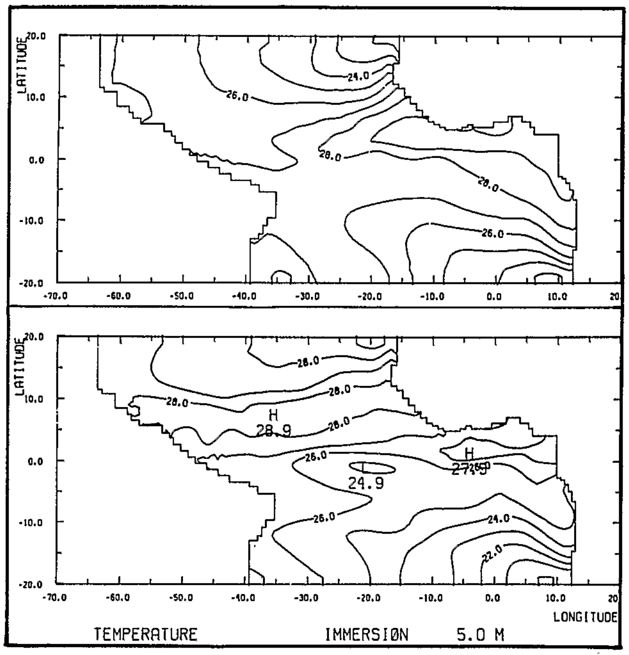

Fig. 3. Mean sea surface temperature simulations for February 1984 (upper panel) and August 1984 (lower panel).

nuary-February and an unusual eastward current was observed south of the equator similar to the one frequently observed in the Pacific ocean during EL NINO (Figure. 1). In summer (July-August) we observed an intensification of the wind returning to more normal conditions. As a consequence we observed a westward SEC of about 40 cm/s, an eastward NECC north of 4°N and a residual eastward South Equatorial Counter Current (SECC) at about 4°S. The simulations of the surface currents presented in Figure 2 for February and September are in good agreement with these observations. In February the model circulation is amorphous with a weak but general eastward flow. In contrast, in September we found the usual westward circulation in the SEC area and eastward in the NECC area characteristic of the tropical Atlantic ocean at this season [cf. Figure 3 of Philander and Pacanowski, 1988]. However the eastward SECC observed south of the Equator does not exist in the model.

The simulations of the SST field obtained for February and August (Figure 3) may be compared with the observations provided by Servain et al.(1987) in Figure 4. The model is usually too warm of about 1°C mostly in the regions of high SST (>27°C) in the vicinity of the ITCZ, but the

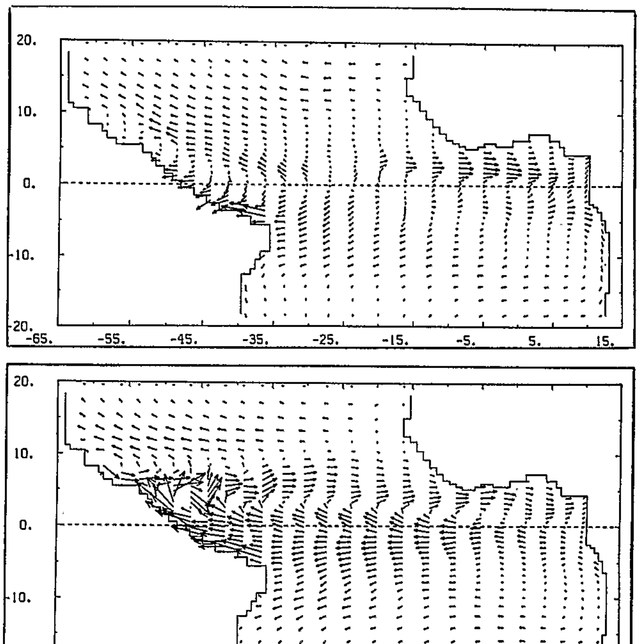

Fig. 2. Mean surface currents simulated by the model for February 1984 (upper panel) and August 1984 (lower panel).

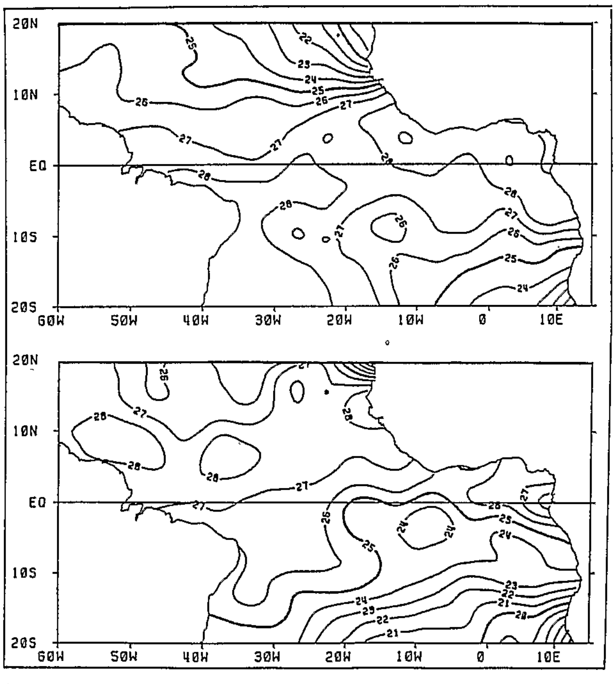

Fig. 4. Mean sea surface temperature observed in February 1984 (upper panel) and August 1984 (lower panel) (From Servain et al., 1987).

