AN EXPERIMENT USING ATMOSPHERIC FORCING FROM AN FGGE ANALYSIS TO DRIVE A MIXED LAYER OCEAN MODEL

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ABSTRACT

In this study we present results of one numerical experiment in which an upper ocean model is driven by surface heat fluxes and stress fields derived from the FGGE SOP-1 GLAS analysis/forecast system (Halem et al., 1982). The model results show that most changes in the mixed layer height and horizontal velocity occur in the first days. On the other hand, changes in the temperature field take a longer time to develop. In the most realistic case (real initial conditions, instantaneous forcing fields from the atmospheric analysis), the resulting changes in temperature were larger than observed and the correlation between observed and predicted changes was poor. The deficiency in the forecast of SST changes may be due to several factors: lack of feedback between the ocean and the atmosphere and the absence of transports by the strong boundary currents and, perhaps, unrealistic surface fluxes of heat and momentum. Unless these problems are alleviated, it will not be reasonable to perform coupled atmospheric ocean forecasts.

1. INTRODUCTION

In this study we present results of one numerical experiment in which an upper ocean model is driven by surface heat fluxes and stress fields derived from the FGGE SOP-1 GLAS analysis/forecast system (Halem et al., 1982).

The ocean model is essentially an oceanic boundary layer coupled with a dynamic model of the upper ocean currents (Schopf and Cane, 1983). The oceanic boundary layer can be viewed as an intermediary zone between the deep ocean circulation and the atmosphere, extending from the surface to a depth of about 10-150 meters. In this layer both the temperature and the salinity fields are almost constant in the vertical. This vertical constancy is due to mixing which is caused by turbulence. The turbulence is in turn caused by breaking waves, shear instabilities, etc.

The aim of this study is to seek a better understanding of the model ocean boundary layer response to various forms of atmospheric forcings and the associated time and space scales involved. It is known that the time scales of the atmospheric flow are smaller than those of the

oceanic flow even for an upper ocean model like ours. On the other hand, the space scales for the baroclinic motion in the ocean are considerably less than in the atmosphere. The grid being used is of 4^{o} by 5^{o} of latitude and longitude, respectively, and was chosen to coincide with that of the atmospheric analysis. However, an accurate description of the oceanic synoptic scales requires a much finer horizontal resolution on the order of 10-50 kilometers. The coarseness of the grid is very significant limitation of our experiments.

Although the distributions of atmospheric wind forcings are very similar in summer and in winter, their intensity is greater in winter (Elsberry and Camp, 1978: Elsberry and Raney, 1978). The source of mechanical energy is proportional to u_{*}^{3}. Thus, during the passage of a winter storm, there is an upward heat flux and the mechanical mixing is enhanced by the strengthening of the wind forcing. As a result of the upward heat flux, the bottom of the mixed layer deepens. After the storm's passage, the cooling effect continues due to entrainment. In summer, the winds are weaker. Consequently, the entrainment at the base of the oceanic boundary layer is almost nonexistent. As a direct consequence of the stabilizing effect of the surface heating, the oceanic boundary layer becomes shallower (Elsberry and Camp, 1978; Elsberry and Raney, 1978).

One of the problems faced in this kind of study is the initialization of the ocean model. A solution may be available in the near future: according to Levoy (1981), it is expected that global SST distributions with higher resolution will be possible to get from satellite radiances. Also, accurate estimates of the surface wind field may be obtained using data from the radar Scatterometer (O'Brien, 1981). However, in the present study somewhat arbitrary initial conditions are used for the mixed layer depth and deep temperature fields. The initial currents were assumed to be zero and the initial SST's were obtained from the GLAS/temperature retrieval system for January 1979 (Susskind et al., 1982). It is very possible that the results may have been dependent on such a choice.

Another characteristic of these experiments is that we have used a one-way coupling mechanism, in which the atmospheric parameters derived from the GLAS analysis/forecast system were used to drive the ocean model. It should be noted that the atmospheric analysis was performed assuming climatological SST's, and that the coupling did not allow any feedback from the ocean model's predicted SST to the atmosphere. The lack of feedback may also be a serious deficiency of our experiments.

2. THE OCEAN MODEL AND ATMOSPHERIC ANALYSIS

The mixed-layer ocean model used in this study is the one developed by Schopf and Cane (1983). Following Kasahara (1974), the model equations of momentum, temperature, continuity and the hydrostatic relation are as follows:

$$\partial(h\underset{\sim}{V})/\partial t + \nabla\cdot(\underset{\sim}{V}h\underset{\sim}{V}) + \partial(w_{e}\underset{\sim}{V})/\partial s - [f + u/a\ \tan\theta]\ \underset{\sim}{k}\times h\underset{\sim}{V} = -h\ \{\nabla p + b\ \nabla z\}$$

$$+ \partial\underset{\sim}{\tau}/\partial s + h\ F_{H}(\underset{\sim}{V})\ , \qquad (1)$$

$$\partial(hT)/\partial t + \nabla\cdot(\underset{\sim}{V}hT) + \partial(w_e T)/\partial s = -\partial Q/\partial s - \partial D_v/\partial s + h\, D_H(T) \ , \tag{2}$$

$$\partial h/\partial t + \nabla\cdot(h\underset{\sim}{V}) + \partial w_e/\partial s = 0 \ , \tag{3}$$

$$\partial P/\partial s = bh \ , \tag{4}$$

where s is a generalized vertical coordinate. The buoyancy, b, is calculated via a linear expression:

$$b = b(T) = g\alpha(T-T_r) \ . \tag{5}$$

Following Niiler and Krauss (1977) and Kim (1976), the equation of entrainment, w_e, needed to close the system is:

$$w_e\, H(w_e)\, \{h_1(b_1 - b_e) + q^2 - m_e|\Delta V|^2\} = 2m_s u_x^3 - 2\varepsilon_0 h_1 + h_1 B_0\, [1-m_b\, H(B_0)] + B_1(h) \ . \tag{6}$$

For a more detailed explanation about the model and the symbolism being used, the reader is referred to the original paper (Schopf and Cane, 1983).

