Proposal to NOAA Office of Global Programs
CLIVAR Pacific and Atlantic Element

Title: The Impact of Global Warming on Interannual to Decadal Variability of the Coupled Ocean/Atmosphere System

Abstract

The global experiment the human race is conducting by increasing the levels of greenhouse gases (GHG) and aerosols in the atmosphere is almost definitely taking effect through the observed increase in the globally averaged surface temperature of the planet. How much the anthropogenic emissions impinge upon the variability of the climate system on interannual to decadal timescales is very much less clear. There is uncertainty as to whether global warming is affecting the so-called climate modes such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), and if the warming can account for the observed trends in both of these modes. Changes in the characteristics of ENSO and NAO can have large impacts on regional climates and thus human society. Modelling studies often produce conflicting results. Here we propose a modeling strategy that should shed light on some of these model discrepancies, by determining the dependency of the characteristics of climate variability, both "natural" and anthropogenically forced, on the specification of the ocean component of a coupled model.

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Multi–Institution Budget: 1 February 2005 – 31 January 2008

Total: $402,292

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B. RESULTS FROM PRIOR RESEARCH PROJECTS

Kelvin Richards (US funded projects)

Mixing in the equatorial Pacific: the role of interleaving (with J McCreary). NSF

This project started January 1 2004. We are investigating the impact of lateral mixing in the equatorial thermocline, with particular emphasis on the role of the observed interleaving of water masses. The goal is to develop a parameterization of interleaving suitable for inclusion in GCMs used in climate studies. The most promising mechanism for the formation of the interleaving is inertial instability. To date, historical datasets have been analyzed to determine the susceptibility of the equatorial current system to inertial instability. The flow is found to be unstable (in the linear sense) 25% of the time with significant decadal variations in the susceptibility. A paper is in preparation. Previous work on the non-linear evolution of the layering has been extended to consider vertical as well as horizontal shear, and a time varying background state. Early results show that zonal flows similar to those observed can develop significant interleaving through the action of inertial instability with substantial meridional fluxes of zonal momentum and tracers.

Cheng, Bleck and Rhines (related studies)

a. Multi-decadal variability of the MOC in a coupled MICOM-CCM3 simulation. DOE Climate Change Prediction Program (Cheng/Bleck)

Cheng coupled a near global MICOM to the NCAR CCM3 and investigated on the multi-decadal thermohaline variability in the coupled model and decadal variability in the North Atlantic. Her work indicated that the thermohaline circulation (THC) variability in this particular model is controlled to a large extent by a collaborative air-sea interaction in the subpolar North Atlantic, and particularly through surface heat flux. While previous work has emphasized the role of surface fresh-water forcing (Weaver and Sarachik 1991, Delworth et al. 1993), Cheng's work found the thermal effect plays a dominant role on setting-up the variability which echos other recent modeling results (e.g., Delworth and Dixon 2000).

Publication:

Cheng, W., R. Bleck, and C. Rooth, 2003: Multi-decadal thermohaline variability in an ocean-atmosphere General Circulation Model. *Climate Dyn.*, DOI:10.1007/s00382-004-0400-6.

b. Effects of high-latitude fresh-water fluxes on the MOC. NOAA/Arctic Research Office and Vetlesen Foundation (Rhines/Cheng)

This study addresses the relative importance of the different deep water sources on the THC by perturbing them individually. It shows that not only the meridional overturning circulation (MOC) in the model responds to the freshwater loading in the North Atlantic, but also the MOC is sensitive to the fresh-water influx pathways, i.e., whether the incoming fresh-water is through the Greenland-Iceland-Scotland Ridge or the Canadian Arctic Archipelago (CAA). The results demonstrated that both the GIN sea deep water and the Labrador Sea

Water are active components of the MOC in the model, even though the former is probably not as strong as that in nature. Overall, the overflow simulation is an isopycnal model like MICOM is closer to reality than that in a Cartesian coordinate model with similar resolutions.

Publication:

Cheng, W. and P. Rhines, 2004: Response of the overturning circulation to high-latitude fresh-water perturbations in the North Atlantic. *Climate Dynamics*, **22**, 359–372.

c. Subtropical circulation cells and their role in the Pacific Decadal Oscillation. NOAA/Office of Global Program (McPhaden/Zhang/Cheng/Rhines)

This is an ongoing research project. As mentioned in the Background, the MICOM-CCM3 model shows distinct decadal power in its NINO3 index; we have also found that the model carries a strong PDO signal which resembles observations. The connection between PDO and decadal ENSO and whether ocean-atmosphere feedbacks are involved in the mechanisms are currently being investigated.

C. PROJECT DESCRIPTION

1 BACKGROUND

There is little doubt that the globally averaged surface air temperature of the Earth has warmed over the last few decades (c.f. *IPCC*, 2001). The improvement in coupled ocean/atmosphere models over the last decade has increased confidence in the hypothesis that the observed warming since the 1970's is caused primarily by the anthropogenic introduction of greenhouse gases (GHGs) and aerosols into the atmosphere as opposed to so-called natural variability of solar irradiance and volcanic activity (as an example see Figure (1, a result from the recent modeling study of *Meehl et al*, 2004). Uncertainties remain as to how much the surface air temperature will increase over the next century or so. The sensitivity of models to GHG emissions scenarios is variable (c.f. *IPCC*, 2001). Ongoing studies are seeking to elucidate the reason for this sensitivity (e.g. CLIVAR CMIP).

