国地球物理学連合 AGU-Ocean Science Meetingでの「海洋混合学」の国際研究動向調査：詳細報告２、講演要旨

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概要

2016年2月21日から26日に米国ニューオーリンズにおいて行われる米国地球物理学連合（AGU）主催の海洋科学会議（Ocean Science Meeting、以後 OSM）は、隔年で世界中の海洋研究者が一堂に会する最も大きな海洋科学の国際会議の一つである。この会議では、混合過程の基礎研究から、海洋大循環に与える鉛直混合の影響、海洋長周期変動に関するセッションが多くたてられ、海洋混合学に関する国際的な研究動向を調査するのに、非常に適した会議であった。この会議において、研究動向を把握するとともに、本新学術を宣伝し、国際共同研究の構築に関わる活動を実施した。

本OSMでは、会議全体にわたって、混合を引き起こす過程とその影響についてのセッションが多数組まれており、海洋科学全体として、混合学が現在取り組まれている最も重要な研究課題であることを示していた。一方、米国では、海洋混合の研究は海洋物理学の中で行われており、化学・生物・気候におよぶ影響を本格的に意識して研究を進めている新海洋混合学OMIXを推進することは、海洋科学の中心地である米国に先んじて、我々が一歩先を行ける可能性を強く感じた。

スケール間相互作用問題：OSM の発表などから見る現在の中心的なテーマとして、西岸境界流や中規模渦、前線など海洋の大循環を構成し、今まで研究されてきた大・中規模の海洋現象から、どのような過程を経て、乱流など鉛直混合を引き起こす過程につながってゆくか、という点が大きな課題として残されている。特に、海洋大循環の一部である西岸境界流から中規模渦や海洋前線が生じ、黒潮など強流帯での鉛直高次モードの渦位勾配の鉛直方向の逆転によって傾圧不安定を通じて水平スケールの小さな(数kmから数10kmの)サブメソスケール渦が発生する他、中規模渦の縁辺や前線付近の冬季混合層周辺では、絶対渦度が負となる対称不安定・慣性不安定・遠心力不安定が生じて地衡流バランスから外れたサブメソスケール渦が発生する。これらのサブメソスケール渦は、絶対値が大きい値を持つ北（南）半球で負（正）の相対渦度を持ち得るため、惑星渦度 f の実効的な値を0の近つけ、鉛直高波数の近慣性の内部重力波動を捕捉しやすくすることで、そこで大きな鉛直混合を発生させる、という筋書きが想定されている。また、絶対値の大きな相対渦度領域に黒潮等の強流域が重なると、大きな鉛直流が生じるために、その鉛直流から内部重力波が発生し鉛直混合を強化する、などの過程も存在する。これらについては、モデルや理論を用いた研究が進行している一方、観測によって実証しようという研究は観測手法を含めて今後の課題となっており、OMIX で開発中の乱流計・ADCP 搭載グライダ等を用いて OMIX が最先端に躍り出るチャンスがあると感じた。

<u>PSI</u>：内部潮汐波の周波数/2と慣性周波数 f が一致する臨界緯度付近では、内部潮汐波と近慣性波動との３波共鳴PSI機構によって、乱流が強化される。PSIについて、いくつか講演があり、様々な議論が進行している。一般流が存在するときに、どのようにPSIによる乱流強化が変るか数値実験で調べた。その結果、一般流を加えると、peak の乱流強度は下がるが、臨界緯度の周りの幅広い緯度で強化された。これは、ドップラシフトで ω/2 が ω/2±Uk/2 と周波数範囲が広がることに対応すると考えられた。

<u>跳水</u>：別な乱流強化過程として跳水現象について実験や観測での検出等興味深い講演がいくつかあった。1) 斜面上を重い水塊が駆け下るときの現象を数値計算を用いて解析。強成層のときは、プルームは斜面中段で斜

面から離れるのに対し、弱成層のときは、斜面底まで駆け下り、斜面から離れる。中間の成層を与えた場合、この２つが両方見られる（flow splitting)。これらの特徴は、プラントル数（Pr）に依らない。2)Ri>1/4 で散逸率が大きくなる場合は、hydraulic jump が関与している可能性がある。
3)縦軸をポテンシャル密度、横軸をその密度の深度、としてデータをプロットしたところ、ある密度よりも低密度で、同じ深度に対して２つの等密度面が生じていた。これは hydraulic jump によっている可能性がある。

鉛直混合効率:乱流の生成効率 Γ は 0.2 で一定とするという Osborn(1980)の提案が長い間使われてきたが、そうではない、という議論が進行中である。水温計による見積もりが十分ではなかったことで、観測からの実証は未だ行う価値がありそう。1) Γ が浮力レイノルズ数 ReB に依存し、ReB～10^2で極大（Γ～0.5）となり、それ以下の範囲で増加傾向、以上で減少傾向となる。2) Osborn(1980)の定式化は一様で定常流に対してのものである。Salehipour & Peltier (JFM, 2015)は、混合効率が浮力レイノルズ数 Reb に依存することを示している。また、Shih et al. (2015)は低 Ri では、Reb の増加に対して E が減少するとした。Γ=E/(1-E)、本研究では、E の極大は大きな Ri に対応し、$E/E^* = (1+2p)(Reb/Reb^*)^p / [(1+2p)(Reb/Reb^*)^{p+0.5}]$、p=0.55 for Reb<Reb*, p=1 for Reb>Reb*と求めて、Γ の全球分布を示した。

CTD 取り付け乱流計観測:OMIX とは別に取り組まれている Ｘpod を CTD に取り付けた観測をもちいたオレゴン州立大の結果が示されつつある。赤道付近の起伏の小さい海底の上で鉛直混合が強化されている、という現象に対して、運動方程式に赤道に固有の f*w（ｘ成分）や f*u（ｚ成分）を加えたときに出てくる波動（Smyth et al. 2015）が下向きに伝搬し、海底付近に捕捉されて慣性不安定を起こして乱流を強化していた。

海洋循環に対する影響:全球熱塩循環に対する鉛直混合の影響は、従来 Munk によって見積もられていた湧昇の全てを鉛直混合で賄う説に代わり、NADW の南極周辺での風による等密度面の上昇と表層での低密度化が AMOC を駆動し、加えて、AABW から NADW への移行に鉛直混合が効く、という説に変わりつつある。一方、北太平洋での深層水の湧昇は、鉛直混合が主要な役割を果たしているはずだが、どれだけ深層水が北上し湧昇しているのか、見積もられる流量にも大きな差があり、未だ良くわかっていない。

気候に対する AMOC 影響:気候の長期変動に NADW の変動が関与している、という海洋から気候への影響を前提として北大西洋でオーバーターンの大規模観測が行われてきた。結果が続々と出つつある。ENSO の第１人者である Mark Cane が、AMO（大西洋数 10 年規模振動）は、AMOC を入れない海を混合層だけにした気候モデル実験でも再現され、長期変動は火山噴火などによるエアロゾル変動、と指摘した。振幅を説明できるか、という議論があった他、太平洋の長期変動は大西洋とは全く異なる、ということを Cane がコメントしており、太平洋の長周期振動が、潮汐 18.6 年周期振動に関わっている可能性は十分にあるという印象を受けた。

気候長周期変動に対する潮汐混合変動の影響：18.6 年周期潮汐振動を唯一研究しているオレゴン州立大の Schmittner のグループのポスター発表があった。我々とは若干異なる方式で潮汐鉛直混合を入れて、気候モデルを走らせ始めた段階であり、今後協力体制を作ろうと、話をした。

栄養塩フラックス・生態系に関しては、講演を聴く機会が無かった。大振幅の内部波によって等密度面が上下する際、ただ等密度面の上下だけだと栄養塩供給にならない。等密度面が上った時に強い鉛直混合が働くと、栄養塩が表層に残って供給されることになる。このような観点で整理することも一つのアイデアかと思う。

受賞講演：***M Susan Lozier****, Duke University, Earth Ocean Sciences, Durham, NC, United States*
大西洋 MOC の研究の歴史をわかりやすく解説した。1920 年代には、高緯度の表層水が中低緯度の中深層水となっていることが Sverdrup などによって発見された。1970 年代に、GEOSECS 観測によって、人為起源炭素の３０％が海に吸収され、海洋内部に入り込むことが He3 などの観測で明らかになった。1990

年代に abrupt climate change が過去に起きたことが古気候データから示され、2000 年代には、AMOC を継続観測する RAPID が始まった。その結果、AMOC は季節でファクタ 5 で変わることが明らかになった。Stommmel・Arons で提唱された深層西岸境界流（DWBC）の概念は、RAFOS 中層フロートが DWBC の経路に沿わず、大きく広がっていることから、改訂を迫られた。また、湾流が表層暖水を北へ運び熱放出によって深層水が形成される、という概念も、亜熱帯水は亜寒帯へ行かないという表層ドリフタの結果（Branbilla Talley）から改訂され、中層の海水が亜寒帯に移動する（Bingham et al. 2007）、ラブラドル海での滞留による深層水形成量変化と DWBC の流量変化は対応しない（Dengler et al. 2006; Fisher et al. 2010）ことが明らかにされている。現在では、NADW は、南大洋で風によって湧昇し、表面近くで軽く変質しながら北上するものは、再び北へ中層水として高緯度で湧昇し、深層水となる一方、南大洋で湧昇した一部は南極沿岸へ向かい、再冷却されて AABW になり、底層を循環する、と考えられている。最近では、SSH の変化から、AMOC 流量の変化を代表させる手法も開発されている（Frajka・Williams2015）。OSNAP（Overturning in the subpolar North Atlantic Program）が開始され、深層水形成量とオーバーフローの流量を観測で計測する計画が開始された。

The ASLO G. Evelyn Hutchinson Award: To the Bottom of Seafloor Ecosystems ***Jack J Middelburg***, *Utrecht University, Utrecht, 3584, Netherlands*

海底生態系を理解する際には、動物の役割の理解が重要。表層では、微生物が栄養塩の再生などで動物をサポート、深層では、動物が表層から有機物を運ぶことで微生物をサポート。サンゴ生態系は、貧栄養の熱帯でのオアシス。それにはスポンジ生物が、DOC や DON を消費し、デトリタスを作ることが関与している。

The TOS Munk Award Lecture: The Imperative of Global Oceanography ***Carl Wunsch***, *Massachusetts Institute of Technology, Boston, MA, United States*

海はインテグレータであり、記憶する。今問題は継続であり、高度計とアルゴは良いコンビ。コンピュータ実験ばかりになり、米国が観測をリードすることを忘れるのではないかと、不安。

下記は調査したセッションと右端の番号は要旨をまとめた詳細報告２におけるページ番号である。

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PO11B Deep and Abyssal Ocean Mixing: From Small-Scale Turbulence to the Large-Scale MOC I

Monday, February 22, 2016

08:00 AM - 10:00 AM

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08:00 AM PO11B-01 Abyssal Recipes II: Behind the Scenes ***Walter Munk****, University of California San Diego, La Jolla, CA, United States Ernest N. Morial Convention Center- 207*

A seemingly lunatic idea gave rise to the paper Abyssal Recipes II, published in 1998. I will informally review how that paper came about, and how it was initially received.

08:15 AM PO11B-02 Does deep ocean mixing drive upwelling or downwelling of abyssal waters? ***Raffaele M Ferrari***[1]*, Trevor J McDougall*[2]*, Ali Mashayek*[1]*, Maxim Nikurashin*[3] *and Jean-Michel Campin*[1]*, (1)Massachusetts Institute of Technology, Cambridge, MA, United States, (2)University of New South Wales, Sydney, NSW, Australia, (3)Princeton University, Princeton, NJ, United States*

It is generally understood that small-scale mixing, such as is caused by breaking internal waves, drives upwelling of the densest ocean waters that sink to the ocean bottom at high latitudes. However the observational evidence that the turbulent fluxes generated by small-scale mixing in the stratified ocean interior are more vigorous close to the ocean bottom than above implies that small-scale mixing converts light waters into denser ones, thus driving a net sinking of abyssal water. Using a combination of numerical models and observations, it will be shown that abyssal waters return to the surface along weakly stratified boundary layers, where the small-scale mixing of density decays to zero. The net ocean meridional overturning circulation is thus the small residual of a large sinking of waters, driven by small-scale mixing in the stratified interior, and a comparably large upwelling, driven by the reduced small-scale mixing along the ocean boundaries.

08:30 AM PO11B-03 Internal-Wave-Driven Turbulence and the Meridional Overturning Circulation ***Eric L Kunze****, NorthWest Research Associates Redmond, Redmond, WA, United States*

Internal-wave-driven turbulent dissipation rates ε and diapycnal diffusivities K are inferred globally from roughly 30,000 hydrographic casts in the WOCE/CLIMOD database using a finescale parameterization based on internal-wave vertical strain ($N^2 - \langle N^2\rangle)//\langle N^2\rangle$. Globally averaged dissipation rates are 4.3 ± 1.0 mW m^{-2} (1.5 ± 0.4 TW), consistent with internal-wave power sources from tides and wind. Basin-averages are largest in the North Pacific and smallest in the South Atlantic. Vertically-integrated dissipation rates vary by several orders of magnitude horizontally with elevated values over rough topography but the dependence on bottom forcing is weaker than that of subgridscale parameterizations based on linear internal tide theory that are used in OGCMs. Average diffusivities are (0.3-0.4) × 10^{-4} m^2 s^{-1}, independent of depth, that is, $\varepsilon = KN^2/\gamma$ scales as N^2. Diffusivities approach or exceed 10^{-4} m^2 s^{-1} poleward of 50º in the Indian and Atlantic Oceans. The longitudinal pattern in the Southern Ocean resembles that of inertial wind forcing. Diapycnal vertical velocities $w*$ inferred from the mixing are 0.2-0.4 cm day^{-1} below 1000-m depth, corresponding to global upwelling transports of 4 Sv below 3000-m depth, mostly from the south hemisphere, and 11 Sv above 2000 m.

