OSM180212

2018/2/12 Monday

- **PL11A** The Driving Forces of the Ocean's General Circulation I

- *Oregon Convention Center*

- *- B113-B115*
    - The focus of this session is on the processes that facilitate the closure of the ocean's general circulation. The processes driving the upper and lower branches of circulation, and interconnecting them are of interest. In particular, the impact of changes in these driving processes on the circulation, thereby on the climate system, on a wide range of time scales will be part of our focus. Example topics of interest include: high latitude coupled dynamics, interior and deep ocean turbulence and mixing, boundary processes and global scale energetics and/or water mass analyses. We encourage contributions that not only focus on physics of processes, but also on their role and interconnections in the large-scale circulation.

Monday, February 12, 2018

08:00 AM - 10:00 AM

- *Oregon Convention Center*

- *- B113-B115*

Primary Chair

- Ali Mashayek
    - *Scripps Institution of Oceanography*

Co-Chairs

- Lynne D Talley
    - *University of California San Diego*
- Sheldon Bacon

- *University of Southampton*
- Colm-cille Patrick Caulfield
- *University of Cambridge*

Moderators

- Ali Mashayek
- *Massachusetts Institute of Technology*
- Lynne D Talley
- *University of California San Diego*

- 08:00 AM**PL11A-01** Warm-route versus cold-route interbasin exchange in the meridional overturning circulation***Paola Cessi****, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States and C. Spencer Jones, Scripps Institution of Oceanography, La Jolla, CA, United States*
- The interbasin exchange of the meridional overturning circulation (MOC) is studied in an idealized domain with two basins connected by a circumpolar channel in the southernmost region. Gnanadesikan(1999)'s conceptual model for the upper branch of the MOC is extended to include two basins of different widths connected by a re-entrant channel at the southern edge and separated by two continents of different meridional extents. Its analysis illustrates the basic processes of interbasin flow exchange either through the connection at the southern tip of the long continent (``cold route'') or through the connection at the southern tip of the short continent (``warm route''). A cold-route exchange occurs when the short continent is poleward of the latitude separating the sub-polar and sub-tropical gyre in the southern hemisphere (the zero Ekman pumping line), otherwise there is warm-route exchange. The predictions of the conceptual model are compared to primitive equation computations in a domain with the same idealized geometry forced by wind-stress, surface temperature relaxation and surface salinity flux. Visualizations of the horizontal structure of the upper branch of the MOC illustrate the cold and warm routes of interbasin exchange flows. Diagnostics of the primitive equation computations show that the warm-route exchange flow is responsible for a substantial salinification of the basin where sinking occurs. This salinification is larger when the interbasin exchange is via the warm route, and it is more

pronounced when the warm-route exchange flows from the wide to the narrow basin.

- 08:15 AM**PL11A-02** Dynamics of an Abyssal Circulation Driven by Bottom-Intensified Mixing on Slopes***Jörn Callies***, *California Institute of Technology, Pasadena, CA, United States and Raffaele M Ferrari, Massachusetts Institute of Technology, Cambridge, MA, United States*
- The large-scale circulation of the abyssal ocean is enabled by small-scale diapycnal mixing, which observations suggest is strongly enhanced towards the ocean bottom, where the breaking of internal tides and lee waves is most vigorous. As discussed recently, bottom-intensified mixing induces a pattern of near-bottom up- and downwelling that is quite different from the traditionally-assumed widespread upwelling. Here the consequences of bottom-intensified mixing for the horizontal circulation of the abyssal ocean are explored by considering planetary geostrophic dynamics in an idealized “bathtub geometry.” Up- and downwelling layers develop on bottom slopes as anticipated, and these layers are well-described by boundary layer theory. The basin-scale circulation is driven by flows in and out of these boundary layers at the base of the sloping topography, which creates primarily zonal currents in the interior and a net meridional exchange in western boundary currents. The rate of the overturning is controlled by the magnitude of the up- and downwelling in boundary layers.

Authors

- **Jörn Callies**
  - *California Institute of Technology*
- Raffaele M Ferrari
  - *Massachusetts Institute of Technology*

- 08:30 AM**PL11A-03** On the diabatic nature of the AMOC***Laura Cimoli***[1], *Ali Mashayek*[2], *David Philip Marshall*[1] *and Helen Johnson*[1], *(1)University of Oxford, Oxford, United Kingdom, (2)Scripps Institution of Oceanography, La Jolla, CA, United States*
- The upper branch of the ocean Meridional Overturning Circulation (MOC), which is primarily in the Atlantic Ocean (AMOC), has largely been considered to be adiabatic in nature between the sinking in the North Atlantic and the return to

surface in the Southern Ocean, while the role of cross-density mixing has often been considered of secondary importance by a number of theoretical and numerical studies. Recently there has been progress in understanding and highlighting the role of near boundary turbulence in diapycnal conversion of water masses. Motivated by this development, we investigate the extent to which diapycnal processes contribute to the regulation of the upper branch of MOC. We combine Argo-based estimates of turbulent mixing in the upper 2000 m with earlier contribution from bottom generated mixing to perform water mass transformation calculations over the global ocean. We show that diapycnal mixing contributes a lower bound of 10 Sv of diapycnal conversion in the global ocean across density levels that correspond to the upper branch of the MOC. About half of this across density upwelling takes place in the Atlantic Ocean, indicating that diapycnal mixing has a first order importance in the dynamics of the AMOC. Taking recent advancement in quantification of mixing efficiency implies an even larger diabatic transformation in AMOC, suggesting values as high as 15 Sv globally and 7 Sv in the Atlantic Ocean. Our study suggests that diapycnal mixing is a leading order process, along with Southern Ocean winds and eddies and northern hemispheric sinking and winds, in controlling the rate of AMOC. Hence, ignoring it in models will need to be compensated by other processes with potential adverse effects for the rest of ocean circulation such as for the modeled Southern Ocean dynamics. This result also implies that tracers move diabatically across density surfaces, upwelling in different density classes in the Southern Ocean, and entering different corridors of the global ocean circulation, with crucial consequences for their global redistribution and ventilation timescales.

Authors

- **Laura Cimoli**
  - *University of Oxford*
- Ali Mashayek
  - *Scripps Institution of Oceanography*
- David Philip Marshall
  - *University of Oxford*
- Helen Johnson

- *University of Oxford*
  - 08:45 AM**PL11A-04** A new look at the potential vorticity distribution in the World Ocean***Arnaud Czaja***[1]*, Arjun Ganguly*[2]*, Thomas Gilders*[2] *and Hamish Miller*[2]*, (1)Imperial College London, London, United Kingdom, (2)Imperial College, London, United Kingdom*
  - In this study, we revisit early works from the late 1980s about potential vorticity (PV) homogenization in the World Ocean using ARGO data. First, by comparison with hydrographic sections across the world oceans, we show that climatologies derived from ARGO floats are accurate at representing the PV distribution. We then introduce an index of PV homogenization along isopycnals which we apply to the 0-2000m water column globally. The analysis indicates a striking partitioning of this index among different ocean basins, with highest PV homogenization observed in the North Pacific, a weak degree of homogenization throughout the Southern Ocean, and a rich behaviour in the North Atlantic (both homogenization and large PV gradients are found there, depending on density layers).

Authors

- **Arnaud Czaja**
  - *Imperial College London*
- Arjun Ganguly
  - *Imperial College, London*
- Thomas Gilders
  - *Imperial College, London*
- Hamish Miller
  - *Imperial College, London*
  - 09:00 AM**PL11A-05** Thermodynamic Constraints on the Global Overturning Circulation***Emily Rose Newsom****, California Institute of Technology, Division of Geological and Planetary Sciences, Pasadena, CA, United States, Andrew F Thompson, California Institute of Technology, Pasadena, CA, United States and Cecilia M Bitz, University of Washington, Seattle, WA, United States*
  - Studies of global ocean dynamics often focus on meridional asymmetries in the ocean system, a focus which reinforces a two-celled, zonal-average model of the Global Overturning Circulation (GOC). In this context, controls on the circulation are

often framed as the influence specific processes have on meridional dynamics. However, recent studies have cautioned that the zonal-average is a misleading representation of GOC dynamics, which have important zonal structure.

- Here, it is argued that zonal-averaging further obscures how global thermodynamics influence ocean behavior. We argue this by demonstrating a global-scale relationship between the surface buoyancy flux and the interior circulation in the fully-coupled climate model CCSM 4. This analysis reveals a major surplus of net buoyancy flux into the Northern Hemisphere Indo-Pacific and surplus of flux out of the Atlantic, across the same latitudes. A steady state is maintained because the isopycnal structure of the GOC naturally conveys buoyancy from the Indo-Pacific through the Southern Ocean and into the Atlantic.
- While circulation and surface flux patterns are inherently coupled, it is argued that the flux distribution is partially constrained by basin width, motivating a new perspective on the GOC: the global circulation must somehow organize to redistribute persistent, geographically-constrained heterogeneities in surface buoyancy flux. This constraint regards the full circulation, and does not separate a "wind-driven" component from a "thermohaline one". It acknowledges that surface buoyancy flux cannot “drive” the circulation, which is instead “driven” by processes which supply energy and “closed” by those that consume it. Instead, surface fluxes fundamentally limit how these driving processes can behave. Specifically, precisely so that buoyancy flux bears no global influence on ocean energetics, driving processes must support a circulation which exactly redistributes buoyancy between surface sources and sinks. This global buoyancy transport can be decomposed to into its diffusive and advective (diabatic and adiabatic) components, a partition which sheds light on the dynamic processes that support it over a global scale.