What is less clear is the impact of GHG emissions on the interannual to decadal variability of the climate system. The tropical Pacific underwent an apparent climate "shift" in the mid-1970's (*Trenberth and Hurrell*, 1994), after which there has been relatively stronger ENSO activity (the 1982/83 and 1997/98 El Niño events are the strongest recorded during the period of the instrumental record). Basin-wide changes on decadal timescales have been detected in the Pacific in SST (*Minobe*, 2002), increases in sub-surface temperature and salinity (comparison of WOCE line P1 between 1985 and 1999, H Freeland, *pers. comm.*), a slowdown of the sub-tropical cells (*McPhaden and Zhang*, 2002; although recent analysis suggests the cells have spun-up over the last pentade, McPhaden *pers. comm.*), decreases in dissolved oxygen (*Emerson et al*, 2001) and changes to the abundance and community structure of the biota (*Karl et al* , 2001). A number of authors contend that the observed increased ENSO activity is *likely* attributable to the increase in GHG emissions (e.g. *Trenberth*, 1999 and *Timmermann et al*,1999). A counter argument is put forward by *Evans et al* (2002) whose analysis of stable isotope δ^{18}O data from corals shows a period of similar relatively vigorous ENSO activity over the period 1820–1860, a time of little anthropogenic GHG emission. (see also *Wunsch*, 1999, for a discussion on statistical significance.)

In the Atlantic sector there has also been anomalous activity in recent years, as measured by the NAO index which has been in a positive phase for the past 30 years. The impacts are discussed by *Visbeck et al* (2003) (and additional articles in the same volume). Again this anomalous behavior has been attributed to anthropogenic GHG emissions (see e.g. *Visbeck et al*, 2001). However, the response of the thermohaline circulation (THC) in the Atlantic to GHG emissions shows a wide range of behavior in various climate models (*IPCC*, 2001), putting into doubt the reliability of any conclusions regarding the impact of GHG emissions on the NAO (the THC plays an important role in regulating climate).

Because of the limited length of the time series of the instrumental record, and relative paucity of observations in the ocean, by necessity we have to rely heavily on modeling studies to try to discriminate between natural and anthropogenically-forced variability of the climate system. But models have their limitations. The robustness of conclusions drawn from modeling studies on climate variability, its predictability and actual climate predictions

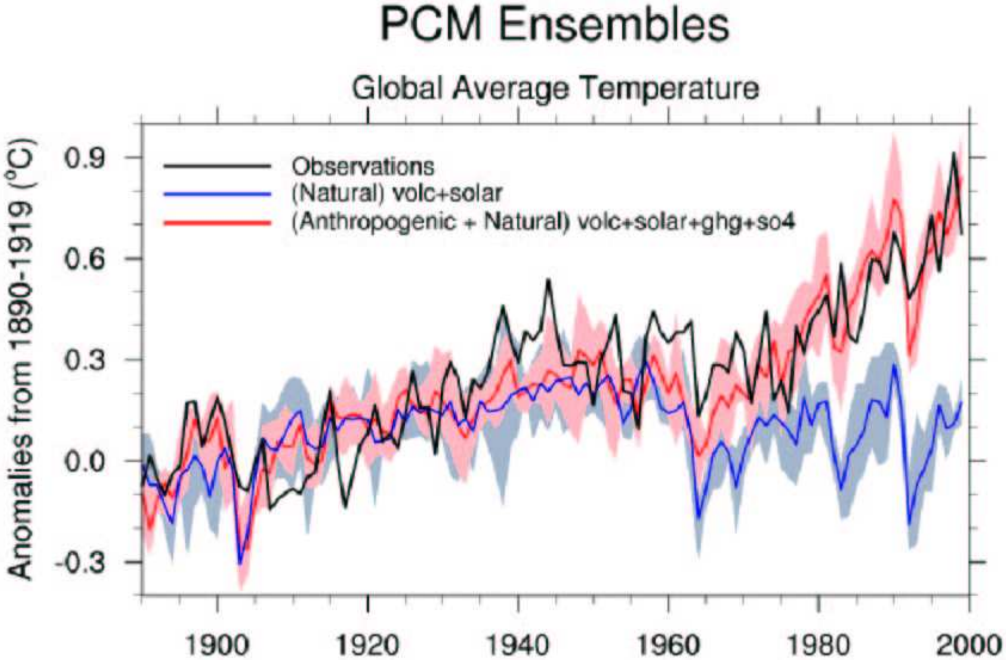

Figure 1: Comparison of the results from a climate model forced with natural and anthropogenic GHG emissions with the observed changes in the globally averaged surface temperature (from Meehl et al, 2004).

depends on the effectiveness of atmosphere and ocean models in capturing the *essential* physics of the problem. What is *essential* has yet to be determined for many of the questions that are being addressed. Computational limitations also mean that compromises have to be made with respect to model resolution, length of runs, and the size of the model parameter space that can be spanned. Progress is made by comparison between model experiments, comparison with observations, looking for consistencies in model results and accounting for differences.

Here we propose to use a relatively new class of climate model to study the interannual to decadal variability of the climate system. The relative *newness* of the model is in the ocean component which employs HYCOM, an ocean model based on a hybrid vertical coordinate. Details of the model and results to date are discussed in the following sections. The joy of using HYCOM is the ability to perform model experiments that range smoothly from those based on purely isopynic coordinates (with the property that water properties are exactly conserved on density surfaces) to an essentially z–coordinate system in the upper layers of the ocean. The use of the model can be seen as increasing the *gene pool* of models addressing the issue of climate variability. Comparison with other modelling studies, and with observations, will determine consistencies between approaches, and highlight discrepancies. To illustrate the potential of such an approach we discuss ENSO in coupled ocean/atmophere models.