08:45 AM PO11B-04 Internal Wave-Driven Turbulent Mixing: an Argo-Based finescale strain approach versus the global internal wave model "IDEMIX" ***Friederike Pollmann***[1]*, Carsten Eden*[1] *and Dirk J Olbers*[2]*, (1)University of*

Hamburg, Institute of Oceanography, Hamburg, Germany, (2)Alfred-Wegener-Institute, Bremerhaven, Germany
Nonlinear wave-wave interactions transfer energy in the internal wave field from the large generation to the small dissipation scales and thereby link internal wave energetics to turbulent mixing. This mixing is considered an essential contributor to driving the large-scale overturning circulation, but cannot be resolved in ocean general circulation models. In order to represent it consistently, recently developed parameterizations involve internal wave dynamics, taking into account that breaking internal waves are thought to be a major source of small-scale turbulence.
The model IDEMIX (``Internal Wave Dissipation, Energy and Mixing") predicts the propagation and dissipation of oceanic internal gravity waves as well as the corresponding diapycnal diffusivities based on a simplification of the spectral radiation balance of the wave field and can be used as a mixing module for global numerical simulations. The model is validated against finestructure estimates of turbulent kinetic energy dissipation rates obtained from Argo-float CTD-profiles following the approach by Kunze et al. (2006).
These estimates are sensitive to the shear-to-strain ratio $R_{¥omega}$, which has to be set to a constant value when using CTD-data only, or to the version of the Garrett-Munk model, that features as a reference in the parameterization, but the related uncertainties lie within the general uncertainty range of the method (factor 2-4). The spatial variation is influenced both by bottom topography and surface winds and features a noticeable seasonal cycle. The IDEMIX-model in general reproduces both the magnitude and the spatial variations of the observed dissipation rates. Sensitivity experiments show that the dissipation rate's strength and pattern (especially in the Gulf Stream) cannot be explained without taking meso-scale eddy energy into account. The observed seasonal cycle, too, can in the model only be explained by the seasonal variations in eddy kinetic energy dissipation. A detailed fine-tuning of the IDEMIX-module will be attempted based on parameters like the symmetrization time scale of the internal wave field, using a global ocean general circulation model and the newer version of IDEMIX, that not only describes the internal wave continuum but treats near-inertial waves and internal tides separately.

09:00 AM PO11B-05 Impacts of Spatial Distribution of Parameterized Local and Remote Tidal Mixing on Large-scale Ocean Circulation and Climate. ***Sonya Legg****, Princeton University, Princeton, NJ, United States, Angelique Melet, LEGOS, CNES, Toulouse, France and Robert Hallberg, Geophysical Fluid Dynamics Laboratory, Princeton, NJ, United States*
Energy extracted from the barotropic tide as it flows over topography can ultimately be used for mixing, which in turn influences large-scale circulation and climate. While the physics of the energy conversion process is now well understood, the eventual location of the resultant mixing is still poorly known, and dependent on a variety of wave breaking processes. Here, we examine the impact of different horizontal and vertical distributions of the mixing by breaking internal tides on the large-scale ocean circulation and climate in a fully-coupled climate model, GFDL’s ESM2G. Internal tides are assumed to dissipate either at the generation site, or in deep ocean basins, over continental slopes, or on continental shelves. The dissipation has a vertical profile which is specified to either: (a) decay exponentially with height above the bottom, or (b) scale with the buoyancy frequency, or (c) scale with the buoyancy frequency squared as suggested by observations of dissipation away from rough topography. The resultant large-scale ocean circulation is highly sensitive to the vertical distribution of dissipation, with bottom

intensified mixing leading to enhanced deep overturning and sharper thermoclines, while profiles with greater dissipation near the surface have stronger subtropical cells, and more diffuse thermoclines. The climate appears less sensitive to these idealized horizontal distributions of mixing. An exception is mixing near regions of deep water formation, such as the continental slopes of the North Atlantic and the Antarctic, where substantial mixing in the descending branch of the overturning circulation leads to a dilution of dense water, and corresponding weakening of the overturning. Motivated by this demonstrated sensitivity of the large-scale ocean circulation, we are refining models of the spatial distribution of internal wave breaking, in collaboration with partners in the Internal Wave Driven Mixing climate process team.

09:15 AM PO11B-06 Dynamical Analysis of the Enhanced Turbulent Mixing Over a Rough Ocean Bottom ***Toshiyuki Hibiya*[1]**, *Robin Robertson*[2] *and Tomoaki Takagi*[1], *(1)The University of Tokyo, Department of Earth and Planetary Science, Graduate School of Science, Tokyo, Japan, (2)The University of New South Wales, School of Physical, Environmental, and Mathematical Sciences, Canberra, Australia*

Although an accurate representation of ocean mixing processes in global circulation models is essential, parameterization of mixing over rough bathymetry remains obscure. We perform here a series of vertical two-dimensional numerical experiments to see how upward propagating internal waves generated by the tide-topography interaction give up their energy to dissipation by nonlinear interaction with the background Garrett-Munk-like internal waves.

The internal waves generated by the tide-topography interaction are classified in terms of the parameters kU_0/ω and N/ω with U_0 the tidal flow amplitude, k the wavenumber of bottom bathymetry, N the buoyancy frequency and ω the semidiurnal tidal frequency. When $kU_0/\omega \ll 1$, *linear internal tides* are generated and propagate upward with the decay scale controlled by bottom roughness rather than by the tidal flow amplitude. When $kU_0/\omega \gg 1$, on the other hand, generated internal waves become more like *quasi-steady lee waves* propagating upward with the decay scale controlled by the tidal flow amplitude rather than by bottom roughness.

To interpret these numerical results, we also perform eikonal calculations for a wide range of physical parameters. We confirm that, for a fixed value of N, the vertical group velocity C_{gz} is inversely proportional to k for *linear internal tides* but proportional to kU_0^2 for *quasi-steady lee waves*. Since the resonant interaction time τ is inversely proportional to k for both cases, the resulting mixing hotspot becomes more restricted to the ocean bottom as bottom roughness increases for $kU_0/\omega \ll 1$ without depending on the tidal flow amplitude, but it extends upward as the tidal flow amplitude increases for $kU_0/\omega \gg 1$ without depending on bottom roughness. In both cases, we can find the trade-off relationship between the energy dissipation rate at the ocean bottom and its vertical extent.

The results of this study are summarized in the attached figure. The accuracy of global circulation models can be improved by reflecting these results in the parameterization of mixing over rough bathymetry.

09:30 AM PO11B-07 Topographic Enhancement of Vertical Mixing in the Southern Ocean ***Ali Mashayek*[1]**, *Raffaele M Ferrari*[1], *Sophia Merrifield*[1] *and Louis St Laurent*[2], *(1)Massachusetts Institute of Technology, Cambridge, MA, United States, (2)Woods Hole Oceanographic Institution, Physical Oceanography, Woods Hole, MA, United States*

Diapycnal turbulent mixing in the Southern Ocean is believed to play a role in setting the rate of the ocean

Meridional Overturning Circulation (MOC), an important element of the global climate system. Whether this role is important, however, depends on the strength of this mixing, which remains poorly qualified on global scale. To address this question, a passive tracer was released upstream of the Drake Passage in 2009 as a part of the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES). The mixing was then inferred from the vertical/diapycnal spreading of the tracer. The mixing was also calculated from microstructure measurements of shear and stratification. The diapycnal turbulent mixing inferred from the tracer was found to be an order of magnitude larger than that estimated with the microstructure probes at various locations along the path of the tracer. While the values inferred from tracer imply a key role played by mixing in setting the MOC, those based on localized measurements suggest otherwise. In this work we use a high resolution numerical ocean model of the Drake Passage region sampled in the DIMES experiment to explain that the difference between the two estimates arise from the large values of mixing encountered by the tracer, when it flows close to the bottom topography. We conclude that the large mixing close to the ocean bottom topography is sufficiently strong to play an important role in setting the Southern Ocean branch of the MOC below 2 km.

09:45 AM PO11B-08 Is the Abyssal Branch of the Overturning Driven by Breaking Internal Waves? ***Casimir de Lavergne**, Université Pierre et Marie Curie, LOCEAN / IPSL, Paris, France, Gurvan Madec, LOCEAN-IPSL, Paris, France, Julien Le Sommer, CNRS, LGGE, Grenoble, France, A. J. George Nurser, National Oceanography Center, Soton, Southampton, United Kingdom and Alberto Naveira Garabato, University of Southampton, Southampton, SO14, United Kingdom*

Processes controlling the strength and structure of the meridional overturning remain poorly identified. Here, we clarify the respective roles of internal tides, lee waves and geothermal heating in supplying buoyancy to the abyss and maintaining the overturning. Using a hydrographic climatology, common GCM-type parameterizations of internal tide and lee wave energy dissipation and two different models for the mixing efficiency, we construct climatologies of buoyancy fluxes and quantify resulting rates of water mass transformation in the ocean interior. We find that upwelling rates induced by bottom-intensified mixing and geothermal heating peak within the $\gamma^n = \sim 28.11$ water mass, which occupies the largest seafloor area and defines the boundary between southward-flowing deep waters and northward-flowing bottom waters. This result is consistent with an overturning characterized by a diabatic, northward abyssal branch contrasting with a predominantly adiabatic, deep southward branch. Nevertheless, we show that topographically-enhanced mixing by breaking internal tides and lee waves cannot account for the full strength of the abyssal branch. Indeed, we estimate that locally-dissipating internal tides contribute only about 4 Sv of bottom water upwelling, mostly north of 30ºS. This is comparable to the estimated ~ 5 Sv of abyssal flow maintained by geothermal heat fluxes. In contrast, breaking lee waves cause significant transformation only in the Southern Ocean, where they decrease the mean density but enhance the northward flow of abyssal waters. The possible role of remotely-dissipating internal tides in complementing bottom or deep water upwelling is explored.

PO12C Deep and Abyssal Ocean Mixing: From Small-Scale Turbulence to the Large-Scale MOC II

Monday, February 22, 2016

10:30 AM - 12:30 PM

Papers

10:30 AM PO12C-01 Spatial Analysis of Abyssal Temperature Variations Observed From the ALOHA Cabled Observatory and WHOTS Moorings *Roger Lukas*[1], ***Fernando Santiago-Mandujano***[2], *Bruce M Howe*[2], *Albert J Plueddemann*[3], *Robert A Weller*[3], *Robert Walter Deppe*[2], *Nordeen G Larson*[4], *David J Murphy*[5] *and Richard Guenther*[4], *(1)Univ Hawaii, Honolulu, HI, United States, (2)University of Hawaii at Manoa, Honolulu, HI, United States, (3)Woods Hole Oceanographic Institution, Woods Hole, MA, United States, (4)Sea Bird Electronics, Bellevue, WA, United States, (5)Seabird Electronics Inc, Bellevue, WA, United States*

The ALOHA Cabled Observatory (ACO) has measured temperature variations at 4726 m (1.8 mab) in the Kauai Deep since June 2011. Starting in June 2012, temperatures 37 m above bottom were also measured from the Woods Hole-Hawaii Ocean Time-series Site (WHOTS)-9 (-10) moorings approximately 11 km to the east (10 km to the southeast) of the ACO, at depths of 4631 (4720) m. RMS potential temperature (θ) differences between ACO and WHOTS were 4.2 mK over 2 years, significantly greater than the accuracy and precision of the Sea-Bird instruments that were used. From mid-2013 onward, three distinct cold events were observed at each of the sites. Two events in 2014 saw drops in temperature >20 mK over only a few days, followed by large oscillations (10-60 days) of about 10 mK. ACO-WHOTS Δθs were greater than 5 mK on numerous occasions during these events, lasting days to weeks. During the 3-day overlap of the WHOTS-9 and -10 moorings (separated by 12 km meridionally and 89 m vertically), dual temperature sensors on each mooring showed near-bottom θ colder than the ACO by 5-8 mK and 3 mK respectively. ACO/WHOTS-9(-10) Δθs were largest during these events suggesting that relatively small spatial scales are important in the dynamics of the cold events in the Kauai Deep. The correlation of WHOTS-9(-10) abyssal θ with the ACO record was 0.69 (0.66). Cross-spectra of Δθ are distinctly different for the two mooring periods, with squared coherence > 0.8 for periods longer than 114 days during the cold events observed by WHOTS-10. A relative coherence peak near 20 days is found in both cases. Temperature - velocity spectra and cross-spectra also suggest energetic non-tidal dynamics.

10:45 AM PO12C-02 Modification of Antarctic Origin Bottom Water in the Samoan Passage by Turbulent Mixing

Glenn S Carter*, University of Hawaii at Manoa, Honolulu, HI, United States, Matthew H Alford, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States, James B Girton, Applied Physics Laboratory University of Washington, Seattle, WA, United States, Gunnar Voet, Scripps Institution of Oceanography, La Jolla, CA, United States, John Mickett, University of Washington, Seattle, WA, United States and Jody M Klymak, University of Victoria, Victoria, BC, Canada*

The majority of the coldest bottom water entering the abyssal North Pacific passes through the Samoan Passage (169 W, 10 S), making this 100 km wide passage a key 'choke point' in the Pacific Overturning Circulation. Approximately 2 Sv of Antarctic origin bottom water (AABW) with a potential temperature (referenced to the surface) of less than 0.7 degree enters the passage, and none exits. The Samoan passage consists of two channels with most of this coldest water following the eastern channel, as the entrance to the more convoluted western channel is partially blocked by two sills. The eastern channel has a ~500-m high sill half way along and a ~300-m

high sill at near the exit. In the eastern channel most of the mixing away of the <0.7 degree occurs just downstream of the second sill.

11:00 AM PO12C-03 Deep near-inertial waves ***Kelly Pearson***[1], *Glenn S Carter*[1], *Gunnar Voet*[2], *James B Girton*[3], *Matthew H Alford*[2] *and John Mickett*[4], *(1)University of Hawaii at Manoa, Honolulu, HI, United States, (2)Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States, (3)Applied Physics Laboratory University of Washington, Seattle, WA, United States, (4)University of Washington, Seattle, WA, United States*

The majority of the transport of water below 4000 m depth into the North Pacific occurs in the Samoan Passage (168.5-170W, 7.5-10S). The Samoan Passage Abyssal Mixing Experiment (2012 - 2014) included seven long-term (approx. 1.5 year) and 17 short-term (6 - 30 days) moorings. Near-inertial waves were observed throughout the passage in moored profiler and point current meter velocity records. Although intermittent, there was no seasonal cycle. Maximum near-inertial energy was centered around the 1 degree C isotherm in the interface between the Antarctic origin bottom water and the overlying water. An array of four long term moorings, equipped with current meters, orientated east to west along the mouth of the passage, showed that the near-inertial wave energy entering the passage was higher in the water column to the west. A cluster of four moorings, north of the long term moorings at the month of the passage, located near a small sill (one 2km upstream, and three spaced 1km apart 3km downstream of the sill) show surprising differences in the inertial band energy. The upstream mooring spectra, 2 km south of the sill, has a double peak presumably from storms at different latitudes. The central downstream mooring retains the double peak, whereas the moorings 1 km on either side have a single near-inertial peak. This implies that interactions with topography, including generation of local vorticity, shadowing and flow steering, are important. An additional 12 short-term moored profiler records further north in the passage display near-inertial energy peaks. Together these moorings provide a unique insight in to the topographic interaction of deeply propogating near-inertial waves at a range of scales.

