at six key points on the lower Strickland River floodplain during 1997 and 2003 and analyzed for a suite of trace elements. In 2003, additional cores were collected at 5 other transects and duplicate cores were collected at all transects for analysis of 210Pb. Particulate silver and lead were used as tracers of mine-derived sediments because a previous investigation had indicated that these metals were present at elevated concentrations in mine tailings relative to pre-mining floodplain sediments. Using these relatively simple chemical tools, it was possible to obtain information on mine-derived sediment dispersion and overbank deposition rates in an extremely complex, diverse aquatic system.

OS12B MCC: 3000 Monday 1340h

Changes in the Heat and Fresh Water Budget of the Ocean From Decades to Centuries I *(joint with H, C, GC)*

Presiding: **I Yashayaev,** Bedford Institute of Oceanography**; A Proshutinsky,** Woods Hole Oceanographic Institution**; B Dickson,** Centre for Environment, Fisheries and Aquaculture Science**; R W Schmitt,** Woods Hole Oceanographic Institution

OS12B-01 1345h

World Ocean heat content, 1955-1999

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We update our earlier estimates (Levitus et al., 2000) of ocean heat content for the world ocean with the additional 1.7 million temperature profiles that have become available as part of "World Ocean Database 2001". The results are quantitatively similar through the early 1990s but the newer estimates are lower for the 1990s due to an error in processing the XBT data for the earlier results. This difference does not affect any previous conclusions regarding the dominance of ocean heat content in the earth's heat balance for this period or possible causes of the heat content variability. The results of multivariate analyses of ocean heat content are presented.

OS12B-02 1400h INVITED

Recent Changes in Large Scale Ocean Salinity Distributions in the Context of Climate Variability

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The oceans serve both as a global reservoir and agent of redistribution for several important constituents of Earth's climate system, among them heat, freshwater, and CO_2. Whereas these ocean components are themselves freely exchanged with the atmosphere, salt is a component that is not. As a widely measured and approximately conserved property, the distribution of salinity in the ocean can be used to diagnose rates of freshwater transport, local ocean mixing, and surface freshwater fluxes. In the lengthening timeline of the instrumental record we are beginning to identify decadal to multi-decadal changes in ocean salinity distributions that appear to have a global structure. In particular, water masses ventilated in the low latitude oceans, where evaporation rates are strong, have become distinctly more saline and warmer in recent decades, while an opposite freshening has been observed in water masses ventilated at higher latitudes of both hemispheres. Because the tapestry of climate variability is richly colored by the interweaving of many threads, it has not yet been feasible to precisely partition the observed changes into their causal components. Nonetheless, certain aspects of the climate system – regional modes of wind and precipitation patterns, a melting cryosphere and enhanced hydrologic cycle associated with warming surface temperatures – stand out as leading candidates and will be discussed in a global ocean context.

OS12B-03 1420h

Contribution of Thermal Expansion to Observed Sea Level Rise During the Past Decade

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Recent studies by Cabanes et al. (2001) and Cabanes (2003) have suggested that thermal expansion of the oceans is likely to be the main cause of observed sea level rise during the recent years. These results were based on a single ocean temperature data set (Levitus et al., 2000) and the comparison with the Topex/Poseidon global mean sea level rise was limited to a 6-year period (1993-1998). In this study, we have compared 3 different ocean temperature data sets to investigate more precisely the steric contribution to sea level rise : the Levitus et al.'s (2000) and Ishii et al.'s (2003) data, which both provide $1^\circ \times 1^\circ$ gridded temperature fields for the upper 500m over 1950-1998, and in situ hydrographic data (temperature and salinity from various sources) collected during the WOCE experiment over 1993-2001. We analysed these data in terms of both temporal global mean steric sea level variations and spatial steric sea level trends. Over 1993-1998 (the period of overlap with Topex/Poseidon observations), computed steric sea level trends based on Ishii et al. and Levitus et al. data show similar spatial patterns. However the Ishii et al.'s map appears smoother, showing less high-frequency signal than Levitus et al.'s trend map. In addition, significant difference between temporal global mean sea level curves is observed, reflecting possible differences in both analysis schemes. When such a comparison is extended over the 1950-1998 time span, less difference is noticed between the two data sets prior to 1990. Inclusion of numerous in situ data over the central Pacific during the 1990s in the Ishii et al.' objective analysis may be the cause of the discrepancy observed with Levitus et al's data set. In another analysis, we compared both data sets with in situ hydrographic data from WOCE, by interpolating the Ishii and Levitus grids at the locations of the in situ temperature measurements on their overlapping period 1993 -1998. A very good agreement was found between steric sea level curves based on WOCE data and Levitus data. Finally we computed the steric contribution over 1993-2001 using the WOCE data and compared with the Topex/Poseidon sea level observations. This comparison confirmed earlier results from Cabanes (2003), i.e., during the past decade, thermal expansion appears to be the dominant contribution to the observed sea level rise.