Authors

- **Emily Rose Newsom**
  - *California Institute of Technology*
- Andrew F Thompson
  - *California Institute of Technology*
- Cecilia M Bitz
  - *University of Washington*

- 09:15 AM**PL11A-06** Ocean Gyres Driven by Surface Buoyancy Forcing***Andrew M. Hogg**, Australian National University, Canberra, ACT, Australia and Bishakhdatta Gayen, Australian National University, Research School of Earth Sciences, Canberra, Australia*

Midlatitude ocean gyres have long been considered to be driven by the mechanical wind stress on the ocean's surface (strictly speaking, the potential vorticity input from wind stress curl). However, surface buoyancy forcing (i.e. heating/cooling or freshening/salinification) also modifies the potential vorticity at the surface.

Here, we present a simple argument to demonstrate that ocean gyres may (in principle) be driven by surface buoyancy forcing. This argument is derived in two ways:

1. A Direct Numerical Simulation, driven purely by buoyancy forcing, which generates strong nonlinear gyers in the absence of wind stress; and
2. A series of idealised eddy-resolving numerical ocean model simulations, in which wind stress and buoyancy flux are varied independently and together, are used to understand the relative importance of these two types of forcing. In these simulations, basin-scale gyres and western boundary currents with realistic magnitudes, remain even in the absence of mechanical forcing by surface wind stress.

These results support the notion that surface buoyancy forcing can reorganise the potential vorticity in the ocean in such a way as to drive basin-scale gyres. The role of buoyancy is stronger in the subpolar gyre than in the subtropical gyre. We infer that surface buoyancy fluxes are likely to play a significant role in governing the future strength, variability and predictability of subpolar gyres.

Authors

- **Andrew M. Hogg**
  - *Australian National University*
- Bishakhdatta Gayen
  - *Australian National University*

- 09:30 AM**PL11A-07** Atmospheric or Oceanic Control of the Atlantic–Pacific Asymmetry in Meridional Overturning Circulation?***Johan Nilsson**, Stockholm University, Department of Meteorology, Stockholm, Sweden, David Ferreira, University of Reading, Department of Meteorology, Reading, United Kingdom, Tapio Schneider,*

California Institute of Technology, Pasadena, CA, United States and Robert Christopher Wills, ETH Swiss Federal Institute of Technology Zurich, Department of Earth Sciences, Zurich, Switzerland

- The North Atlantic has a significant meridional overturning circulation (MOC) that is associated with high-latitude deep water formation; whereas as a corresponding MOC is absent in the North Pacific. It is well established that this asymmetry is tied to the difference in the salinity fields between the two basins. However, it remains unclear whether the basin salinity difference is primarily caused by differences in surface freshwater fluxes (E-P) or in oceanic salt transports. Here, we examine this fundamental issue by analysing observational data and modelling results in a two-dimensional diagram spanned by the net E-P (x axis) and the surface salinity (SSS, y axis). Using a simple horizontal advection–diffusion model, we show that for a purely diffusive salt transport the values of E-P and SSS fall on a straight line in the diagram. For advective–diffusive transport, on the other hand, the values of E-P and SSS fall on elliptic curves in the E-P–SSS diagram. From the features of the ellipses one can estimate the relative strength of advective and diffusive transport processes and an effective SSS relaxation timescale. We then go on to examine E-P–SSS relations based on zonally-averaged data from the Atlantic and the Pacific. We find a primarily "diffusive" in-phase relation, simply reflecting a general correlation between extrema in E-P and SSS. In the North Atlantic, however, the E-P–SSS relation shows an elliptic advective signature, indicating that the relaxation timescale due to mean advection is about four times longer than that associated with "diffusive" eddy mixing. In the North Pacific, the analysis indicates a significantly larger ratio between the advective and diffusive timescales. Furthermore, the effective SSS relaxation timescale is found to be shorter in the Atlantic than in the Pacific. Finally, we make a qualitative attribution of the processes contributing to a higher subpolar SSS in the North Atlantic than in the North Pacific: to the total basin difference in SSS of about 2 psu, the E-P difference accounts for slightly less than 50% and oceanic transports, including inter-basin exchange, accounts for the remainder.

- 09:45 AM**PL11A-08** Testing a new paradigm for the abyssal ocean circulation***Henri F Drake**, Massachusetts Institute of Technology, Atmospheric and Oceanic Sciences,* *Cambridge, MA, United States, Jörn Callies, California Institute of Technology, Pasadena, CA, United States and Raffaele M Ferrari, MIT, Cambridge, MA, United States*

- The upwelling limb of the lower cell of the meridional overturning circulation is primarily driven by diapycnal mixing. In the traditional framework, uniform upwelling of dense waters is balanced by vertical diffusion; the resulting vortex stretching determines the horizontal circulation. Observations suggest that diapycnal mixing in the deep ocean increases toward the bottom such that the sign of the expected vertical advection flips and downwelling is instead expected everywhere in the interior abyssal ocean. It has been suggested that this apparent conundrum is resolved by considering the dynamics of the flow along a stratified and rotating slope, where vigorous upwelling develops within a thin boundary layer. Using a planetary geostrophic model developed by Callies and Ferrari, we will test the hypothesis that the boundary mixing can support enough upwelling within thin boundary layers to account for the observed meridional overturning circulation. While Callies and Ferrari have validated their hypothesis in an idealized bowl-shaped basin with constant stratification, we test its applicability to the real ocean using numerical simulations with realistic topography and stratification.

- **PL12A** The Driving Forces of the Ocean's General Circulation II

- *Oregon Convention Center*

- *- B113-B115*

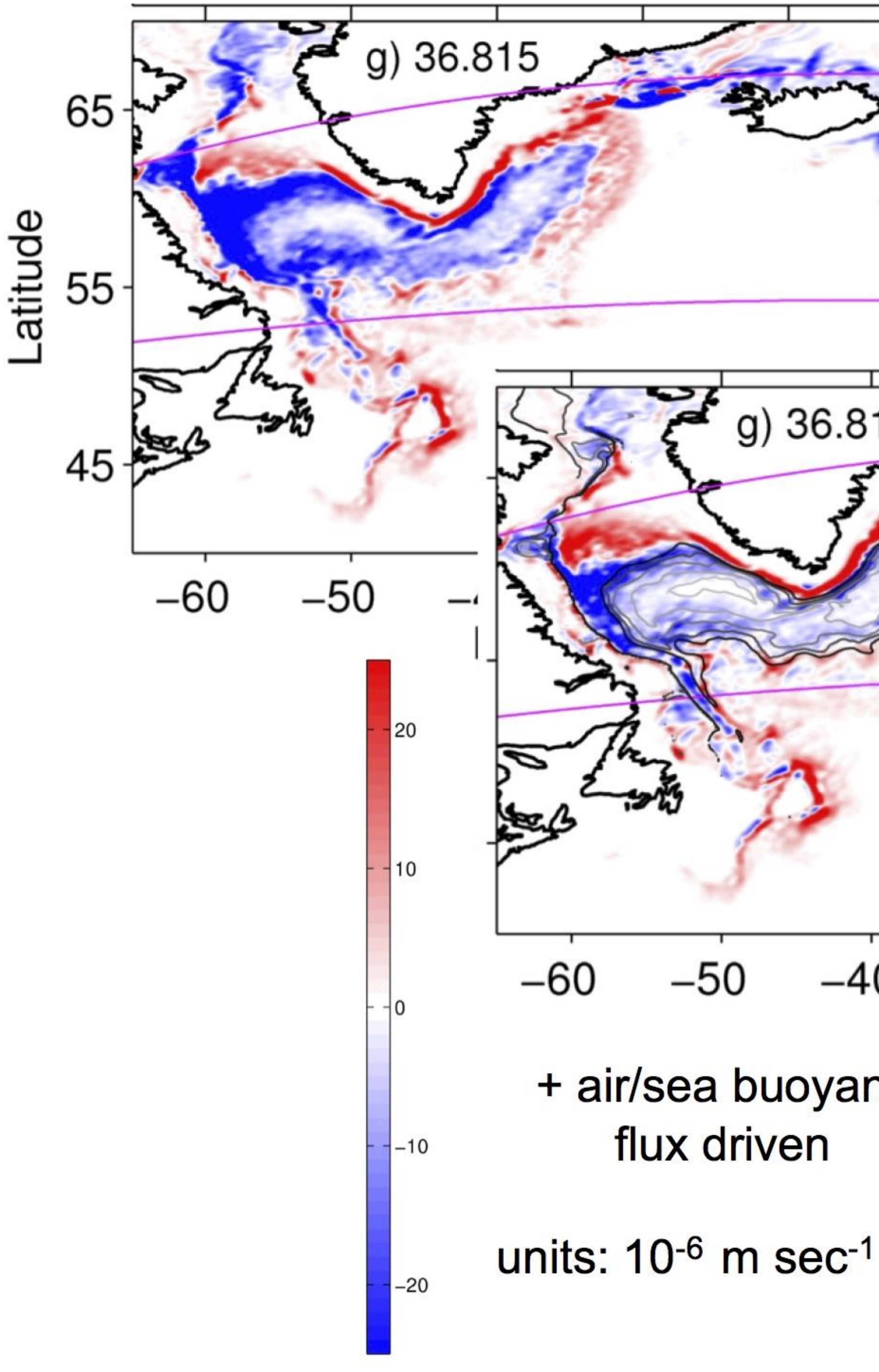
  - 10:30 AM**PL12A-01** Does turbulent mixing drive upwelling or downwelling of deep waters in the Drake Passage?***Raffaele M Ferrari*** *and Ali Mashayek, Massachusetts Institute of Technology, Cambridge, MA, United States*
  - Turbulent mixing produced by breaking of internal waves plays an important role in setting the patterns of upwelling and downwelling of deep waters that result in the global deep ocean overturning circulation. The Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES) used a combination of microstructure profiles and a tracer released at 1,500m to quantify the turbulent diffusivity in the Drake Passage. Here we introduce a new method to directly quantify the rate of diapycnal upwelling and downwelling from the tracer measurements. The new

method is first tested with a high-resolution ocean model of the Drake Passage, where we inject numerical tracers at different depths, and then with the DIMES tracer measurements. We find that the tracer slowly sinks toward the ocean bottom in response to the bottom intensification of the turbulent buoyancy flux, but rapidly rises toward lighter density classes when it encounters topography and enters in the bottom boundary layer above the seafloor, where the turbulent buoyancy flux decays to zero to satisfy the no buoyancy flux boundary condition. The boundary layer upwelling dominates over the interior sinking and results in a net upwelling of deep waters that peaks at the density surface that separates North Atlantic Deep Waters and Antarctic Bottom Waters.

