In the southern oceans meridional gradients in air-sea buoyancy flux act to create a strong polar front along which the Antarctic Circumpolar Current (ACC) flows in thermal wind balance with lateral density gradients. Westerly winds also drive the ACC eastward and, through associated Ekman currents, induce an Eulerian meridional circulation (the Deacon cell) which acts to overturn isopycnals enhancing the strong frontal region. The potential energy stored in the front is released through baroclinic instability and the ensuing eddies play a fundamental role in the dynamical and thermodynamical balance of the ACC.

We are investigating the possibility that the final stratification of the circumpolar front could be set by a balance between the rate at which potential energy is created by mechanical and buoyancy forcing and the rate at which it is released by eddies. A series of idealized laboratory experiments have been performed to examine the processes that govern such phenomena. In a rotating cylindrical tank, the combined action of mechanical and buoyancy sources using pumps acts to build stratification creating a large-scale front. At equilibrium, the depth of penetration and strength of the current is then determined by the balance between lateral/vertical eddy transport and sources and sinks associated with imposed patterns of Ekman pumping and buoyancy fluxes.

There are two governing dimensionless numbers. One is the non-dimensional deformation radius, $L_\rho = (g'H/2)^{0.5}/fR$, a measure of the strength of the buoyancy forcing. This parameter compares the rotation time scale, f^{-1}, to the time it takes a internal gravity wave of half tank depth, H/2, of speed $c = (g'H/2)^{0.5}$ to travel the radius of the tank R. The second is the mechanical forcing parameter $\tau = w_e/Hf$ which compares the rotation time scale to the vertical advective time-scale H/w_e, where w_e is the vertical velocity from a pump. By varying these parameters we controlled the mix of mechanical and buoyancy forcing.

Hence, in a rotating tank we generated a dense current using both a buoyancy and mechanical source. The observed equilibrium depth of the laboratory current, h_c, and the lateral mass flux due to the eddies, M, depend on external parameter thus: $h_c = R(w_e f/g'c)^{0.5}$ and $M = Q/(2\pi R) = \overline{v'h'} = ch_c u$ where c, a baroclinic instability efficiency parameter, takes on the value ~ 0.04, u is the experimental horizontal velocity and Q is the pump flow rate.

Finally, we discuss the implications of our study for understanding those processes that contribute to setting the stratification and transport in the ACC itself. If the above results pertain to the ACC we find that $h_c \sim 1$ km and $Q \sim 10$ Sv, not untypical to what is observed.

OS32U HC: 317 A Wednesday 1330h

Physical Processes in Small Systems

OS32U-01 1330h

Pathways to Dissipation in Lakes

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Energy spectra in lakes are often dominated by motions whose periods can be identified as basin-scale baroclinic seiches. We are interested in the paths taken by the energy flux from the large-scale seiches to the small-scale turbulent eddies, and the resulting distribution of turbulent dissipation rate, ϵ, and mixing. We focus on two questions in particular. (1) What are the relative roles of baroclinicity and bottom drag as sources of small-scale shear? (2) Is energy transferred from seiches to turbulence directly via shear instability, or does the energy cascade via wave-wave interactions?

To address these questions, we have obtained full-water-column, time-series records of temperature and velocity and more than 200 surface-to-bottom, temperature-microstructure casts at a 35-m-deep site on a steeply-sloping boundary of Lake Tahoe, CA. Density structure at the site consisted of a 20-m-deep, surface-mixed layer overlying exponential stratification. Preliminary results indicate that ϵ is usually larger at the top of the thermocline than in the bottom 'boundary layer' and that periods of large ϵ are often associated with the presence of vertical-mode-two motions. Further analysis will quantitatively compare ϵ to properties of the baroclinic motions including: gradient Richardson number Ri, isotherm displacement vertical-mode amplitude, and changes in potential energy.

OS32U-02 1345h

Thermal Bar in Lake Superior in Spring 2001

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The vertical convection thermally induced by descending $\sim 4^\circ$C water, due to the onset of seasonal warming during late winter and early spring in large temperate lakes, known as thermal bars, plays an important role in deep vertical mixing and cross-shelf transport. A survey of the western arm of Lake Superior from May 17 to 20, 2001 consisted of 8 cross-shelf transects using a towed instrument package containing an SBE19 CTD. The investigation is aimed at studying the dynamics of thermal bars and their effects on biological processes. Warming along the shallow south shore (20 m) induces a warm, surface layer (7-8°C) overlying colder water (4-5°C). Along the deep, north shore (70 m), the temperature distribution is relatively homogeneous (2-3°C). Thermal bars were observed near the western end of the arm at approximately the 40m isobath and 1-5km off shore. The structure of thermal bars varies, possibly complicated by horizontal circulation and mesoscale eddies. The dynamics of thermal bars and effects of horizontal and vertical shear on thermal bars are investigated based on field observations and the dynamic equation, leading us to further understanding of secondary circulation patterns and their effects on vertical and cross-shelf transport.