11:15 AM PO12C-04 Observed energy and momentum budget of a hydraulically controlled dense overflow in the Samoan Passage ***Gunnar Voet***[1], *Matthew H Alford*[2], *James B Girton*[3], *Glenn S Carter*[4], *Jody M Klymak*[5], *John Mickett*[6] *and Kelly Pearson*[4], *(1)Scripps Institution of Oceanography, La Jolla, CA, United States, (2)Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States, (3)Applied Physics Laboratory University of Washington, Seattle, WA, United States, (4)University of Hawaii at Manoa, Honolulu, HI, United States, (5)University of Victoria, Victoria, BC, Canada, (6)University of Washington, Seattle, WA, United States*

The flow of dense bottom waters of Antarctic and North Atlantic origin through the Samoan Passage is strongly modified by turbulent mixing as it passes over several topographic constrictions within the Passage. Here we present recent highly-resolved towed and moored measurements of the flow over one of its major sills. The sill is tall enough that the topographic Froude Number $N h_m/U_0¥approx1$, with bouyancy frequency N, sill height h_m and upstream velocity U_0, such that a hydraulic jump downstream is expected and indeed observed. Turbulent dissipation downstream of the sill and within the hydraulic jump reaches 10^{-5}~W/kg. The sill exerts considerable form drag on the flow as expressed by a pressure drop in the flow over the sill. The form drag per unit length of the sill is about 10^5~N/m and power loss due to form drag is above 1~W/m^2. Moored time series reveal tidal modulation of the hydraulically controlled flow and associated turbulent mixing. Current work is investigating the generation of lee waves by interaction of the mean flow with the sill.

係留データを用いて、鉛直エネルギーフラックス w’p’を計算した。サモア海峡では
散逸するエネルギーの 10%以上が風下波(lee wave)から射出されると見積もられた。

11:30 AM PO12C-05 Flow Splitting in Numerical Simulations of Oceanic Dense-Water Outflows ***Gustavo M Marques**, Princeton University, Program in Atmospheric and Oceanic Sciences, Princeton, NJ, United States, Laurence Padman, Earth & Space Research, Corvallis, OR, United States and Tamay Özgökmen, University of Miami, Miami, FL, United States*

Flow splitting, previously observed in laboratory studies, occurs when part of a gravity current becomes neutrally buoyant and separates from the bottom-trapped plume as an intrusion. If flow-splitting occurs in the ocean, it would allow dense-water outflows, e.g., from Antarctic continental shelves, to simultaneously ventilate the abyssal ocean and intermediate water layers. In this study, high resolution (dx=dz=5 m) numerical simulations are used to investigate whether this phenomenon could occur in oceanic gravity currents flowing into linearly stratified environments. The model is configured to solve the nonhydrostatic Boussinesq equations without rotation. First, a set of 2-D experiments were conducted by varying the horizontal turbulent Prandtl number (Pr_H), the ambient stratification frequency (N) and the bottom slope (α). When Pr_H=1, splitting does not occur, regardless of N and α. However, when Pr_H>=10, splitting may occur depending on α and the buoyancy number $B=QN^3/g'^2$ (where Q is the volume flux of the dense water flow per unit width and g' is the reduced gravity), and the flow always splits when $B\sim10^{-2}$ and α=0.1. When Pr_H is increased to 10^3, the parameter space under which flow splitting occurs is expanded ($B\sim5x10^{-3}$ to 10^{-2} and α>=0.01). Results from a 3-D simulation where $Pr_H=10^3$, $B\sim10^{-2}$ and α=0.1 also show flow splitting, consistent with the equivalent 2-D experiment. An important characteristic of simulations that result in flow splitting is the flow transition from a supercritical condition, where the Froude number (Fr) is greater than one, to a slower and more uniform subcritical condition (Fr<1). This transition is associated with an internal hydraulic jump and consequent mixing enhancement. A comparison between numerical results where Pr_H>=10 and oceanic observations suggests that flow splitting may occur in dense-water outflows on steep slopes and with weak ambient stratification, such as the Antarctic outflows.

斜面上を重い水塊が駆け下るときの現象を数値計算を用いて解析。強成層のときは、プルームは斜面中段で斜面から離れるのに対し、弱成層のときは、斜面底まで駆け下り、斜面から離れる。中間の成層を与えた場合、この２つが両方見られる（flow splitting)。これらの特徴は、プラントル数（Pr）に依らない。メカニズムは。。。。。（hydraulic jump とか何とか言っていたが、理解できず）

11:45 AM PO12C-06 Overflow induced Turbulence in a Deep Ocean Channel ***Sandra Tippenhauer**[1], Torsten Kanzow[2], Marcus Dengler[3] and Tim Fischer[3], (1)Alfred Wegener Institute, Climate Science - Physical Oceanography of the Polar Seas, Bremerhaven, Germany, (2)GEOMAR, Kiel, Germany, (3)GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany*

Ri>1/4 で散逸率が大きくなる場合は、hydraulic jump が関与している可能性がある。

In the Southern Ocean, small-scale turbulence can drive diapycnal mixing resulting in the transformation of water masses that are key compnents of the large-scale Meridional Overturning Circulation (MOC). We present direct observations of mixing over the Antarctic continental slope involving Circumpolar Deep Water which comprises the poleward limb of the Southern Ocean MOC. A 12-hour time-series of microstructure turbulence measurements, hydrography and velocity observations on the Antarctic Peninsula continental slope north of Elephant Island, reveals two concurrent bursts of elevated dissipation of {¥itshape O}(10^{-6})Wkg^{-1}, resulting in heat fluxes $¥sim$10 times higher than basin-integrated Drake Passage estimates. This occurs across the boundary between adjacent adiabatic upwelling and downwelling overturning cells. Ray tracing and topography show mixing between 300-400m consistent with the breaking of locally-generated internal tidal waves. Since similar conditions extend to much of the Antarctic continental slope where these water masses outcrop, their transformation may contribute significantly to Southern Ocean upwelling of Circumpolar Deep Water.

12:00 PM PO12C-07 Observations of a Diapycnal Shortcut to Adiabatic Upwelling of Antarctic Cirumpolar Deep Waters ***Yueng Djern Lenn***[1], *Jess Mead Silvester*[1], *Jeff Polton*[2], *Tom Philip Rippeth*[3] *and Miguel Angel Morales Maqueda*[4], *(1)Bangor University, Wales, School of Ocean Sciences, Menai Bridge, United Kingdom, (2)National Oceanography Center, Liverpool, United Kingdom, (3)Bangor University, School of Ocean Sciences, Bangor, Wales, United Kingdom, (4)Newcastle University, Newcastle, United Kingdom*

Theoretical investigations suggest that geothermal (hydrothermal and diffusive) fluxes are important in sustaining the deep ocean stratification and driving the abyssal circulation. Observational evidence in support of this thesis has been obtained during fieldwork in the Panama Basin as part of the UK funded project OSCAR (Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge). The Panama Basin is a miniature basin (~1000 x 1000 km) in the eastern Pacific which, below approximately 2300 m, communicates with the open ocean only through a 20 km wide passage: the Ecuador Trench. The basin contains three fast spreading ridges, the Costa Rica, Ecuador and Galapagos rifts, where heat flow through the crust is ~1 W m^{-2} (10 times larger than the global ocean average). Full water column hydrography (temperature, salinity and currents) and vertical microstructure profiling at 130 stations in the basin, combined with ADCP measurements at the Ecuador Trench, all gathered during OSCAR, have allowed us to create a first order, reduced gravity model of the basin's circulation and of the role of geothermal forcing in driving it. Inflow of water from the Pacific proper into the basin occurs as a northbound bottom boundary layer flow through the Ecuador Trench. At a rate of between 0.35 and 0.7 Sv, this inflow would fill the basin in less than 50 years. To leave the basin, the inflowing water must either be lifted above the 2300 m depth horizon or return into the Pacific as a southbound flow through the Ecuador Trench. The buoyancy input necessary to drive the outflow is contributed by geothermal fluxes from below and by downward heat diffusion from above. Our calculations indicate that about 55% of the buoyancy input is provided geothermally and the remaining 45% is due to downward diffusion with a diffusivity of around 1 x 10^{-4} m^2 s^{-1}, a value which 10 times larger than background ocean mixing rates.

12:15 PM PO12C-08 Abyssal Circulation in the Panama Basin Driven by Geothermal Fluxes? ***Miguel Angel Morales Maqueda***[1,2], *Donata Banyte*[1], *David Smeed*[3], *Richard W Hobbs*[4] *and Alex Megann*[3], *(1)Newcastle University, School of Marine Science and Technology, Newcastle upon Tyne, United Kingdom, (2)National Oceanography Centre, Marine Physics and Ocean Climate, Liverpool, United Kingdom, (3)National Oceanography Centre, Southampton, United Kingdom, (4)University of Durham, Durham, United Kingdom*

縦軸をポテンシャル密度、横軸をその密度の深度、としてデータをプロットしたところ、ある密度よりも低密度で、同じ深度に対して２つの等密度面が生じていた。これは hydraulic jump によっている可能性

がある。

investigations suggest that geothermal (hydrothermal and diffusive) fluxes are important in sustaining the deep ocean stratification and driving the abyssal circulation. Observational evidence in support of this thesis has been obtained during fieldwork in the Panama Basin as part of the UK funded project OSCAR (Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge). The Panama Basin is a miniature basin (~1000 x 1000 km) in the eastern Pacific which, below approximately 2300 m, communicates with the open ocean only through a 20 km wide passage: the Ecuador Trench. The basin contains three fast spreading ridges, the Costa Rica, Ecuador and Galapagos rifts, where heat flow through the crust is ~1 W m^{-2} (10 times larger than the global ocean average). Full water column hydrography (temperature, salinity and currents) and vertical microstructure profiling at 130 stations in the basin, combined with ADCP measurements at the Ecuador Trench, all gathered during OSCAR, have allowed us to create a first order, reduced gravity model of the basin's circulation and of the role of geothermal forcing in driving it. Inflow of water from the Pacific proper into the basin occurs as a northbound bottom boundary layer flow through the Ecuador Trench. At a rate of between 0.35 and 0.7 Sv, this inflow would fill the basin in less than 50 years. To leave the basin, the inflowing water must either be lifted above the 2300 m depth horizon or return into the Pacific as a southbound flow through the Ecuador Trench. The buoyancy input necessary to drive the outflow is contributed by geothermal fluxes from below and by downward heat diffusion from above. Our calculations indicate that about 55% of the buoyancy input is provided geothermally and the remaining 45% is due to downward diffusion with a diffusivity of around 1 x 10^{-4} m^2 s^{-1}, a value which 10 times larger than background ocean mixing rates.

PO13B Deep and Abyssal Ocean Mixing: From Small-Scale Turbulence to the Large-Scale MOC III

Monday, February 22, 2016

02:00 PM - 04:00 PM

02:00 PM PO13B-01 The Efficiency of Deep and Abyssal Ocean Turbulent Mixing ***Colm-cille Patrick Caulfield***[1], *Raffaele M Ferrari*[2], *Ali Mashayek*[2], *Maxim Nikurashin*[3] *and W Richard Peltier*[4], *(1)University of Cambridge, Department of Applied Mathematics and Theoretical Physics, Cambridge, United Kingdom, (2)Massachusetts Institute of Technology, Cambridge, MA, United States, (3)Princeton University, Princeton, NJ, United States, (4)University of Toronto, Toronto, ON, Canada*

乱流の生成効率 Γ は 0.2 で一定とするという Osborn(1980)の提案が長い間使われてきたが、Γ が浮力レイノルズ数 ReB に依存し、ReB～10^2 で極大（Γ～0.5）となり、それ以下の範囲で増加傾向、以上で減少傾向となる。

Turbulent mixing in the deep ocean, produced by various shear-driven mechanisms including internal wave breaking, plays a primary role in the climate through exerting a control upon the upwelling of deep dense waters formed at high latitudes, thereby driving the global ocean overturning circulation. A key parameter used to characterise turbulent mixing in observations, climate models, and global energy budgets is the turbulent flux coefficient $¥Gamma$ (often referred to as `mixing efficiency'). $¥Gamma$ is traditionally defined as the ratio of the portion of the energy input into the deep ocean that is invested in irreversible mixing, to the portion viscously dissipated into heat, and is conventionally assumed to be a constant of approximately twenty percent. We present evidence from both numerical simulations of idealised flows and observations that strongly suggests that $¥Gamma$ varies significantly in the abyssal ocean, and that mixing is predicted to be most efficient, corresponding to values of $¥Gamma ¥simeq 0.5$, near topographic features which host vigorous wave generation and breaking.

02:15 PM PO13B-02 A Comparison Between Internal Waves Observed in the Southern Ocean and Lee Wave Generation Theory ***Maxim Nikurashin****, University of Tasmania, Institute for Marine and Antarctic Studies, Hobart, Australia, Jessica Benthuysen, Australian Institute of Marine Science, Townsville, QLD, Australia, Alberto Naveira Garabato, University of Southampton, Southampton, SO14, United Kingdom and Kurt L Polzin, WHOI, Woods Hole, MA, United States*

Direct observations in the Southern Ocean report enhanced internal wave activity and turbulence in a few kilometers above rough bottom topography. The enhancement is co-located with the deep-reaching fronts of the Antarctic Circumpolar Current, suggesting that the internal waves and turbulence are sustained by near-bottom flows interacting with rough topography. Recent numerical simulations confirm that oceanic flows impinging on rough small-scale topography are very effective generators of internal gravity waves and predict vigorous wave radiation, breaking, and turbulence within a kilometer above bottom. However, a linear lee wave generation theory applied to the observed bottom topography and mean flow characteristics has been shown to overestimate the observed rates of the turbulent energy dissipation. In this study, we compare the linear lee wave theory with the internal wave kinetic energy estimated from finestructure data collected as part of the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES). We show that the observed internal wave kinetic energy levels are generally in agreement with the theory. Consistent with the lee wave theory, the observed internal wave kinetic energy scales quadratically with the mean flow speed, stratification, and topographic roughness. The correlation coefficient between the observed internal wave kinetic energy and mean flow and topography parameters reaches 0.6-0.8 for the 100-800 m vertical wavelengths, consistent with the dominant lee wave wavelengths, and drops to 0.2-0.5 for wavelengths outside this range. A better agreement between the lee wave theory and the observed internal wave kinetic energy than the observed turbulent energy dissipation suggests remote breaking of internal waves.

