P1.4 HINDCASTING OF THE CLIMATE CHANGES OVER NORTH PACIFIC AND NORTH AMERICA FROM HINDCAST OF THE OCEAN MIXED LAYER ANOMALIES IN THE TROPICAL AND MID-LATITUDE PACIFIC

Elena Yulaeva* and Niklas Schneider
Scripps Institution of Oceanography, University of California San Diego, La Jolla, California

1 INTRODUCTION

The climate over North Pacific and North America undergoes fluctuations on interannual-to-decadal time scales, with significant changes in precipitation, surface temperature and geopotential height. We will explore the hindcasting skill and physics of a climate system that hindcasts anomalies of heat flux convergence of the tropical and North Pacific oceanic mixed layer and converts them into the northern hemisphere climate anomalies using a coupled ocean mixed layer - atmosphere general circulation model.

The philosophy underlying the model (see *Yulaeva et. al., 2001*) states that North Pacific/North American climate anomalies on time scales of years to decades result from anomalous conditions in the Pacific equatorial upwelling regions, and the North Pacific Kuroshio-Oyashio extension (KOE), where anomalies in the ocean's thermocline are efficiently coupled to the surface. In these areas, changes of upwelling, thermocline depth, water mass properties and stratification, and advection impact a heat flux convergence of the ocean's surface mixed layer. In response to this forcing, the coupled atmosphere - ocean mixed layer system adjusts, and generates anomalies of sea surface temperature (SST) over the entire Pacific, including the central and eastern North Pacific where the ocean's mixed layer is effectively insulated from the thermocline.

Using the new method, forecast/hindcast of North Pacific/North American climate require prediction/hindcast of the heat flux convergences over the tropics and the KOE region. In the tropical Pacific, interannual SST anomalies associated with ENSO are routinely and skillfully predicted with a lead time of a few seasons. In the KOE, low-frequency anomalies of SST can be predicted/hindcasted from Rossby wave dynamics and observations of the surface wind stress during the preceding years.

2 MODEL AND DATA

The forecast system to be investigated here formulates the predictions described in the introduction in terms of ocean heat flux convergences and applies them as anomalous forcing in coupled ocean-mixed layer (or slab-ocean model/SOM) and atmospheric general circulation model (NCAR Community Climate Model CCM3).

The procedure of forecasting ocean heat flux convergence anomalies in the KOE and tropical Pacific region was explored utilizing various ocean GCMs (HOPE, POP and MIT). Ocean general circulation models were forced with the NCAR/NCEP reanalysis wind stress, while relaxing SST and sea surface salinity (SSS) to their climatological values.

3 DETERMINATION OF OCEAN HEAT FLUX CONVERGENCES

Both in the tropics and in the mid latitudes, the oceanic signals that carry the primary memory of the climate variability are forced by anomalies of the winds. These predictable signals affect the surface heat budget in special regions only, namely in the equatorial upwelling zone and in the KOE and are balanced by the air-sea heat fluxes. *Schneider and Miller, 2001* showed that wintertime sea-surface temperature anomalies in the KOE region can be skillfully predicted with a simple linear forced Rossby wave model at lead times of up to three years. Thus the main goal of our research was to evaluate the skill of more complex ocean general circulation models in hindcasting and forecasting the ocean heat flux convergences in the KOE and tropical Pacific regions and to compare this skill to the simple Rossby wave model. We forced HOPE, POP and MIT models with anomalies of the atmospheric wind stress, while relaxing SST and sea surface salinity (SSS) to their climatological values. The air-sea heat flux is dominated in the KOE by the delayed effect of low-frequency ocean waves, i.e. by the predictable mid-latitude signal. Elsewhere in the mid-latitudes, the air-sea heat flux is much smaller and balance Ekman heat advection. In the tropics, the air-sea heat flux reflects primarily changes of the upwelling heat fluxes and advection, that are part of the predicable El Nino evolution. In these models the anomalies of the air-sea heat flux balance exactly the oceanic perturbations of the surface heat budget for time scales longer than implied by relaxation constant and can be diagnosed from air-sea heat fluxes of these runs

Simulated wintertime thermocline depth and SST anomalies are shown in Figure 1. MIT with 1°x1° resolution and HOPE models exhibit good skill in hindcasting the thermocline depth anomalies in the KOE region. MIT and HOPE models have good skill in hindcasting SST anomalies in the KOE region.