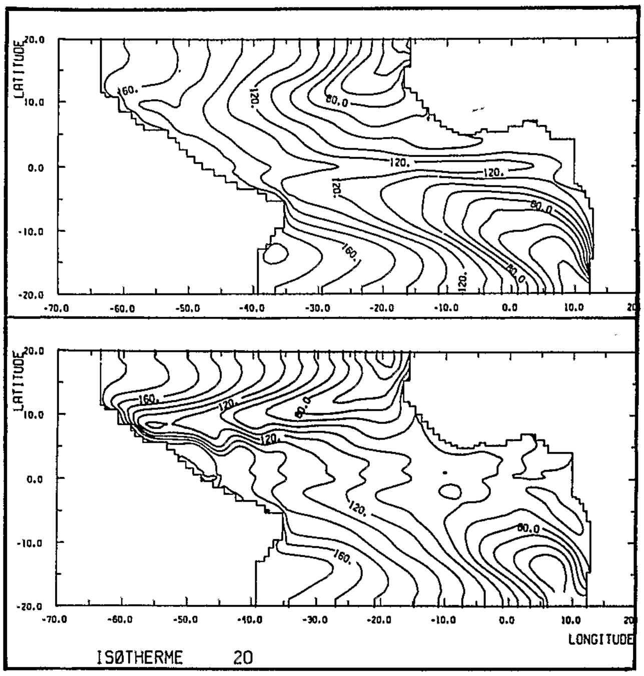

Fig. 5. Topography of the 20°C isotherm simulated by the model. Upper panel: mean topography for February 1984. Lower panel: mean topography for August 1984.

general pattern of the observed SST distribution is reasonably well simulated by the model, particularly in the middle of the basin where we observe an equatorial upwelling in August. Nevertheless the model underestimate the amplitude of the seasonnal variability in the Gulf of Guinea. But by comparison the summer upwelling signal did not appear at all in the simulations made with the FOCAL/SEQUAL wind [P. Delecluse, personal communication, 1988].

Figure 5 shows the model simulation of the topography of the 20°C isotherm for February and August 1984. In February the zonal slope of the thermocline simulated by the model is almost flat all along the equator from 35°W to 10°E. This striking feature, abnormal for this period of the year, was observed during FOCAL cruise (Figure 6). In the central and eastern equatorial Atlantic the 20°C isotherm in January-February 1984 was observed to be more than 50 meters deeper than in normal years such as 1983 (Figure 6). The model simulation for August (Figure 5 lower panel) shows a return to normal, in agreement with the FOCAL cruise 8 observations (Figure 6). The pattern of the present OGCM simulation in early 1984 is in agreement with the simulations made with simpler models by Du Penhoat and Gouriou (1987) and by Andrich et al. (1988).

An equatorial mooring at 28°W (Figure 7) offers the possibility of testing the model simulation for the deeper layers. Variations of the simulated and observed Equatorial Undercurrent (EUC) core speed are in phase, but the amplitude of the simulated variation is about double while its mean value is too small. The core of the simulated EUC (Figure 8) uplifts from about 100 meters in January to about 75 meters in April in good agreement with observations (Fi-

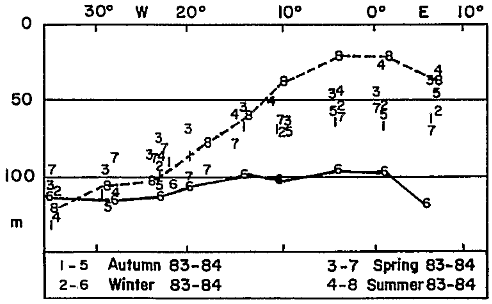

Fig. 6. Averaged values between 1°N and 1°S of the 20°C isotherm depth along the equator between 35°W and 6°30E observed during the FOCAL cruises (as identified by their cruise number). Cruises 1 and 5 refer to October-November 1982 and October-November 1983. Cruises 2 and 6 refer to January-February 1983 and January-February 1984. Cruises 3 and 7 refer to April 1983 and April 1984. Cruises 4 and 8 refer to the July-August 1983 and July-August 1984. (From Hisard and Henin, 1987).