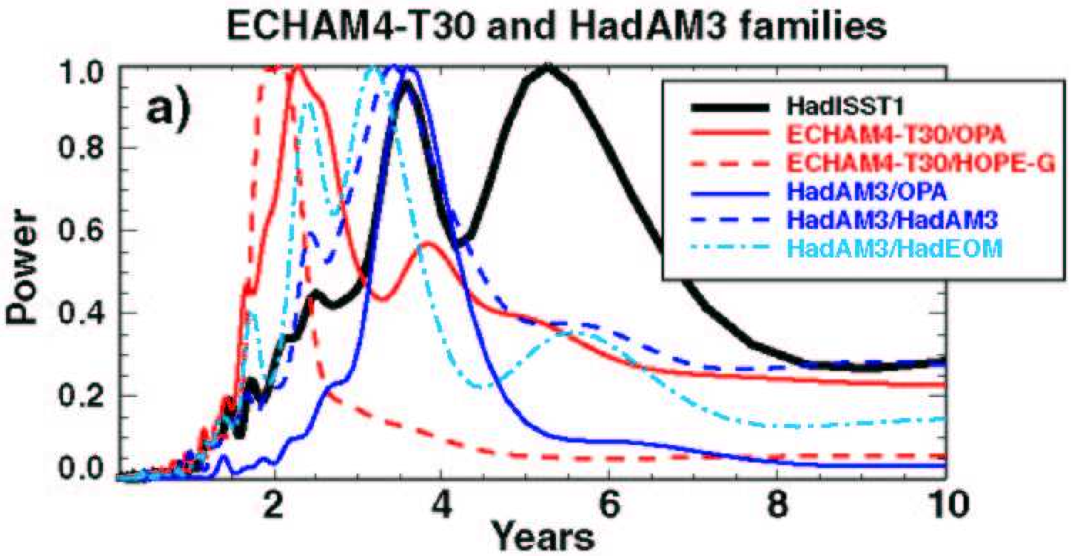

Figure 2: Normalized spectra of Niño3 SST monthly anomalies from SINTEX; ECHAM4T30 and HadAM3 families (taken from *Guilyardi et al, 2004*).

1.1 ENSO in coupled ocean/atmosphere models

A major focus of our study will be the low frequency modulation of ENSO, and the impact of GHG emissions on this modulation. The characteristics of ENSO in model experiments is very model specific as exemplified in the results from the SINTEX project in which various atmosphere and ocean component models were coupled in different combinations (without anthropogenic GHG forcing). The normalized power spectra of the resulting Nino3 SST timeseries are shown in Figure 2, taken from *Guilyardi et al* 2004. The conclusion drawn by the authors is that the spectral characteristics of the model ENSO are dominated by the specification of the atmospheric component of the model. Indeed, in an additional experiment with ECHAM4 (atmosphere) coupled to OPA (ocean), with the atmospheric component at higher horizontal resolution (T106), the dominant ENSO frequency is shifted to be between 3 and 4 years together with an increase of lower frequency variability (in closer agreement with observations).

In contrast to the SINTEX results, we present a comparison of two experiments with essentially the same atmosphere but with different ocean components: CCSM2 (CAM atmosphere coupled to POP ocean, which has a z–level vertical coordinate) and MICOM/CCM3 (CCM3 atmosphere coupled to the MICOM ocean, which has an isopycnic vertical coordinate). The global wavelet spectrum of the Nino3 SST timeseries from the two models is shown in Figure 3. Also shown is the same computed from observations (HadISST). The CCSM3 results come from years 350–600 of a multi-century run of the model (data supplied by Antonietta Capotondi). The MICOM/CCM3 coupled model run is the same as that

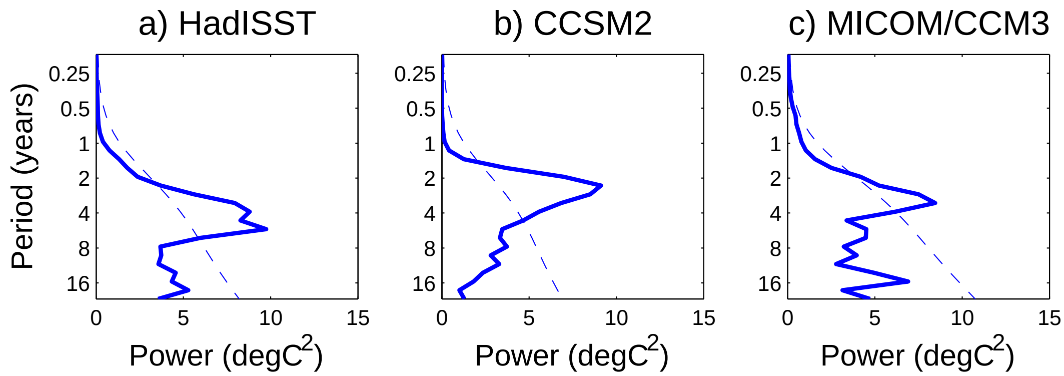

Figure 3: Global wavelet spectra for (a) observations (HadISST), (b) CCSM2, and (c) MICOM/CCM3.

presented in *Cheng et al* (2004). The ENSO signal in CCSM2 has an unrealistic dominant period of close to 2 years, with the power dropping away sharply for longer periods. Earlier versions of the coupled model (including the use of CCM3) have a similar 2 year period for ENSO (see Keihl and Gent, 2004) (the amplitude is increased by decreasing the vertical mixing but the period remains approximately the same – Gent *pers. comm.*). The MICOM/CCM3 run on the other hand has a dominant period between 3–4 years and elevated power levels at longer periods, in closer agreement with observations. These are preliminary results and the reasons for the differences in using the two different ocean components need to be explored (a subject of the present proposal), but they do point to the need to expand the range of ocean models used in climate research.