* *Corresponding author address:* Elena Yulaeva, SIO, UCSD, La Jolla, CA 92093-0224;
e-mail:eyulaeva@ucsd.edu.

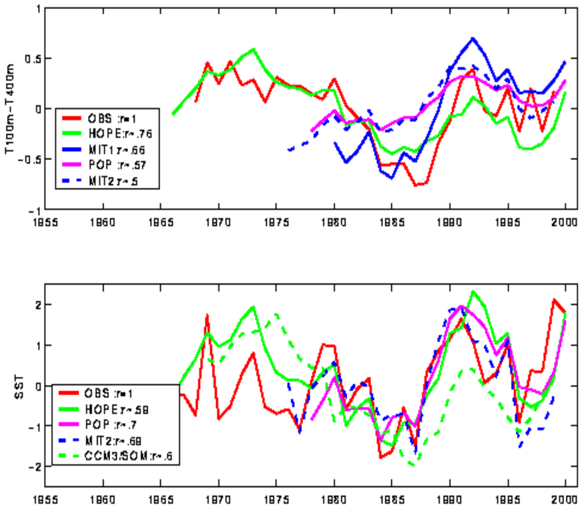

Figure 1. Thermocline depth (upper panel) and SST (lower panel) anomalies in the KOE region hindcasted with different models. Red line shows the observed values, green line shows anomalies from HOPE model, magenta from POP, blue MIT1°x1°, doted blue MIT 4°x4°, dotted green (lower panel) – CCM3 coupled to SOM.

The hindcast skill for the tropical SST anomalies is even better. Figure 2 displays SST anomalies averaged over NINO3.4 region. Time series of MIT, HOPE and POP SSTs are highly correlated with the reanalysis data.

4 THE SKILL OF THE TWO-TIER SYSTEM'S HINDCAST OF THE LOW-FREQUENCY CLIMATE VARIABILITY OVER NORTH PACIFIC/NORTH AMERICA.

In order to determine the possible atmospheric response to these perturbations, the hindcasted monthly oceanic heat flux convergence anomalies for the period of January 1960 to December 1999 in the KOE region and in the tropical Pacific were applied as anomalous forcing in the coupled CCM3/SOM model. We performed 40-year integration of a five member ensemble of the CCM3/SOM forced with the hindcasted monthly oceanic heat flux convergence anomalies for the period of January 1960 to December 1999 in the KOE region and in the tropical Pacific, while elsewhere the climatological forcing was retained. The members of the ensemble were obtained by shifting the initial conditions by one day each.

To identify the atmospheric response to the KOE forcing alone and to validate the statistical analysis, we repeated the CCM3/SOM integration, but applied the ΔQ forcing in the tropical Pacific only. The differences between this integration and the corresponding CCM3/SOM integration with both tropical and KOE forcing indicates the effect of the KOE ΔQ forcing on the mean atmospheric state and on the pdf of the intrinsic atmospheric modes.

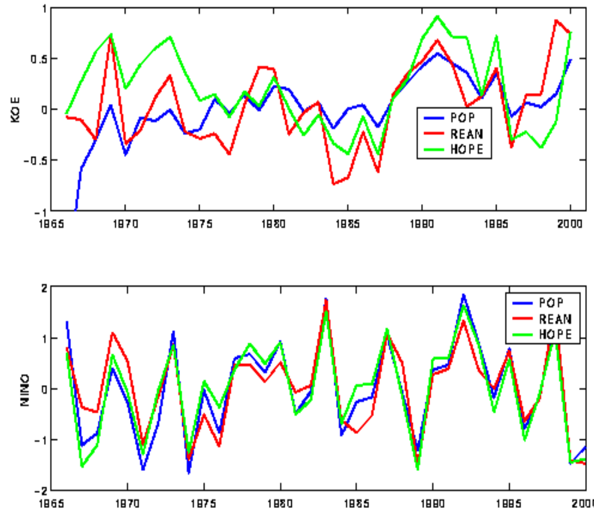

Figure 2. Hindcaset SST anomalies in the KOE (upper panel) and NINO3.4 (lower panel) regions. Red line shows the observed values, green line shows anomalies from HOPE model, blue shows anomalies from POP model.

