models rely on simple, bulk biogeochemical parameterizations, whereas recent ocean observations indicate that floristic shifts may be induced by climate variability, are widespread, complex, and directly impact biogeochemical cycles. Moreover, projected changes in ocean physics occur on regional scales, similar to the scales observed for the response of algal community composition to natural inter-annual climate variability. We present a strategy to incorporate ecosystem function in COAM's and to evaluate the resulting simulations in relation to region-specific ecosystem dynamics using a template of oceanic biogeographical provinces. Illustrative simulations with an off-line multi-species, functional group model suggest significant changes in ecosystem structure on regional scales, with shifts in the areal extent of biomes, by the end of this century.

### OS42L-03 1400h

## Potential responses of lower trophic levels to climate variability and climate change over the industrial era

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A suite of simulations using up-to-date global biogeochemical models is employed to investigate the impact of climate variability and climate change on marine production and ecosystems. Two biological models are used: the first one is a NPZD-type model including one generic phytoplankton limited by phosphate only (Aumont et al., 2001a) ; the second one is based on two phytoplanktonic groups (diatoms and nano/picoplankton) limited by the availability of phosphate, silicate and iron (Aumont et al., 2001b).

Intra-decadal to inter-decadal variabilities as well as potential impact of future global warming are presented. Reconstructions are made above the 1979-1999 period using meteorological archive or satellite observations (Le Qur et al., 2001) and over the industrial period (1860-2100) using a coupled climate-carbon model forced by anthropogenic CO2 emissions (Bopp et al., 2001). Preliminary analysis on variabilities, trends and shifts of both biological properties (chlorophyll, phytoplanctonic groups) and geochemical properties (oxygen, CO2, DMS) will be discussed.

Aumont, O., Belviso, S. and Monfray, P.. DMSP and DMS sea surface distributions simulated from a global 3-D ocean carbon cycle model, J. Geophys. Res., in press, 2001.a

Aumont O. , E. Maier-Reimer, Blain S. and Monfray P., An ecosystem model of the global ocean including Fe, Si, P co-limitations, JGR, submitted, 2001b.

Bopp, L., P. Monfray, O. Aumont, J.-L. Dufresne, H. LeTreut, G. Madec, L. Terray, and J. Orr, Potential impact of climate change on marine export production. Global Biogeochem. Cycles, Vol. 15, No. 1, 81-99, 2001.

Le Qur, C., O. Aumont, J. C. Orr, and P. Monfray, Climate-induced variability of ocean stratification, marine biology and CO 2 during1979-1999, J. of Geophys. Res., submitted, 2001.

### OS42L-04 1415h

## Abrupt Climate Change: Inevitable Surprises

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Recent scientific evidence shows that major and widespread climate changes have frequently occurred with startling speed. For example, roughly half of the north Atlantic warming from the last ice age was achieved in only a decade and was accompanied by significant climatic changes across most of the globe. Similar events, including local warmings as large as 16°C, occurred repeatedly during the slide into and climb out of the last ice age. Human civilizations arose after the end of these extreme, global ice-age climate jumps. However, severe droughts and other regional climate events during the current warm period have shown similar tendencies of abrupt onset and great persistence, often with adverse effects on societies.

Abrupt climate changes were especially common when the climate system was being forced to change. Thus, greenhouse warming and other human alterations of the earth system may be increasing the possibility of large, abrupt, and unwelcome regional or global climatic events.

The new paradigm of an abruptly changing climatic system has been well established by research over the last decade. Yet, this fact is little known and scarcely appreciated in the wider community of natural and social scientists and policy makers. At present, there is no plan for improving our understanding of this issue, no research priorities have been identified, and no policy-making body is currently addressing the many concerns raised by the potential for abrupt climate change. In response to these gaps, the National Research Council established the Committee on Abrupt Climate Change to outline the current state of knowledge related to abrupt climate change, identify the gaps in this knowledge, and provide recommendations on ways to fill these gaps.

The resulting NRC report will be released in December, 2001, and its recommendations presented at a special session of the AGU conference in San Francisco. Therefore, while specific report content is not yet available for release, and thus cannot be provided in this abstract, the findings and recommendations of the study are wide ranging and will address current and potential research in areas such as: coupled atmosphere-ocean behaviors; thresholds and non-linearities in geophysical, ecological, and economic systems; integrated geophysical, ecological, and social science modeling; paleoclimate data which relates to abrupt climate change; and land-use and coastal planning.