Various distinct theories have put forward for the low frequency modulation of ENSO. These include tropical-extratropical interactions in the atmosphere and/or ocean, delayed negative feedback caused by tropical oceanic Rossby waves, tropical stochastic atmospheric forcing, and nonlinear dynamics of the coupled tropical system (see *Picaut et al*, 2004 for a report from a recent workshop on the subject). There has been recent attention focussed on the tropical–extratropical interactions in the South Pacific (the connection to the north is thought to be limited because of the presence of the a PV barrier associated with the North Equatorial Current). In both observations and a coupled model (SINTEX-F, a version of the T106 ECHAM4/OPA model used in SINTEX which exhibits reasonably realistic low frequency ENSO behavior) *Luo and Yamagata* (2001) and *Luo et al* (2003)find evidence for a decadal modulation of ENSO involving SST anomalies in the eastern tropical Pacific, an atmospheric teleconnection to the South Pacific, and the propagation of sub-surface temperature anomalies to the equator (see the schematic shown in Figure 4). Soloman (*pers. comm.*) using an intermediate ocean model finds a similar dominance of the ocean "tunnel" in the South Pacific in tropical–extratropical connections, whilst *Fukumori et al* (2003) find the South Pacific to be the major supplier of source waters for the eastern tropical

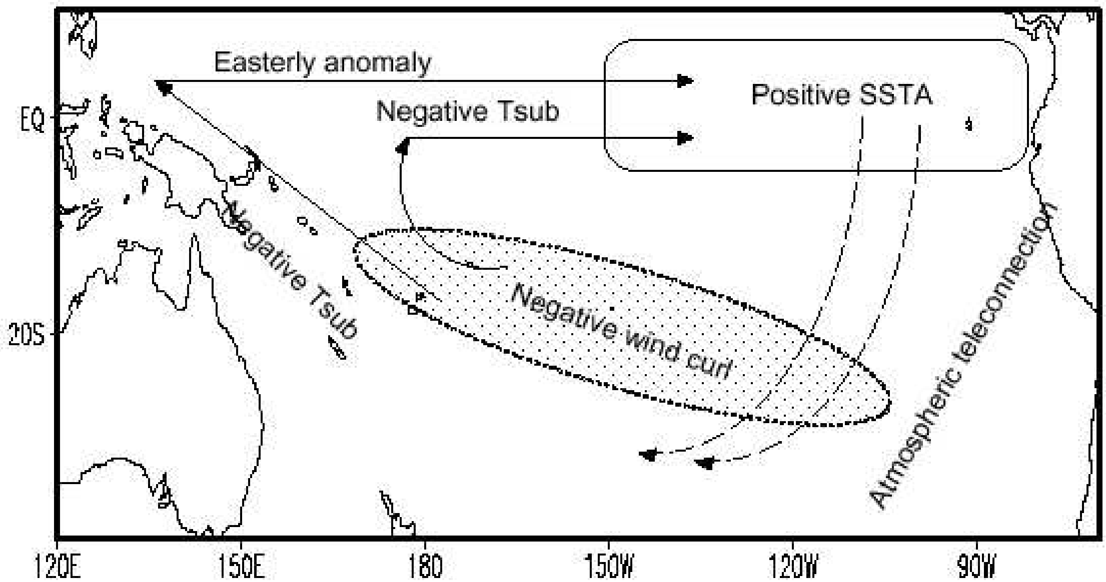

Figure 4: Schematic of tropical–extratropical interactions proposed by *Luo and Yamagata* (2001) respectively.

Paciifc in the ECHO ocean reanalysis. The strength and nature of the atmospheric bridge and oceanic tunnels between the tropics and extra–tropics needs to be determined as the characteristics of a coupled model are varied (again a subject of the present proposal).

A number of studies have considered the impact of global warming on ENSO. The results are again very model specific. Early studies (e.g. *Meehl et al*, 1993; *Tett*, 1995) found very little change in the characteristics of the model ENSO in response to forcing by GHG emissions, but the ENSO signal in these early models was poorly represented. With an improved model (essentially better meridional resolution in the tropics) *Timmermann et al* (1999) did find both the amplitude of ENSO and occurrence of cold events increased as CO_2 levels were increased. *Collins*(2000) found different behavior with respect to increased CO_2 levels in two versions of the Hadley Centre coupled models; HadCM2 in which there was an increase in amplitude and frequency and change phase of ENSO, and HadCM3 in which no significant change in ENSO was found. Collins puts these differences down to subtle changes in the physical parameterization schemes of the two models.

The above results point to the need for a systematic study of the dependency of the interannual to decadal variability in coupled models on the characteristics of the coupled model. This is required if we are to gain *justified* confidence in conclusions drawn from modeling studies of the impact of GHG emissions on climate variability. The present proposal should be viewed as part of such a study.