As expected, the anomalous ΔQ forcing over the tropical Pacific sets the global anomalous climate patterns over North Pacific/North America. These patterns include the SST and air-sea heat flux anomalies over North Pacific. Over the KOE region the SST and heat flux anomalies are strongly correlated with the heat flux forcing of the tropical Pacific.

When the KOE forcing is added, the relationship between the SST and air-sea heat flux anomalies changes in the KOE region. While the air-to-sea heat flux anomalies over the KOE region are uncorrelated with the tropical heat flux anomalies, the SST anomalies in the KOE and NINO3.4 regions are correlated at 0.4 in the run with KOE and NINO3.4 heat flux focing, compared to a correlation of 0.6 with NINO3.4 heat flux forcing alone. This means that the inclusion of the KOE forcing alters the atmospheric teleconnection from the tropics into the mid-latitudes.

The inclusion of the mid-latitude forcing improves the skill of the hindcast of the low-frequency variability over some regions of North America. Figure 3 shows the correlation coefficients between the low-passed filtered (only fluctuations with the time period of five years and longer are left) simulated precipitation (lower row) and two meter temperature (T2m, upper row) fields and the corresponding low-passed filtered fields obtained from the NCEP/NCAR reanalysis. Comparison of the upper left panel (exhibiting the correlation for the precipitation simulated by the model forced with the tropical forcing only) and the upper right panel (exhibiting the correlation for the precipitation simulated by the model forced with both tropical and mid-latitude forcing) reveals that the inclusion of the KOE forcing improves the skill of the precipitation hindcast over east coast of the United Stated and over the parts of the central states. The corresponding

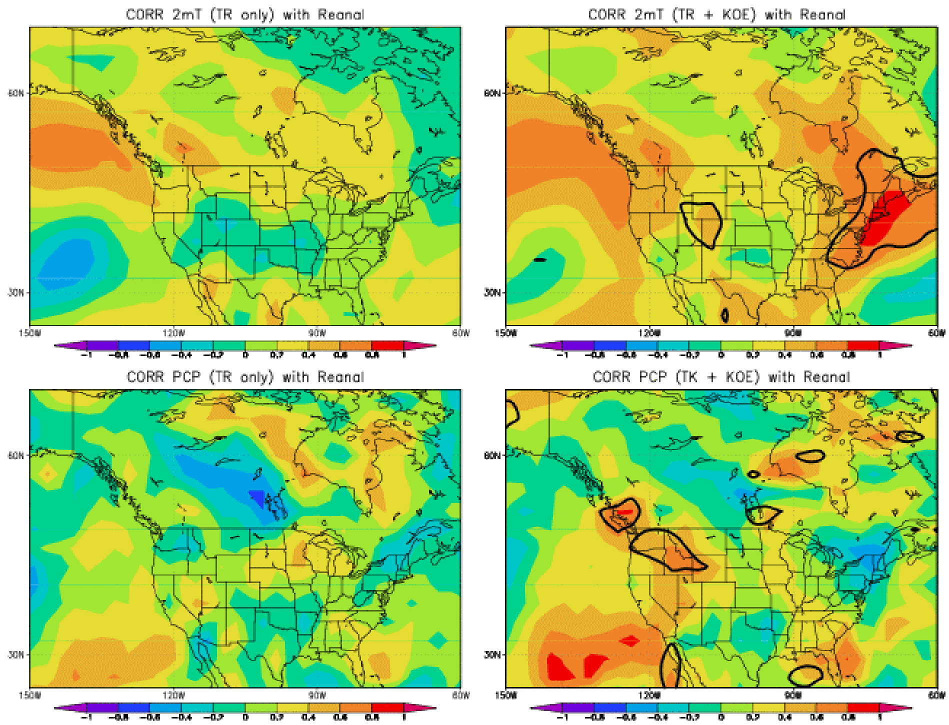

Figure 3. Correlation maps between the simulated fields and the fields obtained from the NCEP/NCAR reanalysis:
a) (upper left panel) two meter temperature (T2m) simulated by the model forced with the tropical forcing only;
b) (upper right panel) T2m simulated by the model forced with the tropical and mid-latitude forcing;
c) (lower left panel) as (a) but for the precipitation;
d) (lower right panel) same as (b) but for the precipitation.

correlation maps for the two meter temperature show the increase hindcast skill over Pacific North-West, over Baja California and over Florida.