- 10:45 AM**PL12A-02** Exploring the weakly stratified bottom boundary layer of the global oceans***Donata Banyte**, Newcastle University, Tyne and Wear, United Kingdom, Miguel Angel Morales Maqueda, National Oceanography Centre, Liverpool, United Kingdom and David Smeed, National Oceanography Center, Soton, Southampton, United Kingdom*
- The weakly stratified bottom boundary layer (wsBBL) of the global ocean is currently unmapped, and there is no consensus as to its precise definition. Recent research points to the wsBBL as the region where most of the abyssal water transformation takes place. In this study, the wsBBL is investigated using the World Ocean Database. The wsBBL forms wherever density layers intercept the bottom. While the wsBBL is just meters thick over the sloping walls of the basins, it is hundreds of meters thick over abyssal plains. Our analysis suggests that, within well bounded ocean basins, the density and pressure of the upper boundary of wsBBL are highly correlated. Diagrams of $¥gamma_{wsBBL}$ versus P_{wsBBL} are used to characterise and differentiate individual ocean basins. These diagrams help to identify the locations where large scale abyssal water transformation occurs: channels that interconnect two basins and some areas of the mid-oceanic ridges.
- 11:00 AM**PL12A-03** Mapping Diapycnal Mixing in the High-Resolution HYCOM Ocean Model***Peter B Rhines**[1], Xiaobiao Xu[2] and Eric P. Chassignet[2], (1)University of Washington, Seattle, WA, United States, (2)Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL, United States*

- Transformation of water masses ('WMT') from one density to another is the essence of the meridional ocean overturning circulation (MOC). There is a close relation between this transformation and meridional transports of mass, heat and fresh-water/salinity anomaly. Localizing the transformations at high resolution is essential to understanding general circulation and climate dynamics, and in connecting with observations. Here we analyze model-based time-mean velocity across potential-density surfaces (the diapycnal velocity, W_D) in the northern Atlantic Ocean (the AMOC). WMT is driven by both air/sea buoyancy flux and interior mixing. More net WMT occurs in 3 dimensions (3D) than is evident in zonally integrated MOC (more by typically 60% in western subpolar gyre, and 40% in subtropical gyre): 'donut'-shaped overturning cells surround dominant convective mode-water sites and 'ribbons' of overturning align with boundary currents. Much downward W_D ('cooling' or salinity increase) is directly related to cold-season convection, hence related to surface-forced overturning calculated from air/sea buoyancy flux. Upward W_D ('warming or freshening') is associated with warm-month restratification of mode waters, also in steadier sub-surface mixing across fronts in boundary currents, dense overflows, and coastal upwelling. With $1/12^0$–latitude resolution the Hybrid Community Ocean Model (HYCOM) is forced by climatological-mean atmospheric observations, with annual cycle. Focus here is on the upper half of the ocean, without considering the important mixing in the dense Nordic Sea overflows at the Greenland-Scotland Ridge system. Detailed analysis is given for 3 regions in the North Atlantic where convective mode waters and boundary current frontal interaction are strong. The results will be model-dependent, yet point the way toward improved isolation of mixing-prone regions.

- The figure shows annual-mean diapycnal velocity at Labrador Sea Water density level (σ_2=36.815) in the subpolar North Atlantic: total; subsurface mixing induced; and air/sea buoyancy flux induced components, respectively. Blue is downward W_D (density increase, often by cooling, also by evaportion), red is upward (density decrease, often by mixing). Black contours show time-mean depths of the density surface near its outcrop.



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- **Plain Language Summary**
- Transformation of water masses ('WMT') from one density to another is the essence behind the meridional ocean overturning circulation (MOC). There is a close relation between this transformation and meridional transports of volume (or mass-), heat and fresh-water/salinity anomaly. Localizing the transformations with high spatial resolution is an essential step in understanding general circulation and climate dynamics and connecting with observations. Here we analyze model-based time-mean velocity across potential-density surfaces (the diapycnal velocity, W_D) in the northern Atlantic Ocean (the AMOC) in 3 dimensions (3D), considering both WMT responding directly to air/sea buoyancy flux and WMT related to interior mixing. More WMT occurs in 3D than is evident in the zonally integrated MOC: 'donut'-shaped overturning cells surround dominant convective mode-water sites and 'ribbons' of overturning align with boundary currents. Much downward W_D ('cooling' or salinity increase) is directly related to cold-season convection, hence related to surface-forced overturning calculated from air/sea buoyancy flux. Upward W_D ('warming or freshening') is associated with warm-month restratification of mode waters, also in sub-surface mixing across fronts in boundary currents, dense overflows, and coastal upwelling. We use high-resolution (1/12^0 latitude) simulations with the Hybrid Community Ocean Model (HYCOM) forced by climatological-mean atmospheric observations, with annual cycle. Focus here is on the upper half of the ocean, without considering the important mixing in the dense Nordic Sea overflows at the Greenland-Scotland Ridge system. Detailed analysis is given for three regions in the North Atlantic where convective mode waters and

boundary current interaction is strong. This 3D view yields stronger total WMT of overturning circulation cells (by about 60% in western subpolar gyre, and 40% in subtropical gyre, corresponding to zonal overturning circulation) than is seen in AMOC streamfunctions

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- The figure shows annual-mean diapycnal velocity (5-year average) for the subpolar North Atlantic: total, subsurface mixing induced, and air/sea buoyancy flux induced components, respectively. Blue is downward (density increase, often by cooling), red is upward (density decrease, often by mixing).
- 11:15 AM**PL12A-04** The Effects of $K_T \neq K_S$ in a Stommel-like Model of the MOC***Ann Gargett**, Institute of Ocean Sciences, Sidney, BC, Canada; Old Dominion University, Norfolk, VA, United States*
- A classical Stommel model consists of a 2-box “equatorial gyre” and a neighbouring 2-box “polar gyre”. With $K_T = K_S$, the standard assumption of equal turbulent vertical diffusivities for temperature T and salinity S, this model has two stable states, one (TD=thermal direct) with convection in the (assumed northern) polar gyre, the other (HD=haline direct) with convection in the equatorial gyre. Allowing $K_T \neq K_S$, with relative values suggested by observations of both double and differential diffusion in the ocean, profoundly modifies this simple mode structure, allowing modes (termed indirect) in which both gyres are stratified over a large range of surface forcings between those that produce TD or HD modes. The presence of these additional modes adds richness to the multiple equilibrium structure of the original Stommel model. In the present work, addition of a “southern polar gyre” produces a 6-box pole-to-pole configuration more suitable for examination of a meridional overturning circulation (MOC). This simple model is used to examine the effects of $K_T \neq K_S$ on MOCs both with and without the presence of Ekman flow driven by Southern Ocean winds. The results will be of relevance to paleo-oceanography, as well as present studies of water mass conversion.
- 11:30 AM**PL12A-05** Where Bottom Water Goes to Die***Andreas M Thurnherr**, Lamont-Doherty Earth Observatory, Palisades, NY, United States, Louis Clement, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, United States*

and Louis St Laurent, Woods Hole Oceanographic Insti, Woods Hole, MA, United States

- Most of the turbulence in the abyssal ocean occurs over rough topography, implying that the water-mass transformations of bottom water also take place primarily there. On the other hand, the available data also indicate dominantly upward buoyancy fluxes in these regions, i.e. how bottom water gains the buoyancy required to close the overturning circulation remains unclear. Using data collected in the Brazil Basin in the 1990s and during the recent DoMORE project we show that there are both regions of buoyancy gain and loss for bottom water on the flank of the Mid-Atlantic Ridge (MAR), which covers more than 50% of the seafloor of the South Atlantic. Above the topographic envelope, mean turbulence levels consistently decrease upward, with the resulting buoyancy-flux divergence implying densification of the water. Within the dozens of fracture-zone (FZ) canyons that corrugate the MAR flank every 60km or so, on the other hand, there is unambiguous evidence for buoyancy-flux convergence causing diapycnal upwelling of bottom water. Observations point to several different canyon-specific processes that give rise to mid-depth maxima in dissipation profiles, consistent with upwelling, including interfacial shear instabilities and hydraulic jumps in overflows, as well as the absorption of downward-propagating internal-wave energy by shear layers on top of the currents of bottom water that flow upward along the FZ canyons. Crucially, however, canyon topography itself introduces a strong bias for downward-decreasing buoyancy fluxes below the crests of the lateral walls, even where local dissipation levels increase all the way to the seabed. Slow-spreading mid-ocean ridges, which make up 2/3 of the global ridge system, and their associated FZ canyons intersect the interface between Antarctic Bottom Water and the overlying water masses in the Atlantic, Indian and in the Southern Ocean. Observations from a random FZ canhon in the Indian Ocean are fully consistent with the South Atlantic data, suggesting that the observations from the Brazil Basin are likely relevant for a significant portion of the upper interface of AABW, and thus of global importance. It appears likely that simulations of the AABW circulation can be improved by accounting for the effects of FZ canyons.