1.2 Relevance to the the goals of the Climate and Global Change Program

To quote from the OGP web page, the main goal of CLIVAR is to increase the skill of global climate prediction on seasonal, interannual, decadal and centennial time scales, with an emphasis on climate events such as the El Nio/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The CLIVAR study proposes to identify and understand the major aspects of climate variability. For FY2005 CLIVAR Pacific "invites proposals to investigate intraseasonal-to-decadal coupled ocean-atmosphere variability and their potential changes on decadal-to-centennial time scales including their linkage with anthropogenic-induced climate change". The present proposal is directly related to the goals of the climate and global change program.

2 PROPOSED RESEARCH

The present proposal aims to determine the impact of global warming on the interannual to decadal variability in a coupled model, but done in the context of the sensitivity of the impact to the characteristics of the particular model used and also in comparison to other modeling and observational studies. ENSO will be the primary focus of the study, although other aspects of climate variability, such as the broader Pacific Decadal Variability (PDV), Tropical Atlantic Variability (TAV) and NAO, will be considered.

2.1 Scientific objectives

The overall scientific objectives of the project are :

OBJECTIVE 1: To determine the interannual to decadal variability of a coupled atmosphere/ocean model under pre–industrial conditions, and to establish the dependency of the variability on the characteristics of the coupled model.

In particular we seek to establish how the characteristics (both spatial and temporal) of the modes of variability (such as ENSO, PDO, TAV and NAO) vary with the specification of the vertical coordinate and lateral dissipation in the ocean component of a coupled model, and how these characteristics compare with observed modes of variability. An important aspect of the approach taken here is that the sensitivity study is done with the coupled model, as opposed to with atmosphere and ocean components separately, as has been done in the development of some coupled models such as CCSM.

OBJECTIVE 2: To determine the impact of greenhouse gas emissions and aerosols over the 20th century on the interannual to decadal variability of the climate system.

In the context of the model configurations utilized for Objective 1, the differences of the variability in model experiments with and without anthropogenic GHG emissions and aerosols will be assessed. Of particular interest is how these differences depend on the model configuration.

2.2 Approach

2.3 Models used

2.3.1 Ocean component: HYCOM: The horizontal grid used in the present and previous studies is based on a Mercator projection with resolution 2^o longitude x 2^ocosine(latitude) yielding 111x111 km^2 resolution at 60^o latitude. At 60^oN the Mercator grid is smoothly connected to a bipolar grid patch, whose two poles are placed in Canada and Siberia, to cover the North Pole. To resolve the equatorial waveguide the meridional resolution is increased in the vicinity of the equator to be 5^o of latitude.

2.3.2 Atmospheric components: CAM3 and GISS: The NCAR Community Atmospheric Model series of models have a long heritage dating back over 15 years. The predecessor to CAM2 is CCM3. CCM3 is a spectral model in the horizontal which employs a terrain-following hybrid vertical coordinate, and incorporates a shape-preserving semi-Lagrangian transport scheme for advecting water vapor. CAM2 incorporates significant improvements to the physics package (e.g., generalized cloud overlap for radiation calculations), new capabilities such as the incorporation of thermodynamic sea ice (*Briegleb et al*, 2002), and a number of enhancements to the implementation. CAM3, which will be released on June 2004, incorporates further refinements of the model physics, and is the atmospheric component used in CCSM3. We use the standard spectral resolution which is T42 (equivalent to approximately 2.8^o of latitude).

The GISS atmospheric model version model E is based on model SI2000 with a finer vertical resolution which numerous improvements to basic physics, the stratospheric circulation and forcing fields (see *Schmidt et al*, 2004). The horizontal grid which has been in previous coupled studies, and in the present study is 4^ox5^o. The sea–ice model which is used with the coupled GISS/HYCOM is the thermodynamic ice model of *Russell et al* (2000) combined with the dynamic ice model of *Zhang and Rothrock* (2000).

2.3.3 Previous results: HYCOM has been successfully coupled to the GISS atmospheric model, whilst its predecessor, MICOM, has been coupled to CCM3. Both coupled models reproduce the current climate in a reasonable fashion without flux correction, and have reasonable ENSO and NAO signals. For results from CCM3/MICOM see *Cheng and Rhines* (2003) and *Cheng et al* (2004), and from GISS/HYCOM see *Sun and Bleck* (2001a and b) and *Sun and Hansen* (2003). Results from GISS/HYCOM will be used in the next IPCC report.

Characteristics of the ENSO signal from CCM3/MICOM have been shown in Figure 3 in comparison with observations and CCSM2. The ENSO signal in GISS/HYCOM is found from preliminary results to be sensitive to the vertical grid. Here we propose to do a systematic study of the effects of the vertical grid from an isopycnic formulation to a z–coordinate (Objective 1). The reason we wish to study the effects of the level of lateral mixing (also part of Objective 1) comes from a number of ocean only and coupled studies. The state of the equatorial Pacific is known to be sensitive to the form and magnitude of lateral mixing (see e.g. *Pezzi and Richards*, 2003) whilst changing the orientation of the mixing of tracers from horizontal to isopycnic improves the structure of the tropical thermocline and modifies the characteristics of ENSO (*Raynaud et al*, 2000). Changing the parameterized