02:30 PM PO13B-03 Evidence for Seafloor-Intensified Mixing by Surface-Generated Equatorial Waves ***Ryan Holmes***[1], *Jim N Moum*[2] *and Leif N Thomas*[1], *(1)Stanford University, Stanford, CA, United States, (2)Oregon State Univ, Corvallis, OR, United States*

Xpod を CTD に取り付けた観測をもちいて、赤道付近の起伏の小さい海底の上で鉛直混合が強化されている、という現象に対して、運動方程式に赤道に固有の f*w（x 成分）や f*u（z 成分）を加えたときに出てくる波動（Smyth et al. 2015）が下向きに伝搬し、海底付近に捕捉されて慣性不安定を起こして乱流を強化していた。

Turbulence-enhanced mixing in the abyssal ocean is thought to derive its energy from tidal and wind forcing in roughly equal proportions. While much work has focused on mixing generated by tidal flow over rough topography, less is known about wind-driven mixing in the abyss. In addition, most observational studies have focused on the mid- and high-latitudes, while inverse models suggest that most of the zonally-integrated diapycnal transport in the abyssal overturning cell occurs in the tropical oceans. We address these issues by analyzing full-depth microstructure turbulence profiles obtained near 110°W, 0°N in the Eastern Pacific. Mixing was intensified over the bottom 700m where the diffusivity κ_T reached values of $10^{-3}m^2s^{-1}$, of similar intensity and structure to that found elsewhere over rough topography. Here, in contrast, a patch of seafloor-intensified mixing characterized by turbulent kinetic energy dissipation rates ε reaching $10^{-8}Wkg^{-1}$ was found over smooth topography. The strong turbulence was associated with flow unstable to both vertical shear instability and lateral inertial instability, as quantified using the Richardson number and absolute momentum. We suggest that these instabilities and the subsequent mixing were driven by a surface-generated equatorial wave, opening a unique energy pathway through which wind-generated wave energy directly drives seafloor-intensified mixing at low latitudes, with implications for the abyssal overturning circulation.

02:45 PM PO13B-04 Is it Always True that the Mixing Efficiency Decreases for Large (>400) Values of the Buoyancy Reynolds Number? ***Alberto D Scotti***, *University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States and Brian L White, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States*

Traditionally, oceanographers have assumed that turbulent processes in the stratified ocean interior achieve a constant mixing efficiency $\gamma\approx 1/6$, where the efficiency is defined as the ratio of turbulent buoyancy flux to total production (i.e. dissipation ε plus buoyancy flux). This value is currently used in ocean models to parameterize the eddy diffusivity when the dissipation is known. Numerical simulations and some observations appear to paint a different picture: 1/6 represents a peak efficiency that is attained within a narrow range of values of the buoyancy Reynolds number $Re_b = \varepsilon/\nu N^2$. In particular, the efficiency is reported to decay as C $Re_b^{-1/2}$ when the buoyancy

Reynolds number is large. However, the value reported for C ranges from 0.7 (DNS simulations, Shih et al., 2005) to 50 (observations in the Atmospheric Boundary Layer, Lozovatsky and Fernando, 2013). Recently, de Lavergne et al. (2015) have shown that replacing a constant efficiency with a decaying efficiency with C=4 profoundly affects, *inter alia,*the upwelling of AABW in the Southern Ocean. It is therefore extremely important to ascertain to what extent the Reynolds buoyancy number can be considered a good predictor of the efficiency in the energetic regime. In this talk, we show that a one-to-one relationship between the buoyancy Reynolds number and the mixing efficiency cannot exist in shear-driven turbulent mixing. We do this combining theoretical analysis with simulations. Our results indicate that the constant value assumed by oceanographers represents a reasonable compromise for the type of turbulent processes that are expected to dominate energetic mixing in the ocean. If anything, 1/6 should perhaps be revised upward.

This work was supported by NSF, under grant OCE-1155558,
and ONR under grant N00014-09-1-0288. Computer time was provided by UNC ITS.

03:00 PM PO13B-05 Inertial Gravity Waves in Eddying Flows ***Jin-Song von Storch****, Max Planck Institute for Meteorology, Ocean, Hamburg, Germany*

Recent estimates based on high-resolution OGCMs suggest that about three fourth of the kinetic energy of oceanic motions reside in time-varying flows, predominantly related to mesoscale eddies. Since mesoscale eddies tend to transfer energy upscale within the paradigm of geostrophic turbulence, the constant generation through barotropic and baroclinic instabilities of large-scale circulations must be balanced by processes that transfer energy from mesoscales to smaller scales, at which small-scale turbulence can complete the down-scale cascade of energy to dissipation. Here we investigate a route to dissipation via IGWs that are emitted by eddying flows and propagate subsequently within the eddying flows. The investigation is based on a 0.1-degree simulation, in which the general circulations including the related eddy field are realistically simulated, but leaving out tides and, to a considerable degree, also wind-induced near-inertial waves. We show that this route to dissipation is capable of transferring energy from mesoscale eddies to the smaller scales, despite of the fact that the wave emission can be small for flows having small Rossby numbers. We argue that the wave intensity is not only determined by the wave generation itself. After being generated by eddying flows, the waves, presumably low-mode internal waves, will propagate within the flows, whereby being refracted and captured by the flows. During the wave capture process, the intrinsic group velocity vanishes and the wavenumber and wave amplitude grow exponentially. It is this wave capture process that makes the emitted waves 'visible' and allows the energy transfer to smaller scales, whereby supplying power needed for interior mixing.

03:15 PM PO13B-06 Observations of near-inertial kinetic energy inside mesoscale eddies. ***Beatriz Ixetl Garcia Gomez****, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Physical Oceanography, Ensenada, Mexico, Enric Pallas Sanz, CICESE, Ensenada, Mexico and Julio Candela, Centro de Investigación Científica y de Educación Superior de Ensenada, San Diego, CA, United States*

The near-nertial oscillations (NIOs), generated by the wind stress on the surface mixed layer, are the inertia gravity waves with the lowest frequency and the highest kinetic energy. NIOs are important because they drive vertical mixing in the interior ocean during wave breaking events. Although the interaction between NIOs and mesoescale eddies has been reported by several authors, these studies are mostly analytical and numerical, and only few observational studies have attempted to show the differences in near-inertial kinetic energy (KEi) between anticyclonic and cyclonic eddies. In this work the spatial structure of the KEi inside the mesoscale eddies is computed using daily satellite altimetry and observations of horizontal velocity from 30 moorings equipped with acoustic Doppler current profilers in the western Gulf of Mexico. Consistent to theory, the obtained four-year KEi-composites show two times more KEi inside the anticyclonic eddies than inside the cyclonic ones. The vertical cross-sections of the KEi-composites show that the KEi is mainly located near the surface and at the edge of the cyclonic eddies (positive vorticity), whereas the KEi in anticyclonic eddies (negative vorticity) is maximum in the eddy's center and near to the base of the eddy where the NIOs become more inertial, are trapped, and amplified. A relative maximum in the upper anticyclonic eddy is also observed. The cyclonic eddies present a maximum of KEi near to the surface at ~70 m, while the maximum of KEi in the anticyclonic eddies occurs between 800 and 1000 m. It is also shown the dependence between the distribution and magnitude of the KEi and the eddy's characteristics such as radius, vorticity, and amplitude.

03:30 PM PO13B-07 A multi-parameter parameterization of ocean diapycnal mixing efficiency: global estimates inferred from Argo-float based profiles ***Hesam Salehipour***[1], *W Richard Peltier*[2], *Caitlin Whalen*[3] *and Jennifer A MacKinnon*[3], *(1)University of Toronto, Department of Physics, Toronto, ON, Canada, (2)University of Toronto, Toronto, ON, Canada, (3)University of California San Diego, La Jolla, CA, United States*

Osborn(1980)の定式化は一様で定常流に対してのものである。Salehipour & Peltier (JFM, 2015)は、混合効率が浮力レイノルズ数 Reb に依存することを示している。また、Shih et al. (2015)は低 Ri では、Reb の増加に対して E が減少するとした。Γ=E/(1-E)、本研究では、E の極大は大きな Ri に対応し、$E/E^*=(1+2p)(Reb/Reb^*)^p/[(1+2p)(Reb/Reb^*)^{p+0.5}]$、p=0.55 for Reb<Reb*, p=1 for Reb>Reb*と求めて、Γ の全球分布を示した。

We propose a dynamic parameterization for irreversible mixing efficiency (E) based on an extensive Direct Numerical Simulation (DNS) database of inhomogeneously stratified shear-induced turbulence. The Osborn formula for estimating diapycnal diffusivity K_ρ with its canonical flux coefficient of 0.2 is replaced by a generalized-Osborn formula with a flux coefficient that varies non-monotonically with both the buoyancy Reynolds number, $Re_b = \varepsilon/(\nu N^2)$ (where ν is the kinematic viscosity and ε and N^2 denote turbulent dissipation and density stratification respectively) and the gradient Richardson number, $Ri = N^2/S^2$ where S denotes the vertical shear. Using estimates of Re_b inferred from the global array of Argo floats, we analyze the global maps of $\Gamma = E/(1-E)$ and discuss their important spatial variability and Ri-dependence. Moreover we elaborate on the depth dependent global averages of K_ρ .

03:45 PM PO13B-08 Impact of a mean current on internal tide energy dissipation at the critical latitude ***Oceane Richet***[1], *Caroline j Muller*[2] *and Jean Marc Chomaz*[1], *(1)Ecole polytechnique - Ladhyx, fluid dynamics, palaiseau, France, (2)LMD - Ecole Normale Superieure, Paris, France*

内部潮汐波の周波数/2 と慣性周波数 f が一致する臨界緯度付近では､内部潮汐波と近慣性波動との３波共鳴 PSI 機構によって、乱流が強化される。一般流が存在するときに、どのように PSI による乱流強化が変るか数値実験で調べた。その結果、一般流を加えると、peak の乱流強度は下がるが、臨界緯度の周りの幅広い緯度で強化された。これは、ドップラシフトで ω/2 が ω/2±Uk/2 と周波数範囲が広がることに対応

すると考えられた。

In many regions of the ocean, the abyssal flow is dominated by tidal flow. A large fraction of the tidal energy input in the ocean is dissipated via the generation of internal waves above rough topography. Idealised simulations suggest that internal tide energy is transferred and dissipated at smallerscales by the formation of a resonant triad between near-inertial waves, internal tides and subharmonics waves. Furthermore, the energy dissipation is enhanced at the critical latitude (28.8^{o}), corresponding to the *Parametric Subharmonic Instability* (PSI). In the ocean, the presence of background flow, for instance due to the passage of a mesoscale eddy, can modify energy transfer mechanisms and the amount of energy dissipation. In this study, we investigate the generation and dissipation of internal tides in the presence of a background flow. We use a high-resolution two-dimensional nonhydrostatic numerical model (the MITgcm), with realistic multiscale topography representing the Brazil basin region. The purpose of this study is to understand the impact of the mean flow on the generation and dissipation of tidal waves. Our particular interest is how the maximum of energy dissipation at the critical latitude is impacted by the mean flow.

PO14C Deep and Abyssal Ocean Mixing: From Small-Scale Turbulence to the Large-Scale MOC IV Posters

Monday, February 22, 2016

04:00 PM - 06:00 PM

Papers

PO14C-2798 Performance of microstructure measurements using fast-response thermistors attached to a CTD-frame ***Yasutaka Goto***, *Ichiro Yasuda and Maki Nagasawa, University of Tokyo, Bunkyo-ku, Japan*

PO14C-2799 Global Ocean Circulation in Thermohaline Coordinates and Small-scale and Mesoscale mixing: An Inverse Estimate. ***Sjoerd Groeskamp***, *Lamont-Doherty Earth Observatory, Ocean and Climate Physics, New York, NY, United States, Jan David Zika, University of Southampton, Southampton, SO14, United Kingdom, Trevor J McDougall, University of New South Wales, Sydney, NSW, Australia and Bernadette Sloyan, CSIRO Marine and Atmospheric Research Hobart, Hobart, TAS, Australia*

I will present results of a new inverse technique that infers small-scale turbulent diffusivities and mesoscale eddy diffusivities from an ocean climatology of Salinity (S) and Temperature (T) in combination with surface freshwater and heat fluxes.

First, the ocean circulation is represented in (S,T) coordinates, by the diathermohaline streamfunction. Framing the ocean circulation in (S,T) coordinates, isolates the component of the circulation that is directly related to water-mass transformation.

Because water-mass transformation is directly related to fluxes of salt and heat, this framework allows for the formulation of an inverse method in which the diathermohaline streamfunction is balanced with known air-sea forcing and unknown mixing. When applying this inverse method to observations, we obtain observationally based estimates for both the streamfunction and the mixing. The results reveal new information about the component of the global ocean circulation due to water-mass transformation and its relation to surface freshwater and heat fluxes and small-scale and mesoscale mixing.

The results provide global constraints on spatially varying patterns of diffusivities, in order to obtain a realistic overturning circulation. We find that mesoscale isopycnal mixing is much smaller than expected. These results are important for our understanding of the relation between global ocean circulation and mixing and may lead to improved parameterisations in numerical ocean models.