In these experiments the model has been used in a global configuration with a resolution of 4^o of latitude by 5^o of longitude. While no slip conditions are used at the coastal boundaries, no flux of temperature is allowed through these same boundaries. The time step used is of three hours.

Because salinity is not predicted in the model, and in order to avoid complications associated with ice generation, artificial boundaries have been arbitrarily placed at 70^oN and 58^oS.

3. DESCRIPTION OF THE EXPERIMENTS

The parameters that drive the ocean model are: the surface heat budget, the wind stress and the friction velocity. The components of the surface heat budget include the latent and sensible heat fluxes and the incoming and outgoing radiative fluxes. Thus, the surface heat balance, Q, is computed as:

$$Q = (S_w - X_w - E_v - S_H)/\rho \ , \tag{7}$$

where S_w, X_w, E_v and S_H represent the solar radiation at ground level, the long wave radiation at ground level, the latent heat, and the sensible heat flux, respectively. A reference sea density is represented by ρ.

The surface wind stress, τ, is computed as in the atmospheric model while the friction velocity, u_x, is calculated as usual (Sommerville et al., 1974).

The geopotential height, horizontal wind, and relative humidity are analyzed at mandatory pressure levels in the GLAS objective analysis scheme (Baker, 1983). The 6-hour model forecast supplies a first-guess for the above fields at 300mb and sea level. The assimilation/forecast model is a fourth-order global atmospheric model which is based on an

energy-conserving scheme with all horizontal differences computed with fourth-order accuracy (Kalnay-Rivas et al., 1977; Kalnay-Rivas and Hoitsma, 1979).

Preliminary experiments coupling the atmospheric forcing from the GLAS FGGE analysis showed unrealistic large changes in the sea surface temperature (SST). In order to understand the causes of these unrealistic variations, a series of simpler idealized experiments were conducted. The main objectives in setting up these experiments were to study the time evolution and seek a better understanding of the time scales involved in the development of asymmetric oceanic features. Only one of those experiments will be analyzed.

In this experiment the instantaneous values of all the externally atmospheric forcings were used in the time integration.

4. RESULTS

The discussions of the experiment will be limited to the open ocean regimes. Thus, I will avoid the study of the especially complex circulations in coastal regions, were the lack of boundary currents in the initial conditions and the coarseness of the grid make the model particularly unrealistic.

We will begin with an analysis of the one week results. In this case, in the belt between 35°S and 60°S the deepening of the mixed layer is well organized globally (Figure 1). The changes in temperature after one week (Figure 2) are generally smaller than 1°C. The main exception is near the East coast of North America. It is interesting to notice that the use of time varying wind stress and friction results in smaller changes in ML depth. A discontinuous temperature front can be observed to the Southeast of Africa.

After five weeks the deepening of the ML observed in most of the South Atlantic may be explained by the deficit of surface heat balance which counterbalances the effects of the very light easterlies observed in the region. Opposite reasons are valid for the shallowing of the ML observed in the South Pacific down to 40°S (Figure 3 and 4). Also very light easterly winds are observed in the South Pacific after five weeks (Figure 5). As far as the temperature in the north and central Indian Ocean is concerned, the deficit of a strong surface heating balance, combined with the minimal balancing effects of the light winds, produces a decrease in the temperature fields. The light winds do not balance the deficit of a strong surface heating balance, thus decrease in the temperature fields (Figure 6). Because of the absence of easterly winds west of southern Africa, we observe a great increase in the SST. The same is true of the west of South America. Furthermore, north of 10°S the deficit of heat balance produces a decrease in the SST in the Atlantic Ocean up to 35°N.