OS12B-04 1435h

Contribution of Climate-Driven Change in Continental Water Storage to Recent Sea-Level Rise

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Using a global model of continental water balance, forced by interannual variations in precipitation and near-surface atmospheric temperature for the period 1981-1998, we estimate the sea-level changes associated with climate-driven changes in storage of water as snow pack, soil water, and ground water; storage in ice sheets and large lakes is not considered. The 1981-1998 trend is estimated to be 0.12 mm/yr, and substantial interannual fluctuations are inferred; for 1993-1998, the trend is 0.25 mm/yr. At the decadal time scale, the terrestrial contribution to eustatic (i.e., induced by mass exchange) sea-level rise is significantly smaller than the estimated steric (i.e., induced by density changes) trend for the same period, but is not negligibly small. In the model the sea level rise is driven mainly by a downtrend in continental precipitation during the study period, which we believe was generated by natural variability in the climate system.

OS12B-05 1450h INVITED

Freshwater Flux Variations and Impacts on the North Pacific Ocean

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Salinity profiles measured 100 km north of Oahu during the past 15 years as part of the Hawaii Ocean Time-series (HOT) reveal important changes in the upper ocean and thermocline. A prolonged freshening started first on shallower isopycnals within the thermocline during the mid-1990s, occurring progressively later on deeper isopycnals. The freshening trend was reversed in the upper pycnocline during 1998 in concert with a pronounced increase in mixed layer salinity. The increased upper ocean salinity was attributed to the regional drought associated with the 1997-98 El Niño event, however the trend continued after that event ended and through 2001 resulting in a salinity change of approximately 1 psu. The ECCO data assimilation results show corresponding large-scale high salinity anomalies in the North Pacific for the period 1998-2001. The impacts of the salinity variations at ALOHA include a pronounced reduction of the stratification of the upper ocean during this period (with deeper wintertime mixing), as well as a significant reduction in the oceanic CO_2 sink. A pattern of drought associated with the Pacific Decadal Oscillation appears to be responsible for the persistence of the HOT salinity anomaly. The pycnocline freshening has been attributed to the subduction and subsequent southward advection of earlier wintertime precipitation anomalies in the storm track region north of Hawaii. The apparent time scale of these variations is about a decade. The 1998-2001 North Pacific surface salinity anomaly pattern roughly corresponds to the precipitation and net freshwater flux anomalies for the same period from the CMAP rainfall and the NCEP/NCAR reanalysis evaporation.

OS12B-06 1510h

The Hydrologic Cycle, Ocean Mixing and Abrupt Climate Change: What do we Need to Measure?

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The hydrologic cycle occurs mostly over the oceans, yet research programs purporting to address the global water cycle focus largely on the much smaller terrestrial water cycle. (E.g.: a mere one percent of Atlantic Ocean rainfall would double the discharge of the Mississippi river.) This is understandable in the context of societal concern for freshwater supplies, but there is now strong evidence that significant changes are underway in the oceanic water cycle that may have dramatic effects on climate. Specifically, evidence from paleoclimatic data indicates that high latitude freshening caused abrupt circulation and climate changes in the past, and model results suggest that the ongoing freshening of the Northern Atlantic could lead to regional cooling in the future. However, the threshold for abrupt change in the oceanic thermohaline circulation is crucially dependent on the relationship between the intensity of hydrologic forcing and the rate of interior ocean mixing. As both these variables are poorly known, concerted efforts to understand the oceanic hydrologic cycle and mixing processes are required. One approach to both tasks must be a better assessment of the variations in oceanic salinity. The upper ocean salt content reflects the history of air-sea water exchange and is thereby an integral measure of the difference between evaporation and precipitation. The salinity distribution also controls the density stratification at high latitudes and thus has large impacts on mixing rates, air-sea exchange and sea-ice formation. However, aside from a handful of time-series sites and diminishing numbers of research cruises, the database for salinity is sparse. An expanded program of systematic salinity measurements is called for, to provide the data necessary to discern variability in the global water cycle, and to assess the impact on oceanic mixing and dynamics. The salinity sensing capabilities of profiling floats along with developing technology for long-lived sensors for surface drifters can contribute to the formation of a robust in-situ salinity-monitoring network. Long-term maintenance of such a network is required to assess the salinity variations of consequence for climate and will also be an important ground-truth-provider during the period of the Aquarius satellite mission.