PO14C-2800 Diapycnal Diffusivities over the Southwestern Indian Ocean Ridge

ABSTRACT WITHDRAWN

PO14C-2801 Vertical structure of turbulent mixing in the Bussol' Strait and its impact on water masses in the Okhotsk Sea and the North Pacific ***Ichiro Yasuda***, *The University of Tokyo, Atmosphere and Ocean Research Institute, Kashiwa, Japan*

PO14C-2802 Sensitivity of Inverse Box Model Estimates to Mesoscale and Interannual Variability

ABSTRACT WITHDRAWN

PO14C-2803 Direct microstructure observation in the northern South China Sea ***Qingxuan Yang***, *Xiaodong Huang, Wei Zhao and Jiwei Tian, Ocean university of China, Qingdao, China*

Microstructure observation was conducted in upper layer of the northern South China Sea, along with horizontal velocity, temperature and salinity measurements. Based on these data, a spatial distribution of mixing diffusivity is given, which shows a decreasing variability from the north to the south. During the observation period, a warm eddy existed over the field experiment area. The measurements spanning the mesoscale eddy are analyzed. Result shows the mixing level in the eddy is elevated significantly in the mixed layer when compared to that outside the eddy. In contrast, the mixing levels in and outside the eddy differ slightly below the mixed layer. Further analysis suggests that in the mixed layer the diffusivity value in the margin of the eddy is clearly larger than that in the center of the eddy. The associated mechanism is explored, which indicates that a potential candidate for this high diffusivity values in the margin of the eddy is sub-mesoscale process. This study provides a way to assess the influence of the mesoscale eddy on the small scale mixing.

PO14C-2804 Diapycnal Mixing Deductions From the Large-Scale, Time-Mean, World Ocean Temperature-Salinity Distribution ***Olivier Arzel*** *and Alain Colin de Verdière, Laboratoire de Physique des Océans, Brest, France*

The turbulent diapycnal mixing in the ocean is intimately linked to the strength of the oceanic circulation and is currently obtained from microstructure measurements, dye experiments and large scale hydrographic budgets. We use a large scale view point here and show how the numerous observations of temperature and salinity (which allow to construct a meaningful time-mean of these quantities) can be used to obtain the diapycnal mixing through the water column. The new method makes use of a general circulation model to compute a World Ocean Circulation forced by the climatology of temperature and salinity through restoring terms and surface winds. At steady state the large scale advection of these tracers is balanced by the divergence of turbulent fluxes which are given by the restoring terms. After interpolating these restoring terms on neutral density coordinates, we obtain diapycnal fluxes that can be interpreted as diapycnal diffusion and henceforth the diapycnal mixing coefficient throughout the water column. The geography of diapycnal mixing for selected water masses in the various basins along with the errors associated is discussed. In all ocean basins, diapycnal diffusivities increase with depth and are stronger in western boundary current regions with values reaching $O(10^{-3})$ m^2s^{-1}. In the ocean interior, the pattern of diapycnal diffusivities is more disorganised with local patches of positive and negative diffusivities. On the global average, effective diffusivities increase downward, peaking at about $5x10^{-4}$ m^2s^{-1} near the bottom, in agreement with previous estimates based on inverse modelling or direct measurements. In the upper ocean, heat is pumped downward resulting in negative global average effective diffusivities there.

PO14C-2805 The internal gravity wave spectrum in two high-resolution global ocean models ***Brian K Arbic***[1], *Joseph K Ansong*[1], *Maarten C Buijsman*[2], *Eric L Kunze*[3], *Dimitris Menemenlis*[4], *Malte Müller*[5], *James G Richman*[6], *Anna Savage*[1], *Jay F Shriver*[7], *Alan J Wallcraft*[8] *and Luis Zamudio*[6], *(1)University of Michigan Ann Arbor, Ann Arbor, MI, United States, (2)University of Southern Mississippi, Stennis Space Center, MS, United States, (3)NorthWest Research Associates Redmond, Redmond, WA, United States, (4)Jet Propulsion Laboratory, Pasadena, CA, United States, (5)Norwegian Meteorological Institute, Norway, (6)Florida State University, Tallahassee, FL, United States, (7)Naval Research Lab, Stennis Space Center, MS, United States, (8)Naval Research Laboratory, Stennis Space Center, MS, United States*

We examine the internal gravity wave (IGW) spectrum in two sets of high-resolution global ocean simulations that are forced concurrently by atmospheric fields and the astronomical tidal potential. We analyze global 1/12th and 1/25th degree HYCOM simulations, and global 1/12th, 1/24th, and 1/48th degree simulations of the MITgcm. We are motivated by the central role that IGWs play in ocean mixing, by operational considerations of the US Navy, which runs HYCOM as an ocean forecast model, and by the impact of the IGW continuum on the sea surface height (SSH) measurements that will be taken by the planned NASA/CNES SWOT wide-swath altimeter mission. We (1) compute the IGW horizontal wavenumber-frequency spectrum of kinetic energy, and interpret the results with linear dispersion relations computed from the IGW Sturm-Liouville problem, (2) compute and similarly interpret nonlinear spectral kinetic energy transfers in the IGW band, (3) compute and similarly interpret IGW contributions to SSH variance, (4) perform comparisons of modeled IGW kinetic energy frequency spectra with moored current meter observations, and (5) perform comparisons of modeled IGW kinetic energy vertical wavenumber-frequency spectra with moored observations. This presentation builds upon our work in Muller et al. (2015, GRL), who performed tasks (1), (2), and (4) in 1/12th and 1/25th degree HYCOM simulations, for one region of the North Pacific. New for this presentation are tasks (3) and (5), the inclusion of MITgcm solutions, and the analysis of additional ocean regions.

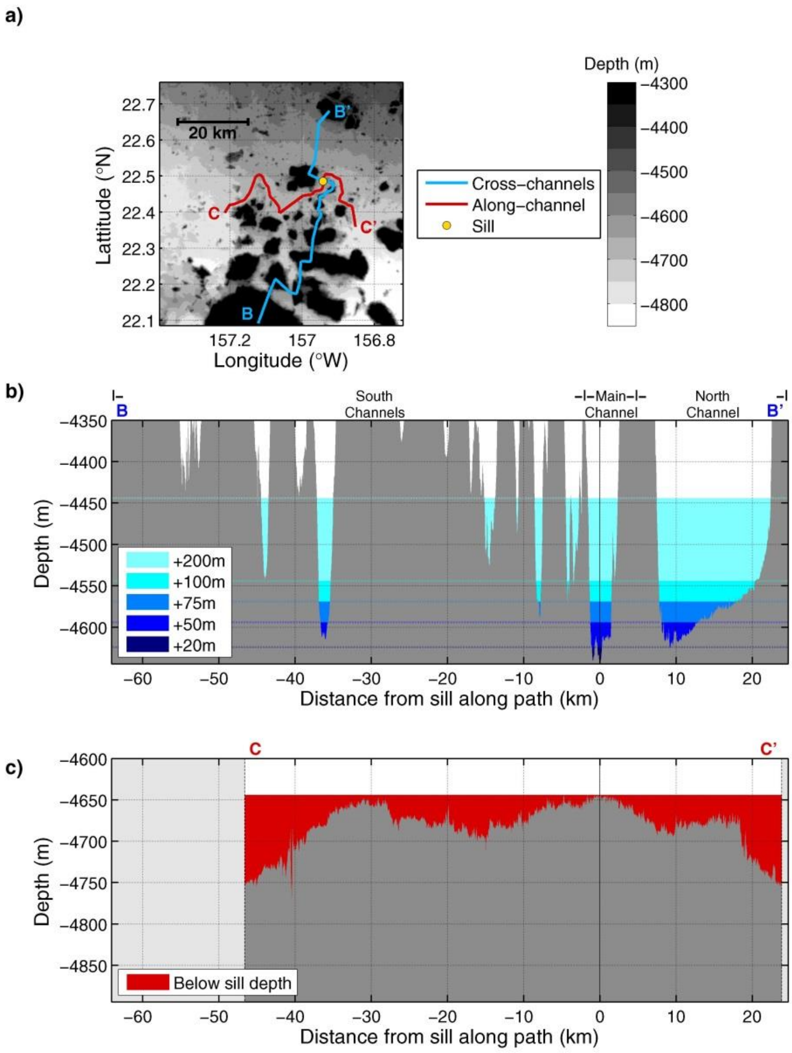
PO14C-2806 Observation and Modelling of Turbulent Mixing in a Northwestern Pacific Ocean Trench ***Hongzhou Xu***[1], *Liu Yu*[1], *Shiqiu Peng*[2] *and Qiang Xie*[1], *(1)Sanya Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences, Sanya, China, (2)SCSIO South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China*

Turbulent mixing plays important role for maintaining global ocean circulation and substance exchange between deep and upper oceans, especially for deep trench with > 6000 m depth. In this study, we use historic observed data and a numerical model to investigate the vertical distribution of turbulent mixing coefficients (Kv) in the deepest trench of the World, i.e. southwestern Mariana Trench (SMT) of the Northwestern Pacific Ocean (NPO). It is found that Kv has large scale with 10^-3 m^2/s at 4000 m-5000 m depths above the SMT. In addition, same magnitude of Kv appears at above bottom of the Trench, even at the deepest place with 10000 m depth. Results suggest salty and cold Antarctic Bottom Water (AABW) from the Southern Ocean intrude into the SMT through the NPO at 4000 m depth and mix with warm and fresh water above the Trench sufficiently that cause large scale of Kv at this depth. Different with the upper trench, the large Kv above bottom of the SMT is generated by internal tide breaking in which barotropic tides (principally include M2 tide) are propagated into the SMT, then trapped by the topography of the SMT and transformed into internal tides. The internal tides interact with topography and motivate strong vertical mixing near bottom of the SMT.

Keywords: Turbulent mixing coefficient, Antarctic Bottom Water (AABW), Internal tide, Mariana Trench

PO14C-2807 Characterization of bathymetric constraints on deep ocean circulation in the Kauai Deep region around Station ALOHA ***Robert Walter Deppe***, *Roger Lukas and Fernando Santiago-Mandujano, University of Hawaii at Manoa, Honolulu, HI, United States*

Episodic overflows of cold abyssal water from a deep basin (Maui Deep) into another (Kauai Deep) through a dividing sill have been observed at Station ALOHA (22.75° N, 158° W), 100 km north of Oahu, Hawaii. New high-resolution (0.0005°) bathymetry dataset and a new sill-finding algorithm based on Otto and Thurnherr (2007) were used to develop a detailed characterization of the sill region separating the two deep basins. The controlling sill that is expected to hydraulically regulate these abyssal overflows is found to be located at 22.4855° N, 156.9420° W, at a depth of 4644 m. This is deeper and further south than reported by previous studies that used lower-resolution bathymetry. The sill region has very complex bathymetry and an overflowing water mass is expected to pass through multiple channels along the boundary between basins to achieve the volume flux estimates from past studies. For these transports, the bulk of overflowing water from the Maui Deep would pass through the broad, shallower channel to the north of the controlling sill. The specifics of the sill on the northwest side of the Kauai Deep could not be determined due to low data quality in that region; however, that sill appears to be deeper than the eastern sill. Targeted observations in the region are needed to further the characterization of the dynamics of cold events and to better understand the influences of bottom topography on abyssal circulation and water mass properties at Station ALOHA.



PO14C-2808 Abyssal Upwelling and Downwelling and the role of boundary layers

ABSTRACT WITHDRAWN

PO14C-2809 Circluation of the Lau Basin ***Elizabeth Simons***, *Geophysical Fluid Dynamics Institute*

PO14C-2810 The Effect of Mixing Locality on Overturning Circulation ***Angus Gibson***, *Australian National University, Research School of Earth Sciences, Canberra, Australia and Andrew Hogg, Australian National*

University, Canberra, ACT, Australia

Diapycnal mixing is an important process for maintaining the meridional overturning circulation in the ocean. One contribution to diapycnal mixing in models is spurious, resulting from numerical operators such as horizontal advection. The spurious mixing present in models leads to a lower bound on effective diffusivity, so that low diffusivity regimes can't be simulated. Commonly-used methods for quantifying the spurious mixing in models require closed basins without buoyancy forcing, and are at best able to provide a single vertical profile for the entire domain. An estimate of the amount of spurious mixing and its spatial location can however be diagnosed from tracer variance statistics (e.g. Burchard and Rennau, 2007).

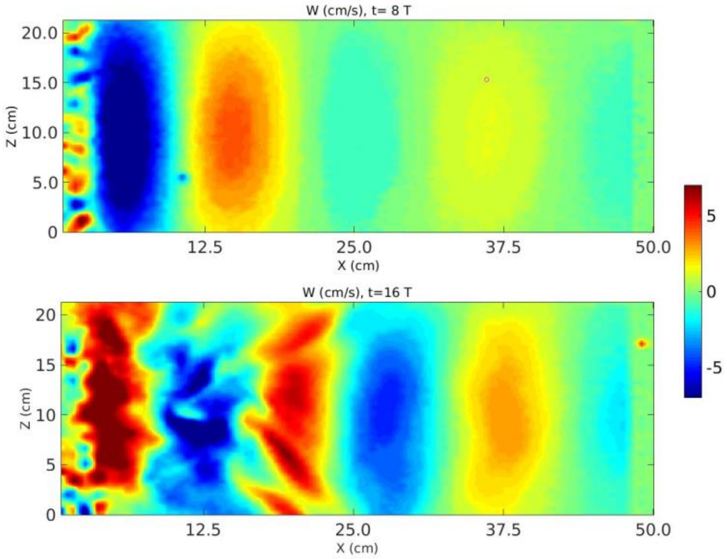
We investigate the sensitivity of an overturning circulation to variations in mixing by specifying the spatial location of diffusivity in an idealised numerical model. To minimise spurious mixing in the interior, a hybrid vertical coordinate is used, combining a z^* mixed layer with an isopycnal interior, with a transition layer in between. The spurious diffusion is diagnosed using the variance decay method. By reducing the lower bound on spurious diffusivity, we are able to directly test a wide range of diffusivity profiles, including profiles that are uniform with depth, surface-enhanced, and boundary-enhanced.

PO14C-2811 *Experimental description of turbulent energy fluxes associated with the parametric subharmonic instability* ***Yvan Dossmann****, Philippe Odier, Christophe Brouzet, Sylvain Joubaud, Baptiste Bourget and Thierry Dauxois, Ecole Normale Supérieure de Lyon, Laboratoire de Physique, Lyon, France*

the ocean, the parametric subharmonic instability (PSI) is a potential energy pathway to irreversible mixing that is not fully understood. It consists in the destabilization of a primary internal wave generation leading to the radiation of two secondary waves of lower frequencies and different wave vectors. In the process, internal wave energy is carried down to smaller scales.