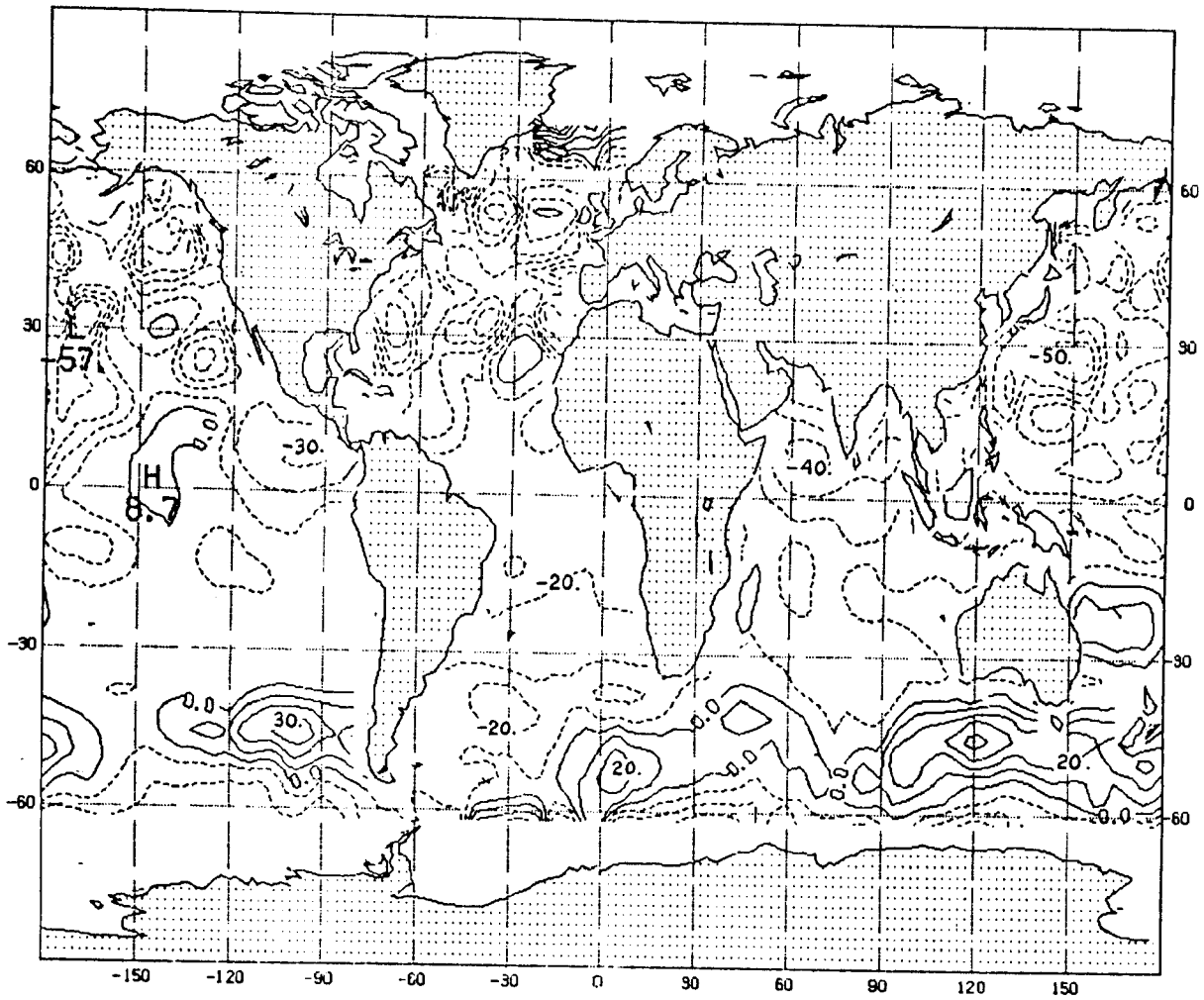

Fig. 1 - Weekly averaged ML height changes after one week.
Contour interval of 10m.