### OS42L-05 1430h

## Linking Ecological Time-Series To Climatic Variability Using Artificial Neural Network (ANN): The Gullmar Fjord Case Study

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A 12 year time-series (1985-1996) of monthly observations on a set of ecological and climatic variables from the Gullmar Fjord (Sweden) was used to test the possibility of using an artificial neural network (ANN) model to detect the set of variables most closely related to the observed fluctuations in the primary productivity (PP). The results indicated that ANN showed a lower root mean square error of prediction (RMSEP) compared to multiple regression analysis. ANN indicated that the North Atlantic Oscillation (NAO) was among the variables linked to the observed fluctuations in PP. The use of ANN in ecological and climate research could be regarded as a new semantic or grammar when the number of ecological and climatic co-variates are large.

### OS42L-06 1445h

## Plankton, fish and climate change in the North Atlantic

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Evidence from the Continuous Plankton Recorder (CPR) survey in the North Atlantic suggests that plankton can integrate hydrometeorological signals and provide additional information on oceanographic variability to physico-chemical measurements. Upper layer plankton sampled by the CPR provides data on changes in the upper, intermediate and deep-water layers of the ocean as many species undergo large daily or seasonal vertical migrations. Combined hydrographic and biological evidence shows that major changes have occurred in the last few decades in the circulation of the North Atlantic. For example, increased penetration of oceanic water from the Slope Current appears to have had a major effect on North Sea ecosystems contributing to a regime shift that occurred circa 1988. Some of these changes are linked to the North Atlantic Oscillation, the dominant mode of atmospheric variability in the region. In the recent period with a high NAO index, an increase in warmer water and southerly plankton species has occurred in the eastern basin with a reverse situation in the western basin (Labrador and Irminger Seas). At the same time deep water in the Norwegian Sea has markedly reduced and Labrador Sea intermediate water increased. Penetration of the North Atlantic current into the Norwegian Sea also appears to have reduced as deep-water formation in the Greenland Sea has become capped. The scale of the changes seen in the plankton may be providing the first evidence of ecosystem changes at an ocean basin scale that are a consequence of global warming.

URL: http://www.npm.ac.uk/sahfos

### OS42L-07 1520h

## Modal Shifts in Slope-Water Circulation and the Flip-Side of the North Atlantic Oscillation

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The Atlantic and Pacific Oceans experienced extreme events in ocean climate during the late 1990s. Although overshadowed by the global impacts of the most intense El NinoSouthern Oscillation event on record, a large, single-year drop in the North Atlantic Oscillation (NAO) Index during 1996 had major regional- and basin-scale impacts for several years throughout the North Atlantic Ocean. One of the most dramatic effects of this event was a modal shift in the slope-water circulation of the NW Atlantic. By placing these occurrences in the context of physical and biological time-series data collected from the region over the past half century, it is possible to show that such modal shifts and their ecological consequences are commonly associated with phase reversals in the NAO. Here, we use a model developed from these time-series data to predict over the next two years the likelihood of a modal shift in the slope waters of the NW Atlantic after the phase reversal in 2001 to negative NAO conditions.

### OS42L-08 1535h INVITED

## Climate, Copepods, and Calves: Predicting Physical and Biological Responses to Climate Variability in the NW Atlantic.

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Recent work in the Northwest Atlantic has revealed that the physical oceanographic conditions in this region fluctuate between two characteristic states, and the fluctuations are associated with winter atmospheric conditions over the North Atlantic. Using a simple time series model, it is possible to predict that state of the physical conditions in the NW Atlantic from the North Atlantic Oscillation Index. The physical state of the NW Atlantic is also associated with changes in the abundance of zooplankton species, most notably, the copepod *Calanus finmarchicus*. This species is an important food resource for many species, including the endangered northern right whale. We develop a simple model of right whale reproduction using a genetic algorithm. The results of this model demonstrate that a portion of right whale reproductive variability can be linked to North Atlantic climate through *Calanus* abundance. Furthermore, the model could be used to predict calving rates in future years.

### OS42L-09 1550h

## Simulation Modelling of Population Dynamics of Calanus finmarchicus in the Labrador Sea

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We present results from a stage-based population model for Calanus finmarchius in the Labrador Sea. The dominant zooplankter of the North Atlantic, Calanus, is predominantly an open ocean organism. We develop a model that depends on food supply, as determined from SeaWifs data, and temperature in order to determine conditions necessary for the simulation of the life cycle of Calanus in the Labrador Sea. We show how the generation cycle, and diapause entry and release, are related to latitude, food supply and temperature. Coupling the population model with a circulation model of the Labrador Sea region we determine the geographic stability of populations and the simulated role of the open ocean in influencing shelf populations of this organism. We use historical data to force

the simulations for many years to determine the impact of interannual variability of life history and population dynamics of Calanus.