We investigate mixing induced by the process of PSI relying on turbulent fluxes measurements in laboratory experiments. Simultaneous two-dimensional velocity and density measurements at high resolution are performed using combined PIV/LIF techniques. The turbulent diffusivity is directly assessed from turbulent fluxes calculations. It reaches values up $Kt=2.10^{-5}$ m^2/s in the configuration of unstable PSI. It is comparable to the pelagic value for turbulent diffusivity in the ocean. These results could help to refine parameterizations of the role played by the PSI mechanism in diapycnal mixing in oceanic numerical simulations.

Development of the parametric subharmonic instabilty for a mode-1 internal wave.



PO14C-2812 Modelling the Effect of Large Submarine Sandslides on the Ocean Circulation ***Alessandro Mozzato***[1], *David R Munday*[2], *Helen Louise Johnson*[3] *and Peter J Talling*[1], *(1)National Oceanography Centre, Southampton, United Kingdom, (2)British Antarctic Survey, Cambridge, United Kingdom, (3)University of Oxford, Department of Earth Sciences, Oxford, United Kingdom*

Submarine landslide can be orders of magnitude larger than terrestrial landslide, moving up to thousands of kilometers of sediment. Submarine landslides have been suggested to be able to play an important role in extreme climate events although at present no study has been focused on this aspect.

The Storegga Slide is the biggest Holocene Slide mapped off the Norwegian Margin, with an estimated volume of 3000 km^3. The slide failure is coincident with the last major cold event, the 8.2k cold event. The work presented is focused on the investigation of the connection between the Storegga Slide and the 8.2k cold event. The main focus is the study of the dense mud cloud generated after the release of the landslide. Studies have suggested that the generated mud cloud have had a concentration as high as 4% and a height of 800m. The hypothesis tested is if this dense mud cloud can interfere with the meridional overturning circulation at to which extent.

For this study a regional Arctic coupled ocean-sea-ice model was set up using the MITgcm general circulation model. The mud cloud was simulated using salinity perturbation as a proxy for the increased density of the water column. Results indicate a strong response from the ocean currents to the perturbation. The dense water mass formed by the perturbation moves northward slowly infilling the Arctic and affecting the whole water column up to the top. The results so far exclude a direct effect of the Storegga Slide on the MOC via a perturbation of the dense water formation in the North Atlantic. However, given the response of the circulation to the perturbation the results suggest that the Storegga Slide could have played a role in the 8.2k cold event. Work is still needed to precisely assess the magnitude of the impact of the perturbation on the circulation and the dynamics of this effect.

PO14C-2813 Large Kelvin-Helmholtz Billow Trains Observed in the Kuroshio above a Seamount ***Ming-Huei Chang***[1], *Sin-Ya Jheng*[1] *and Ren-Chieh Lien*[2], *(1)IONTU Institute of Oceanography National Taiwan University, Taipei, Taiwan, (2)Univ Washington, Seattle, WA, United States*

Trains of large Kelvin-Helmholtz (KH) billows were observed within the Kuroshio core, off southeastern Taiwan, at ~230-m depth above a seamount in shipboard echo sounder, ADCP, and LADCP/CTD profiling, and moored ADCP measurements. The large KH billow trains were present in a strong shear band along 0.55 ms^{-1} isotach within the Kuroshio core as a result of the Kuroshio current interacting with the rapid changing topography. Each individual billow, resembling a cats' eye, had a horizontal length scale of 200 m and a vertical amplitude scale of 100 m, and a propagation timescale of 7 minutes, near local buoyancy period. Overturns were frequently observed in both the billow core and the upper eyelid. The shear instability criterion ($Ri < 0.25$) was reached in the billow core. The dissipation rate of turbulent kinetic energy in the core and in the eyelid is comparable at an average value of $O(10^{-4})$ WKg^{-1} and a maximum value of $O(10^{-3})$ WKg^{-1}. The KH billows derive energy from the Kuroshio kinetic energy. The corresponding turbulence mixing allows the water mass exchange between the Kuroshio and the surrounding water. These small-scale processes play an important role in the energy and water mass budgets within the Kuroshio.

PO14C-2814 Vertical Velocities and Mixing Estimated from Seagliders *Eleanor Frajka-Williams, University of Southampton, Southampton, SO14, United Kingdom,* ***Victoria Sian Hemsley****, National Oceanography Centre Southampton, Ocean Biogeochemistry and Ecosytems, Southampton, United Kingdom, Adrian P Martin, National Oceanography Centre, Southampton, United Kingdom and Stuart C Painter, National Oceanography Center, Liverpool, L3, United Kingdom*

Using Seagliders equipped with a standard suite of hydrographic sensors, we document a geography of vertical velocity and mixing under different stratification and forcing conditions. Vertical velocities in the world's oceans are typically small, on the order of 1 cm/s, posing a significant challenge to observational techniques. Using Seagliders, we estimate vertical velocity by differencing observed glider vertical velocity (derived from pressure measurements) from expected glider vertical velocity (estimated from a glider flight model). Further filtering of rms-velocities allows an estimation of relative values of turbulent dissipation.

Here we present a geography of vertical velocities and turbulent dissipation in the Labrador Sea: in the surface mixed layer and during deep convection, and below the mixed layer in the presence of tides and eddies. Mixing estimates are high in the surface mixed layer and during deep convection, where the relative strength of mixing scales with the intensify of surface forcing. Below the mixed layer, dissipation shows modulations of up to two orders of magnitude over the span of days. While this method does not determine the absolute values of turbulent dissipation, Seagliders equipped with only the standard hydrographic suite of instruments allow extended duration, time-varying vertical profiles of oceanic mixing.

PO14C-2815 Spatial variability of deep mixing in a Mid-Ocean Ridge fracture zone in the Brazil Basin ***Louis Clement****, Lamont-Doherty Earth Observatory, Columbia University, United States, Andreas M Thurnherr, Lamont-Doherty Earth Observatory, Palisades, NY, United States and Louis St Laurent, Woods Hole Oceanographic Institution, Physical Oceanography, Woods Hole, MA, United States*

Mid-Ocean Ridge fracture zones channel bottom waters in the eastern Brazil Basin and are known to be regions of intensified deep mixing. Despite the essential role of bottom waters in the oceanic circulation, the mechanisms responsible for the deep turbulent mixing inside fracture zones are still subject to debate. To investigate the hydrography and the small scale turbulence in a particular Mid-Ocean Ridge fracture zone, a survey of cross-canyon tow-yos and individual CTD/LADCPs was carried out along 21°S, covering ~150 km of canyon axis. Based on the turbulent kinetic energy dissipation rate e inferred both from a Thorpe scale analysis and from vertical kinetic energy, a pattern is found of enhanced mixing near a major sill and over the canyon walls with $e=10^{-8}$ W kg^{-1} compared with a background value of $e=10^{-9}$ W kg^{-1}. The locations and magnitudes of the density overturns along with the 3d bottom velocity field suggest hydraulic control at the sill. Based on a comparison between the topographic slopes of the lateral canyon walls and the slopes of semidiurnal internal wave energy propagation we hypothesize that enhanced turbulence over the sidewalls is due to a mechanism involving internal tides. The observations are interpreted in the context of a heat budget inside the canyon.

PO14C-2816 The BP Blow-out Oil Material, Steady-state, Deepwater, Horizontal Plume: Analysis of this Opportunistic, Mesoscale, Hydrocarbon-tracer Field Data for Isopycnal and Diapycnal Eddy Diffusion Coefficients. ***Louis J Thibodeaux***[1]*, Adam Melvin*[1]*, Arthur Rost Parsons*[2]*, Edward B Overton*[3] *and Scientific Team of modeling horizontal oil spill intrusions, (1)Louisiana State University, Baton Rouge, LA, United States, (2)National Oceanographic Data Center, Silver Spring, MD, United States, (3)Louisiana State University, Environmental Sciences, Baton Rouge, LA, United States*

PO14C-2817 On Boundary Mixing *Truk Nizlop, Self Employed, Washington, DC, United States, **Kurt L Polzin**, WHOI, Woods Hole, MA, United States and unindicted co-conspirators*

We report here on three different control volume budgets / tracer release experiments combined with fine- and / or microstructure estimates of turbulent mixing. One (BBTRE) is an example of a tidally dominated environment. The other two, concerning the northern deepwater GOM and AABW in the Scotia Sea, appear to have substantial subinertial contributions to near-boundary mixing. We forward the hypothesis that these subinertial contributions are dominated by mixing associated with non-propagating form drag.

Our proposed hypothesis has roots in a discussion between Garrett and Armi (1979, J. Geophys. Res.). Armi interprets detached mixed layers in CTD casts from the western North Atlantic as providing evidence for ventilation of the abyssal ocean at rates of $O(1x10^{-4}$ m^2 $s^{-1})$. Garrett criticizes this on energetic grounds, suggesting that the required energy source is not to be found with a quadratic drag law, U ~ O(0.1 m s^{-1}) and C_d = $1x10^{-3}$. Garrett also points to an issue of a likely reduction in mixing efficiency with the bottom mixed layer and an issue of transporting mixed fluid away from the boundary.

Our response to this is that Garrett is simply looking at the wrong problem. The issue is one of form drag above rough topography, not shear stresses associated with hydrodynamically smooth surfaces. With form drag, the effective drag coefficients are orders of magnitude larger and mixing is associated with highly sheared regions in well stratified regions of O(U/N) height above the bottom. The 3-dimensional character of topographic roughness likely makes for more efficient off-boundary buoyancy transport.

These issues are explored with preliminary numerical simulations.

PO14C-2818 Deep water velocities and particle displacements induced by acoustic-gravity waves from submarine earthquakes ***Tiago Castro Alves Oliveira** and Usama Kadri, University of Haifa, The Hatter Department of Marine Technologies, Haifa, Israel*

An uplift of the ocean bottom caused by a submarine earthquake can generate Acoustic-Gravity Waves (AGW), progressive compression-type waves that travel at near the speed of sound in water. The role of AGW for oceans hydrodynamics has recently became a topic of increasing scientific interest. Kadri [Deep ocean water transport by acoustic-gravity waves, J.Geo. Res. Oceans, 119, (2014)] showed theoretically that AGW can contribute to deep ocean currents and circulation.

We analyze and simulate the fundamental AGW modes generated by a submarine earthquake. We consider the first five AGW modes and show that they may all induce comparable temporal variations in water particle velocities at different depths in regions far from the epicenter. Results of temporal variations of horizontal and vertical fluid parcel velocities induced by AGW confirm chaotic flow trajectories at different water depths. A realistic example based on the 2004 Indian Ocean earthquake shows that vertical water particle displacements of $O(10^{-2})$ m can be generated at 1 Km depth in a 4 km water depth ocean.

We show that the velocity field depends on the presence of the leading AGW modes. Each AGW mode becomes evanescent at a critical time, at which energy is transferred to the next higher modes. Consequently, the main pattern of the velocity field changes as the leading mode change. As an example, for a reference point located at 1000 Km from the epicenter, the first five AGW become evanescent after 1.6, 4.6, 7.7, 10.8 and 13.8 hours, respectively.

Our analysis and simulations shed light on the spatio-temporal evolution of the deep water velocities and particle displacements induced by AGW that radiate during submarine earthquakes. Thus, this work is a contribution to understand the role of high moment magnitude submarine earthquakes in deep water mixing mechanism.

PO14C-2819 Eikonal Simulations for the Energy Transfer in the Deep Ocean Internal Wave Field near Mixing Hotspots ***Takashi Ijichi*** *and Toshiyuki Hibiya, The University of Tokyo, Department of Earth and Planetary Science, Graduate School of Science, Tokyo, Japan*

In the proximity of mixing hotspots, the observed internal wave spectra are usually distorted from the Garrett-Munk (GM) spectrum and are characterized by the high energy level E as well as the shear/strain ratio R_ω quite different from the corresponding value for the GM spectrum ($R_\omega = 3$). Accurate parameterization of the energy transfer toward dissipation scales that takes into account the effects of E and R_ω is therefore indispensable to quantify the deep ocean mixing.

In this study, a series of eikonal simulations are carried out to examine energy transfer within such distorted internal wave spectra. The obtained results are used to assess the recently proposed parameterization for energy dissipation in the distorted internal wave field near mixing hotspots (Ijichi and Hibiya, 2015). In particular, several factors neglected by these authors in formulating the parameterization such as the background vertical divergence and the WKB horizontal scale-separation between small-scale test waves and the background waves are all taken into account throughout the eikonal simulations.

It is shown that the calculated energy transfer rate ε is fairly consistent with the scaling $\varepsilon \sim E^2N^2f$ with N the local buoyancy frequency and f the local inertial frequency. Furthermore, the calculated results exhibit strong R_ω dependence quite similar to that predicted from the parameterization by Ijichi and Hibiya (2015), suggesting the validity of their formulation.

PO14C-2820 Effects of temporal variation in tide-induced vertical mixing on thermohaline circulation: Numerical experiments for the case of the Okhotsk Sea ***Tomohiro Nakamura***[1], *Keisuke Uchimoto*[2], *Humio Mitsudera*[1] *and Masaaki Wakatsuchi*[1], *(1)Hokkaido University, Sapporo, Japan, (2)RITE, Kyoto, Japan*

Tidally-induced vertical mixing is important for thermohaline circulation. Previous estimations of tidal mixing have aimed to obtain time-averaged values, and ocean general circulation models (OGCMs) typically parameterize such mixing using a temporally constant diffusivity coefficient. However, tidal mixing varies temporally during tidal or spring--neap cycles. Here, we investigate the effects of temporal change in tidally induced vertical diffusivity (κ) in the Kuril Straits using an OGCM. The results show that variations of vertical mixing on diurnal, 2-week, and 1/2-year timescales induce significant differences in the net effect of mixing and, therefore, in the thermohaline circulation originating in the Okhotsk Sea. For diurnal and 2-week variations, the net effect of tidal mixing depends on (1) the period and length of the duration over which κ is larger than the temporal average and (2) the amplitude of the temporal variation of κ, even if the time-averaged values are the same. This is explained by the relative importance of two states. In a quasi-equilibrium state, a larger κ results in weaker stratification and vice versa, and thus the net tidal mixing effect is weaker when κ is variable. Conversely, in an adjustment stage just after an increase in κ, a larger κ acts on stronger stratification and vice versa, resulting in a stronger net effect. For a 1/2-year variation, the net effect of tidal mixing also depends on the phase relationship with seasonal variation in stratification. These results imply the necessity of considering temporal change when estimating tidal mixing from observations and understanding its net effects.

