crucial role in the estuarine carbon budget and is subject to changing physical, chemical and biological parameters in the estuary. Among the rivers entering the Arctic Ocean Ob and Yenisei alone account for about one third of the total annual riverine discharge. While data on water discharge are relatively robust this is not true for estimates on annual DOM transport to the Kara Sea, mainly due to insufficient temporal resolution of dissolved organic carbon (DOC) data during the spring-flood and winter periods. Based on DOC data from 4 cruises in the Kara Sea we estimate the annual DOC transport of Ob and Yenisei to be 7.5-9.6 TgC. Conservative distribution of both DOC and dissolved organic nitrogen (DON) along the salinity gradient indicate the predominantely refractory character of this riverine DOM. This observation is consistent with laboratory experiments which showed only minor losses due to flocculation processes and bacterial decomposition as well as low in situ respiration measurements. The distribution of optical and chemical properties of DOM in the Kara Sea underlines its conservative behavior, but also supplies clues about the potential importance of brine rejection and photooxidation for DOM in the Eurasian shelf. The role of heterotrophic bacteria for DOM cycling in the Kara Sea is currently under investigation and will allow to estimate the importance of biological versus physical factors for DOM processing in the Kara Sea.

OS32T HC: 317 B Wednesday 1330h

Southern Ocean Circulation

Presiding: **D Luther,** University of Hawaii at Manoa

OS32T-01 1330h

Comparison of Methods of Estimating Mean Synoptic Current Structure in "Stream Coordinates" Reference Frames: Impact on Structure, Transport and Dynamical Inferences With an Example From The Antarctic Circumpolar Current

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Stream coordinates techniques, that is, the methods of deriving the mean "synoptic" structures of narrow meandering ocean currents, have been in use for nearly two decades and have resulted in improvements in our understanding of the dynamics and transports of such currents. Stream coordinates have been applied to a wide range of currents, including the Gulf Stream, North Atlantic Current, Kuroshio, and Antarctic Circumpolar Current (ACC). Studies of these currents have involved different types of measurements, and have employed somewhat different assumptions to convert Eulerian measurements into a stream-coordinates reference frame. The key issues are how to determine, at any particular time, the location and direction of the core of the meandering jet relative to observations taken at fixed geographical locations. A recent experiment in the ACC's Sub-Antarctic Front (SAF) southwest of Tasmania, involving overlapping arrays of current meter moorings, inverted echo sounders, and horizontal electric field recorders, has provided an opportunity to test various stream coordinates methods to determine how well they achieve the goal of producing an accurate mean "synoptic" picture of the SAF current. It is found that, at least for the SAF southwest of Tasmania, the common assumption of a meandering "frozen field" baroclinic structure leads to the concealment of real baroclinic divergence and to an incorrect broadening of the current and temperature structures. The impact of the differing stream coordinate structures on dynamical inferences and transport estimates will be discussed.

OS32T-02 1345h

Synoptic Structure of the Sub-Antarctic Front Southwest of Tasmania: Temperature, Salinity and Absolute Velocity

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The mean "synoptic" structure of the northern, strongest, branch of the Antarctic Circumpolar Current southwest of Tasmania - the Sub-Antarctic Front (SAF) - is estimated by a stream-coordinates analysis of data from overlapping arrays of current meter moorings, inverted echo sounders, and horizontal electric field recorders deployed during the 1995-97 Sub-Antarctic Flux and Dynamics Experiment (www.soest.hawaii.edu/oceanography/dluther/SAFDE/index.html). An accurate stream coordinates reference frame is constructed without the usual suppositions about the behavior of the structure of the density or current fields (e.g. a frozen field assumption). The stream coordinates are derived from a daily objective mapping of the temperature field obtained from combining the IES travel time measurements with an empirical vertical mode structure constructed from the extensive hydrography acquired during WOCE (SR3 line). Full-water-column stream-coordinates sections of temperature, salinity and absolute velocity will be discussed and compared with prior observations of the SAF and other fronts. Separating the baroclinic and barotropic currents (using the Fofonoff bottom current definition of barotropic) reveals that (i) the SAF currents are divergent - both baroclinically and barotropically - in the cross-stream direction, and (ii) the cross-stream shear of the along-stream velocity is strongest on the cold side of the front. The barotropic contribution to the mean total transport is small. Dynamical inferences will be drawn from the stream coordinates sections.