OS12B-07 1525h

The Sensitivity of Ocean Circulation and Carbon Uptake to the Rate of CO2 Increase and the Resultant Changes in Climate and Hydrological Cycle

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We investigate an important feedback loop in the climate-carbon cycle system that involves increase in atmospheric CO2 and the resulting changes in temperature, the hydrological cycle, ocean circulation, and oceanic carbon uptake. This study is conducted using the coupled atmosphere-ocean-carbon cycle component of the Integrated Science Assessment Model (ISAM). The coupled model includes an energy-moisture balance atmosphere module, a thermodynamic sea-ice module, and a zonal mean ocean module. The ocean component resolves major ocean basins and is based on the balance equations of momentum, temperature, salinity and carbon and its isotopes. The coupled model has the ability to successfully simulate historical and current climates, the ocean thermohaline circulation (THC), oceanic carbon uptake, and bomb 14C. Global warming may cause a weakening or even a collapse of the THC through the increased sea surface temperature and an enhanced hydrological cycle, which can reduce oceanic carbon uptake, thus accelerate the global warming. Recent studies find that the change in the THC is dependent not only on the concentration of atmospheric CO2, but also on the rate of CO2 increase. Using a variety of CO2 increase scenarios (e.g., 0.5%, 1%, 2%/yr CO2 increase from present concentration to the level of doubling or quadrupling of CO2), we extend previous studies by assessing the effect of the rate of CO2 increase, temperature, and hydrological cycle not only on the THC but also on the oceanic carbon uptake. We also explore the threshold values of the rate of CO2 increase and the absolute amount of atmospheric CO2 that are likely to induce the collapse of the North Atlantic Deep Water (NADW) formation, which can have dramatic effects on oceanic uptake of CO2.

OS12C MCC: 3000 Monday 1600h

Changes in the Heat and Fresh Water Budget of the Ocean from Decades to Centuries II *(joint with H, C, GC)*

Presiding: **I Yashayaev,** Bedford Institute of Oceanography**; A Proshutinsky,** Woods Hole Oceanographic Institution**; B Dickson,** Centre for Environment, Fisheries and Aquaculture Science**; R W Schmitt,** Woods Hole Oceanographic Institution

OS12C-01 1600h INVITED

Observing and Modeling the Arctic-Atlantic Climate Connection

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Communication of fresh water, heat, volume and tracers between Arctic and subpolar oceans bears on the meridonal overturning circulation and climate. The spectrum of fresh water transport will be discussed, and illustrated using observations from Davis Strait and several numerical circulation models. Glaring sensitivity in both models and observations is seen on shallow continental shelves and in neighboring boundary currents. The steric height contributed by low-salinity surface waters provides a dominant resistance to deep convection, and its geography is particularly rich and difficult to resolve. As a result, our image of the balance between Labrador Sea Water and deeper overflow waters in the construction of North Atlantic Deep Water is model-dependent and observational-array dependent. It follows that the intensity and focus of decadal variability of models also depends on this balance. A somewhat analogous problem exists in the atmospheric storm track overhead, whose location and intensity bears heavily on these oceanic fluxes. The Atlantic storm track involves continous propagation of cyclonic systems from mid-latitudes to high in the Arctic. These storms are embedded in the larger cyclonic backgroung low which invades the Arctic in years of high NAO index. Wind ducts exist in the complex, strong topographies of the Canadian Arctic Archipelago and the Greenland ice cap, and the slipperiness of upper-ocean low-salinity water (owing to its buoyant inhibition of mixing) makes it susceptible to this stress. Strategy for long-term observations of ocean circulations and atmospheric forcing critcial to decadal climate variability in the Arctic/SubArctic system will be discussed.

URL: http://www.ocean.washington.edu/research/gfd/gfd.html

OS12C-02 1620h INVITED

Inter-basin Versus Meridional Ocean Freshwater Disparity and Global Ocean Conveyor

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This presentation contributes to the ongoing discussion on the role of freshwater transport in the global ocean thermohaline circulation (THC). The current paradigm presumes that the meridional freshwater transport and northern high-latitudinal freshwater impacts in the Atlantic Ocean are the most critical for THC dynamics. Not only does this paradigm belittle the role of the southern freshwater impacts, it also underrates the role of the well-known asymmetry in sea surface salinity (SSS) between the Atlantic and Pacific Oceans and to a lesser extent between other parts of the World Ocean. A disparity in redistribution of freshwater between the Atlantic and Pacific Oceans, both by the atmosphere and by the ocean circulation itself, has long been recognized as a major cause of the observed asymmetry in SSS. However, it has not yet been examined whether this asymmetry accounts for the functioning of the global ocean conveyor, and whether there is a threshold that would trigger such a conveyor. In fact, although the significance of the zonal inter-basin SSS contrasts has never been disputed, their role in driving the global conveyor has inspired far fewer modeling efforts than the more obvious high-latitudinal sea surface freshening, especially in the North Atlantic Ocean and Nordic Seas. In a series of recent publications, we have shown that even if SSS is zonally averaged and thus retains only schematic inter-basin contrasts, it can yield a reasonable global conveyor. In a subsequent series of sensitivity experiments, we have also shown that despite the southern (versus the northern) freshwater impacts are indeed the important controls of THC dynamics, the inter-basin SSS contrasts may be even more important. Our results favor zonal versus meridional SSS contrasts as most critical for building up and maintaining the global THC. Based on those results, we have introduced a hypothesis that inter-basin SSS gradients, regardless of their genesis and even with only rudiment SSS latitudinal distributions in different basins, can be accountable for the global character of THC. To test this hypothesis, we have used an ocean circulation model in a series of sensitivity experiments with an idealized SSS that mimics either meridional, or zonal freshwater disparity, or both. Our experiments have revealed the Atlantic-Pacific SSS asymmetry being one of the most critical elements, if not the most critical one for sustaining the global character of THC. We have also estimated how freshwater must be redistributed consistently in order to facilitate a genuinely global ocean conveyor. We also conclude, albeit preliminary, that high-latitudinal freshwater impacts, as a mechanism of altering the global THC, may be less effective than inter-basin freshwater communications.