The increase of the skill is due not only to the linear response to the mid-latitude forcing but also due to the non-linear effects caused by the additional forcing over the KOE region that augments the teleconnection patterns from the tropics. The changes are exhibited in the surface variables as well as in the free atmosphere. Figure 4 shows the regression maps of the two meter air temperature onto the low-passed filtered SST anomalies averaged over NINO3.4 region. Comparison of the upper left panel (regression of the T2m simulated by the model forced with the tropical forcing only), upper right panel (regression of the T2m simulated by the model forced with both tropical and mid-latitude forcing) and lower left panel (regression of the T2m obtained from the NCEP/NCAR reanalises) reveals that the inclusion of the KOE forcing realistically changes the relationship between the tropics and the T2m over the northern part of the western United states and over the east coast. The analogous maps for the precipitation (Figure 5) reveals that the teleconnection pattern has the most pronounced change over Pacific North West.

5 SUMMARY AND CONCLUSIONS

The goal of our research is to explore the underlying physics of a two-tiered prediction system for climate anomalies over North America for lead times of seasons to years. In contrast to the traditional approach that forecasts anomalies of SST, the first tier of this system will predict anomalies of the oceanic heat flux convergences in areas where the surface ocean is impacted by predictable subsurface variability, namely in the tropics and in the Kuroshio-Oyashio extension (KOE) region. The second tier will forecast associated anomalies of the global atmosphere and, in particular, of climate over North America by forcing a coupled slab-ocean atmospheric general circulation model (AGCM/SOM) with surface heat budget anomalies obtained during the first phase.

We addressed the following questions:

1. Can the hindcast skill of predicting surface anomalies in the KOE region be improved over the simple equivalent barotropic Rossby wave model by using a full ocean general circulation model (OGCM) driven by observed winds?

2. What is the skill of the two-tier system's hindcast of the low-frequency climate variability over North Pacific/North America? In particular, does the inclusion

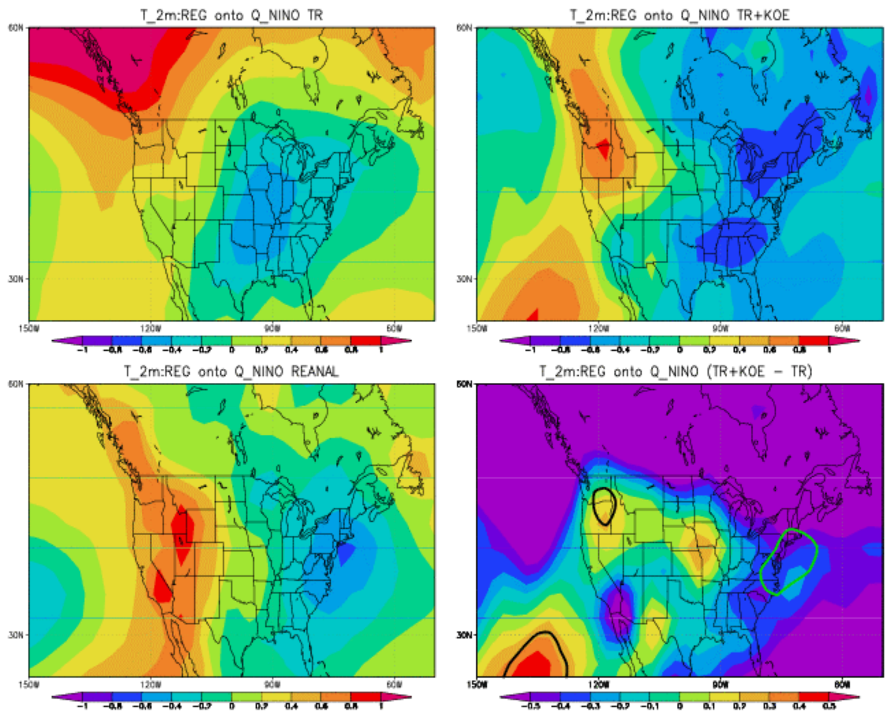

Figure 4. The regression maps of the two meter air temperature onto the low-passed filtered sst anomalies averaged over NINO3.4 region.
a) (upper left panel) regression of the T2m simulated by the model forced with the tropical forcing only; b) (upper right panel) regression of the T2m simulated by the model forced with both tropical and mid-latitude forcing; c) (lower left panel) regression of the T2m obtained from the NCEP/NCAR reanalises; d) difference between (b) and (a), the contours show the difference that is statistically significant at 95%.

