6.5 THE ATMOSPHERIC RESPONSE TO OCEAN PERTURBATIONS IN THE KUROSHIO OYASHIO EXTENSION

Elena Yulaeva * and Niklas Schneider
Climate Research Division, Scripps Institution of Oceanography,
University of California - San Diego, La Jolla, CA

1. INTRODUCTION

There is significant evidence of interannual-to-decadal climate variability over the North American continent. Predictions of climate anomalies over North America have therefore the potential for important socio-economical benefits. Ocean-atmosphere-coupling in mid-latitudes is of particular importance for prognostication of North American climate.

To resolve the question of the impact of mid-latitude ocean anomalies on atmospheric variability, modeling studies are often used. The classical approach towards simulating atmospheric effect of oceanic anomalies involves "AMIP type" experiments. In these simulations, surface temperature (SST) anomalies are specified as the lower boundary condition of atmospheric general circulation models (AGCM). The main inherent disadvantage of "AMIP type" simulations of low frequency climate variability lies in the prescription of SST anomalies that effectively translates into the assumption of the infinitely large heat capacity of oceanic mixed layer. This assumption does not hold on timescales longer than a month characteristic of the SST response to the atmospheric forcing. Low frequency SST anomalies are driven by air-sea heat fluxes due to internal atmospheric variability, air-sea feedbacks, and the dynamics of the mixed layer. The dynamical perturbations are caused by local atmospheric forcing, and by oceanicly induced variations of the surface layer heat budget that are independent of the current state of the atmosphere. The latter include changes of oceanic advection, thermocline depth or temperature of waters entering the mixed layer, and result from past climate variations. These changes represent the "memory" of low frequency climate variations and therefore the predictable aspect of decadal climate variability (e.g. Latif and Barnett 1994). Therefore anomalies of the mixed layer heat budget, rather than anomalies of surface temperature (which are then a part of the response in the upper ocean-atmosphere system) need to be prescribed for determining the role of air-sea feedback in decadal climate variations.

In this paper, we investigated the response of a coupled atmosphere mixed-layer-ocean model (AGCM/SOM) to prescribed perturbations of the oceanic heat budget in the North Pacific. While over large areas in the central and eastern North Pacific low-frequency variability in SST results primarily from local atmospheric fluxes (Barnett et al., 1999, Pierce et al., 2000), in the western boundary region (i.e. Kuroshio Current extension region) oceanic perturbations indicative of past, basin-wide atmospheric forcing, significantly influence SST (Miller and Schneider, 2000). Therefore, we will concentrate on investigation of the atmospheric response to the perturbation of the surface layer heat budget in this region.

* *Corresponding author address*: Elena Yulaeva, Climate Research Division, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA, 92093-0224, e-mail: eyulaeva@ucsd.edu

2. PREDICTING LOW-FREQUENCY PERTURBATIONS IN THE NORTH PACIFIC OCEAN

Climate prediction for time scales of seasons to years typically invokes the long memory of the ocean to extrapolate current conditions to a future date. This is based on the expectation that oceanic anomalies, generated by present or past climate perturbations, will affect the ocean surface and atmosphere in a systematic way at some time in the future.

Regions of particular importance for climate anomalies over North America are the tropical Pacific and mid latitude North Pacific (Latiff and Barnett, 1994). SST anomalies in the tropical Pacific are routinely predicted (Mason et al. 1999) and are used as a boundary forcing in atmospheric general circulation models for North American climate predictions.

Over large areas of the central and eastern North Pacific, SST anomalies are the result of atmospheric forcing rather than the cause of atmospheric anomalies. In particular, the SST pattern over the central and eastern North Pacific associated with the famous 1976/77 climate shift is a direct response to atmospheric forcing, namely, air-sea heat fluxes, advection by Ekman currents and vertical mixing (Schneider et al., 2000). Recent analysis of an extended coupled model integration and available observations (Schneider et al., 2000, Miller and Schneider, 2000) shows that an additional region of low-frequency variability of SST exists in the Kuroshio-Oyashio extension (KOE). Anomalies of SST in this region are not forced by the contemporaneous atmosphere. Rather, anomalies are directly forced by changes of the ocean circulation and are damped by air-sea heat fluxes.