OS32U-03 1400h

High Frequency, Near Bottom Current Measurements in Eastern Lake Ontario

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High frequency measurements of near-bottom current velocities were made in water with a depth of 6.5 meters, approximately 1 km from the eastern end of Lake Ontario as part of ELOSTS (Eastern Lake Ontario Sediment Transport Study). Measurements were made during both the unstratified and weakly stratified (April and May) as well as strongly stratified (September and October) periods of 2001. A specially modified, inverted Aanderaa RCM-9 acoustic doppler current meter was mounted in a tetrahedral frame in order to minimize disturbances to extant water flow was used to measure velocities 20 cm above the sediment-water interface at a frequency of about 5 Hz. Pressure and turbidity measurements were also recorded at a similarly high frequency. To enable monitoring for an extended period of time and under varying conditions, measurements were recorded for an interval of 150 seconds during each hour. Previously reported earlier observations, made with a vector-averaging current meter 1 meter above the bottom, show that while during the unstratified season the flow is steadily northward, as stratification strengthens through the summer season and into the fall, the northward flow is interrupted by intervals of southward flowing water which appear to be associated with long internal wave activity. The present data show that periods of high turbidity, and presumably sediment resuspension and transport, are associated with periods of high values of standard deviation of pressure and current velocity, attributed to surface waves. These periods are analyzed to determine the effects of internal waves and synoptic-scale surface weather patterns in order to ascertain preferred directions of sediment transport.

OS32U-04 1415h

Observed and Modeled Wave Characteristics in Southern Lake Michigan

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Time series measurements of water depth were made with underwater pressure sensors during 18 deployments in southern Lake Michigan between 1998 and 2000 in water depths between 10 and 55 m. Most of the deployments were made during the winter and spring (November-April). Measurements were made at either 2 (or 4 Hz) for 2048 (4096) observations either every hour or half hour for periods between 1 and 6 months. The significant wave height, peak-energy wave period, wave orbital velocity at the bottom, and bottom stress were calculated from the pressure measurements using linear wave theory. Agreement between the wave orbital velocities calculated from the pressure measurements and those calculated from direct measurements of the velocities is excellent (r2 > 0.9 for each of 7 deployments).

The results were then compared to values calculated by the GLERL wave model implemented on a 2-km grid. The wave model was calibrated by comparing its results to those measured by 2 Nomad buoys located in the center of the northern and southern basins of the lake during the spring, summer, and fall (March-November) of the study period. For observed heights greater than 1 m, the wave model results agree quite well with the heights observed at the nomad buoys (r2=0.69, based on 9200 observations), but the wave periods are far more variable (r2=0.29). When a similar comparison is made between the results from the pressure measurements and the wave model, the results are not as good (r2=0.55 for the wave heights and 0.33 for the wave periods based on 6000 observations), but the results for the bottom orbital velocities and bottom stresses are somewhat better (r2=0.66). Because both the wave heights and the wave periods calculated by the wave model tend to be lower than those calculated from the pressure measurements, the orbital velocities and stresses determined from the wave model also tend to be smaller than those calculated from the pressure readings. The results indicate that wave periods in Lake Michigan during winter storms are somewhat larger than previously thought (over 10 seconds during several storms each year), which implies that sediment resuspension occurs at greater depths than previously supposed. If the results from the wave model are incorporated into a sediment transport model without modification, they may under-predict the frequency and the magnitude of sediment resuspension events during the winter months.

OS32U-05 1430h

Transport Timescales: No Two Approaches are Alike

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In aquatic systems most of the living biomass and masses of nutrients, contaminants, dissolved gases and suspended particles are carried in a fluid medium, so it is essential to understand hydrodynamic processes that transport water and its constituents. We often measure or estimate a retention time scale and then compare it with time scales of external inputs or biological or chemical processes to calculate water and material budgets or to understand dynamics of populations and chemical properties. Three transport time scales, flushing time, age, and residence time, are fundamentally different time scales yet they are often used interchangeably in ecological applications. Our goals here are to: (1) define and compare the three transport time scales used to measure the retention of water or scalar quantities transported with water, (2) review the underlying assumptions associated with each time scale, and (3) illustrate pitfalls when real-world systems deviate from these simple idealizations using numerical model simulations. We illustrate how different approaches can yield time scales differing by an order of magnitude, even when applied to the same problem. And we illustrate how the complexities of real aquatic systems, including non-steady flows, spatial heterogeneity, and high-frequency transports associated with tidal currents, violate the theory and can greatly influence the magnitude of calculated transport times.