PO14C-2821 From Internal Waves to Mixing and Transformation Rates: Observations in the Southern Ocean ***Amelie Meyer***, *Norwegian Polar Institute, Ocean and Sea Ice, Tromsø, Norway, Bernadette Sloyan, CSIRO Marine and Atmospheric Research Hobart, Hobart, TAS, Australia, Kurt L Polzin, WHOI, Woods Hole, MA, United States, Helen Elizabeth Phillips, University of Tasmania, Institute for Marine and Antarctic Studies, IMAS, Hobart, Australia and N L Bindoff, CSIRO Marine and Atmospheric Research Hobart, Hobart, Australia; University of Tasmania, Institute for Marine and Antarctic Studies, IMAS, Hobart, TAS, Australia*

Understanding the dynamics that maintain the deep ocean stratification structure is of fundamental importance to understanding large-scale ocean circulation. Dissipating internal waves are the main source of mixing in the stratified ocean. Here we explore the link between internal waves, mixing, and the overturning circulation near the Kerguelen Plateau in the Southern Ocean. Based on observations from profiling floats, we describe the internal wave field properties, the distribution and intensity of mixing, and estimate water mass transformation rates.

The data consist of 914 temperature, salinity, pressure and horizontal velocity profiles from Electromagnetic Autonomous Profiling Explorer (EM-APEX) floats deployed northeast of the Kerguelen Plateau in 2008. We first identify and characterize 46 internal waves. We then estimate diapycnal mixing in the upper 1600 m of the water column applying a shear-strain fine-scale parameterization. In the context of the Southern Ocean overturning circulation, we also estimate the water mass transformation rates both locally and scaled to the entire Southern Ocean.

These observational results provide a clear connection between the internal wave field properties, and the distribution and intensity of mixing. The internal wave characteristics are dependent on regional dynamics, suggesting that different generation mechanisms dominate in different dynamical zones. We find evidence that some of the internal wave energy is advected away from the region, contributing to the stratification and driving the overturning circulation downstream. Mixing intensities show strong spatial and temporal variability. Small scale topographic roughness at the seafloor, flow strength, large-scale flow structure and atmospheric forcing are identified as important factors in determining local dynamical regimes for both the internal waves and the mixing rates. In particular, identified fronts of the Antarctic Circumpolar Current are associated with intense internal wave activity, with intense mixing and with substantial water mass transformation rates. We show evidence that local generation of internal waves can set the large-scale stratification of the Southern Ocean.

PO11D Oceanic Energy Pathways: From the Global Circulation to the Submesoscale I

Monday, February 22, 2016

08:00 AM - 10:00 AM

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Papers

08:00 AM PO11D-01 A simple model of eddy saturation ***David Philip Marshall***[1], *Maarten Ambaum*[2], *David R Munday*[3], *Lenka Novak*[2] *and James R Maddison*[4], *(1)University of Oxford, Oxford, United Kingdom, (2)Univ Reading, Reading, United Kingdom, (3)British Antarctic Survey, Cambridge, United Kingdom, (4)University of Edinburgh, School of Mathematics, Edinburgh, United Kingdom*

A simple model is developed for eddy saturation of the Antarctic Circumpolar Current (ACC): the relative insensitivity of its volume transport to the magnitude of the surface wind stress in ocean models with explicit eddies. The simple model solves prognostic equations for the ACC volume transport and the eddy energy, forming a 2-dimensional nonlinear dynamical system. In equilibrium, the volume transport is independent of the surface wind stress but scales with the bottom drag, whereas the eddy energy scales with the wind stress but is independent of bottom drag. The magnitude of the eddy energy is controlled by the zonal momentum balance between the surface wind stress and eddy form stress, whereas the baroclinic volume transport is controlled by the eddy energy balance between the mean-to-eddy energy conversion and bottom dissipation. The theoretical predictions are confirmed in eddy-resolving numerical calculations for an idealised reentrant channel. The results suggest that the rate of eddy energy dissipation has a strong impact not only the volume transport of the ACC, but also on global ocean stratification and heat content through the thermal wind relation. Moreover, a vital ingredient in this model is a relation between the eddy form stress and eddy energy derived in the eddy parameterisation framework of Marshall et al. (2012, J. Phys. Oceanogr.), offering the prospect of obtaining eddy saturation in ocean models with parameterised eddies.

08:15 AM PO11D-02 The Geometric Decomposition of Eddy Feedbacks: Insights into the Energetics of Scale Interactions ***Stephanie Waterman***, *University of New South Wales, Climate Change Research Centre & ARC Centre of Excellence for Climate System Science, Sydney, Australia; University of British Columbia, Earth, Ocean and Atmospheric Sciences, Vancouver, BC, Canada, Jonathan M Lilly, NorthWest Research Associates, Redmond, WA, United States and Kial Douglas Stewart, Australian National University, Research School of Earth Science, Canberra, Australia*

Understanding eddy-mean flow interactions is a long-standing problem in geophysical fluid dynamics, with modern relevance to the task of representing eddy effects in coarse resolution ocean models while preserving their dependence on the underlying dynamics of the flow field. A promising approach is to express the eddy forcing of the mean flow in the form of gradient operators applied to an eddy stress tensor. Such a formulation yields what we term the “geometric decomposition” of eddy feedbacks, a framework in which eddy-mean flow interactions are expressed in terms of the eddy energy together with geometric parameters describing the average variance ellipse (or in 3D, ellipsoid) shape and orientation. This framework has the potential to offer new insights into eddy-mean flow interactions in a number of ways: 1. it identifies the components of the eddy motions that can force mean flows; 2. it links eddy effects to the spatial patterns of eddy geometry, providing potential insight into the mechanisms underpinning these effects; and 3. it illustrates the importance of resolving the characteristic shape and orientation of eddy fluctuations, and not just the eddy energy, to accurately represent eddy feedback effects. Here we consider the utility of the geometric decomposition in elucidating the energetics of scale interactions, with a particular focus on the insights that this decomposition can provide on mean-eddy energy transfers, as well as the bounds that the eddy energy places on the eddy forcing of the mean flow. For example, the tilts of the variance ellipses provide an intuitive description of the exchange of energy between the eddy- and mean- flows, while the ellipse anisotropies are interpretable as geometric expressions of the bounds that the eddy kinetic and potential energies place on eddy fluxes, and ultimately on the eddy forcing of the mean flow. These important concepts will be both discussed and illustrated.

08:30 AM PO11D-03 Flavours of Baroclinic Instability in the Global Ocean ***Shane R Keating***, *University of New South Wales, Sydney, NSW, Australia and K Shafer Smith, New York University, Courant Institute of Mathematical Sciences, New York, NY, United States*

The transfer of energy from the global ocean circulation to mesoscale eddies is primarily mediated by baroclinic instability, which releases the superabundant available potential energy stored in sloping isopycnals by basin-scale wind and buoyancy forcing. However, the details of the local shear and stratification can give rise to qualitatively distinct flavours of baroclinic instability. In particular, the presence of outcropping isopycnals (or, equivalent, a thermal wind shear at the upper surface) can have a strong impact on the necessary conditions for baroclinic instability and the resulting nonlinear cascade to submesoscales. In this article, a simple framework is described for categorizing baroclinic instability in terms of two non-dimensional parameters, the Charney-Green number and the Phillips supercriticality. We analyze the influence of a non-zonal mean flow on growth rates and the baroclinic conversion of available potential energy to eddy kinetic energy. Finally, hydrographic profiles are used to form a global atlas of baroclinic instability in the ocean, and regional patterns are discussed.

08:45 AM PO11D-04 Parameterizing subgrid-scale eddy effects using energetically consistent backscatter ***Malte Jansen***[1], *Alistair Adcroft*[2], *Stephen Matthew Griffies*[3], *Robert Hallberg*[3] *and Isaac Held*[4], *(1)University of Chicago, Geophysical Sciences, Chicago, IL, United States, (2)Princeton University, Princeton, NJ, United States, (3)Geophysical Fluid Dynamics Laboratory, Princeton, NJ, United States, (4)Princeton Univ, Princeton, NJ, United States*

In the near future we expect the resolution of many IPCC-class ocean models to enter the “eddy-permitting” regime, where models can produce reasonable eddy-like disturbances, but can still not properly resolve geostrophic eddies at all relevant scales. Adequate parameterizations representing sub-grid eddy effects are thus necessary. Most eddy-permitting models presently employ some kind of hyperviscosity, which is shown to cause a significant amount of energy dissipation. However, geostrophic turbulence exhibits a forward enstrophy cascade but an inverse energy cascade. This phenomenology suggests that enstrophy should be dissipated below the grid-scale, whereas energy dissipation should occur only in boundary layers.

To obtain a closure that is in agreement with this basic physical principle, we propose to combine a standard bi-harmonic hyperviscous closure with a representation of energy “backscatter”, which ensures the conservation of energy. The parameterization of energy backscatter is formulated based on an explicit sub-grid EKE budget. Energy dissipated by hyperviscosity acting on the resolved flow is added to the sub-grid EKE, while a backscatter term transfers energy back from the sub-grid EKE to the resolved flow. The backscatter term is formulated deterministically via a negative Laplacian viscosity, which returns energy at somewhat larger scales than the hyperviscous dissipation, thus ensuring dissipation of enstrophy. The general idea has been demonstrated in idealized models, where the parameterization greatly improves simulations at typical eddy-permitting resolutions. First sucessfull tests have also been performed using GFDL’s MOM6 ocean model in a global configuration with an eddy permitting resolution of 1/4 degree. Kinetic energy levels are enhanced and more closely match the observations, and the representation of various eddying currents is improved.

09:00 AM PO11D-05 Probing the Timescales of Mesoscale Eddy Equilibration ***Anirban Sinha***, *Columbia University, Applied Physics and Applied Mathematics, New York, NY, United States and Ryan P Abernathey, Columbia University of New York, Palisades, NY, United States*

Stratification in the Southern Ocean is determined by a competition primarily between westerly wind driven upwelling and baroclinic eddy transport. The presence of multiple timescales in the wind field calls for a better understanding of the underlying mechanisms of ocean eddy response to variable dynamic forcing. We investigate the timescales of mesoscale eddy equilibration in the SO in response to changing winds through a hierarchy of models. An analytical framework describing the energetic pathways between wind input, available potential energy, eddy kinetic energy, and dissipation, provides a simple theory of the phase and amplitude response to oscillating wind stress. We hypothesize that the transient ocean response to variable winds lies between the two limits of Ekman response (high frequency limit) and “eddy saturation” (low frequency limit). The Ekman response is characterized by the isopycnals adjusting to the wind forcing quickly, while in the eddy saturated limit, all of the wind energy goes into mesoscale eddy kinetic energy. Motivated by an analogy with electric circuits, the system’s frequency response is characterized by a complex transfer function: the "eddy filter”. Both the phase and amplitude response of circumpolar transport, eddy kinetic energy, and potential energy, predicted by the linear analytic framework are verified using multiple ensemble experiments in a high-resolution isopycnal layered coordinate model (GOLD) with different time-periodic wind forcings. The results from the numerical experiments show agreement with the linear theory and is in accord with previous dynamical arguments and modeling studies of eddy saturation. The implications of these results for baroclinic instability, eddy mixing and heat transport in the Southern ocean are discussed.

09:15 AM PO11D-06 How do Ocean Heat Fluxes Depend on Bottom Pressure Torque? ***Maike Sonnewald***, *Massachusetts Institute of Technology, The Department of Earth, Atmospheric and Planetary Sciences, Cambridge, MA, United States, A. J. George Nurser, National Oceanography Centre Southampton and Joel Hirschi, National Oceanography Centre, Southampton, United Kingdom*

Successfully describing ocean physics entails a correct interpretation of the fundamental underlying mechanisms. Ocean physics are an integral part of the climate, and being able to model them with confidence leads to reduced uncertainty and predictive power. Our theoretical understanding of ocean physics is largely based on a laminar view of the ocean, assuming the non-linear vorticity terms are small. Here we investigate the balance of forces in a coarse (1^o), an eddy permitting ($1/4^o$) and an eddy resolving ($1/12^o$), version of the NEMO general circulation model. All three versions of the model use the same surface forcing for the period from 1978 to 2007. We find that in the 30-year mean the baroclinic contribution to ocean heat transport becomes increasingly important with higher resolution, especially in the Southern Ocean. This implies that resolving eddies leads to a shift in the balance of forces and to a different partitioning of the ocean heat transport. We investigate this shift using the depth integrated vorticity equation, demonstrating that changes in the bottom steering in terms of the bottom pressure torque in the instantaneous and 30-year mean are particularly evident in the Southern Ocean.

09:30 AM PO11D-07 Jet-Topography Interactions: What Sets the Vertical Structure of Eddy Effects Around Topography? ***Alice Barthel****, University of New South Wales, Climate Change Research Centre & ARC Centre of Excellence for Climate System Science, Sydney, NSW, Australia, Andrew Hogg, Research School of Earth Sciences & ARC Centre of Excellence for Climate System Science, Australian National University, Canberra, Australia and Stephanie Waterman, University of New South Wales, Climate Change Research Centre & ARC Centre of Excellence for Climate System Science, Sydney, Australia; University of British Columbia, Earth, Ocean and Atmospheric Sciences, Vancouver, BC, Canada*

In the Southern Ocean, strong eastward flows interact with large topographic features, generating localized regions of high eddy activity. The resulting eddies play an important role in the circulation, contributing both to the mean Southern Ocean stratification, and to the meridional fluxes of tracers such as heat and nutrients. We report on a study that investigates how the structure of the flow impinging on topography sets the vertical distribution of the eddy effects that result from jet-topography interactions. We use an ocean model with an imposed unstable jet encountering a topographic obstacle, in a configuration relevant to an Antarctic Circumpolar Current frontal jet. We investigate the spatial structure of eddy energy terms and eddy fluxes, and their sensitivity to changes in forcing. This study focuses on improving our understanding of the processes which set the vertical distribution of eddy effects near topography. The results have implications for how eddy feedbacks on the mean flow might respond to future changes in Southern Ocean circulation.