The KOE ocean circulation anomalies result from anomalous wind stress over the North Pacific during the preceding years (Schneider et al. 2000) and are communicated to the west via long Rossby waves. This implies that anomalies in the KOE region can be predicted from observations of the surface wind stress. Using the simplest possible formulation of these processes, Schneider and Miller (2001) are indeed able to predict anomalies of SST in the western North Pacific with nontrivial skill at lead times of one to two years. Experiments with the stand-alone oceanic GCM forced with observed wind stress revealed that the skill of the SST anomalies hindcast exceeds the skill of the linear barotropic Rossby wave model (Schneider and Miller, 2001). The HOPE model was forced with the NCEP/NCAR reanalysis surface wind stress anomalies for 1965 – 2000. The variance of the simulated SST anomalies is largest in central tropical Pacific and in the KOE region. The timeseries (Figure 1) of the simulated and observed SST anomalies averaged over the KOE region are highly correlated (correlation coefficient ~ 0.75 for the last fifteen years) with the reanalysis data. Therefore, oceanic anomalies in the mid-latitude Pacific appear predictable with oceanic GCM. In the following, we discuss how to exploit this oceanic prediction for a forecast of climate variability over the Northern Hemisphere and North America.

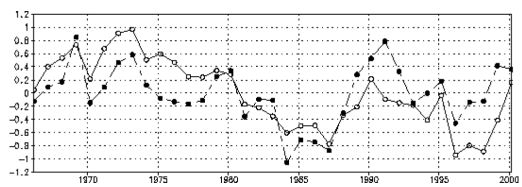

Figure 1 Time series of the hindcasted and observed SST anomalies averaged over the KOE region

3. DETERMINING THE ATMOSPHERIC RESPONSE TO WESTERN NORTH PACIFIC OCEAN ANOMALIES

To eliminate the drawbacks of prescribed SST anomalies we forced an AGCM/SOM by regionally prescribed anomalies of the oceanic heat budget. The combined upper ocean/atmosphere system responded to the forcing anomalies via reorganization of the air-sea heat fluxes that in turn led to global SST anomalies. Wintertime model response to mixed-layer heat-budget perturbations of up to 40 W m^{-2} in the Kuroshio extension region show statistically significant anomalies of 500 mb geopotential height (Z500) in the mid-latitudes (Figure 2b) that resembles Western Pacific pattern, the second mode of the internal variability of the atmosphere. It is baroclinic, with the maximum of 80 m at (60°N, 160°W). Examination of the vorticity and thermodynamic budgets reveals the crucial role of sub-monthly transient eddies in maintaining the anomalous circulation in the free atmosphere.

At the surface the response manifests itself in changes of surface temperature (Fig. 2a) and wind stress (Fig. 2c). The amplitude of response to KOE forcing in SST field at the Kuroshio Current Extension region is up to .75 K. The wind stress field alters Ekman pumping in such a way that the expected change of the oceanic gyre, as measured by the Sverdrup transport would counteract the prescribed forcing in the Kuroshio extension region, thus causing a negative feedback. This response is consistent with the hypothesis that quasi-oscillatory decadal climate variations in the North Pacific result from mid-latitude ocean-atmosphere interaction. The results of the mid-latitude experiment provide a consistent description of the roles that ocean and atmosphere play in the process of excitation and maintaining of low frequency variability in mid-latitudes. The corresponding Ekman pumping would decrease the Sverdrup transport into the forcing region, thus causing the cooling in the Kuroshio Current extension region.