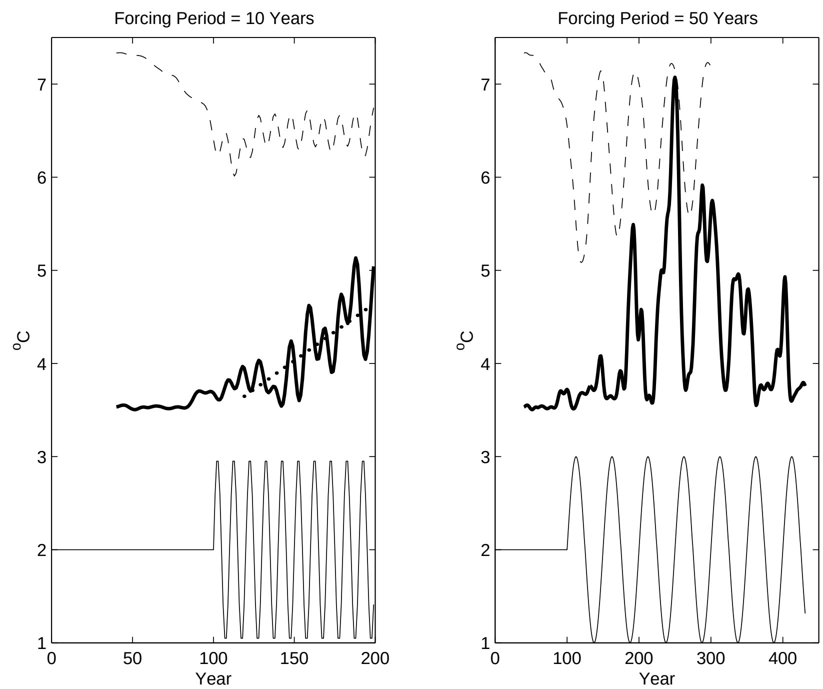

Figure 5: SST in the NAC of an isopynic ocean model forced by an NAO-like wind-stress pattern, with two different periods: dashed lines using moderate thickness diffusion, solid line with low thickness diffusion. Lower curve indicates the phase of the forcing. Taken from *Bellucci (2003)*

eddy transport in an isopynic model (the level of thickness diffusion in MICOM) also changes the ventilation characteristics of the model in both the Atlantic (*Haines et al*, 2003) and Pacific (*Endo et al*, 2004). The oceanic response to an NAO–like forcing is also affected (see Figure 5). Reducing the level of thickness diffusion is seen to not only produce a larger amplitude response but the response becomes irregular (*Bellucci*, 2003: see also *Colin de Verdiere and Huck*, 1999, *Raa and Dijkstra*, 2002 and related papers). Since the ocean may play an important role in North Atlantic decadal variability (see e.g. *Timmermann et al*, 1998: *Delworth and Graetbatch*, 2000) Bellucci's result may have implications for the NAO itself. The above points to the need to consider the effects of the level of lateral mixing in the context of the coupled system.

2.4 Numerical Experimentation

The numerical experimentation will be done in two phases: Phase 1 to establish the sensitivity of the coupled model to the specification of the vertical grid and lateral dissipation in the ocean component (Objective 1), and Phase 2 to assess the impact of GHG and aerosol emissions on climate variability (Objective 2). Here we describe the planned experiments. Adjustments to the precise series of experiments may be made in light of results as they are obtained.

Phase 1: The following sensitivity experiments will be performed with CAM3/HYCOM with pre–industrial levels of GHGs and aerosols. All experiments will be of O(200 years) duration. Shorter duration experiments will be conducted to assess the 'best' series of the limited number of longer experiments.

- **Vertical grid** The near surface vertical grid in HYCOM will be varied from a specified mixed layer and isopycnic layers beneath to an essentially fixed z–coordinate. Of order 3 experiments will be conducted spanning these two extremes.
- **Lateral mixing** Using the preferred vertical grid the lateral mixing will be varied in HYCOM from moderate values (O 1000 m^2s^{-1}) to relatively low values. Tests with an earlier version of the coupled model show that the model can be run with the thickness diffusion at least as low as ? m^2s^{-1} (at the equator). Further tests will be performed to ascertain if all diffusion coefficients (viscosity and isopynic tracer) can be reduced to this level. If the moderate and low mixing cases show significantly different interannual to decadal variability in ENSO a third (and possibly fourth) experiment will be conducted with the low mixing case but with enhanced mixing within the equatorial thermocline (c.f. *Richards and Edwards*, 2003), and/or an intermediate global value of the mixing coefficients. The intent here is to span the range of plausible values of mixing coefficients (for instance, c.f. *Ferreira et al*, 2003) and establish the sensitivity of the coupled model to the level of lateral mixing. If great sensitivity is found this points to the need for improved eddy parameterisation. This is beyond the scope of the present study, although results will be relayed to groups that are actively involved in such studies.

A second series of experiments will be performed using GISS/HYCOM to establish partially how dependent the above results are on the atmospheric component. The number of experiments will be dependent on time and computer resource considerations, but it is hoped to perform at least two experiments with configurations of HYCOM that produce relatively high and low interannual to decadal variability in CAM1/HYCOM.

Phase 2: Based on the analysis of the results from Phase 1, and comparison with observations and other modeling studies, **two** configurations of CAM1/HYCOM will be chosen as the controls for the anthropogenic GHG and aerosol forced runs. The basis of selection will be the relative level of interannual to decadal variability of ENSO and NAO in the model experiment, with the two controls having distinctly different values. If possible one control will be chosen to be close to the observed variability (as far as this can be done with the limited instrumental record pre 1970). The elements of each experiment include

- An ensemble of 5 members starting at year 100 (approx.) of the given control run.