- 11:45 AM**PL12A-06** Salt's Role in the Basin-Width Dependence of Northern Deep Convection***Madeleine K Youngs**, Massachusetts Institute of Technology, Cambridge, MA, United States and Raffaele M Ferrari, MIT, Cambridge, MA, United States*
- In the current climate, there is deep convection in the North Atlantic but not the North Pacific. Zonal asymmetries in freshwater forcing or inter-basin exchange have been hypothesized to explain this discrepancy. This study examines the role of basin width in selecting the basin in which convection occurs. We start by examining convection in single-basin oceans of different widths. As the magnitude of freshwater forcing is increased, the convection shuts off at a weaker forcing in wider basins. A conceptual model is introduced to predict the dependence of the overturning strength, the salinity gradients, and the freshwater forcing value at which convection shuts off on basin width. A non-linear dependence of the overturning strength on basin width leads to relatively weaker transport in a wider basin and a larger salinity gradient between mid and high latitudes, leading to a stronger salt-advection feedback. A stronger salt-advection feedback in a wider basin indicates that for a given change in forcing, the change in overturning strength is relatively larger. This study proposes that the width-dependence of the salt-advection feedback causes a wider basin to have a smaller shut-off freshwater forcing value than the narrow basin, suggesting basin width as a contributing factor in promoting convection in the North Atlantic but not in the North Pacific.
- 12:00 PM**PL12A-07** Using phasor diagrams to distinguish internal wave breaking mechanisms in data and models***Matthew H Alford**[1], Jody M Klymak[2], Jennifer A MacKinnon[1], Ali Mashayek[3], Jonathan D Nash[4], Robert Pinkel[5] and Gunnar Voet[1], (1)Scripps Institution of Oceanography, La Jolla, CA, United States, (2)University of Victoria, Victoria, BC, Canada, (3)Massachusetts Institute of Technology, Cambridge, MA, United States, (4)Oregon State Univ, Corvallis, OR, United States, (5)Univ California San Diego, La Jolla, CA, United States*
- Internal waves may break via a variety of mechanisms: via their own shear instability, by modulating existing shear in low-frequency flows, or by convective instability. The presence of topography can in turn alter the kinematics of the breaking waves and the character of the turbulence; e.g. subcritical, critical and supercritical slopes relative to semidiurnal characteristics, or the presence of corrugations and roughness. Knowledge of the mechanism, structure and phasing

of breaking is crucial in setting the efficiency of the mixing, the appropriateness of inferences such as Thorpe scales, and the exchange of mixed fluid with the interior; yet these are seldom known from data at a single location. Using moored and shipboard ocean data and realistic numerical models from the Tasman continental slope, the Samoan Passage and Palau, we explore the use of a new technique in which we construct phasor diagrams of wave-variable pairs colored by turbulence intensity to identify the specific breaking mechanism occurring.

- 12:15 PM**PL12A-08** Diapycnal Upwelling of Abyssal Waters in Mid-Ocean Ridge Fracture Zones***Louis Clement***, *Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, United States and Andreas M Thurnherr, Lamont-Doherty Earth Observatory of Columbia University, New York, NY, United States*

- Turbulent mixing plays a fundamental role in the ventilation of the lower branch of the overturning circulation. In the topographically closed Brazil Basin of the South Atlantic, which is connected to neighboring basins via a small number of deep passages, heat budgets previously estimated that ~4 Sv of Antarctic Bottom Water must upwell across isopycnals. Despite the presence of a tidal modulation of the dissipation rate of kinetic energy over the flanks of the Mid-Atlantic Ridge, the mechanisms responsible for the diapycnal upwelling of bottom waters is still surrounded by many uncertainties. On the face of it, vertical profiles of dissipation appear to imply a counterintuitive deep-water downwelling.

- In this study, we present evidence for a novel interaction mechanism within mid-ocean ridge fracture zones between downward-propagating near-inertial waves and a 2-layer mean flow. In a year-long record from a McLane Moored Profiler, we observe that downward-propagating near-inertial energy and the inverse Richardson number are reduced below 4000 m. Given the background flow and stratification, a ray tracing simulation of downward-propagating near-inertial waves predicts enhanced near-inertial energy at each layer depth depending on the wavepacket horizontal direction. Consistent with near-inertial waves approaching a critical layer, 45% of the microstructure profiles taken within fracture zones have their peak dissipation several hundreds of meters above the seafloor. These mid-depth dissipation maxima are associated with enhanced downward-propagating kinetic energy. Within the ~40 fracture zones of the Brazil Basin, we estimate that this wave-mean flow interaction mechanism can ventilate up to 0.59—0.89 Sv of bottom water.

- **PL13A** The Driving Forces of the Ocean's General Circulation III

- *Oregon Convention Center*

- *- B113-B115*

02:00 PM**PL13A-01** Rapid laundering of Antarctic Bottom Water in an abyssal boundary current***Alberto Naveira Garabato***[1], *Eleanor Frajka-Williams*[1], *Carl Spingys*[1], *Kurt L Polzin*[2], *Alexander Forryan*[1], *Christian E. Buckingham*[3], *Einar Povl Abrahamsen*[3], *Sonya Legg*[4], *Stephen Matthew Griffies*[5], *Keith W Nicholls*[3] *and Michael Paul Meredith*[3], *(1)University of Southampton, Southampton, United Kingdom, (2)WHOI, Woods Hole, MA, United States, (3)British Antarctic Survey, Cambridge, United Kingdom, (4)Princeton University, Princeton, NJ, United States, (5)NOAA/GFDL, NJ, United States*

The intensity and climatic impacts of oceanic overturning are critically shaped by deep-ocean turbulent mixing, which transforms cold waters sinking at high latitudes into warmer, shallower waters. The effectiveness of turbulent mixing in driving this transformation is jointly set by two factors: the intensity of turbulence near topographic boundaries, and the rate at which well-mixed boundary waters are exchanged with the stratified ocean interior. Yet while many near-boundary turbulent processes have been documented, little is known about the mechanisms regulating boundary – interior exchange. Here, we use observations of the turbulent properties of a major outflow of Antarctic Bottom Water (AABW) from the Weddell Sea to identify a new mechanism of deep-ocean mixing, by which near-boundary turbulence and boundary – interior exchange are concurrently intensified. The observations included high-resolution fine- and microstructure measurements across the AABW flow through the Orkney Passage, and were obtained with ship-deployed instrumentation and the autonomous underwater vehicle Autosub Long Range under the auspices of the U.K. DynOPO (Dynamics of the Orkney Passage Outflow) programme. The cornerstone of the new mechanism is the generation of submesoscale dynamical instabilities by the flow of deep-ocean waters along a

steep topographic boundary. The dynamics and large-scale implications of this mode of mixing will be discussed.

02:15 PM**PL13A-02** Contribution of topographically-generated submesoscale turbulence to Southern Ocean overturning

Xiaozhou Ruan[1], *Andrew F Thompson*[1], *Mar Flexas*[1] *and Janet Sprintall*[2], *(1)California Institute of Technology, Pasadena, CA, United States, (2)Scripps Institution of Oceanography, La Jolla, CA, United States*

Upwelling across the Southern Ocean's Antarctic Circumpolar Current (ACC) and into the mixed layer, coupled to water mass modification by surface buoyancy forcing, has been highlighted as a key process in the closure of the upper branch of the global overturning circulation. However, relatively less is known about diabatic processes associated with the lower branch at depth. Here we use hydrographic data from ocean gliders to identify conditions conducive to different hydrodynamic instabilities, as well as their impact on near-bottom mixing and water mass modification over the continental shelf and slope in Southern Drake Passage.

Positive potential vorticity signals in narrow bands are observed over the continental slope indicating the likely presence of symmetric instability. Evidence of enhanced near-bottom mixing comes from the O(100)m, and up to 250m, thick bottom mixed layers. Lower Circumpolar Deep Water (LCDW), instead of outcropping at the surface, intersects sloping topography in narrow and strong ACC boundary currents. Potential temperature-salinity diagrams are presented to demonstrate the lightening of LCDW due to near-bottom mixing together with estimates of the O(10^{-7}) W/kg dissipation and O(0.5) Sv local water mass transformation rates. The latter are based on parameterizations of mixing and water mass transformation. Interactions between narrow frontal currents and topography occur elsewhere along the path of the ACC, which leads us to conclude that topographic contribution must be considered in closing the overturning circulation in the Southern Ocean.

02:30 PM**PL13A-03** Numerical Simulations of Mixing in Dense Water Flowing through the Orkney Passage

Sonya Legg[1], *Einar Povl Abrahamsen*[2], *Christian E. Buckingham*[2], *Alexander Forryan*[3], *Eleanor Frajka-Williams*[3], *Stephen Matthew Griffies*[4], *Michael Paul Meredith*[2], *Alberto Naveira Garabato*[3], *Keith W Nicholls*[2], *Sarah Nickford*[5], *Kurt L Polzin*[6], *Jean-baptiste Sallee*[7] *and Carl Spingys*[3], *(1)Princeton University, Princeton, NJ, United States, (2)British Antarctic Survey, Cambridge, United Kingdom, (3)University of Southampton, Southampton, United Kingdom, (4)NOAA/GFDL, NJ, United States, (5)Stony Brook*

University, School of Marine and Atmospheric Sciences, Stony Brook, NY, United States, (6)WHOI, Woods Hole, MA, United States, (7)LOCEAN - Sorbonne Universités - UPMC/CNRS/IRD/MNHN, Paris, France

One source of Antarctic Bottom Water is the dense water that flows from the Weddell Sea into the Scotia Sea through gaps in the South Scotia Ridge. As the dense flow passes over the complicated topography of the ridge, a variety of different topographically-induced mixing processes may occur, modifying the properties of the AABW in the Scotia Sea, which ultimately flows into the abyssal Atlantic. The deepest of these gaps, the Orkney Passage, and its environs, were the focus of intensive sampling during the recent Dynamics of Orkney Passage Outflow field program. The field program traced the dense water from the Weddell sea, over sills into the Orkney Deep, through the narrow straits of the Orkney Passage, and along the northern boundary of the Orkney Plateau. In support of the field program, several numerical simulations at regional and small-scales were performed, focusing on mixing induced in down-welling Ekman layers, hydraulic jumps, shear layers and tidally-oscillating sloping boundary layers. Through the use of numerical simulations, we can examine the sensitivity of these processes to changing forcing, such as wind-driven barotropic flow, and hence estimate their ultimate impact on AABW properties.