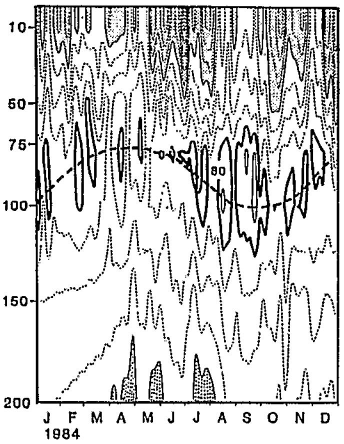

Fig. 7. Zonal component of equatorial current observed at the equatorial and 23°W during 1984 (From Weisberg et al., 1986).

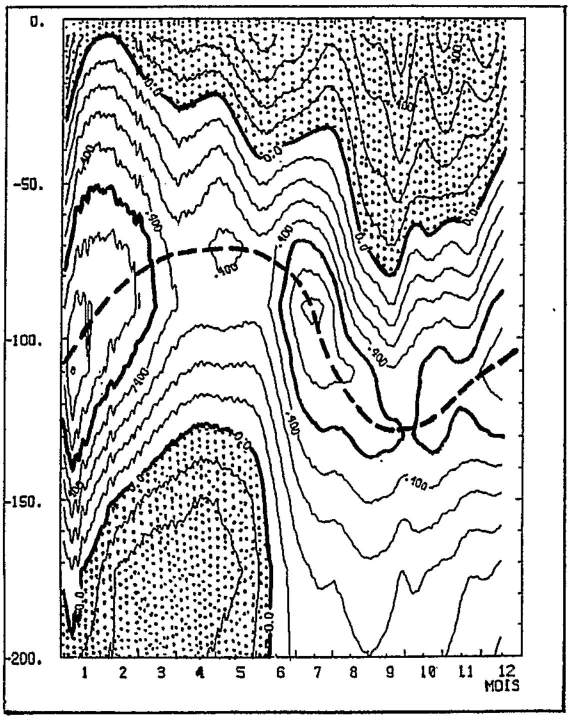

Fig. 8. Seasonal variation of the current zonal component simulated by the model at the equator and 28°W.

gure 7) and then deepens to a maximum depth of about 120 meters in September-October. The speed at the core of the EUC, given by the model, varies from 40 to 70 cm/s. Its mean value is weaker by about 20 cm/s than the observed speed, but the amplitude of its variation is much greater. Nevertheless, the observed intensification of the EUC in the second half of 1984 corresponds also to an intensification in the model simulation. In summary, many of the characteristic features of the seasonal variability of the surface and subsurface circulation at the equator are realistically simulated by the LODYC model. These results are encouraging in view of the inaccuracy of the wind field and the monthly average that filter the high frequencies which are known to represent an important fraction of the energy of the wind variability in the tropics. Furthermore, the poor account of thermodynamics is probably responsable for an important part of the discrepancies between the model and the observation at the surface and in the mixed layer.

Toward an operational now-casting of the tropical Atlantic ocean

The simulation by Leetmaa (1987) of the 1987 Pacific EL NINO and the results presented here for the 1984 warm event in the Atlantic indicate that we are close to realistic operational now-casting of the tropical oceans. The quality of the simulations obtained with our model in the tropical Atlantic will be greatly improved in the near future by two axes of development:

a) Reinitialization by assimilating observed oceanic data.
b) Improvement of the wind and thermodynamic forcing fields.

Reinitialization experiments planned for early 1988 will use the thermal field issued by the model as a guess field for an objective analysis of in situ observations. The observations available are thermal profiles from Expendable Bathy Thermographs (XBT) routinely acquired along two ship lines crossing the 20°N-20°S Atlantic domain. The thermal field including the XBT observations for a month is then used as a new initialization field for the model. We plan to study the effect of the reinitialization frequency on the quality of the simulation. First we will reinitialize the model by steps of one month. But given the space and time distribution of the data we could be led to extend the time averaged period.

Another area for improvement is the wind field. Leetmaa (1987) and Harrison et al. (1988) have found that outside the equatorial waveguide the uncertainty in the curl of the wind stress caused important discrepancies in the hindcasts. Another major deficiency of the present ship wind is the absence of high frequency due to the monthly average. We plan to experiment with the wind issued by the ECMWF 4 times per day to see the effect of averaging the winds for periods from one day to one month. These hindcasts and the one made with the monthly ship wind will be compared to available in situ measurements.

Important climatic signals, such as El Nino in the Pacific ocean and similar warm events in the Atlantic, need to be monitored continuously (TOGA objectives). These OGCM's, run operationally, will provide coherent pictures of large-scale thermal and dynamic conditions, the analogs of weathermaps. The gridded data sets from the models will make it possible to answer questions about oceanic mass and heat budgets, questions which cannot be answered on the basis of measurements alone. The OGCM, in short, will become a tool as powerful and widely used in oceanography as the general circulation model in meteorology.

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