URL: http://www.personal.psu.edu/dxs60

OS12C-03 1635h

Nonlinear Gulf Stream interplay With the Deep Western Boundary Current: Observations and Model Results

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Results from a two-way-coupled duo grid adaptation of the DieCAST ocean model to the North Atlantic/Gulf of Mexico/Caribbean Sea system are discussed, including animations. The model Deep Western Boundary Current (DWBC) strongly affects the Gulf Stream (GS) separation and path. Labrador-Sea-modified dense DWBC water arrives in the Grand Banks shelfbreak area after 10 model years. Its arrival results in: GS separation near its observed Cape Hatteras separation location; GS path much closer to observations; offshore thermocline outcropping along an intense GS front; and relatively flat time mean isopycnals between strongly sloping GS and DWBC isopycnals. Such flattening is clearly seen in Yashayaev's non-diffused climatology, and indicates eddy dynamics characteristic of baroclinic instability rather than diffusive lateral mixing between the GS and DWBC. The wedge shaped region between the separated Gulf Stream and continental shelf slope is filled with eddies, including intense warm core eddies that pinch off the northern tips of Gulf Stream meanders. The flattened isopycnals in this region's interior, in both climatology and model results, suggests that the nonlinear eddy system is fueled at least partly by regional potential energy release because, by their very nature (in contrast to diffusive mixing), such potential energy releasing eddies act to REDUCE isopycnal slopes in the region's interior; the larger slopes at the region's boundaries are maintained by open boundary transports from outside the wedge shaped region. This is analagous to the nonlinear wave regime of the rotating annulus experiments, whose interior isotherms have significantly less slope than in more dissipative wave and axisymmetric regimes, while the larger slopes at the boundaries are maintained by conduction at the annular walls. The strikingly flat nature of the time mean interior isopycnals and strength of the eddies suggests that dissipation is small and that little potential energy release is needed to maintain the eddy energy. Based on these observations and model results, we suggest that climatologically important, eddy-available-potential-energy generating, cross-mean-isopycnal potential density transports are small, but concentrated near the edges of the wedge as a result of frontal eddies. The resulting potential energy release fuels the eddy field, which disperses the energy away from its frontal source regions. To simulate such climatologically important behavior, models must have realistically low dissipation. arrives in the Grand Banks shelfbreak area after 10 model years. Its arrival results in: GS separation near its observed Cape Hatteras separation location; GS path much closer to observations; offshore thermocline outcropping along an intense GS front; and relatively flat time mean isopycnals between strongly sloping GS and DWBC isopycnals. Such flattening is clearly seen in Yashayaev's non-diffused climatology, and indicates eddy dynamics characteristic of baroclinic instability rather than diffusive lateral mixing between the GS and DWBC.

OS12C-04 1650h

Deep North Atlantic Freshening Simulated in a Coupled Climate Model

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We have analysed an ensemble of four coupled climate model (HadCM3) simulations with all major historical forcings (natural and anthropogenic). The model has simulated a sustained freshening trend in the deep sub-polar North Atlantic Ocean during the past four decades, which is very similar to recent observations. The source of the freshening is associated with decreased ice cover and increased river runoffs in the Arctic. We do not find any significant changes in E-P over the polar ocean regions. Along with this deep ocean freshening, we find an upward trend in the North Atlantic overturning circulation. The model projects a rapid reverse in the early 21st century of the freshening trend in Labrador Sea due to the collapse of deep convection under increasing anthropogenic forcing.

OS12C-05 1705h

Diagnostic Studies of Global Oceanic Evaporation Variations

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Analyses of global oceanic evaporation derived from the version 2 of the Goddard Sea Surface turbulent Flux data set (GSSTF2) show significant long-term trends and large inter-annual variations. Parameters that affect the oceanic evaporation such as surface wind speed, sea-air humidity difference, presented in the

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