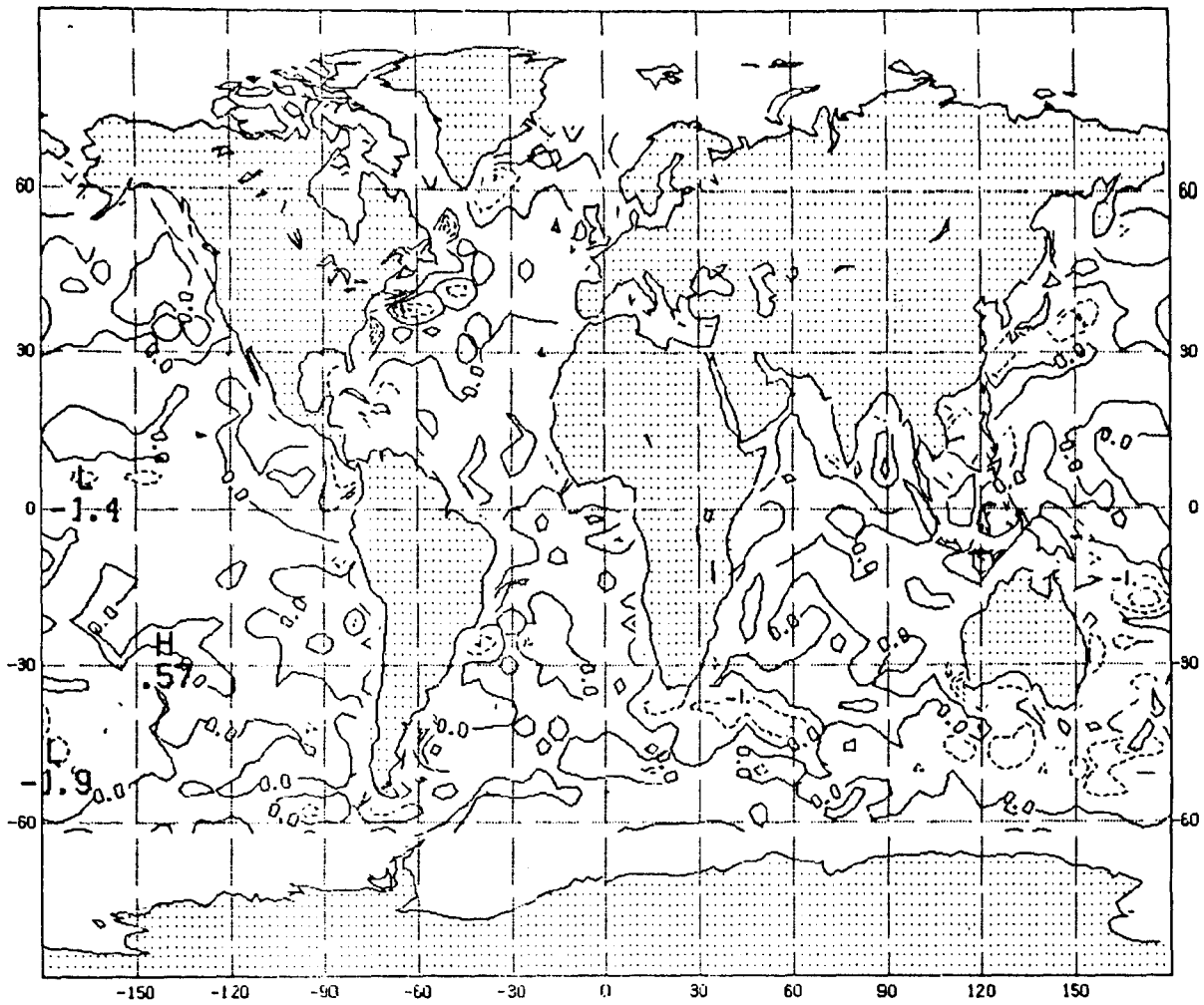

Fig. 2 - Weekly averaged ML temperature changes after one week. Contour interval of 1°C.

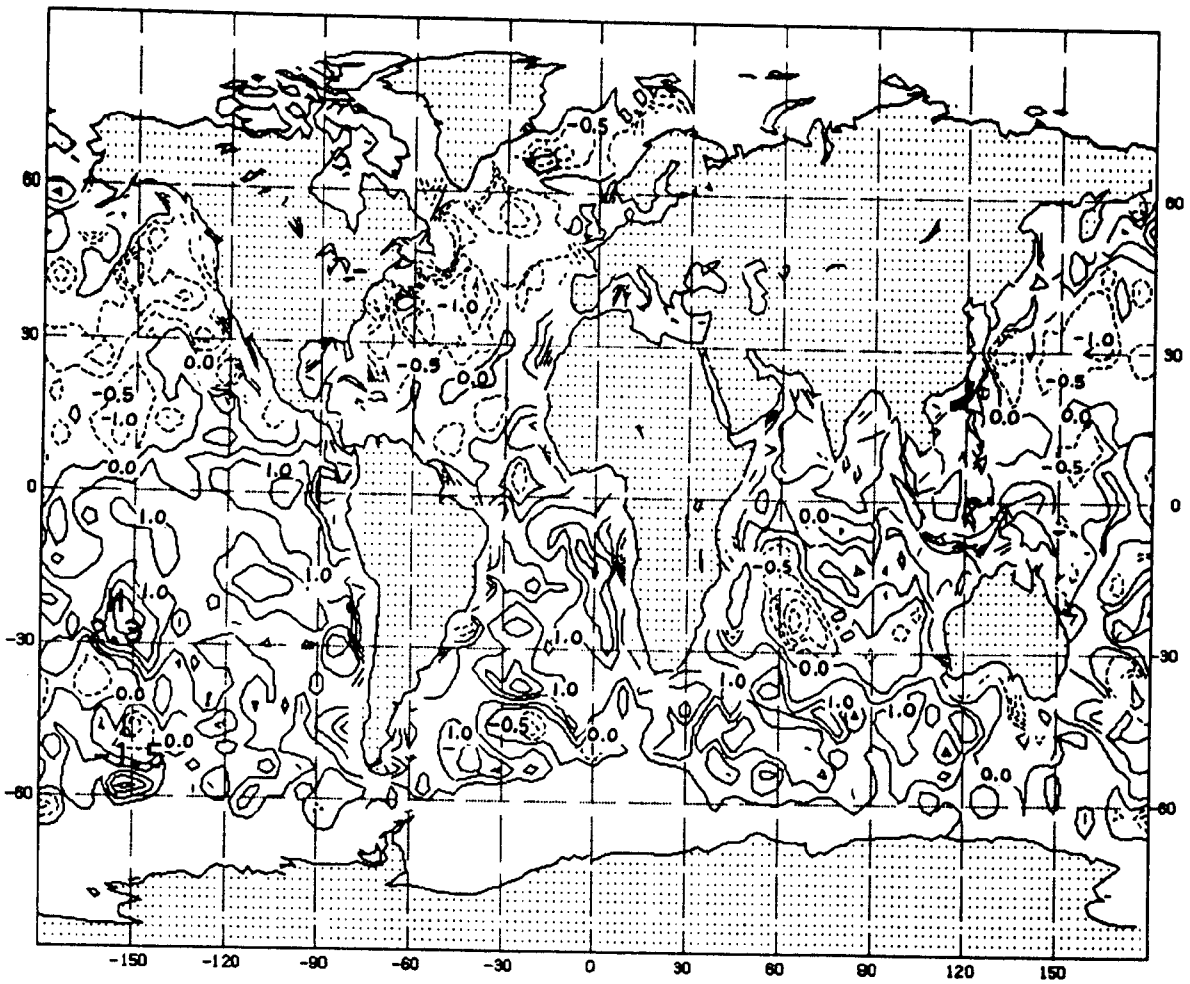

Fig. 3 - Weekly averaged value of surface heat balance.
Contour interval of 20 Watts/m^2.