02:45 PM**PL13A-04** Adjustment of the Antarctic Circumpolar Current and global stratification to forcing anomalies in an eddy saturated ocean***David Philip Marshall***[1]*, James R Maddison*[2]*, Julian Mak*[2]*, David Roy Munday*[3]*, Maarten Ambaum*[4] *and Lenka Novak*[4]*, (1)University of Oxford, Oxford, United Kingdom, (2)University of Edinburgh, School of Mathematics, Edinburgh, United Kingdom, (3)British Antarctic Survey, Polar Oceans, Cambridge, United Kingdom, (4)Univ Reading, Reading, United Kingdom*

The Antarctic Circumpolar Current (ACC) is the strongest current in the ocean and has a pivotal impact on global stratification, heat content, and carbon content. The circumpolar volume transport and global stratification are relatively insensitive to Southern Ocean winds in models that resolve turbulent ocean eddies, a process termed “eddy saturation.” Recently we have developed a simple model that explains the physics of eddy saturation with three ingredients: a momentum budget, an eddy energy budget, and a relation between the eddy form stress and eddy energy. Here we extend this simple model to study the response of the circumpolar volume transport and global stratification to changes in Southern Ocean winds and other forcing anomalies in an eddy saturated ocean. The adjustment time scale is very different in models that include the global ocean - millenia -

versus just the Southern Ocean - decadal - calling into question some recent results obtained for idealized Southern Ocean channel models. The adjustment process involves a subtle interplay between the growth and decay of eddy energy, and the stability/instability of the ACC, leading to damped oscillations about the equilbrium, with the potential to be excited by stochastic forcing; these damped oscillations are analogous to those found in a recent model of an atmospheric storm track.

03:00 PM**PL13A-05** Structure and dynamics of an Indian Deep Eastern Boundary Current along the southern coast of Australia***Veronica Margaret Tamsitt**, Scripps Institution of Oceanography, Physical Oceanography, La Jolla, CA, United States and Lynne D Talley, Scripps Institution of Oceanography, La Jolla, CA, United States*

Deep boundary currents are the dominant way deep waters are transported from low to high latitudes. In the Southern Hemisphere, in addition to the Deep Western Boundary Currents, pathways along the eastern boundaries of the southern Atlantic, Indian and Pacific transport deep water poleward into the Southern Ocean where these waters upwell to the sea surface. These eastern boundary deep water pathways and their physical cause are not well characterized, particularly those carrying carbon and nutrient-rich deep waters from the Indian and Pacific. Here we characterize the eastern Indian Deep Water (IDW) pathway and investigate its underlying dynamics with a combination of hydrographic observations and Lagrangian experiments in an eddy-permitting ocean model. Previous analysis of WOCE observations identified a deep current at 115°E by its eastward transport and low oxygen content, characteristic of IDW, but sparse observations of deep ocean properties have precluded a more detailed analysis of this pathway. Compiling hydrographic observations with the data assimilating Southern Ocean State Estimate, we find an eastward flow and the low-oxygen signature of IDW extending between 1500 m and 4000 m along the Australian continental slope, reaching the ACC southwest of Tasmania. We investigate the role of both eddies and topography in the dynamics of this pathway. A westward train of Tasman eddies south of Australia and high eddy kinetic energy southwest of Australia are similar to the Agulhas ring configuration of the South Atlantic. Thus, we hypothesize that an eddy thickness flux mechanism that has been shown to drive an eastern deep water pathway in the Atlantic may also operate in the Indian.

- 03:15 PM**PL13A-06** The role of convection in driving geostrophic gyres and overturning circulation***Bishakhdatta Gayen**[1], Catherine Ann Vreugdenhil[1], Andrew M. Hogg[2] and Ross W*

Griffiths[2], (1)Australian National University, Research School of Earth Sciences, Canberra, Australia, (2)Australian National University, Canberra, ACT, Australia

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We use direct numerical simulations (DNS) to examine the effects of wind stress and surface buoyancy forcing on a circulation similar to the North Atlantic Ocean. Simulations are performed in a closed square basin. Half the base is cooled and the other half heated to achieve Rayleigh number $Ra \sim 10^{12}$, where Ra is defined in terms of the basin length L. Baroclinic Rossby number is Ro = 0.04, Prandtl number is Pr = 5 and the Coriolis parameter is sinusoidal with latitude as on a spherical earth. Wind stress magnitude is varied over a series of simulations. The results show that surface buoyancy forcing alone can drive basin-scale subtropical and subpolar gyres along with full-depth overturning circulation (shown in the figure). The results also show that mass transport and heat throughput are governed by horizontal geostrophic flow in the thermal boundary layer, increasing with wind stress. Vertical heat transport from the surface layer into the deep interior mostly occurs in open-ocean chimney convection within the subpolar gyre. Net vertical transport of water is both within chimneys and against side boundaries. We calculate mechanical energy budgets at the buoyancy forcing currently feasible in DNS and find that the two energy sinks (dissipation and irreversible mixing) are largely confined to the thermal boundary layer.

Plain Language Summary

The ocean circulation is a vital part of the global climate system, absorbing and transporting heat energy, melting polar ice-shelves, upwelling nutrients and controlling the natural uptake of CO_2. The circulation involves motions having a large range of length scales, from small scale convection at high latitudes in the polar regions, through a range of mesoscale phenomena to large-scale gyre recirculation across the width of the ocean. Global Climate Models underpin future climate projections and their accuracy relies on the identification and incorporation of physics governing all parts of the climate system. These models do not accurately model vertical convection and turbulence, and we need to develop a better understanding of these mechanisms in order to incorporate them into complex climate models. Here we study the influence of high-latitude convection (including the mean sinking of dense water) in ocean circulation, notably the deep meridional overturning circulation (MOC) and the quasihorizontal circulations of the North Atlantic gyres using turbulent resolving simulations.

03:30 PM**PL13A-07** Deep Mixing driven by the Shoaling Internal Tide on the East Tasman Slope: Observations from TTIDE Leg II***Robert Pinkel***[1]*, Matthew H Alford*[2]*, Jody M Klymak*[3]*, Andrew Lucas*[2]*, Jennifer A MacKinnon*[2]*, Ruth C Musgrave*[4] *and Nicole L Jones*[5]*, (1)University of California San Diego, La Jolla, CA, United States, (2)Scripps Institution of Oceanography, La Jolla, CA, United States, (3)University of Victoria, Victoria, BC, Canada, (4)Massachusetts Institute of Technology, Department of Mechanical Engineering, Cambridge, MA, United States, (5)University of Western Australia, Crawley, WA, Australia*

There are relatively few observations of ocean mixing at depths below 1 km. Of particular interest is the sequence of events that lead to the development of turbulence: the energy pathway from large to small scales. The challenge is to field instrument systems that resolve a broad range of space and time scales deep within the sea. In 2014-5, the NSF TTIDE Experiment attempted such measurements on the eastern slopes of Tasmania. Here, a ~5 GW, 1-2 KW/m semidiurnal tidal beam shoals after propagating across the Tasman Sea from its generation site south of New Zealand. Numerical studies suggest and measurements confirm that large areas of the Tasman Slope are reflective to the incoming tide. Only 10-30% of the incoming flux driving mixing on the slope. Much of the mixing is associated with two specific sites, a gullied super-critical region in the south and a ~10 km long seamount cresting at 1900 m in the north.

Using SIO’s FAST CTD, multiday series of repeated density profiles have been obtained in the vicinity of the northern seamount. An altimeter on the CTD enabled profiling to within 15 m of the sea-floor. Intense mixing is associated with the breaking of the fundamental tide and the instability of a lee wave at the seamount crest, as well as with along-seafloor bores. Repeated tow-yos across the seamount can be converted into movies that are instructive in separating spatial and temporal scales. The primary and first- harmonic waves, both incoming and reflected, work together to establish the dominant space-time patterns. Extensive T-S variability is seen in the slope-waters 300-600 m above the seafloor. These filament-like features are perhaps formed at distant mixing sites, advecting into the observational domain. In the active mixing regions just above the seafloor T-S variability is

markedly reduced. The depth-along slope distribution of mixing seen in TTIDE can be compared with numerical output to refine our models of intense mixing in the deep sea.