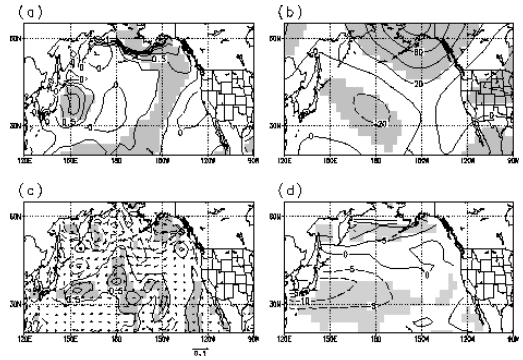

Figure 2 Winter time response to the forcing in the Kuroshio Current Extension region : (a) SST anomalies, contour interval .2 K; (b) Z500, contour interval 5 m; (c) vectors: surface wind stress (N m^{-2}) and Ekman Pumping velocity (contours, interval 1 m s^{-1}); (d) Sverdrup transport , contour interval 2 Sv; Negative values are dashed. Shading indicates the regions where response is more than 90% significant.

Of particular interest to our study is the response over North America. Figure 3 shows the winter-time response to oceanic heat budget anomalies in the KOE region. Comparison with the correlation between the PDO index and wintertime air temperature and precipitation showed that the model has skills in predicting 2m temperature over most of Canada and northern part of the United States. There is also some skill in predicting precipitation over some parts of the United States and Canada. Therefore, oceanic anomalies in the KOE region appear to affect climate anomalies over North America and predictions of KOE conditions might contribute to an improved climate forecast

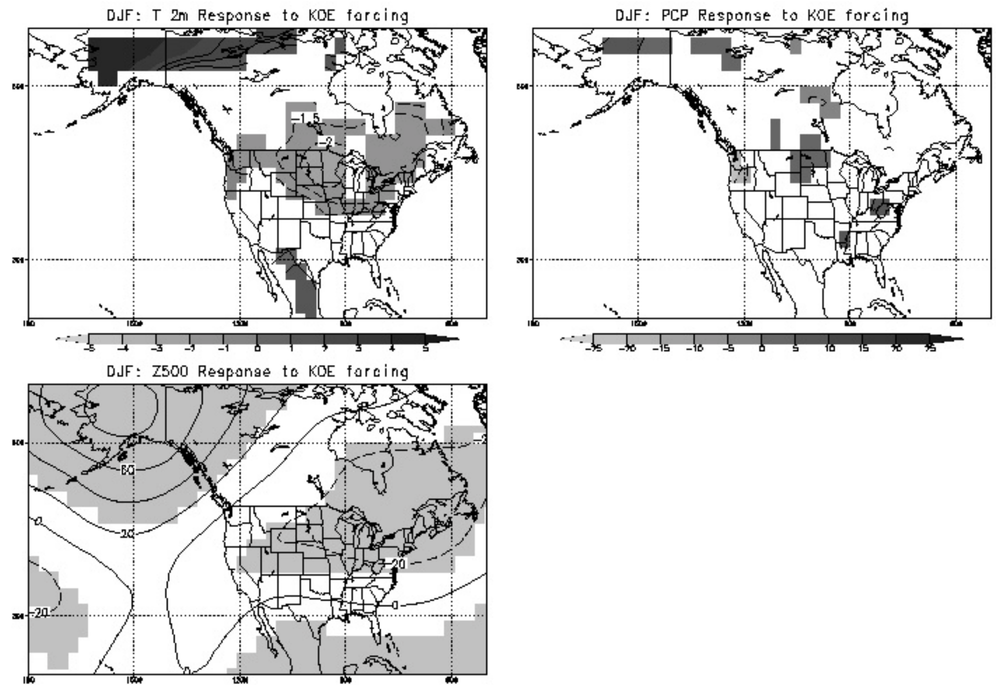

Figure 3: *Winter time response in 2m temperature, precipitation and 500 mb height fields over North America. The data was masked so that only regions where response is more than 90% significant are shown*.

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