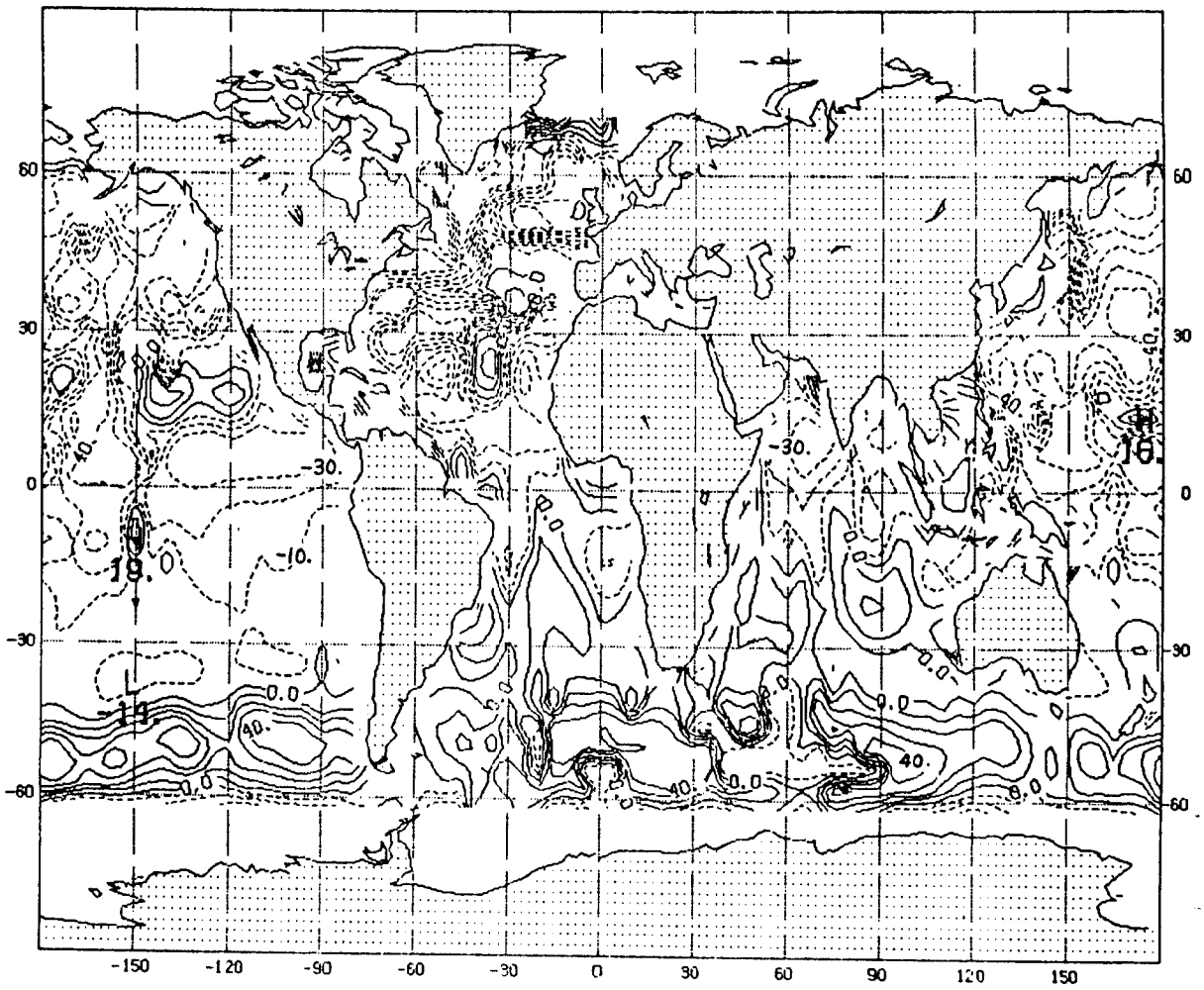

Fig. 4 - Weekly averaged ML height changes after five weeks. Contour interval of 10m.