- 03:45 PM**PL13A-08** Knocking on the doors of non-equilibrium mesoscale turbulence***Georgy E Manucharyan***, *California Institute of Technology, Pasadena, CA, United States and Glenn Flierl, MIT, Cambridge, MA, United States*

    - Understanding the impact of mesoscale eddies on large-scale circulation and its variability is a long-standing problem in ocean dynamics. The eddies typically form via baroclinic instabilities that drain the potential energy from large-scale flows by inducing potential vorticity fluxes. The problem of eddy-flux closure has traditionally been addressed using equilibrium frameworks that relate the fluxes to properties of the associated large-scale flows. A widely used Gent-McWilliams parameterization implements a down-gradient diffusion of isopycnal thickness but makes a dubious assumption that the time-scale associated with the local eddy field equilibration is fast compared to the evolution of the large-scale flow. Here, we demonstrate that the eddy equilibration time scale is not at all negligible and that the eddy fluxes depend not only on the current state of large-scale flow but on the history of its evolution over a characteristic “Eddy Memory” time scale.
    - We simulate baroclinic instabilities in a conventional two-layer quasi-geostrophic model and, in conjunction with a theoretical Green’s function approach, explicitly diagnose the eddy memory which exists throughout the entire oceanographically-relevant parameter space. The memory is longest for marginally unstable flows and decreases rapidly with increasing baroclinic instability growth rates. Using an idealized mathematical representation of the memory, we develop a simple model of eddy-mean flow interactions to highlight a number of major effects on the spatial and temporal variability of ocean currents. In particular, the existence of the memory gives rise to a low-frequency mode that dramatically enhances the variability of geostrophic ocean currents. Our results suggest that the mesoscale eddy field associated with unstable flows is inherently out of equilibrium at any relevant temporal or spatial scales, and hence cannot be accurately described using conventional scaling laws.

- **PL14A** The Driving Forces of the Ocean's General Circulation IV Posters

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    - **PL14A-1749** Tide, Ocean and Climate on Exoplanets around Low-mass Stars***Jun Yang** and Yidongfang Si, Peking University, Beijing, China*
    - On Earth, tide is a main part of the driving force for the deep ocean overturning circulation. For habitable planets around low-mass stars, the tidal force is expected to be much stronger than that on Earth, due to the fact that the habitable zone is very close to the host stars and that tide force is inversely proportional to the orbital distance cubed. The deep ocean overturning circulation on this type of planets is therefore expected to be much stronger than that on Earth, if all else being equal. We test this hypothesis using a fully coupled atmosphere-ocean model, the Community Climate System Model version 3 (CCSM3). Our results show that the intensity of oceanic meridional overturning circulation (MOC) is approximately proportional to K^1/3, where K is the mixing coefficient across density interfaces and it is mainly determined by the strength of the tidal force. As a result of the enhanced MOC, more heat is transported to dark regions and sea ice melts completely there, and meanwhile more heat is mixed from the surface to the deep ocean and thereby the entire ocean becomes much warmer. Positive feedbacks associated with cloud, water vapor and lapse rate further warm the global ocean and atmosphere. The final enhanced global surface warming is as large as 10-40^oC. These results imply that one planet with a stronger tidal force will likely enter a globally ice-covered snowball state at a lower stellar flux and enter a moist greenhouse or runaway greenhouse state at also a lower stellar flux, meaning that the tidal force acts to push the habitable zone outward. This study significantly improves our understanding of the possible coupling between planetary orbit, ocean, climate, and habitability on exoplanets.
    - **PL14A-1751** The effect of Northern Hemisphere winds in the meridional overturning circulation***Paola Cessi**, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States, Laura Cimoli, University of Oxford, Oxford, United Kingdom and Ali Mashayek, Massachusetts Institute of Technology, Cambridge, MA, United States*

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The current paradigm for the meridional overturning cell and the associated mid-depth stratification is that the wind-stress in the subpolar region of the Southern Ocean drives a northward Ekman flow which, together with the global diapycnal mixing across the lower boundary of the mid-depth waters, feeds the upper branch of the interhemispheric overturning. The resulting buoyancy flux proceeds to the Northern Hemisphere of the North Atlantic where it sinks, to be eventually returned to the Southern Ocean at depth. Seemingly, the wind-stress in the Atlantic basin plays no role. This asymmetry occurs because the Ekman transport in the Atlantic Ocean is assumed to return geostrophically at depths much shallower than those occupied by the interhemispheric overturning. However, this vertical separation fails in the North Atlantic subpolar gyre region. Using a conceptual model and an ocean general circulation model in an idealized geometry, we show that the return of the Ekman transport in the North Atlantic opposes sinking in this region reducing the total overturning and the mid-depth stratification.

Plain Language Summary

The current paradigm for the meridional overturning cell and the associated mid-depth stratification is that the wind-stress in the subpolar region of the Southern Ocean drives a northward Ekman flow which, together with the global diapycnal mixing across the lower boundary of the mid-depth waters, feeds the upper branch of the interhemispheric overturning. The resulting buoyancy flux proceeds to the Northern Hemisphere of the North Atlantic where it sinks, to be eventually returned to the Southern Ocean at depth. Seemingly, the wind-stress in the Atlantic basin plays no role. This asymmetry occurs because the Ekman transport in the Atlantic Ocean is assumed to return geostrophically at depths much shallower than those occupied by the interhemispheric overturning. However, this vertical separation fails in the North Atlantic subpolar gyre region. Using a conceptual model and an ocean general circulation model in an idealized geometry, we show that the return of the Ekman transport in the North Atlantic opposes sinking in this region reducing the total overturning and the mid-depth stratification.

- **PL14A-1752** Energetics and Overturning Dynamics of a Model Ocean Basin with Surface Buoyancy and Wind Forcing***Varvara Zemskova***[1]*, Brian L White*[2] *and Alberto D Scotti*[1]*,*

(1)University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States, (2)University of North Carolina at Chapel Hill, Chapel Hill, NC, United States

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We present numerical results for an idealized rotating, buoyancy- and wind-forced channel as a simple model for the Southern Ocean branch of the Meridional Overturning Circulation (MOC). The flow is driven by differential buoyancy forcing applied along the horizontal surface, with surface cooling at one end (to represent the pole) and surface warming at the other (to represent the equatorial region) and a zonally re-entrant channel to represent the Antarctic Circumpolar Current (ACC). Zonally-uniform surface wind forcing is applied with a similar pattern to the westerlies and easterlies with varying magnitude relative to the buoyancy forcing. The problem is solved numerically using a 3D DNS model based on a finite-volume solver for the Boussinesq Navier-Stokes equations with rotation. The overall dynamics, including large-scale overturning, baroclinic eddying, turbulent mixing, and resulting energy cascades are studied by calculating terms in the energy budget using the local Available Potential Energy framework introduced in Scotti and White (2014, J. Fluid Mech.). The basic physics of the overturning in the Southern Ocean are investigated at multiple scales by comparing the output from the fully-resolved DNS simulations with results from global (ECCO2) and Southern Ocean (SOSE) eddy-permitting state estimates. We find that both the magnitude and shape of the zonal wind stress profile are important to the spatial pattern of the overturning circulation. However, perhaps surprisingly, the essential circulation and the energetics in the DNS simulations with wind are similar to the base case with buoyancy forcing alone, suggesting that surface APE generation by the buoyancy forcing plays an essential role in setting the circulation.

PL14A-1753 The Wind Work Input into the Global Ocean Revealed by a 17-year Global Hybrid Coordinate Ocean Model Reanalysis***Zhitao Yu**, US Naval Research Laboratory, Washington, DC, United States, Yalin Fan, US Naval Research Laboratory, LA, United States, E. Joseph Metzger, John C. Stennis Space Center, Stennis Space Center, MS, United States and Ole Martin Smedstad, Vencore, Inc., Oceanography Division, New Orleans, LA, United States*

Outputs from a 17-year (1999-2015) HYbrid Coordinate Ocean Model reanalysis are used to calculate the wind work to the oceanic circulation. In particular, we investigate how the

wind work varies with the sampling time intervals. The mean part of the wind work on the geostrophic currents is calculated as 0.81 TW, in good agreement with the previous estimate. The eddy part of the wind work on the geostrophic currents is -0.1 TW using 10-day average model output, different than the previous estimate. This is due to the fine horizontal resolution (0.08°), which is global eddy resolving, and including surface currents in the surface wind stress formulation. The mean part of the wind work on the ageostrophic currents is 1.29 TW whereas the eddy part of the wind work on the ageostrophic currents is 1.40, 7.38, and 13.11 TW calculated from 10-day average, daily average, and hourly instantaneous model outputs, respectively. The total wind work to the oceanic circulation calculated using the daily average (9.4 TW) and hourly instantaneous (15.1 TW) outputs is much larger than the previous estimates.

PL14A-1754 Labrador Sea Water formation and its relationship to buoyancy forcing***Anastasia Romanou***[1], *M Susan Lozier*[2], *Feili Li*[3], *Kayla Rosann Flynn*[4], *Maria Aristizabal-Vargas*[4] *and Joy Romanski*[5], *(1)NASA Goddard Institute for Space Studies, New York, NY, United States, (2)Duke University, Durham, NC, United States, (3)Duke University, NC, United States, (4)Trinnovim, New York, NY, United States, (5)Columbia University of New York/NASA GISS, New York, NM, United States*

The subpolar North Atlantic is a region of intense air-sea interactions which at short time scales drive local overturning and the formation of different water masses. In particular, Labrador Sea Water (LSW) that forms in the Labrador Sea is sensitive to air-sea exchanges and local atmospheric events which are communicated to the surface and mid-depth ocean within hours to days. The interannual variability of this linkage is now emerging from atmospheric as well as oceanic high resolution and fidelity observations in the area. In this presentation, we investigate, based on observations, how the spatial and temporal variability of LSW formation is connected to buoyancy forcing at daily frequency, and relate the strength, spatial and temporal signature of this buoyancy forcing to the amount of deep water formed each winter.