of the forcing in the KOE region affects the hindcast skill of the climate anomalies over North America.

We can summarized our findings as follows:

I. Different ocean general circulation models have good hindcasting skills in the KOE and tropical regions .

a) HOPE and MIT models have good skills in hindcasting thermocline depth and SST anomalies in the KOE region.

b) The hindcast skill of the tropical SST anomalies is very hight for MIT, HOPE and POP models.

II. Prescribing oceanic heat flux convergences in the tropical and extra-tropical 'windows' of surface ocean to the oceanic memory in the thermocline is a viable alternative to estimating the low-frequency teleconnected atmospheric responses.

6 REFERENCES

Schneider, N., A. J. Miller and D. W. Pierce, 2002: Anatomy of North Pacific decadal variability. J. Climate, 15, 586-605.

Schneider, N. and A. J. Miller, 2001: Predicting western North Pacific ocean climate. J. Climate, 14, 3997-4002.

Yulaeva, E., N. Schneider, D. W. Pierce and T. Barnett, 2001: Modeling of North Pacific climate variability forced by oceanic heat fluxes anomalies. J. Climate, 14, 4027-4046.

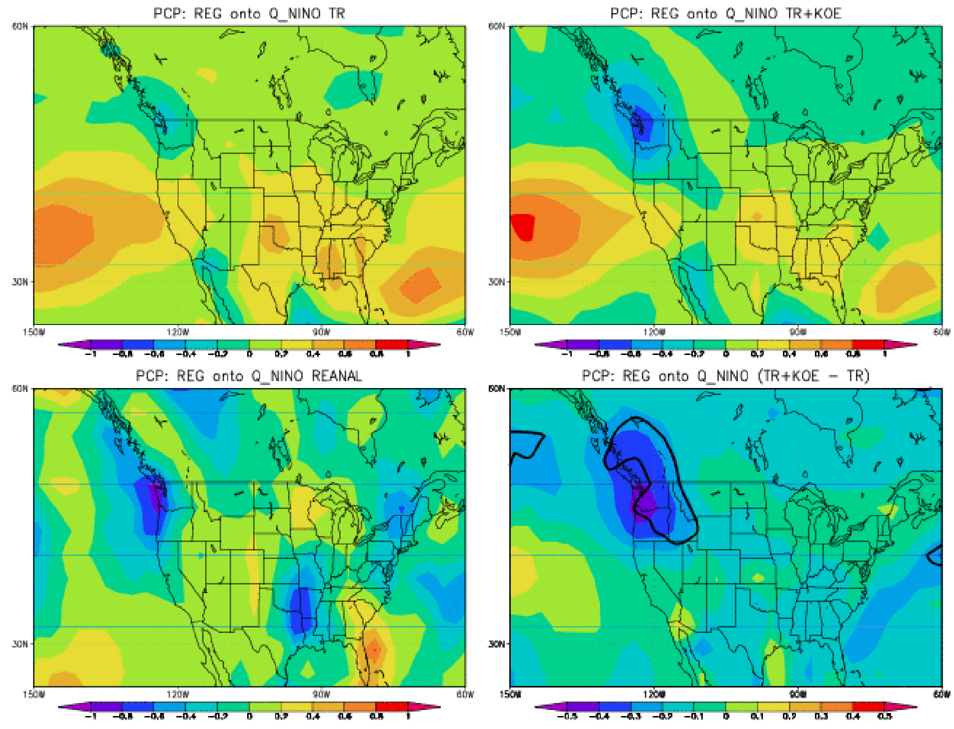

Figure 5. Same as Figure 4 but for the precipitation