OS32T-03 1400h

Interpreting Wind-Driven Variability of the Southern Ocean in a Stochastic Framework

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A stochastic model is derived from wind stress and bottom pressure gauge data to reexamine the response of the Antarctic Circumpolar Current (ACC) transport to wind stress forcing. A general method is used to estimate the drift and diffusion coefficients of a continuous stationary Markovian system. The response of the ACC to wind stress forcing can be described by a multivariate Ornstein-Uhlenbeck process. The stochastic model can serve as a null hypothesis for studies of wind driven ACC variability. Using this hypothesis, we show that a stochastic parameterization of the bottom drag can decrease the effective damping of the flow by means of a "noise-induced transition". The stochastic representation of the damping term indicates the fluctuations of the damping parameter and implies that the stochastic forcing is multiplicative. Multiplicative noise can substantially change the dynamical behavior of the underlying system; in this particular case the stochastic parameterization of the bottom drag results in an effective decrease of the damping. While observations suggest a phase lag between wind forcing and ACC transport, ocean models have not shown this effect, possibly because the effective damping is too large. Therefore, we suggest that this model deficit may have its origin in the traditional use of constant damping parameters.

OS32T-04 1415h

Mid-Depth Warming Trends in the Southern Ocean

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Temperatures measured in the Southern Ocean during the 1990s by Autonomous Lagrangian Circulation Explorer (ALACE) floats are consistently warmer than older hydrographic temperature measurements from the region. As part of the World Ocean Circulation Experiment, ALACE floats returned nearly 13,000 mean temperatures from depths between 700 and 1100 m, time averaged for 10 to 25 day intervals. Point by point comparisons of the ALACE temperatures with hydrographic profiles suggest a total warming of about 0.17 C between the 1950s and the 1980s. (Some of the floats also provided vertical profiles of temperature.) Warming is fastest near the Antarctic ice edge and within the core of the Antarctic Circumpolar Current, where the rate of mean temperature rise is nearly 1 C per century. This rate of increase is faster than the warming of the global ocean as a whole reported by Levitus and coauthors, and it is comparable in magnitude to ground level atmospheric temperature rises reported from islands within the Southern Ocean.

OS32T-05 1430h

A deep cyclonic gyre in the Australian-Antarctic Basin

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World Ocean Circulation Hydrographic Program sections I8S and I9S provide two quasi-meridional crossings of the South Australian Basin and the Australian-Antarctic Basin. Full water column conductivity and temperature profiles, a suite of nutrient measurements and two independent direct-velocity measurements (shipboard and lowered acoustic Doppler current profilers) are used to determine the pathways of Antarctic Bottom Water and Lower Circumpolar Deep Water from the Australian-Antarctic Basin into the South Australian Basin and to quantify the strength of the deep cyclonic gyre within the Australian-Antarctic Basin.

A western boundary current along the Kerguelen Plateau in the Australian-Antarctic Basin acts as the western limb of a deep cyclonic gyre and brings cold dense water north from the margins of Antarctica. Deep water sources for the western boundary current derive from the convergence of westward and eastward flow along the Antarctic continental slope, and a cyclonic recirculation within the Australian-Antarctic Basin. At the northern boundary of the Australian-Antarctic Basin, deep water within the western boundary current turns east, flows beneath, and merges with the Antarctic Circumpolar Current. This northern limb of the deep cyclonic gyre flows east along the southern flank of the Southeast Indian Ridge. Further downstream a saddle in the Southeast Indian Ridge, the Antarctic Discordance, allows a portion of the deep water to pass from the Australian-Antarctic Basin into the South Australian Basin. Rather than a simple bifurcation of the northern arm of the cyclonic gyre, the deep waters appear to take a meandering pathway to the Antarctic Discordance.

OS32T-06 1445h

Kinematics and Dynamics of Unstable Waves in the Antarctic Circumpolar Current

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Baroclinic and barotropic instabilities of the Antarctic Circumpolar Current (ACC) are evaluated based on linear stability analysis of ACC flow fields simulated by the Parallel Ocean Climate Model (POCM). Merdional transects of flow velocity are extracted at 4 degree longitude intervals from POCM for the area between 43S and 63S, a region which includes the Subantarctic and Polar fronts. Kinematic and dynamic properties of unstable modes are computed by applying quasigeostrophic linear stability analysis to a 3-layer representation of each y-z velocity transect. Properties of unstable modes are first evaluated as a function of location within the Southern Ocean for calculations which include the contribution of meridional topographic slopes to the vorticity equation. The effect of north-south sloping topography on unstable mode kinematics and dynamics is then evaluated by comparing (1) linear stability results computed by including the meridional topographic slope in the vorticity equation with (2) linear stability results computed by neglecting this term in the vorticity equation.

OS32T-07 1500h

Thermocline Depth and Exchange Fluxes Across Circumpolar Fronts

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W E D

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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