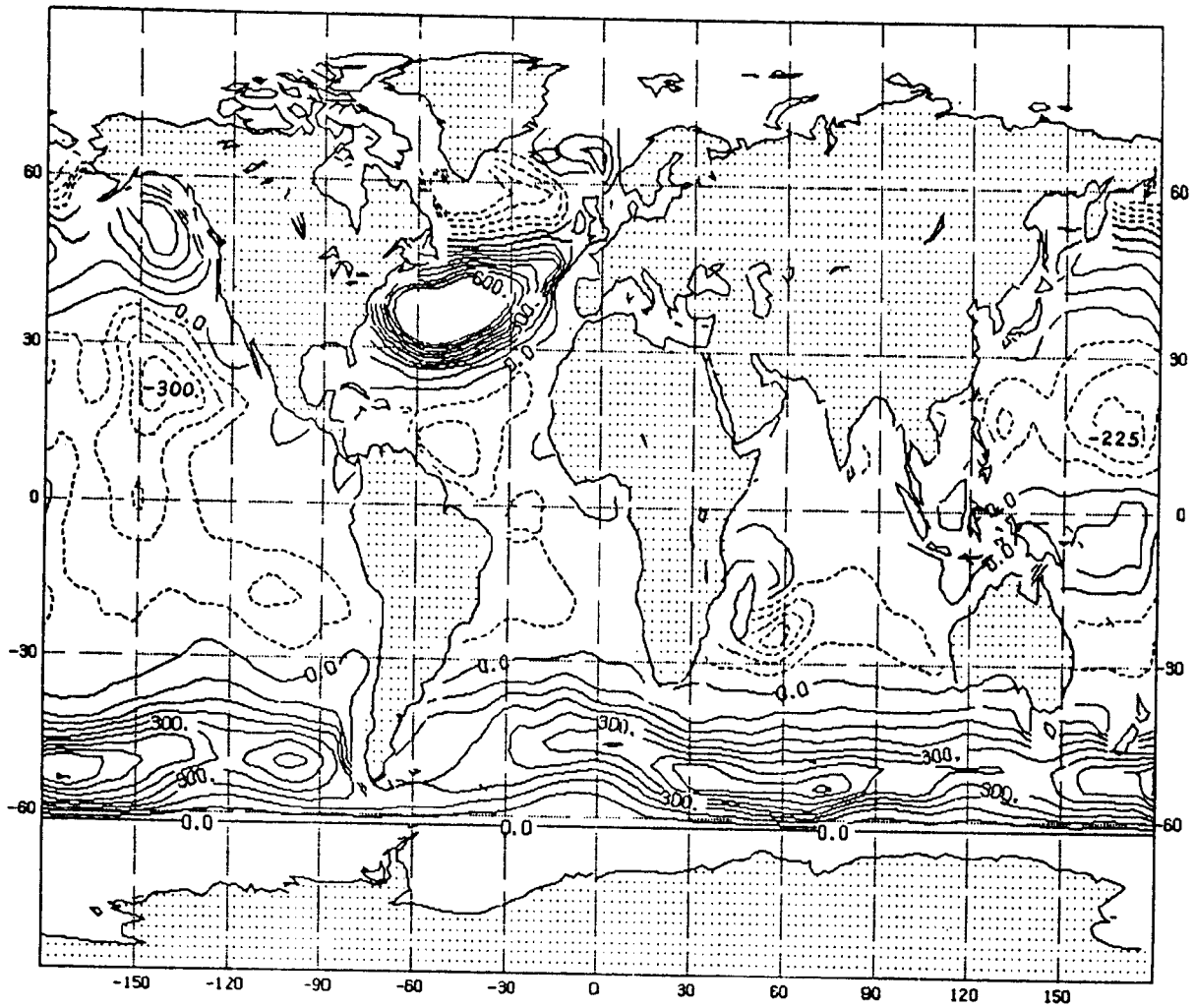

Fig. 5 - Weekly averaged value of the wind stress in the x direction. Contour interval of 75 10^{-3} N/m^2.

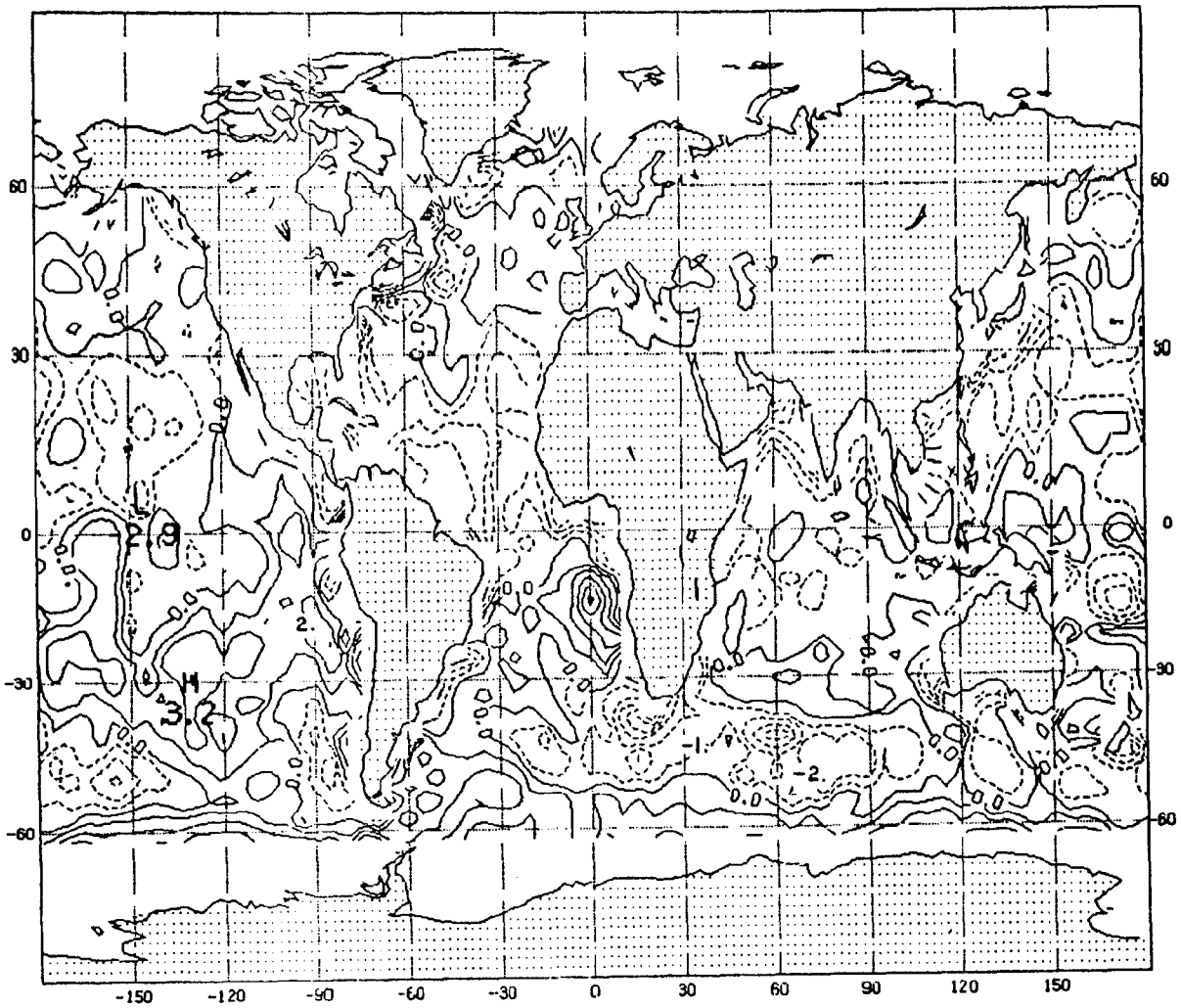

Fig. 6 - Weekly averaged ML temperature changes after five weeks. Contour interval 1°C.

