This statement provides for external academic reviewers an overview of my research, education and service over the past nine years, the period for which this career review primarily applies. A complete listing of publications, including reprints, since 1986 can be found on my home page: http://meteora.ucsd.edu/~miller. Scientific service and educational activities are listed on my accompanying curriculum vitae.

Research Accomplishments Since 1999

My research has continued to expand in a variety of topics including climate dynamics, physical oceanography, oceanic ecosystem response to physical forcing, ocean data assimilation and atmospheric dynamics. Funding for my research has come from NSF, NOAA, NASA, ONR, DOE and CDBW. Here, I briefly summarize some of the major results of a subset of my recent papers, grouped into research topics.

a. Decadal Variability of the Pacific

Miller and Schneider (1999, Progress in Oceanography) is a synthesis paper in which we summarize the various popular theories about decadal variability in the Pacific and critically evaluate them in the context of observations. This is where Niklas and I first pointed out that observations were inconsistent with the original Latif-Barnett gyre-mode hypothesis. We showed that a strengthened Aleutian Low cools (not warms) the sea-surface temperature (SST) in the Kuroshio-Oyashio Extension (KOE) region with a 5-year lag that had not been previously identified in observations. We also summarize how the large-scale physical variations may be linked to marine ecosystem variability on decadal timescales. This paper continues to be of interest to both physical and biological oceanographers. This was based on an invited Keynote Lecture that I gave at the PICES Annual Meeting in Vladivostok in October, 1999.

In Schneider, Miller and Pierce (2002, Journal of Climate), we examined in great detail the full-physics coupled model (ECHO2) in which the celebrated Latif-Barnett gyre mode was assumed to be active. We found that the physics that they had originally proposed was not active. That is, the delayed negative feedback oscillator via gyre adjustment did not occur in the model in which everyone presumed it should be occurring. Dozens of simple models had been published based on that incorrect assumption. Instead, a positive feedback occurs which leads to enhanced variance at low frequencies. Either sampling error or external (tropical?) forcing leads to weak peaks at
20-30 year periods. This result was startling, but no one has challenged our analysis and the paper is still of interest to dynamicists studying Pacific decadal variability.

Even though no oscillatory coupled mode exists in the Latif-Barnett model (ECHO2), there is still a source of predictability that we identified and quantified in Schneider and Miller (2001, *Journal of Climate (letters)*). We show that Rossby waves excited in the interior ocean by wind stress curl propagate to the western boundary and influence SST in the KOE region up to three years later. We then applied the model to the real observations and found that it actually provides quantifiable observational forecast skill. At one-year leads, the skill is comparable to ENSO forecasting, which is an amazing result for midlatitudes. We also believe this is the first quantified demonstration of forecast skill (beating persistence forecasts) at two-year, and even three-year, leads in the ocean. These forecasts may be crucial to ecosystem biologists and fisheries managers who deal with the productive ecosystem of the KOE region.

In Miller *et al.* (2003, *Bulletin of the American Meteorological Society*), we describe the possible ways that marine ecosystems in the Pacific can influence and feedback on decadal climate variability. We explain the two main ways that biology can impact the climate system: through altered absorption of radiation by chlorophyll in the upper ocean and by the emission of DMS fluxed into the atmosphere by phytoplankton, which causes CCNs. We then show how the Gu-Philander subduction decadal mode and the Latif-Barnett gyre decadal mode may be altered by the presence of these feedbacks. This paper was conceived as part of the Surfside Climate Workshop that I co-organized with Niklas in 2003.


**b. Coupled Ocean-Atmosphere Dynamics**

For many years, Dr. John Roads (deceased, 2008) and I had been thinking about building a coupled ocean-atmosphere model here at Scripps to address scientific issues that were of interest to us. When Climate Sciences student Hyodae Seo arrived at Scripps in the fall of 2002 with a desire to study ocean-atmosphere processes, he decided to work with us on that topic. Hyodae designed a flux coupler for the Regional Spectral Model (RSM) and the Regional Ocean Modeling System (ROMS) and implemented the codes in MPI on our local COMPAS cluster. The result was SCOAR, the Scripps Regional Coupled Ocean Atmosphere Regional model.