OS32U-06 1445h

Scales and Structures of Large Lake Eddies

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Observations of currents and near-surface temperatures from Lake Superior reveal a surprisingly rich field of eddies that extended throughout the water column and were present throughout the lake and during all seasons. Vertical profiles of horizontal were measured with a 150 kHz vessel-mounted acoustic Doppler current profiler (RD Instruments) currents in a coordinate system moving with the ship. Vessel motion and position information are obtained using a TSS POS/MV320, which can achieve +/-0.05 degree accuracy in roll, pitch and heading, and sub-meter horizontal resolution using a fully integrated system of inertial sensors and survey grade DGPS receivers. Currents in mid-lake were surface intensified with speeds reaching as much as 20 cm/sec in a layer bounded from below by the thermocline. Velocities near the bottom of the lake had magnitudes of approximately 5-10 cm/sec. Surface temperature data were used to characterize the distribution of the eddies and to address how the temperature anomalies were generated by the turbulent dynamics. A spectral slope was calculated from averaged surface temperature spectra in a range of wavelengths between 4.5 and 32 kilometers. During all time periods, the spectral energy density decayed at rates between $k^{-1.5}$ and $k^{-2.4}$. The shapes of mid-summer surface temperature anomaly spectra were consistent with a spectrum expected for a passive tracer within geostrophic turbulence.

OS41A HC: Hall III Thursday 0830h

Quantification and Regionalization of Benthic Flux Rates: Implications for Ocean Budgets II

Presiding: **C Hensen,** Fachbereich Geowissenschaften Universitt Bremen **;** **M Zabel,** Fachbereich Geowissenschaften Universitt Bremen **;** **C E Reimers,** Oregon State University

OS41A-01 0830h POSTER

Ba Preservation and Re-dissolution in Surface Sediments of Different Oceanic Regions in the South Atlantic

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Barium in the form of $BaSO_4$ (barite) is used as a geochemical sediment proxy to reconstruct present and past primary production. The knowledge of the burial efficiency of the proxy is crucial in this approach and there is a strong variation in estimates for barite preservation given in the literature.

Dissolved Ba concentrations were measured in the pore waters of the sediment at locations on the continental slope of the northern Angola, the Cape and the Argentine Basin. All measured concentration profiles exhibit a Ba release in the upper centimetres. Below this subsurface maximum dissolved Ba concentrations are on a constant level. This 'equilibrium concentrations' are approximately equal for the profiles measured in each of the oceanic regions. Differences exist between the three basins. The concentrations increase in the order: Angola Basin (ca. 185 nmol l^{-1}), Cape Basin (ca. 220 nmol l^{-1}) and Argentine Basin (ca. 245 nmol l^{-1}) corresponding to the Ba concentrations measured in the bottom water. Additionally, we calculated the biogenic Ba content and the accumulation rate of biogenic Ba from the measured total Ba concentration in the solid phase.

The transport and reaction model CoTReM was used to simulate the redissolution flux of Ba into the bottom-water, the amount of Ba buried in the sediment and the flux of biogenic Ba to the sediment surface for the assumed boundary conditions (sedimentation, bioturbation). By this approach we determined the burial efficiencies of biogenic Ba for the different oceanic regions to identify possible mechanisms which effect the Ba preservation in the sediment (e.g. organic matter mineralisation, saturation state of the bottom-water with respect to barite).

OS41A-02 0830h POSTER

Characterisation of Benthic Biogeochemical Provinces - An Approach for Reliable Budgeting of Flux Rates on the Global Scale

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A huge number of studies have frequently shown that benthic oxygen, carbon and nutrient flux rates depend on a complex interplay of different control parameters such as the primary and/or export productivity, the rain ratio, or the sediment composition. Especially the last one includes the important physical effects of lateral advection by currents which are often underestimated. Unfortunately, data give also evidence that these connections predominately do not have global validity. The weighting between the factors influencing transformation and exchange rates at the sea floor is rather determined by oceanographic conditions and seems to be specific for each component additionally. On the other hand, its no question that benthic flux rates play an important role for ocean budgets. Because field studies are very expensive and time-consuming they cannot be carried out ocean-wide which makes obvious the necessity of global estimates.

Inspired by Longhurst et al. (1995), who have defined provinces for the primary production, in this project we try characterize biogeochemical processes in the deep sea. Geostatistical methods and Geographic Information Systems (GIS) were used both to formulate specific spatial functions describing the relationship between the benthic release and control parameter(s) and to optimise the construction of regional distribution maps. The first is mostly restricted to regions with high data density. Applications of the transfer functions on areas with comparable oceanographic and sedimentary conditions but sparse benthic results, give first very promising results (please cf. Seiter et al. at this session).