This decrease in temperature is not as remarkable in the Pacific Ocean because of a strong surplus of surface heat balance. The presence of moderate easterly winds tends to counterbalance the effects of the surplus of surface heat balance in the belt between 10°N and 30°N in the Central Pacific, explaining the slight decrease in the SST observed in that area. North of 30°N, in the same Pacific Ocean, the surplus of surface heating tends to counterbalance the effects of the easterlies, thus generating no net change in the temperature fields.

Because the time scale of response of the mixed layer temperature to the atmospheric wind forcing is a matter of hours, the instantaneous effects of the stronger wind stress will have a greater impact than in the time averaged case. Then, after five weeks the temperature front observed in the Indian Ocean at 35°S is stronger than after one week. Simultaneously, the decrease in temperature observed after five weeks in the belt between 40°S and 60°S is even greater than after one week. East of Asia, the decrease in SST can be explained by the deficit of surface heating in that area.

We now compare the five week temperature changes predicted by the model (Figure 6) with the actual observed changes from January to February 1979 (Figure 7). First of all we should point out that the model has less skill in predicting the changes than climatology (Figure 8). Although there is some skill in predicting the sign of the change, their magnitudes are generally overpredicted. The model has correctly predicted cooling in the North Atlantic and North Pacific. The observed warming west of South America and South Africa are also predicted, but larger than observed. The cooling in the South Indian Ocean and in the Australian region is well predicted, but the model predicted cooling in the Arabian Sea and Bay of Bengal, whereas warming was observed. Similarly, the model overpredicted the cooling northeast of South America. A major failure occurred in the belt between 30°S to 60°S, where there was generally observed warming, with some small regions with cooling. Here the model predicted strong cooling, presumably through excessive deepening of the mixed layer by the roaring forties.

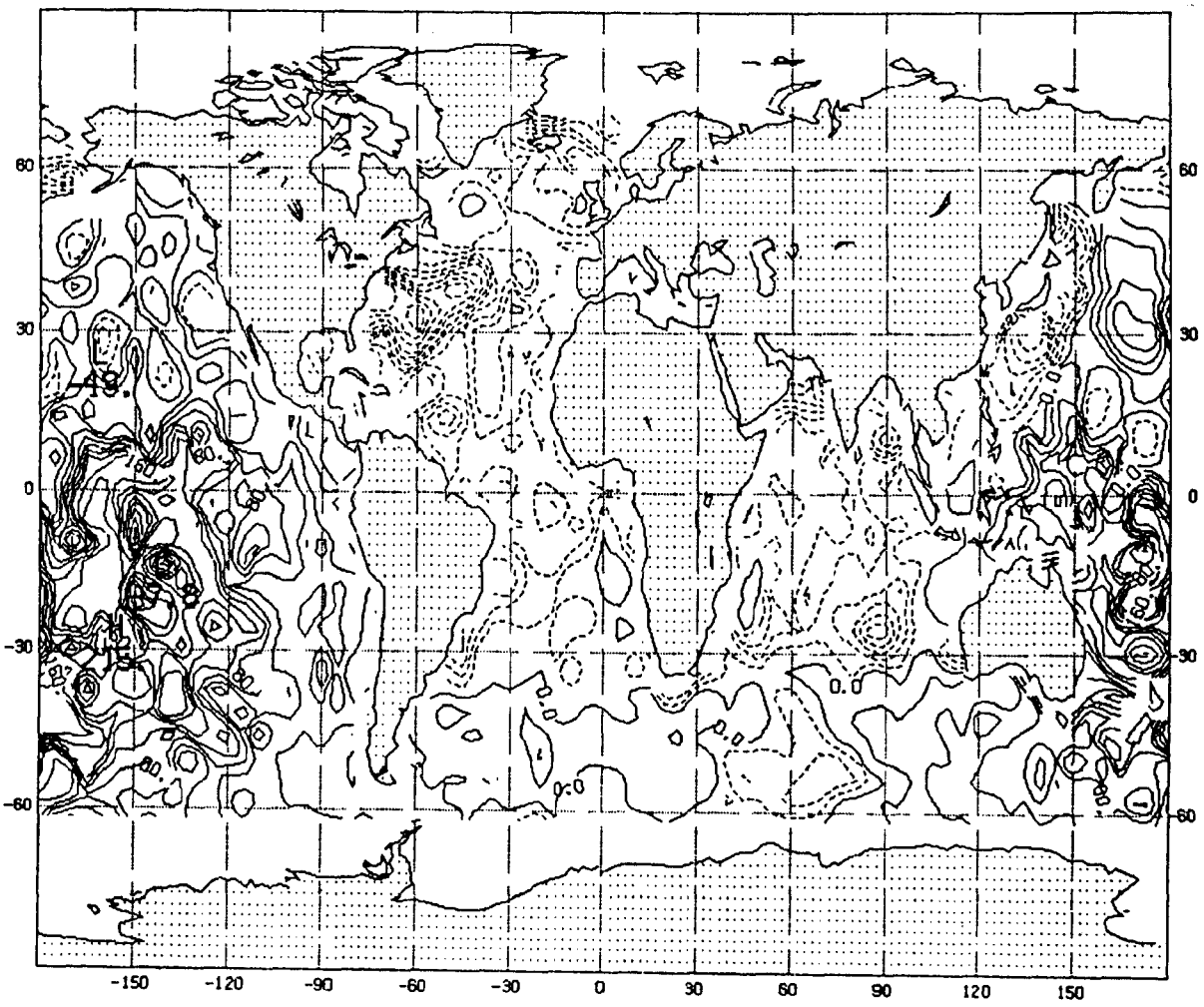

Fig. 7 - Observed sea surface temperature difference between February and January 1979 (Susskind et al., 1982). Contour interval of 0.5°C.