The first results (Seo, Miller and Roads, 2007, *Journal of Climate*) were very exciting. They revealed the coupling that occurred between SST and surface (momentum and heat)
flux fields in Tropical Instability Waves (TIW’s) in the Pacific. This was the first full-physics mesoscale coupled model to simulate the “hot topic” patterns of mesoscale coupling observed in satellite observations of wind stress and SST by Prof Dudley Chelton (Oregon State), Prof Shang-Ping Xie (Hawaii), and others. We also applied the model to California Current eddies and gap winds in Central America. Hyodae presented these results at several meetings and won an “Outstanding Student Paper Award” at the 2006 Ocean Sciences meeting in Honolulu. This work also eventually landed him a “NOAA Climate and Global Change Post-doctoral Fellowship”.

In 2005, we began an extensive collaboration with Prof Ragu Murtugudde (University of Maryland) and Dr. Markus Jochum (NCAR) to explore the effects of TIW’s on the climate of the tropical Atlantic. We uncovered several remarkable things in the first paper from this work (Seo et al., 2006, Geophysical Research Letters). First, the size of the ocean domain can influence the rainfall patterns over northeast Brazil and the Sahel – that is, including one or two extra “hot SST” grid points can seriously alter the atmospheric convection to redistribute the precipitation patterns over land. The mean ocean state really matters here. This became especially evident when considering the effect of mesoscale eddies in affecting the mean state of SST in coastal upwelling regions along the west coast of Africa. Second, the fluctuations of TIW’s in the Atlantic serve to “jiggle” the ITCZ, weakening its sharp spatial peak near the equator and increasing rainfall up to 1500km away. The ocean mesoscale does matter, even for the mean state of the atmospheric precipitation field. This paper was awarded the “2006 Frieman Prize” for excellence in graduate student research at Scripps.

Those results were for the case of increasing ocean resolution while keeping atmospheric resolution fixed. We continued those Atlantic experiments using increased atmospheric resolution that matches the scale of the TIW SST variations. The results (Seo et al., 2007, Journal of Climate) reveal how coupling with wind stresses serves as damping term in the TIW energy budget, as well as several other interesting rectification effects.

We next showed that increased resolution of African Easterly Waves (AEWs) in the coupled model results in much stronger mean and more realistic variability of the ITCZ rainfall patterns in the tropical Atlantic (Seo et al., 2008, Journal of Climate). Significant differences between the high- and low-resolution model simulations are found in the precipitation fields, where heavy rainfall events occur in the region of strong cyclonic shear of the easterly waves only on the higher resolution grid. This is because the low-level convergence due to the waves is much larger and more realistic in the fine resolution simulation, which enables heavier precipitation events that skew the rainfall distributions towards longer tails. The variability in rainfall on these AEW time scales accounts for more than 60-70% of the total variability, contributing to an improved ITCZ in the higher-resolution case.

We turned our attention to the Indian Ocean as well, to investigate the effects of coupling on monsoonal flow predictability and dynamics (Seo et al., 2008, Ocean Modelling). Observations of the western Arabian Sea over the last decade have revealed a rich filamentary eddy structure, with large horizontal SST gradients in the ocean, developing in response to the southwest monsoon winds. This summertime oceanic
condition triggers intense mesoscale coupled interactions, whose overall influence on the longer-term properties of this ocean has been unclear. We used SCOAR to study the coupling between the near-surface winds and mesoscale SSTs, which generates Ekman pumping velocities (~ 1 m/day = ~10-20% of the total vertical velocity) at the scale of the cold filaments. SST features associated with cold filaments substantially reduce the latent heat loss (~10-15 W/m2). This study shows the importance of the mesoscale features on the large-scale momentum and heat balances in the region.

