Comments on "Slowly Propagating Disturbances in a Coupled Ocean–Atmosphere Model"

ROBERT L. HANEY AND MARY ALICE RENNICK

Department of Meteorology, Naval Postgraduate School, Monterey, CA 93943

15 August 1985

Anderson and McCreary (1985, hereinafter AM) recently examined the solutions to a new model of the equatorial ocean–atmosphere system. The model is a reduced gravity model, generalized to include a prognostic equation for the ocean surface temperature. Anderson and McCreary interpreted the model solutions in terms of the El Niño Southern Oscillation (ENSO) phenomenon in the Pacific and Indian oceans. Some of the solutions involved land as well as ocean, and a dominant feature was eastward-propagating large amplitude oscillations with periods ranging from 2 to 11 years, depending on the value of certain model parameters. The purpose of this comment is to point out an unrealistic feature of AM's ocean model and to encourage further sensitivity studies with an easily corrected and more realistic model.

The basic problem concerns the parameterization of turbulent vertical mixing in the ocean part of the coupled model. Specifically, "the tendency for wind stirring to entrain fluid into the layer from below, thereby deepening the mixed layer and increasing its potential energy" is expressed [see (2.8) and (2.7) in AM] as

$$\frac{\partial T}{\partial t} = \cdots \frac{-2\delta}{h^2} \tag{1}$$

$$\frac{\partial h}{\partial t} = \cdots \frac{2\delta}{hT}, \tag{2}$$

where all notation is the same as in AM. The critical (and in our view, erroneous) assumption of AM is that $\delta = \delta_0/h$ with δ_0 a constant. This formulation results in an entrainment heat flux term which is proportional to h^{-3} and an entrainment velocity which is proportional to h^{-2}. By contrast, a typical mixed layer model (e.g., Kraus and Turner, 1967) has the following entrainment terms,

$$\frac{\partial T}{\partial t} = \cdots \frac{(\overline{w'T'})_{-h}}{h} \tag{3}$$

$$\frac{\partial h}{\partial t} = \cdots w_e, \tag{4}$$

where $(\overline{w'T'})_{-h}$ is the turbulent entrainment heat flux, and w_e the entrainment velocity. In a slightly generalized version of the Kraus and Turner model, these entrainment terms are given by

$$(\overline{w'T'})_{-h} = -w_e\Delta T = \frac{-(1+k)mw_*^3}{\alpha gh} - (\overline{w'T'})_0 + Q + (1-k)H[(\overline{w'T'})_0]. \tag{5}$$

In (5), $w_* = (\tau/\rho_0)^{1/2}$ is the surface friction velocity in the ocean, ΔT is the temperature drop below the surface layer, $\rho_0 C_p(\overline{w'T'})_0$ is the upward flux of sensible heat, latent heat and longwave radiation at the sea surface, and Q is the downward flux of solar radiation at the sea surface. The constants k and m essentially account for turbulence dissipation in the mixed layer and are known to within a factor of 2 (Niiler and Kraus, 1977). Since AM presumably intended to neglect the effects of surface cooling and solar radiation on entrainment, we restrict our attention to the first term in (5), which is the wind stirring term. Substituting this term from (5) into (3) and (4), we obtain

$$\frac{\partial T}{\partial t} = \cdots \frac{-\delta_1}{h^2} \tag{1$'$}$$

$$\frac{\partial h}{\partial t} = \cdots \frac{\delta_1}{h\Delta T}, \tag{2$'$}$$

where $\delta_1 = (1+k)mw_*^3/\alpha g$. If we identify ΔT with AM's layer temperature T, we see that the wind stirring terms in (1)′ and (2)′ can be computed directly from the model variables. In this case the wind stirring would properly depend on the local wind stress, or w_* (predicted by the atmospheric model), the ocean layer depth h, and the layer temperature T. The formulation given by (1)′ and (2)′ clearly represents a more *consistent* and physically realistic parameterization of entrainment mixing than that given by (1) and (2). Numerical solutions to the coupled model based on (1)′ and (2)′ would therefore be of much greater relevance to the actual ocean–atmosphere system.

Equations (1)′ and (2)′ can be reduced to a form that is analogous to (1) and (2) by using a constant value for w_* instead of the value predicted by the atmospheric model. In this case, δ_1 is a constant, and the entrainment heat flux and entrainment velocity are proportional to h^{-2} and h^{-1}, respectively. Such a dependence is in sharp contrast to the h^{-3} and h^{-2} form in the present AM model. Using the formulations given by (1)′ and (2)′ with δ_1 a constant would therefore represent a more realistic and consistent parameterization of wind mixing for the case in which the effect of variations in the wind on entrainment are neglected. The steady state solutions to this version of the coupled model in the absence of dynamical processes and when T is uniform (i.e., corresponding to (2.9) in AM) is

$$\bar{T} = \frac{\gamma T^*}{(\gamma + W)}, \quad \bar{h} = \frac{\delta_1(\gamma + W)}{\gamma W T^*}. \qquad (2.9)'$$

This result shows that $\bar{T}$ is unchanged but that $\bar{h}$ is more sensitive to the model parameters δ_1, γ, W and T^* than in the original AM model.

The formulation (1)′ and (2)′ is a further improvement over (1) and (2) because δ_1 is a relatively well-known coupling coefficient (under the assumptions made), not simply a model tuning parameter as treated by AM. Using a surface wind speed of 5 m s^{-1} (as used in AM's formulation of the drag coefficient) and a value of $(1 + k)\,m = 2.4$ (Niiler and Kraus, 1977), we obtain $\delta_1 = 1 \times 10^{-4}$ m^2 °C s^{-1}. The value of δ_0 which makes (1) and (1)′ the same is $\delta_0 = \delta_1 h/2$. Using $h = 100$ m, we get $\delta_0 = 5 \times 10^{-3}$ m^3 °C s^{-1}, whereas AM used $\delta_0 = 4 \times 10^{-2}$ m^3 °C s^{-1}. This result shows that even if the mixing formulation of AM were justified, the value used for δ_0 was nearly an order of magnitude too big to be consistent with our present understanding of wind stirring in the upper ocean.

In view of the above noted discrepancies between the parameterization of wind stirring used by AM and the more realistic form given in (1)′ and (2)′, and in view of the extreme sensitivity of the model solutions to the various parameters as shown by AM, it is suggested that further sensitivity studies with such an improved, yet equally simple, mixing parameterization would perhaps contribute to a better understanding of the behavior of the actual ocean–atmosphere system. As it now stands, the solutions presented by AM can not be considered to represent, even qualitatively, those of the real coupled system.

Acknowledgments. This research was supported by the National Science Foundation under NSF Grant ATM-8406625. This support is gratefully acknowledged.

REFERENCES

Anderson, D. L. T., and J. P. McCreary, 1985: Slowly propagating disturbances in a coupled ocean–atmosphere model. *J. Atmos. Sci.*, **42**, 615–629.

Kraus, E. B., and J. S. Turner, 1967: A one-dimensional model of the seasonal thermocline. *Tellus*, **19**, 98–106.

Niiler, P. P., and E. B. Kraus, 1977: One-dimensional models of the upper ocean. *Modelling and Prediction of the Upper Layers of the Ocean*, E. B. Kraus, Ed., Pergamon, 143–172.