- Each ensemble member will be run for the period 1880-2000 with the observed atmospheric greenhouse gas and aerosol concentrations for that period. The forcing dataset will be that of *Hansen et al* which has just been completed.

As in Phase 1, the above will be repeated with GISS/HYCOM as time and resources permit.

2.5 Analysis

The analysis of the model output will be done along the lines of previous modeling and observational studies to facilitate comparison with these studies. Clearly with up to 4000 years of model integration it will not be possible to analyze every model run in detail under this project (the output will be made freely available to the community). It will be an easy matter to calculate indices such as Nino3 SST, the North Pacific Index, NAOI, and the Indian Ocean Dipole Index, that have been used extensively to characterize climate variability. Composite analysis of surface fields based on these indices, as well calculating EOFs will be done. In addition oceanic subsurface diagnostics such as the depth and thickness of the equatorial thermocline and the strength of the overturning circulation in the N Atlantic will be calculated. (The CLIVAR Pacific Panel is constructing a list of easily calculated model diagnostics to allow comparison between ocean reanalyses, ocean only and coupled models. We will compute these diagnostics.) The mean state (for phase 1 expts.) and the amplitude and spatial patterns of the seasonal to decadal variability of the model (with varying model parameters) will be compared with observations and other modelling studies. Wavelet analysis is a powerful tool to study the spatial and frequency characteristics of this variability (see *Torrence and Compo*, 1998)

Documenting the characteristics and differences of model runs and observations is relatively straightforward. Accounting for the differences is harder. We will employ techniques that have proved useful in elucidating possible cause and effect in previous studies. For instance *Luo and Yamagata* (2001) and *Luo et al* (2003) use a combination of joint complex EOF analysis (see *Horel*, 1984) to highlight the importance of propagating sub–surface anomalies in the South Pacific in both observational and the SINTEX–F model (see Figure 4). A similar analysis will be used on selected model runs here, to ascertain if a similar mechanism operates in the CAM1/HYCOM (and GISS) runs, and if its presence or absence can account for variations in the low frequency modulations of the model ENSO (as opposed to changes in the mean state).

Use will be made of established links with other groups and colleagues working on climate variability. The IPRC (UH) has much expertise in analyzing both coupled model output and observations. We will call on this expertise and make the model output readily available to IPRC scientists and the broader community through the IPRC APDRC and the NCAR MSS. Comparison with other modelling studies is made possible through active collaboration between the IPRC and the SINTEX–F project (both in Japan and Europe), and starting collaborations with NCAR scientists (in particular Peter Gent) on analysis of CCSM3 output.

2.6 Outcome

The expected outcome of the project includes

- a greater diversity in the class of models being applied to the study of climate variability.
- an assessment of the ability of the CAM3/HYCOM and GISS/HYCOM to capture observed interannual to decadal variability.
- an improved understanding of the factors that control interannual to decadal variability in coupled models.
- an improved understanding of the impact of increases in GHG and aerosol concentrations on ENSO, NAO and other interannual to decadal variability of the climate system.

3 Computing Resources

The extensive computer resources at both LANL and GISS/NASA will be utilized for this project. Computing resources at LANL include a 256–processor SGI Altix, one half of which is dedicated to ocean and climate modeling. Use will also be made of the SGI Origins and Compaq AlphaServer at the NASA Center for Computational Sciences (NCCS). Output will be placed on the mass storage systems at NCAR and NCCS. The IPRC has an SGI Altix and a number of SGI Origin machines which will be used for analysis of model output.

4 Project management

Kelvin Richards (UH) will coordinate the overall project. Wei Cheng (UW) and Shan Sun (MIT/GISS) will be responsible for setting up the model codes and running the numerical experiments. Rainer Bleck (LANL) is a designated collaborator on the project. He has expressed his support for the project and willingness to participate in terms of his own time and providing access to LANL computing resources (see letter of support, Section H). All participants will be involved in the analysis of model results. Peter Rhines (UW) will provide advice on an as needed basis on a no cost basis.

Good communication between participants will be kept throughout the duration of the project. At least once a year the team will meet for extensive discussions, assessment of progress, planning of future experimentation and setting of tasks and deadlines.

The research work will not be done in a void. Communication of results an exchange of ideas will be made with other modeling groups, in particular CCSM and SINTEX scientists as well as through scientific meetings and journals.

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D. BUDGET JUSTIFICATION

Support is requested for a 3-year period from February 1, 2005 to January 31, 2008.

D.1 University of Hawaii

Personnel:

Kelvin Richards, Principal Investigator Kelvin Richards will direct and coordinate the project as PI, as well as analyze model results. The proposed budget requests salary to cover 2 months per year of his time.

Shan Sun Dr Sun (MIT/GISS) will be sub–contracted on a sub-award to undertake numerical experiments with the GISS/HYCOM coupled model and to analyze results. 2 months salary plus overhead is requested to cover Dr Sun's time spent on the project.

Programmer The project involves extensive handling of model output, transferring output between sites and writing of code for model analysis. The programmer, based at the IPRC, will undertake a significant fraction of these tasks. 2 months salary per year is requested to cover the time spent by the IPRC programmer.