Work with SCOAR is continuing. Climate Sciences student Dian Putrasahan is now running her version of SCOAR in the VOCALS domain in the eastern tropical Pacific upwelling regions to explore issues of ocean-atmosphere feedback influencing the stratocumulus deck and SST biases. Climate Sciences student Aneesh Subramanian, is studying the Indian Ocean run to understand SST and Hadley Cell influences on the monsoons.

c. California Current Climate Regime Change

Some of my recent work is focused on the ecosystem change that occurred in the California Current System (CCS) after the climate shift of 1976-77. In McGowan, Bograd, Lynn and Miller (2003, Deep-Sea Research), we summarized the biological and physical evidence for a regime shift. Di Lorenzo, Miller, Schneider and McWilliams (2003, Journal of Physical Oceanography) show with numerical simulations that, in spite of an increase in upwelling favorable winds, the CCS warms in the decades after 1976-77 due to surface heat flux forcing combined with meridional advection of temperature anomalies by the mean flow. The implication is that the CCS upwelling cell was capped by a warm surface layer, suppressing vertical nutrient flux, much like the process that was adumbrated in McGowan et al. (2003) from data alone. This paper, which was the heart of Manu’s Ph.D. dissertation, was highlighted in the April 2005 issue of the Bulletin of the Meteorological Society.

Climate Sciences student Hey-Jin Kim came to Scripps in 2002 with a desire to study physical-biological interactions in the ocean, which has been a longstanding topic of interest to me. In Kim and Miller (2007, Journal of Physical Oceanography), we analyzed the 50 years of physical-biological observations from CalCOFI and discovered that, contrary to the celebrated published results of Roemmich and McGowan (1995, Science), the thermocline in the California Current did not deepen after the 1976-77 climate regime shift. It simply warmed. Moreover, we also showed that the Temperature-Nitrate relationship changed after the shift in this region. These results suggest that different (nutrient-poorer) waters have been upwelling in this region, possibly contributing to the well-known decline of bulk zooplankton volume.

A new climate mode, called the North Pacific Gyre Oscillation (NPGO), is attracting widespread interest. It links physical ocean changes with biological variables in the eastern North Pacific and was identified by (my former student) Prof Emanuele Di Lorenzo (Georgia Tech) in Di Lorenzo et al. (2008, Geophysical Research Letters). Using eddy-resolving models runs of the eastern North Pacific from 1950-2004, Manu
noticed that the second mode of sea-level height in the North Pacific had the same temporal variability as the salinity variations in the Southern California Bight. This is a startling result because the salinity variations in the CalCOFI data had been known for years to be uncorrelated with temperature data and their driving mechanism was unknown.

After Manu pieced together the links between wind-stress curl, sea level, SST and salinity, it became apparent that the structures he was focusing on had already been discussed in the literature, although no one had explained them dynamically. The NPGO index turned out to be essentially the same time series as the “Victoria mode” of SST (2nd EOF of Bond et al., 2003) and the “breathing mode” of sea-level height (1st mode of Cummins and Freeland, 2007). Many variables in the CalCOFI data now seem to be influenced by the NPGO, including chlorophyll, nitrate, silicate, phosphate and oxygen, none of which are explained by the Pacific Decadal Oscillation (PDO) index, which many researchers had assumed was the dominant climate mode. Hence, the NPGO appears to be a coherent physical-chemical-biological climate mode in the North Pacific, which may eventually be used for diagnostics of climate regimes and possibly even forecasting of biological populations.

More than 25 years ago, Prof John McGowan initiated a twice-weekly Scripps Pier chlorophyll observational time series. The paper by Kim, Miller, McGowan and Carter (2008, *Progress in Oceanography, sub judice*) is the first publication on this remarkable dataset. We uncovered a wide variety of interesting results that were distilled down to the following key points. The first is that there is a gradual long-term trend towards an increased concentration of chlorophyll. The second is that the blooms that occur in the later years are stronger and more frequent than in the earlier years. The third is that the timing of the blooms has changed towards earlier months in the spring during the more recent years.

*d. Gulf of Alaska Climate Regime Change: The Steller sea lion decline*

Several recent papers relate to developing an explanation for the decline of Steller sea lion populations by 80% from the 1970’s to the 1990’s in the western Gulf of Alaska (GoA). In Miller *et al.* (2005, *Atmosphere-Ocean*) we show that after the 1976-77 regime shift the mean flows and eddy circulation in the western Gulf changed considerable, while the eastern Gulf remained relatively unchanged. This provides a novel explanation for the physical mechanism behind why the ecosystem underwent a radical shift in speciation, e.g., from fatty fish to lean fish, which likely influenced Steller sea lion diets and fecundity.