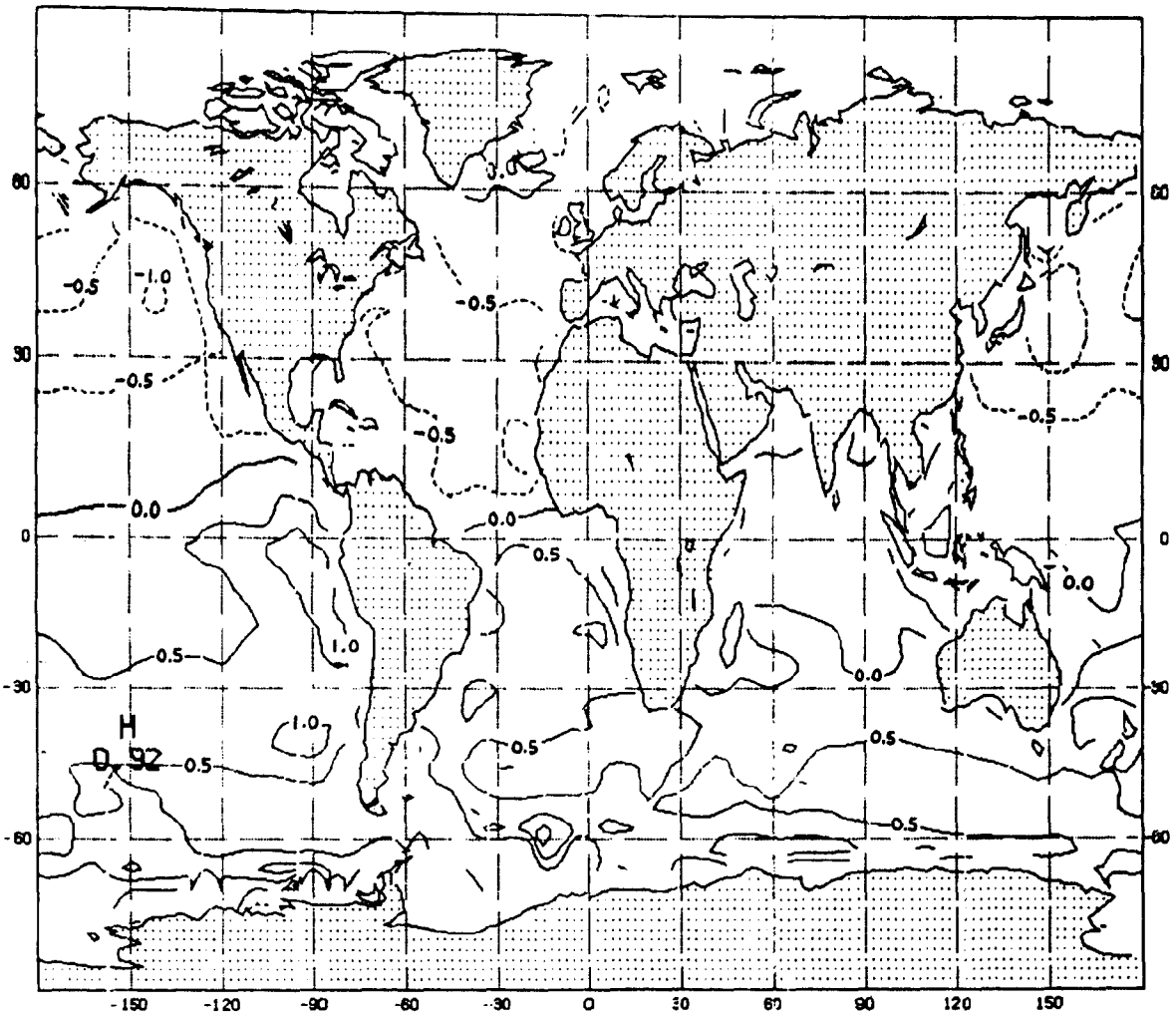

Fig. 8 - Climatological sea surface temperature difference between February and January. Contour interval of 0.5°C.

5. CONCLUSIONS

We have performed an experiment with the Schopf and Cane (1983) upper ocean model driven by surface fluxes derived from the GLAS atmospheric analysis for January 1979, with SST's derived for January 1979 by Susskind et al. (1982), and starting from a state of rest.

The model results are generally qualitatively reasonable. Namely, that whenever we have strong winds a deepening of the oceanic boundary layer is observed, and vice versa. Conversely, the opposite is also true. Furthermore, the temperature changes respond to the surface heat budget. Whenever and upward heat flux is observed, the boundary layer model responds by a decrease of temperature and vice versa.

The model results show that most changes in the mixed layer height and horizontal velocity occur in the first days. On the other hand, changes in the temperature field take a longer time to develop. The best forecast was obtained in other experiment where the driving surface

stress and friction velocity were zonally and time averaged, and the surface heat flux was time averaged. In the most realistic case (real initial conditions, instantaneous forcing fields from the atmospheric analysis), the resulting changes in temperature were larger than observed and the correlation between observed and predicted changes was poor.

The deficiency in the forecast of SST changes may be due to several factors: lack of sufficient ocean resolution, improper initialization, lack of feedback between the ocean and the atmosphere and the absence of transports by the strong boundary currents and perhaps unrealistic surface fluxes of heat and momentum. Unless these problems are alleviated, it will not be reasonable to perform coupled atmospheric ocean forecasts.

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