### OS42L-10 1605h

### Interannual Variations in Environmental Conditions and Calanus spp. Abundance and Transport in the North West Atlantic

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Calanus finmarchicus is the dominant copepod of the NW Atlantic in spring and early summer, including the Labrador Sea and the Scotian Shelf. Calanus hyperboreus is also present in both areas, although generally more abundant on the eastern than on the western Scotian Shelf, and generally less abundant in the central Labrador Sea than over its shelves and at its margins. In spring 1998, there was cool slope water along and beyond the entire Scotian Shelf shelf-break, whereas in 1999 and 2000, warm slope water abutted the shelf-break in the western regions. In fall, along the shelf-break off Banquereau Bank (eastern Scotian Shelf) concentrations of C. finmarchicus and C. hyperboreus at depth were much higher in 1999 than in 1998 or 2000, probably due to an increased input from the Gulf of St. Lawrence. Beyond the shelf-break off Banquereau Bank, both C. finmarchicus and C. hyperboreus concentrations were higher in 1998 than in the other years. Similarily, off Browns Bank (western Scotian Shelf) both C. finmarchicus and C. hyperboreus were found in relatively large numbers at depth in the fall of 1998, whereas C. finmarchicus numbers were generally lower and very few C. hyperboreus were found in fall of 1999 and 2000. The patterns of abundance and depth distribution suggest that there was an increased influx of Calanus spp. from the northeast (Labrador Sea/Shelf) in 1998, relative to the other years. Another contributing factor in the west, however, might be a difference in circulation patterns on the Scotian Shelf. For example, in spring and early summer of 1998 perhaps most of the Calanus spp. produced on the Scotian Shelf were transported off the shelf to the east of Browns Bank, whereas in 1999 and 2000, perhaps a higher proportion was transported north of Browns Bank to the Gulf of Maine. In 2001, cool slope water was again present at and beyond the Scotian Shelf shelf-break. Sampling in the fall (November) is expected to show Calanus spp. distribution patterns similar to those of 1998.

### OS42L-11 1620h

### Pathways of Calanus finmarchicus transport between the Labrador Sea and the Slope Sea

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In the Gulf of Maine-Georges Bank region decadal-scale variability of C. finmarchicus abundance appears to be related to the NAO, with higher abundance during warmer periods when the NAO index is higher, and lower abundance during colder, low NAO periods. We suggest that variations in the flow linking the Slope Sea (from which the GOM populations appear to be derived), to the Labrador Sea, provide a mechanism linking climate forcing to the observed interannual variability of Calanus populations. Links between these two regions are limited by the presence of the Grand Banks and the close proximity of the warm water of the Gulf Stream to the Grand Banks as it "reattaches" to the western boundary and is topographically steered around the Grand Banks. Potential pathways past the Tail of the Grand Banks include the baroclinic Labrador Current (LC) and the upper part (700-2000m) of the barotropic Deep Western Boundary Current (DWBC), which both flow from the Labrador Sea to the Slope Sea, and the Gulf Stream, which flows in the opposite direction. Volume transport in the DWBC is enhanced during high NAO years and is associated with increased production of Labrador Sea Water. In contrast, volume transport in the Labrador Current past the Tail of the Grand Banks is reduced and appears to be episodic. During the fall and winter when Calanus is resting at depth (500-2000m) it will be advected by the DWBC. We suggest that the DWBC provides a significant source of Calanus to the Slope Sea.

### OS42L-12 1635h

### Modeling Transport, Connectance and Seeding in Georges Bank and Mid Atlantic Bight Sea Scallops.

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Sea scallops are protected from fishing in a number of areas on Georges Bank and in the Mid Atlantic Bight. The scallop population structure within these areas has changed significantly and recruitment has generally improved. Using hydrodynamic and biological modeling capabilities developed within SABRE and USGLOBEC we will explore the degree of connectance among the closed areas and between closed and fishable areas. Data from the period of 1982 to the present will be used to support this work. This work may have implications for the rational siting of marine protected areas.

