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Final Technical Report
to the
National Aeronautics and Space Administration
for the Grant NAG 5-137
entitled

"Mechanisms of Interannual Ocean-Atmosphere Interactions"

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This research has been undertaken to improve our understanding of the interaction between ocean and atmosphere on the annual-to-decadal time scale. The main goal was to develop a simplified numerical model of the ocean-atmosphere-continent system and to perform basic theoretical studies of the coupling and feedback between the different constituents in the middle latitudes. Separate studies of the oceanic response to atmospheric forcing, and of the atmospheric response to oceanic forcing were also conducted. The main findings are the following:

1. Dynamics of sea surface temperature anomalies. A first study was aimed at interpreting monthly sea surface temperature anomaly data over the North Pacific in terms of a stochastically forced oceanic mixed-layer model. The results are given in:

C. Frankignoul and R. W. Reynolds, 1983. Testing a dynamical model for mid-latitude sea surface temperature anomalies. JPO, 13, 1131-1145. Abstract:

A slab model of the oceanic mixed layer is used to predict the statistical characteristics of the sea surface temperature anomalies that are forced by day-to-day changes in air-sea fluxes in the presence of a mean current. Because of the short time scale of the atmospheric fields, the model validity can be tested without quantitative information on the atmospheric forcing. A procedure is developed for the case where the mean current is given. It is applied to sea surface temperature (SST) anomaly data from the North Pacific using ship drift data as estimates of the mean ocean currents. At the 95% level of significance the model is consistent with the data over more than 85% of the investigated region. The results indicate that the atmospheric forcing acts as a white noise forcing; in regions of large currents, advection effects are important at low frequencies. However, SST anomaly autospectra are equally well represented by a local model where advection is neglected.

The available meteorological data are then used to estimate the forcing due to heat flux and Ekman advection anomalies. This forcing compares well with the stochastic forcing estimated from the SST data over most of the North Pacific. It is found that heat flux anomalies play a more important role than advection by anomalous Ekman currents; direct wind forcing and the resulting mixed-layer depth variability seem important at high latitudes but could not be estimated here. Finally, the cross-correlations between the SST anomaly and the atmospheric forcing fields are consistent with the stochastic forcing model and suggest that heat exchanges also contribute to the SST anomaly damping, thereby acting as a negative feedback.

A second study was aimed at determining the role of the short time scale weather fluctuations in the seasonal cycle of the upper ocean variability. A numerical one-dimensional mixed-layer model was used for long-term simulations of the oceanic conditions at Weathership N (30°N, 140°W) during a 17-year period. This work, which was done in collaboration with M. Cane, MIT, has been completed and a paper is in preparation. The main findings are: (1) to simulate correctly the seasonal cycle, the short-time scale weather fluctuations must be taken into account explicitly, (2) changes in surface heat flux and wind stress are correlated and induce similar mixed-layer changes, (3) the weather forcing acts as a vertical diffusion for the averaged seasonal changes, but true diffusion is needed for long-term simulations, and (4) advection plays a role at low frequencies.

2. Planetary wave response to sea surface temperature anomalies. The linear wave response to sea surface temperature anomalies in the midlatitudes has been investigated analytically, using a simple β -plane model. The emphasis was on the relationship between sea surface temperature and heating anomalies, and on the back interaction of the atmosphere onto the ocean. This work is being continued under grant NGR-22--9727 and a paper entitled "Sea surface temperature anomalies,

planetary waves and air-sea feedback in the middle latitudes" is in preparation. The results suggest in particular that the forced atmospheric response to typical sea surface temperature anomalies should be of moderate magnitude, and that it should contribute to the damping of the oceanic anomalies. At low wavenumbers, the damping should be weak and the planetary wave should act as an eastward propagator. At high wavenumbers, the damping should be strong. This is consistent with the observed scale dependence of the persistence of sea surface temperature anomalies.

3. Numerical model of the ocean-atmosphere continent system. A first version of a simplified midlatitude ocean-atmosphere model has been designed in collaboration with E. Kalnay and K. C. Mo, NASA/Goddard Space Flight Center, Greenbelt. It includes a two-layer quasi-geostrophic atmospheric model, a continent and a copper plate oceanic mixed layer. The model is on a β -plane, has dimension $10,000 \times 9,000$ km, and is periodic in the zonal direction. The system is forced by seasonally changing solar radiation, and the atmospheric thermodynamics is related to the oceanic temperature via a simple parameterization of the air-sea heat exchanges. A mountain has been included in some of the simulations. Several five-year runs of the model have been made in a variety of conditions to investigate the effect of geometry and land-sea contrast (land only, ocean only, ocean and land with and without mountain). It has been found that the presence of land to the north of the ocean had an overwhelming influence on the position and strength of the jet stream, and that a more realistic seasonal cycle was achieved by using an ocean covering the eastern half of the domain. However, the model is not baroclinically unstable under these latter circumstances, for realistic solar radiation. Since the short time

scale variability of the atmospheric fluxes will be the primal source for the climate variability in the model, further tuning is needed.

In parallel, a two-layer quasi-geostrophic ocean model has been designed. The model will respond to the wind forcing and it will be used to advect the oceanic mixed-layer. Thus, oceanic and atmospheric circulations will be coupled on the gyre time scale. The oceanic model has been tested with different spatial resolution and it is ready for coupling to the atmospheric component. This work is being continued under grant NGR-22009:27.