Longhurst, A., Sathyendranath, S., Platt, T., Caverhill, C. (1995): An estimate of global primary production in the ocean from satellite radiometer data.- J. Plankton Res., 17(6), 1245-1271.

URL: http://www.geochemie.uni-bremen.de/

OS41A-03 0830h POSTER

Assessing Sediment-Water Nutrient Exchange Processes in the North Sea.

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Inorganic macro nutrient species are often thought to be a major limiting factor for primary producers in marine systems; ultimately, therefore, production is dependent on the amount of new and regenerated nutrients. It is generally held that greater than 90 percent of marine primary production is remineralised within the marine system. However, the contribution to this figure from benthic remineralisation and exchange processes is poorly understood. Areas of high fishing intensity typically exhibit a proliferation of smaller benthic organisms, and receive elevated amounts of organic matter in the form of offal and discards. Smaller benthic organisms are more productive yet less effective at turning over the sediment. This effectively reduces bioturbation activity, thereby altering sediment redox state and nutrient dynamics. This study examines the potential impact of bottom fishing on early diagenetic transformations and benthic nutrient exchange in coastal seas, using a number of observational and experimental approaches. Insitu measurements (benthic nutrient profiling) as well as laboratory based experiments (chamber flux measurements) were used. Bioturbation contribution and benthic disturbance were accounted for. Mesocosm experiments were used to isolate flux contributions from different assemblages of benthic organisms and bottom fishing. Benthic coring was used to obtain nutrient pore water profiles for flux rate modelling. These data were modelled to give an annual benthic flux rate for the North Sea, for nitrate, nitrite, ammonium and phosphate. The implications of the findings for Bioturbation and other biogeochemical implications are discussed and evaluated.

OS41A-04 0830h POSTER

Quantifying Pore Water Exchange Across the Sediment-Water Interface in the Deep Sea With In Situ Tracer Studies

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Benthic flux chambers have been widely used to measure the in situ fluxes of nutrients and oxygen in biogeochemical studies. In many cases, an inert tracer such as NaBr is injected at the start of the incubation and monitored throughout the experiment. A linear extrapolation of the tracer data has been used in the past to estimate the initial chamber concentration and water volume. Here we interpret the exchange of NaBr tracer between chamber waters and underlying pore waters in several in situ experiments conducted at four deep sea locations: the California margin, North Carolina margin, Ceara Rise, and Cape Verde Plateau. We examine the accuracy of previous chamber volume and flux estimates and assess sediment-water solute exchange rates.

A centered finite difference scheme was developed to simulate NaBr transport. Model results reveal an initial period of rapidly decreasing tracer concentrations that is missed by the widely-spaced sampling intervals generally employed during in situ experiments. The results suggest that the linear extrapolation scheme previously employed overestimates chamber volumes and hence benthic fluxes. The magnitude of the effect depends on sampling interval and effective solute exchange rate. At locations where interface exchange is dominated by molecular diffusion and reasonable sample intervals are used, chamber volumes are generally overestimated by 10 - 50 percent. At locations where exchange is enhanced by the activities of macrobenthic organisms and/or widely spaced sampling intervals are employed, larger overestimates can occur. The model is also used to estimate overall solute interfacial exchange rates. At locations where rates of organic matter remineralization are low, exchange is consistent with molecular diffusive rates. At locations where organic matter remineralization is rapid, exchange can be significantly faster than molecular diffusion alone, but may be controlled by the presence of macrofauna and hence bottom water oxygen concentrations. These observations are consistent with previously reported correlations between benthic solute exchange and respiration rates.

OS41A-05 0830h POSTER

Porewater Exchange in Permeable South Atlantic Bight Continental Shelf Sediments

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South Atlantic Bight continental shelf sediments are characterized by high permeabilities, substantial benthic microalgal photosynthesis, and rapid tidally-driven bottom current velocities. These factors restrict the utility of conventional benthic chambers for estimating benthic remineralization. Intact sediment core incubations from a 27 m depth station were employed ten times over an annual cycle to evaluate the relative contributions of diffusional and advective pore water exchange on the benthic flux of dissolved constituents. Replicate sediment cores recovered at each sampling period were incubated in circulating seawater in the dark at in situ temperatures for 9 -15 days depending on season, and porewaters were collected at 1-cm intervals periodically throughout the incubation. Replicate cores were incubated with and without surface pistons to evaluate diffusive losses from surface sediments into the overlying incubation waters. Using the observed rate of silicate concentration increase at each depth interval as a measure of opal dissolution, the rate of pore water exchange required to achieve the initial pore water silicate distribution was calculated. Results were incorporated into computer models describing exchange processes as combinations of molecular diffusion/nonlocal exchange or molecular diffusion/enhanced diffusion. Given the large natural variability, no seasonality was observed in the magnitude of porewater exchange. When represented as a