PL14A-1755 Role of the cold water in the formation of the East Korea Warm Current in East/Japan Sea : A numerical experiment in realistic topography***Yong-Yub Kim***, *Seoul National University, Seoul, South Korea, Young Ho Kim, Korea Institute of Ocean Science & Technology, Seoul, Korea, Republic of (South) and Yang-Ki Cho, School* *of Earth and Environmental Sciences/Research Institute of Oceanography, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, South Korea*

The East/Japan Sea (EJS) is a marginal sea of the western Pacific with an average depth of 2,000 m. The water exchange between the EJS and the Pacific occurs through the Korea Strait and Tsugaru Strait corresponding to the inlet and outlet respectively. The Tsushima Current flowing into the ESJ through the Korea Strait is divided into two main branches, the Nearshore Branch flowing along the Japanese coast, and the East Korean Warm Current (EKWC) heading northward along the Korean coast. In our previous study by using idealized simple model with uniform topography, it has been shown that the formation of the EKWC is dominated by the cold water underneath the bottom of the Korea Strait. In this study, we have introduced the realistic bottom topography to the model. We have investigated quantitatively effects of cold water on the formation of the EKWC in the realistic topography.

- **PL14A-1756** Controls on the NKM circulation in the Western Pacific Ocean***Junlu Li**, Hong Kong University of Science and Technology, Division of Environment and Department of Mathematics, Hong Kong, Hong Kong and Gan Jianping, Department of Mathematics and Division of Environment, Hong Kong University of Science and Technology, Hong Kong*
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In the tropical Western North Pacific, North Equatorial Current, Kuroshio and Mindanao current form the NKM circulation system. This system is closely linked with the characteristics of the tropical and subtropical gyre, and controlled by large-scale atmospheric forcing and local multi-dynamics elements. In this study, an idealized three-dimensional ocean model based on regional ocean modelling system (ROMS) was utilized to examine the effect of these forcing and elements on the NKM circulation. We find that atmospheric heat flux and wind forcing have a comparable effect on the strength of the circulation system. The thermal forcing is particularly critical to the formation of the subtropical countercurrent. Variation of coastline, especially the existence of marginal seas, i.e., Celebes Sea and South China Sea, plays a significant role on regulating spatiotemporal variability of the NKM system qualitatively and quantitatively. The circulation in the marginal seas and the NKM system interact with each other and form a coupled dynamic system. We will provide underlying physics to upgrade our understandings of NKM circulation system and its interaction with circulation of the marginal seas in the Western Pacific Ocean.

PL14A-1757 Wind-driven oscillations of cross-equatorial Meridional Overturning Circulations in a numerical ocean model***Adam Tobias Blaker**, National Oceanography Centre, Southampton, United Kingdom, Joel Hirschi, National Oceanography Centre, MSM, Southampton, United Kingdom and Mike Bell, Met Office, Exeter, United Kingdom*

High temporal resolution output from simulations performed with an eddy-permitting global ocean model (NEMO) suggests the existence of large amplitude oscillations in the Meridional Overturning Circulations (MOCs) in the Atlantic, Indian and Pacific oceans confined to the equatorial region. Their spectral peak has a period of about 7 days. Their amplitude is roughly proportional to the width of the ocean basin and is typically about 200 Sv in the Pacific. The oscillations are a response to the variability in the surface wind forcing and if winds are kept constant within 10 degrees of the Equator the large MOCs oscillations gradually fade and disappear within a few months. This suggests that the oscillations are locally generated within the equatorial region rather than being a response to remote forcing from higher latitudes. We investigate whether oscillations in the matter terms, M, of the equatorial components of the atmosphere's angular momentum, which are essentially free solutions of Laplace's tidal equations and have been shown to exhibit a spectral peak with a similar period, are sufficient to drive the equatorial MOC variability found in NEMO.

PL14A-1758 Lagrangian decomposition of the Indian Ocean shallow meridional overturning circulation***Weiqiang Wang**, South China Sea Institute of Oceanology, Chinese Academy of Sciences, State Key Laboratory of Tropical Oceanography, Guangzhou 510301, China, Tiecheng Zhang, Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences, Sanya 572000, China; University of Chinese Academy of Sciences, Beijing 100049, China and Chen Zhaozhang, Xiamen University, State Key Laboratory of Marine Environmental Science, Ximan 361005, China*

Based on the high-resolution OFES output, the shallow meridional overturning circulation (SMOC) in the Indian Ocean are decomposed by Lagrangian tracing method aiming to get the relative contributions from open boundaries. The tracers are released on the eastern boundary of the Indian Ocean at 114E, which mainly concludes the ITF transport, and the southern boundary at 34S trans-ocean section, which is used to capture transport exchange between the Indian Ocean and the Southern Ocean. Compared to the Euler annual stream function of the SMOC, the experiments reveal that ~60% of the SMOC tranport can be derived from the southern boundary and the rest is from the eastern boundary. Most of the particles released in the east boundary are less than 200m and cross the ocean basin within the upper layer. In contrast, the particles from the southern boundary experience subduction in the southern Indian Ocean and are at ~400m depth at 6S before it cross the equator.

PL14A-1759 Southern Ocean Origin of Multidecadal Variability in the North Brazil Current***René M. van Westen****, Institute for Marine and Atmospheric research Utrecht, Department of Physics and Astronomy, Utrecht, Netherlands and Hendrik A Dijkstra, IMAU - Institute for Marine and Atmospheric Research Utrecht, Physics, Utrecht, Netherlands*

The North Brazil Current transport displays a pronounced multidecadal variability with about a 7 Sv peak-to-peak amplitude. Although it has been suggested that this variability is related to that of the Atlantic Meridional Overturning Circulation, its origin is still unknown. Here we present results of an analysis of model data from a long (200 years) simulation of a high-resolution (0.1° horizontally) version of the Parallel Ocean Program that indicates a connection between multidecadal variability in the Southern Ocean, due to the so-called Southern Ocean Mode, and multidecadal variability in the North Brazil Current. The interaction of the large-scale ocean circulation and eddies is crucial for the existence of the Southern Ocean Mode. We present the mechanisms of this teleconnection in detail, which involves the vertical displacement of isopycnals, generation of Rossby waves and meridional propagation of sea surface height and ocean heat content anomalies. In addition, we show that the same mechanism connecting Southern Ocean and North Brazil Current multidecadal variability is also found in a (200 years) simulation of a high-resolution global version of the Community Earth System Model, with the same horizontal ocean resolution of 0.1°. The results provide a new mechanism for the multidecadal variability of the North Brazil Current.

PL14A-1761 An analysis of the interannual variability of the Brazil Current***Sudip Majumder****, Cooperative Institute for Marine and Atmospheric Studies, University of Miami and*

Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, FL, United States and Marlos P Goes, University of Miami, Miami, FL, United States

The Brazil Current constitutes the western limb of the South Atlantic subtropical gyre. Previous observations and model based studies showed that the geostrophic transport of this current varies from a minimum of about 5Sv in the north (22S) to a maximum of about 15Sv in the south (34S) where this current extends to the deeper layers. In this study the importance is given to understand the interannual variability of this current at 22S and 34S using observations-based (altimetry and hydrography) reconstructed time series of volume transport in conjunction with numerical model simulations in the years 1993 and 2015. A wavelet analysis of the reconstructed time series of transport at these latitudes reveals two important time scales of variability; i) mesoscale (45 - 160 days) and, ii) interannual variability (2-4 years). Variability at these timescales is further explored by performing Empirical Orthogonal Function (EOF) and Complex Empirical Orthogonal Function (CEOF) analysis on sea surface height , sea surface temperature, and ocean heat content. Possible inter-basin teleconnections are also analyzed using a composite analysis of NINIO 3.4 indices and the times series of volume transport. In addition, a wind-driven gyre based analysis is conducted to understand the role of wind to the interannual variability.

Plain Language Summary

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PL14A-1764 Changes in the Subtropical Front position and its relationship with the Agulhas region variability

***Martim Mas**, USP University of Sao Paulo, São Paulo, Brazil and Ilana C Wainer, Univ of Sao Paulo, Sao Paulo, SP, Brazil*

Indian-Atlantic water exchanges are thought to be regulated by the wind field, either by displacement of the zero wind stress curl line or by changes in intensity of the westerlies. These exchanges happen south of Africa due to eddy shedding by the Agulhas Current retroflection. The Subtropical Front (STF) position at this region is known to respond to changes of the wind field and act as a gatekeeper for this shedding process, although it has also been suggested that its position is strongly tied to topography. Using the results from the National Center for Atmospheric Research Community Earth System Model (NCAR-CESM) ocean component we evaluate changes of the STF position over the Agulhas region. Our results show the STF south of Africa to be significantly north of the zero wind stress curl line, far from the latitude of maximum westerlies and thus not directly linked to wind stress forcing. However, comparisons to changes in the Barotropic Stream Function field show that the STF responds to the dynamics of both Indian and Atlantic ocean subtropical gyres, especially the Indian Ocean gyre expansion. Thus, we conclude that the STF at the Agulhas region responds to subtropical gyre dynamics despite not being directly connected to the wind field.

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Plain Language Summary

How much water that enters the Atlantic Ocean from the Indian Ocean is thought to be regulated by winds, either by changes in the latitude of the strongest westerly winds at the sea surface or by changes in their intensity. The connection between both oceans happens south of Africa, at the Agulhas region, through waters that escape the Agulhas Current into the Atlantic Ocean. The position of the Subtropical Front, a region of high contrast between relatively warmer and colder waters, is known to answer to changes in the winds and to control how much water enters the Atlantic south of Africa. However, other studies suggest this front position could not control it because it is far from the latitude of the strongest westerly winds and held in place by features of the ocean floor. Using ocean model results from the National Center for Atmospheric Research (NCAR) we evaluate the changes of this front position at the Agulhas region. Our results show it to be well north of the maximum westerly winds and therefore not directly connected to them. On the other hand, looking at the ocean currents we find this front to be connected to the larger scale current system of both Indian and Atlantic Oceans. Since its position follows closely the southward expansion of the Indian Ocean current system, which is caused by changes in the winds, we conclude that despite not being a direct relationship, this front south of Africa answers to changes in the large scale wind system.