URL: http://science.whoi.edu/users/jquinlan/Scallops/index.html

## OS42M HC: 315 Thursday 1330h

## Equatorial Oceanography IV

*Presiding:* **M McPhaden,** NOAA/PMEL**; L M Rothstein,** Graduate School of Oceanography, University of Rhode Island

### OS42M-01 1330h INVITED

### Seasonal Rectification Processes in the Western Equatorial Pacific: The (Subtle) Role of Salinity

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This talk will address the dynamical and thermodynamical components of the equatorial ocean's response to relatively strong, intraseasonal surface forcing in the presence of the strong density fronts associated with the eastern edge of the tropical Pacific Warm Pool. The application is the seasonal rectification of the zonal migration of the Warm Pool front due to intraseasonal mechanical fluxes. However, buoyancy fluxes (i.e. rainfall) associated with these winds significantly augment the mechanical response and cannot be safely ignored. The tools used to understand this problem are a rather limited observational basis, a hierarchy of numerical simulations, and equatorial theory. A proper application of theory requires augmenting relatively familiar non-linear equatorial wave theory (i.e. non-linear Kelvin waves) with the subtle roles of both the background, large-scale salinity gradient and the salinity gradients that locally evolve due to the rainfall observed to be associated with intraseasonal wind events. This all argues for the important role of intraseasonal variability for understanding seasonal-to-interannual variability.

### OS42M-02 1355h

### Interannual sea Surface Salinity and Temperature Changes in the Western Pacific Warm Pool during 1992-2000

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Sea Surface Salinity (SSS) and Sea Surface Temperature (SST) in the western Pacific warm pool (130E-180; 10N-10S) are analyzed for the period 1992-2000 taking advantage of complementary data from the ship of opportunity program and the TAO-TRITON array of moored buoys. Co-variability of these variables with surface wind stress, surface zonal currents, evaporation, precipitation, and barrier layer thickness is also examined. These fields all go through large oscillations related to the El Nino Southern Oscillation (ENSO) cycle, most notably during the record breaking 1997-98 El Nino and subsequent strong 1998-2000 La Nina. East of about 160E, during El Nino, precipitation minus evaporation increases in the equatorial band, in conjunction with anomalous increases in westerly winds, eastward surface currents, SST, and decreases in SSS. Opposite tendencies are evident during La Nina. Peak to peak 2N-2S averaged variations reached as much as 1.2 m/s for zonal currents and 1.5 psu for SSS. West of about 160E, SST cools during El Nino and warms during La Nina, opposite to what occurs further east. To understand these SST tendencies west of 160E, a proxy indicator for barrier layer formation is developed in terms of changes in the zonal gradient of SSS. Zonal SSS gradients have been shown in modeling studies to be related to barrier layer formation via subduction driven by converging zonal currents in the vicinity of the salinity front at the eastern edge of the warm pool. Correlation between changes in zonal gradient of SSS and changes in SST a few degrees longitude to the west is significantly nonzero, consistent with idea that increased barrier layer thickness is related to warmer SSTs during periods of westward surface flow associated with La Nina, and vice versa during El Nino. Direct evidence of barrier layer thickness variations in support of this hypothesis is also presented.

### OS42M-03 1410h

### Can the Ocean Salinity Stratification Challenge the Role of Westerly Wind Burst in the Onset of El Nino?

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Reliable forecasts of El Nino-Southern Oscillation (ENSO), the largest observed climate variability, depend crucially on model initial conditions. However, the physical processes implied in the onset phase of ENSO are not fully understood. Westerly Wind Burst (WWB) as an El Nino trigger is the most accepted process but is still subject to debate. In addition to remotely forced equatorial Kelvin waves, WWBs generate a local response over the warm and fresh pool of the western Pacific. The eastward displacement of the eastern edge of the warm pool increases the fetch of the WWB leading to a growing mode of the ocean-atmosphere interactions. Specific salinity stratification of the warm pool known as the barrier layer has been proposed to be important in this growing mode. It maintains surface waters warmer than 28C (threshold for organized atmospheric convection) by reducing the entrainment cooling from below the mixed layer. It also confines the forcing of the WWB in a shallow mixed layer thus increasing the eastward displacement of the eastern edge of the warm pool. The importance of the barrier layer in the onset of El Nino is investigated using an oceanic general circulation model of the tropical Pacific coupled to a global atmospheric general circulation model. The Meteo-France/ARPEGE and the LODYC/OPA coupled model is able to reproduce self-sustained El Nino events together with WWBs. At the onset of three El Nino events of different intensities, the stratification resulting from salinity only is cut off in the vertical mixing parameterization. This cutoff is restricted either to the eastern or the western side of the equatorial band (4N-4S). The impact over the eastern side (SST<28C) is modest. It does not modify the El Nino dynamics with the exception of the amplification of coastal warming. On the opposite, the impact over the western side (SST>28C) deeply modifies the onset of each event. Interactions between the ocean and the atmosphere over the warm pool do not amplify and each El Nino aborts. All perturbed experiments continue to exhibit WWBs and within six months return close to the seasonal cycle. Heat budget in the mixed layer confirms that the combined role of the barrier layer and zonal advection is crucial to amplify ocean-atmosphere interactions over the warm pool. Salinity stratification should be considered in coupled models in order to improve El Nino forecast.

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