Trites, Miller, Maschner *et al.* (2007, *Fisheries Oceanography*) is a synthesis paper based on contributions from roughly 10 research projects funded by NOAA CIFAR. At the invitation of the NOAA program manager, Dr. John Calder, I co-organized and hosted a synthesis workshop in which these results were presented and discussed. I also gathered all the contributions, gave an invited talk on the preliminary results of the workshop at the 2004 Alaska Marine Sciences Symposium in Anchorage, wrote the
initial draft of the paper, and handled all correspondence with the editor and referees. I decided that Prof. Andrew Trites, who is a leading expert on Stellers, would be the more appropriate first author to give the paper a much stronger biological impact.

e. Ocean Data Assimilation

I have been fortunate to be involved in the development of the data assimilation tools for the Regional Ocean Modeling System (ROMS). Moore et al. (2004) is the first paper to be published from our collaboration with Dr. Hernan Arango (Rutgers) and Prof Andy Moore (University of Colorado/UC Santa Cruz) on developing the tangent linear, adjoint and associated generalized sensitivity analysis and data assimilation programs for the Regional Ocean Modeling System (ROMS). ROMS is used by hundreds of scientists worldwide, so this paper is a benchmark reference for data assimilation and generalized stability analysis tools of ROMS.

Di Lorenzo et al. (2007, Ocean Modelling) is the first paper on our joint effort to successfully implement Prof Andrew Bennett’s (OSU) indirect “representer” method (the Inverse Ocean Model system; IOM) in ROMS. Manu compared the efficacy of weak constraints (dynamics that allow unphysical forcing functions) versus strong constraints (dynamics that are consistent with nature) in matching a model run to observations and in allowing the model to forecast into time intervals of independent data. An “identical twin” experiment showed how the use of the assimilated solution in a 10-day fit of ocean flows for the strong constraint case successfully reduced the initial model-observation misfit by 75%. This run also improved the model fields at locations where observations were not assimilated. In the weak constraint case, the misfit was reduced by 89%. The quality of the two assimilated solutions was then tested by running the model in forecast mode. Both cases showed forecast skill for 10-20 days that was greater than either persistence forecasts or climatological forecasts.

Miller et al. (2000, CalCOFI Reports) is our first paper on eddy-resolved California Current modeling in which we make our first attempts to fit individual surveys of CalCOFI observations using a Green’s function, strong constraint, data assimilation technique. We show that the technique works in certain test cases and explain how dynamical diagnostics, predictability assessment, and biological response will follow. Di Lorenzo et al. (2004, International Journal of Remote Sensing) is another application of a Green’s function data assimilation strategy using CalCOFI data in ROMS. It also includes our first attempt to fit the model chlorophyll to observations using a ROMS ecosystem model during a single CalCOFI survey during the El Nino winter of 1997-98. The original poster of this work won an award at the ‘Oceans from Space’ meeting in Venice, Italy, 2000.

f. Barotropic Rossby Waves

For several years, I have been part of a group of ocean observationalists, led by Dr. Brian Dushaw (APL) and Prof Doug Luther (Hawaii), who have been trying to initiate a program to measure the barotropic Rossby wave (BTRW) radiation from the Gulf
Stream. Miller et al. (2007, Geophysical Research Letters) executed some preliminary modeling work by looking in a high-resolution North Atlantic version of ROMS and found strong evidence for this BTRW radiation. The meandering model Gulf Stream radiates BTRW southward through preferred corridors defined by topographic features. The smoother region between the Bermuda Rise and the mid-Atlantic Ridge is a particularly striking corridor of barotropic wave radiation in the 20–50 day period band. BTRW are also preferentially excited at higher frequencies over the Bermuda Rise, suggesting resonant excitation of topographic Rossby normal modes. The prevalence of these radiated waves suggests that they may act as an important energy sink for the equilibrium state of the Gulf Stream.