Benefits: The benefits rate is presently 2.5% for UH staff.

Travel: *Domestic* Travel costs for Drs Richards, Cheng and Sun to meet at LANL once a year is requested to cover airfare, per diem and car rental. *Foreign* Travel costs are requested for Dr Richards to attend the EGU meeting in the second and third years of the project to disseminate results from the project to European colleagues and to discuss progress with SINTEX scientists.

Other Costs: Computer and network charges of $1000 per year is requested to cover computer maintenance and networking. Publication costs for 3 papers led by KJR is requested (average $2000 per paper). $500 per year is requested for postage, xerox and general office supplies..

Indirect Costs: Indirect costs are calculated at 36.3% for UH.

D.2 University of Washington

Personnel:

Peter Rhines, Principal Investigator Peter Rhines will direct the project as PI at UW on an as needed basis. No funds for salary are requested for the PI.

Wei Cheng, Co-Principal Investigator The proposed budget requests salary to cover 6 months per year for Dr. Cheng, who will undertake numerical experiments with the CAM3/HYCOM coupled model and analyze results. Dr Cheng is a research appointee at JISAO.

Benefits: The benefits rate is presently 24.6% for UW professional staff Research Scientists.

Travel: Travel for one domestic meeting (AGU fall or Ocean Sciences) per year for Dr. Cheng is requested in the amount of $1,500 to cover airfare, lodging and per diem.

Other Costs: Publication of papers led by Dr Cheng in the second and third year of the project is anticipated therefore costs in the amount of $2,500 per year are requested to cover page charges.

Indirect Costs: The indirect cost rate for projects conducted on-campus at the University of Washington is presently 51.6% of total direct costs, set by the indirect cost rate agreement of December 19, 2003.

E. BUDGET

BUDGET: UNIVERSITY OF HAWAII
JIMAR-NOAA
The impact of global warming on interannual to decadal variability of the coupled ocean/atmosphere system

February 1, 2005 to January 31, 2008

	YEAR 1	YEAR 2	YEAR 3	TOTAL
A. PERSONNEL				
Salaries and Wages				
K. Richards, P.I. (2 mos.)	$23,081	$24,235	$26,416	$73,732
Programmer (2 mos)	$8,334	$8,750	$9,188	$26,272
Total Salaries and Wages	$31,415	$32,985	$35,604	$100,004
Fringe Benefits (2.5%)	$785	$825	$890	$2,500
Total Personnel	$32,200	$33,810	$36,494	$102,504
B. EQUIPMENT	$0	$0	$0	
C. TRAVEL				
DOMESTIC: to visit LANL (3 per year) (Each trip: Airfare-$900; 7 days per diem @ 160/day; car rental-$200)	$6,660	$6,660	$6,660	$19,980
FOREIGN: 2 RT to attend Conference (Airfare-$1200; 7 days per diem @ 160/day; conf. fees-$200;car rental-$200)	$0	$2,720	$2,720	$5,440
Total Travel	$6,660	$9,380	$9,380	$25,420
D. OTHER DIRECT COSTS				
Materials and supplies (incl. software)	$0	$0	$0	$0
Computer & Network Charges	$1,000	$1,000	$1,000	$3,000
Publications		$2,000	$4,000	$6,000
Communications	$0	$0	$0	$0
Misc. (postage, xerox, etc.)	$500	$500	$500	$1,500
Total Other Direct Costs	$1,500	$3,500	$5,500	$10,500
E. SUBAWARD				
MIT (Shan Sun - 2mos salary plus overhead)	$11,212	$11,773	$12,361	$35,346
Total Direct Costs	$51,572	$58,463	$63,735	$173,770
INDIRECT COST				
36.3% of MTDC (except Computer charges, and Equipment)	$18,358	$20,859	$22,773	$61,990
TOTAL BUDGET REQUEST	$69,930	$79,322	$86,508	$235,760

BUDGET: UNIVERISTY OF WASINGTON
JISAO-NOAA
The impact of global warming on interannual to decadal variability of the coupled ocean/atmosphere system

February 1, 2005 to January 31, 2008

	YEAR 1	YEAR 2	YEAR 3	TOTAL
A. PERSONNEL				
Salaries and Wages				
W. Cheng, P.I. (6 mos.)	$25,800	$26,832	$27,905	$80,537
Total Salaries and Wages	$25,800	$26,832	$27,905	$80,537
Benefits (24.6%)	$6,347	$6,601	$6,865	$19,813
Total Personnel	$32,147	$33,433	$34,770	$100,350
B. EQUIPMENT	$0	$0	$0	
C. TRAVEL				
DOMESTIC:				
(Attend AGU/Ocean Sciences)	$1,500	$1,500	$1,500	$4,500
Total Travel	$1,500	$1,500	$1,500	$4,500
D. OTHER DIRECT COSTS				
Materials and supplies (incl. software)	$0	$0	$0	$0
Computer & Network Charges	$0	$0	$0	$0
Publications	$0	$2,500	$2,500	$5,000
Communications	$0	$0	$0	$0
Misc. (postage, xerox, etc.)	$0	$0	$0	$0
Total Other Direct Costs	$0	$2,500	$2,500	$5,000
Total Direct Costs	$33,647	$37,433	$38,770	$109,850
INDIRECT COST				
51.6% of MTDC	$17,362	$19,315	$20,005	$56,682
TOTAL BUDGET REQUEST	$51,009	$56,748	$58,775	$166,532