- **PL14A-1765** Dynamical Controls on the Export of Antarctic Bottom Water from the Weddell Gyre (Invited) ***Alberto Naveira Garabato***[1], *Eleanor Frajka-Williams*[1], *Alexander Forryan*[1], *Carl Spingys*[1], *Kurt L Polzin*[2], *Michael Paul Meredith*[3], *Einar Povl Abrahamsen*[3], *Keith W Nicholls*[3], *Christian E. Buckingham*[3], *Sonya Legg*[4] *and Stephen Matthew Griffies*[5], *(1)University of Southampton, Southampton, United Kingdom, (2)WHOI, Woods Hole, MA, United States, (3)British Antarctic Survey, Cambridge, United Kingdom, (4)Princeton University, Princeton, NJ, United States, (5)NOAA/GFDL, NJ, United States*
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During the last three decades, AABW has exhibited a striking warming and contraction in volume over much of the global ocean abyss, particularly in the South Atlantic basin. The causes of these changes are unknown. In the Atlantic sector, observations strongly suggest that climatic variations in the basin-scale properties of AABW downstream of its sources in the Weddell Sea are primarily controlled by wind-forced changes in export, via a mechanism involving the modulation of small-scale turbulent mixing in the Orkney Passage. To test this hypothesis, the U.K. DynOPO (Dynamics of the Orkney Passage Outflow) programme set out to measure the circulation of AABW in the Passage, and to assess the dynamical controls underpinning the water mass' transformation in the region. With this goal in mind, a finescale-resolving mooring array was recently deployed in the Passage for 2 years (2015 - 2017), and a research cruise was conducted in March - May 2017 to measure the turbulent properties of the AABW outflow with fine- and microstructure instrumentation and the autonomous underwater vehicle Autosub Long Range (aka Boaty McBoatface). Here, we will present initial results from the project. These indicate that: (1) the AABW outflow experiences concurrent broadening, deceleration, and intense (lateral and vertical) mixing as it navigates the Passage; (2) these changes may be explained by a distinct mechanism involving downslope Ekman flows and submesoscale dynamical instabilities. The implications of these findings for our starting hypothesis will be discussed.

PL14A-1767 Scale analysis of Ocean circulation: insight into Baroclinic conversion and energy spectrum

Mahmoud Mostafa Sadek[1,2], *Hussein Aluie*[2], *Matthew W Hecht*[3] *and Geoffery Vallis*[4], *(1)Cairo University, Cairo, Egypt, (2)University of Rochester, Rochester, NY, United States, (3)Los Alamos Nat'l Lab, Los Alamos, NM, United States, (4)University of Exeter, Exeter, United Kingdom*

The ocean is mechanically driven by wind and buoyancy at the surface which produce sloping isopycnals with a reservoir of available potential energy (APE). APE can be converted to kinetic energy via the baroclinic instability, which is believed to drive mesoscale eddies. The widespread belief that mesoscale eddies are generated through the baroclinic instability is partly based on apparent accord between observations and linear stability analysis, using idealized models. In reality, the ocean is never under such idealized conditions. At present, aside from crude order of magnitude estimates, we still lack direct measurements evidencing the extent to which this instability is responsible for eddy generation at various locations in the ocean.

To this end, we implement a coarse-graining framework, recently developed to study flow on a sphere, to directly analyze the conversion between potential (PE) and kinetic energy (KE) as a function of scale and geographic location. We apply our method to strongly eddying high-resolution simulations in the North Atlantic and in the Southern Ocean, using POP and ECCO data. In this fully nonlinear realistic ocean setting, we determine (i) the scales and the rate at which PE is stored via Ekman pumping, and (ii) the scales and the rate at which PE is released back to drive oceanic flow via baroclinic conversion. Using our coarse-graining framework, we then measure the KE spectrum of the flow and correlate it with the baroclinic forcing. We find that while the strongest PE to KE conversion occurs at a scale that is correlated with the Rossby deformation scale, there is significant PE to KE conversion over an entire range of oceanic scales.

PL14A-1768 Reproducibility of BMOC in a global ocean model: sensitivity on isopycnal diffusion scheme

Shogo Urakawa, *Hiroyuki Tsujino, Hideyuki Nakano, Kei Sakamoto, Goro Yamanaka and Takahiro Toyoda, Meteorological Research Institute, Tsukuba, Ibaraki, Japan*

Antarctic Bottom Water (AABW), the densest water in the world ocean, is one of major water masses in the deep ocean, which constitutes the bottom limb of meridional overturning circulation (BMOC). Because AABW is a large reservoir of mass and materials

such as oxygen and nutrients, it plays an important role in global ocean circulation, material and carbon circulations. So, it is one of key issues for future projection of climate change to improve reproducibility of BMOC in global ocean models. Japan Meteorological Agency has developed a global ocean model for our Earth system model that will be used in Coupled Model Intercomparison Project Phase 6. We conducted several sensitivity experiments based on the Ocean Model Intercomparison Project protocol with this eddy-less model and checked BMOC reproducibility there. These experiments revealed that a northward transport of bottom waters (BWs) was strongly affected by parameters for a tapering scheme of isopycnal diffusion coefficient. In our model, a tapering factor rapidly decreases to zero if an isopycnal slope exceeds a prescribed criterion. We found that this factor became nearly zero at the depth of 1 to 3 km along the north side of Pacific-Antarctic Ridge if we used a criterion commonly used in global ocean models (0.01). Because this factor is multiplied to all terms of isopycnal diffusion tensor except for horizontal diagonal terms in our model, isopycnal diffusion causes diapycnal diffusion in such a steep slope region even in the interior ocean. It is speculated that this diapycnal diffusion led to large buoyancy gain of BWs there and a short circuit of BMOC. We diagnosed water mass transformation rate due to isopycnal diffusion using Walin’s (1982) method and confirmed that BWs were transformed into lighter waters at the rate of about 9 Sv in this region. Reproducibility of BMOC in a global ocean model could be strongly affected by implementation of isopycnal diffusion scheme.

PL14A-1769 The Role of Bottom-Intensified Mixing in an Overturning Circulation Maintained by Surface Buoyancy Forcing***Kial Douglas Stewart**, Australian National University, Research School of Earth Science, Canberra, ACT, Australia and Paul Landesman, l'Ecole Centrale de Nantes, France*

Recently developed theories suggest that the observed enhancement of turbulent mixing nearing the seafloor has a leading order influence on the large-scale overturning circulation of the global oceans. These theories, while challenging established paradigms set by canonical oceanographers, are themselves challenging to verify by either observations or numerical models. This is because observations at the ocean bottom are scarce and the signals of interest are small, and ocean bottom processes are not directly simulated in numerical ocean models. Here, the role of externally imposed bottom-intensified mixing in an overturning circulation forced by differential surface buoyancy fluxes is examined with a laboratory experiment. The scientific insights and preliminary findings of these experiments are presented, and their implications discussed.

PL14A-1770 Internal tide dissipation: triadic instability and existence after the critical latitude ***Oceane Richet***[1], *Caroline j Muller*[2] *and Jean Marc Chomaz*[1], *(1)Ecole polytechnique - Ladhyx, fluid dynamics, palaiseau, France, (2)CNRS, Paris Cedex 16, France*

Several previous numerical studies suggest the presence of a critical latitude corresponding to an enhanced energy dissipation and a strong latitudinal dependence of the local energy dissipation. The purpose of this study is to understand mechanisms behind this latitudinal dependence.

We separate the evolution of the energy dissipation with latitude in two parts: before the critical latitude, where internal waves are propagative and after the critical latitude, where internal waves can be evanescent. Before the critical latitude, we propose a mechanism in 3 stages involving triadic resonant instability. At the critical latitude, the peak of energy dissipation is explained by inertial waves with small vertical scales. After the critical latitude, the presence of near-inertial evanescent waves generated by the parametric subharmonic instability explains dissipation on several degrees of latitude after the critical latitude.

The study combines theoretical results and 2D idealized numerical simulations.

- **PL14A-1771** Global Warm-to-Cold Ocean Heat Transport Controlled by the Eastern Pacific Cold Tongue ***Ryan Holmes***, *University of New South Wales, Climate Change Research Centre, ARC Centre of Excellence for Climate System Science and School of Mathematics and Statistics, Sydney, NSW, Australia, Jan D Zika, University of New South Wales, School of Mathematics and Statistics, Sydney, Australia and Matthew H England, University of New South Wales, Climate Change Research Centre and ARC Centre of Excellence for Climate System Science, Sydney, NSW, Australia*
    - The rate at which the ocean moves heat from the tropics towards the poles, and from the surface towards depth, depends on diabatic processes associated with surface forcing and diffusive mixing. Here, we use a global ocean sea-ice model at two horizontal resolutions (1/4° and 1/10°) to quantify the transport of heat across temperature classes (i.e. the *diathermal* ocean heat transport). Such an approach removes the effects of adiabatic advection and isolates the competition between

surface forcing, which acts to increase temperature contrasts within the ocean, and the homogenisation of ocean temperatures through diffusive mixing. By examining the spatial and temporal structure of the diathermal processes, we find that much of the global net flux of heat across temperature classes between 15°C and 25°C is driven by intense mixing in the eastern equatorial Pacific during austral spring. This region, covering less than 2% of the ocean's surface area, is a hot spot for ocean heat uptake due to a large air-sea heat flux, a shallow, intense thermocline and strong wind- and shear-driven turbulence. These results have implications for the role of small-scale processes in global climate and the variability of ocean heat uptake over interannual and decadal time-scales.