09:45 AM PO11D-08 The structure of baroclinic turbulence in an idealized family of baroclinically-unstable flows

K Shafer Smith*, New York University, New York, NY, United States and Shane R Keating, University of New South Wales, Sydney, NSW, Australia*

We present and investigate the nonlinear equilibrated states of a two-parameter family of idealized local mean flows that capture the primary mesoscale baroclinic instability types found in the world's oceans. The model flow yields a mean potential vorticity (PV) gradient that consists of baroclinic part, equal to the stretching term from the baroclinic shear, and a depth-averaged part, equal to the sum of beta and the stretching associated with lateral buoyancy gradients at the ocean's surface. The model may be susceptible to Phillips-type baroclinic instability, arising from sign changes in the baroclinic PV gradient, Charney-type instability, which occurs when the surface buoyancy gradient has the opposite sign of the barotropic PV gradient, or both (and may be stable for a narrow slice of parameter space). The two instability types (which may occur alone or in the same flow) lead to distinct turbulent states and eddy fluxes. In some instances, the equilibrated flow exhibits a transition scale below which energetic submesoscale flows develop, displaying features that bear resemblance to Surface Quasigeostrohphic (SQG) turbulence. When such flows result from a Charney-type instability, however, the submesoscale range is non-inertial, being forced at all scales by submesoscale instabilities (akin to, but weaker than Mixed Layer Instabilities). These flows also exhibit a turbulent 'boundary layer,' with a thickness given roughly by the Charney depth scale from the associated linear instability problem. The detailed structure of the turbulence resulting from this family of mean flows provides a useful simplified model for the regional variation of eddy structure in the global ocean.

PO12D Oceanic Energy Pathways: From the Global Circulation to the Submesoscale II

Monday, February 22, 2016

10:30 AM - 12:30 PM

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Papers

10:30 AM PO12D-01 Rapid Energy Exchange Between Balanced Eddies and Near-Inertial Waves at Fronts. ***Leif N Thomas***, *Stanford University, Stanford, CA, United States*

Inertia-gravity waves, mesoscale eddies, and density fronts are ubiquitous in the ocean. Classical theory predicts that the interaction between the fast, unbalanced waves and the slow, balanced eddies should be weak. A new theory will be described that demonstrates, however, that this interaction can be strong in regions of frontogenesis, where mesoscale strain intensifies lateral density gradients. Such frontogenetic strain leads to an exponentially fast increase in the vertical shear of the along-front geostrophic flow and a concomitant cross-front ageostrophic circulation that is vertically-sheared as well. These changes in geostrophic flow modify the polarization relation of inertia-gravity waves that are present, making their horizontal velocity rectilinear and resulting in a Reynolds stress that draws energy from the eddies. The process is most effective for near-inertial waves and for a geostrophic flow with low Richardson number. Nonetheless, even in a background flow that is initially strongly stratified, frontogenesis leads to an exponentially fast reduction in the Richardson number, facilitating a rapid energy extraction by the waves. The theory predicts that the kinetic energy transferred from eddies is ultimately lost to the unbalanced ageostrophic circulation and hence the near-inertial waves play a catalytic role in loss-of-balance. The theory is tested with numerical simulations configured with an array of barotropic eddies that strain a density front. Simulations run with and without a field of near-inertial waves are compared to isolate the wave-mean flow interactions. The modifications of the polarization relations and consequent energy exchange with the mean flow predicted by the theory are realized in the simulations. However, unlike the theory, inhomogeneities in the wave field are allowed in the simulations and are analyzed to quantify the wave-driven accelerations of the mean flow.

10:45 AM PO12D-02 The Energetics of Centrifugal Instability ***William K Dewar***, *Florida State Univ, Tallahassee, FL, United States*

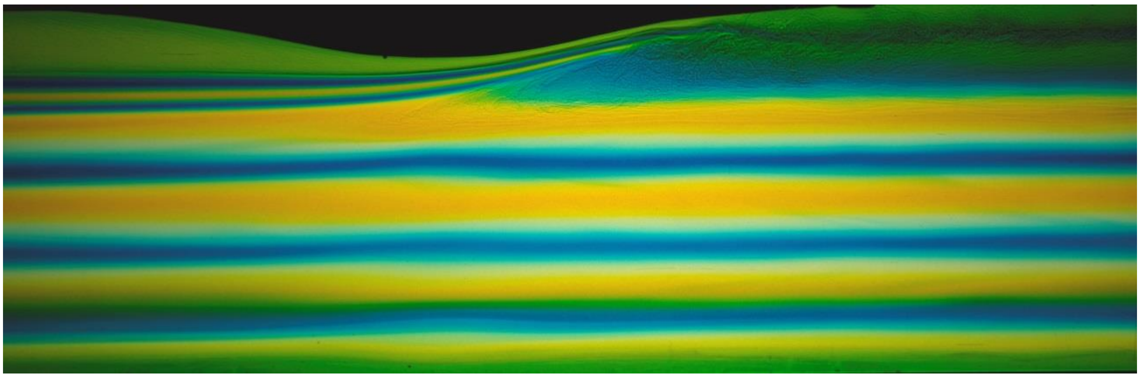
A recent study has argued that the California Undercurrent, and poleward eastern boundary currents in general, generate mixing events through centrifugal instability (CI). Conditions favorable for CI are created by the strong horizontal shears developed in turbulent bottom layers of currents flowing in the direction of topographic waves. At points of abrupt topographic change, like promontories and capes, the coastal current separates from the boundary and injects gravitationally stable but dynamically unstable flow into the interior. The resulting finite amplitude development of the instability involves overturnings and diabatic mixing. The purpose of this study is to examine the energetics of CI in order to characterize it as has been done for other instabilities and develop a framework in which to estimate its regional and global impacts. We argue that CI is roughly twice as efficient at mixing as is Kelvin-Helmholtz instability, and that roughly 10% of the initial energy in a CUC-like current is lost to either local mixing or the generation of unbalanced flows. The latter probably leads to non-local mixing. Thus centrifugal instability is an effective process by which energy is lost from the balanced flow and spent in mixing neighboring water masses. We argue the importance of the mixing is regional in nature, but of less importance to the global budgets given its regional specificity.

11:00 AM PO12D-03 Topographically Induced Mixing: Remote versus Local ***Andrew Hogg***[1], *Yvan Dossmann*[2], *Ross W Griffiths*[1], *Madelaine Rosevear*[3], *Graham Owen Hughes*[1] *and Michael Copeland*[3], *(1)Australian National University, Canberra, ACT, Australia, (2)Ecole Normale Supérieure de Lyon, Laboratoire de Physique, Lyon, France, (3)Australian National University, Canberra, Australia*

海底の起伏を底層流が乗り越える際の風下波動に伴い、遠方エネルギー散逸と局所エネルギー散逸の比率が、フルード数 Fu に依存し、Fu～2 の付近でのみ遠方散逸の比率が高まることが、室内実験で示された。

The interaction of balanced abyssal ocean flow with submarine topography is expected to generate both lee waves that can carry energy into the ocean interior and local turbulent mixing near the boundary. The relative amounts of remote and local energy dissipation governs the distribution of mixing within the water column, carrying implications for the evolution of the abyssal stratification and overturning circulation. We report results from laboratory experiments with a topographic ridge towed through a stratified fluid. The experiments span three parameter regimes including linear lee waves, nonlinear flow and an evanescent regime in which wave radiation is weak.

Full field density measurements provide the depth-dependence of energy loss to turbulent mixing, allowing separation of the local mixing in the turbulent wake and remote mixing by wave radiation. Remote mixing is significant only for a narrow band of forcing parameters where the flow speed is resonant with internal waves; in all other parameter regimes local mixing close to the topography is dominant. The results suggest that mixing by local nonlinear mechanisms close to abyssal ocean topography may be much greater than the remote mixing by lee waves.



11:15 AM PO12D-04 A Novel Approach to Unravelling Energy Pathways in the Ocean ***Hussein Aluie***, *University of Rochester, Rochester, NY, United States, Matthew W Hecht, Los Alamos National Laboratory, Los Alamos, NM, United States and Geoffrey K Vallis, Princeton Univ, Princeton, NJ, United States; University of Exeter, Exeter, United Kingdom*

乱流の解析などに用いられてきたフーリエ成分間のエネルギー移動は適用性に制限が強かった。本研究では、空間フィルターを導入して、空間スケール間の相互作用・エネルギー移動を求めることができる手法を開発し、湾流の数値シミュレーションに適用した。

The oceans display energetic dynamics across a wide range of spatial scales, and researchers have long worked to better understand the energy coupling between these various scales. While there have been previous attempts to understand energy pathways, assumptions of homogeneity and isotropy have presented a limitation upon the applicability of the analyses. Here we present a more general technique, unrestricted by the usual assumptions of homogeneity or isotropy, which allows one to simultaneously probe the dynamics in both space and time. We make use of a novel coarse-graining framework, which accounts for the spherical geometry of the problem, to directly analyze the coupling between scales. We apply this technique to strongly eddying high-resolution simulations using LANL's Parallel Ocean Program.

11:30 AM PO12D-05 Role of Gravity Waves in the Dissipation of Mesoscale Eddies ***Manita Chouksey***, *University of Hamburg, Institute of Oceanography, Theoretical Oceanography, Hamburg, Germany, Nils Brueggemann, Delft University of Technology, Netherlands and Carsten Eden, University of Hamburg, Institute of Oceanography, Hamburg, Germany*

ロスビー数 Ro が大きく、リチャードソン数 Ri が小さい場合、非地衡流レジームとなり小スケールへエネルギーが輸送され、Ro<<1 で Ri>>1 の場合には、準地衡流レジームとなり大スケールへエネルギーが輸送されることが先行研究で示されている。重力波の役割を調べるために、モード分離を行ったところ、非地衡流レジームでは重力波のエネルギーの比率が準地衡流レジームより大きいが、それでもほとんどのエネルギーは地衡流で占められていた。

The energy of the oceans is finally dissipated at molecular scales by viscous dissipation, related to small-scale turbulence. However, most of the ocean is in a geostrophic balance wherein turbulent flows exhibit a transfer of energy from smaller to larger scales. The exact mechanism of dissipation from the large-scales, however, is not well understood and hence not well represented in ocean models. It is thus important to understand and parametrize the process of dissipation of mesoscale eddies, to better represent the energy cycle and to improve ocean models.

Previous results (Brüggemann and Eden, JPO, 2015) show a dominant forward energy cascade for a large Rossby number (Ro) and a small Richardson number (Ri) in an idealized channel model, while for Ro«1 and Ri»1 the inverse energy cascade dominates. We discuss the role of gravity waves for the forward cascade of energy. A spectral analysis of energy in frequency-wavenumber space for different regimes characterized by a range of Ri, shows that energy contained in the super-inertial frequencies corresponding to gravity waves is much higher for an ageostrophic regime than for a quasi-geostrophic regime. A linear modal decomposition into geostrophic and gravity wave modes, indicates that there is surprisingly low energy in the gravity wave modes and much higher energy in the geostrophic mode even for super-inertial frequencies. Further, a non-linear decomposition of the balanced flow into geostrophic mode and linear and non-linear gravity wave modes also shows that most of the energy is contained in the geostrophic mode. A modal decomposition of the spectral fluxes of energy in wavenumber space provides more insight about how much energy is contained in which mode.

11:45 AM PO12D-06 Energetics of Eddy-Mean Flow Interactions in the Gulf Stream Region ***Dujuan Kang*** *and Enrique N Curchitser, Rutgers University, Department of Environmental Sciences, New Brunswick, NJ, United States*

The Gulf Stream and associated eddies play an important role in mixing the ocean energy, momentum, and biogeochemical properties in the Northwest Atlantic. The Gulf Stream mean flow and eddies can interact to each other through barotropic and baroclinic instability processes. We perform a detailed energetics analysis of their interaction using a high-resolution multidecadal regional ocean model simulation. The energy equations for the time-mean and time-varying flows are derived as a theoretical framework for the analysis. The eddy-mean flow energy components and their interactions show complex spatial distribution in the Gulf Stream region. The cross-stream and cross-bump variations are seen in the along-coast region, whereas a mixed mean-to-eddy and eddy-to-mean interaction pattern is observed in the off-coast region. When considering the domain-averaged energetics, the eddy-mean flow interaction shows significant along-stream variability. In the along-coast and upon-separation regions, the energy is mainly transferred from the mean flow to the eddy field through flow instabilities. In the off-coast region, an inverse conversion from the eddy field to the mean flow dominates the power transfer, indicating that eddies act to drive the mean circulation.

12:00 PM PO12D-07 Mesoscale Atmosphere-Ocean Coupling Enhances the Transfer of Wind Energy into the Ocean. ***David Byrne***, *ETH Zurich, Department of Environmental, Zurich, Switzerland, Matthias Munnich, ETH Zentrum, Zurich, Switzerland, Ivy Frenger, Princeton University, Program in Atmospheric and Oceanic Sciences, Princeton, NJ, United States and Nicolas Gruber, ETH Swiss Federal Institute of Technology Zurich, Zurich, Switzerland*

Ocean eddies receive their energy mainly from the atmospheric energy input at large scales, while it is thought that direct atmosphere-ocean interactions at this scale contribute little to the eddies' energy balance. If anything, the prevailing view is that mesoscale atmosphere-ocean interactions lead to a reduction of the energy transfer from the atmosphere to the ocean.

From satellite observations, modelling studies and theory, we present results in contrast to this. Specifically, we describe a novel mechanism that provides a new energy pathway from the atmosphere into the ocean that directly injects energy at the mesoscale, shortcutting the classical main pathway from the larger scales. Our hypothesis is based upon recent evidence that the 'coupling strength' i.e., the magnitude of the atmospheric response to underlying sea surface temperature anomalies associated with eddies, is dependent upon the background wind speed. We argue that ocean eddies rarely live in an area of constant background wind, particularly not in the Southern Ocean, and that the horizontal gradients in the wind across ocean eddies lead to an increased/decreased work on one side of the eddy that is not compensated for on the other. Essentially, this asymmetry provides a 'spin up' or a 'spin down' forcing such that the net result is an increase in kinetic energy for both warm and cold core eddies that reside in a negative wind gradient and a decrease in kinetic energy when they are located in a positive wind gradient.

This result has strong implications for the Southern Ocean, where large regions of positive and negative wind gradients exist on both sides of the wind maximum. We show from diagnosing the local eddy scale and domain wide energy balance in a high-resolution coupled atmosphere-ocean regional model in the South Atlantic, there are different energy transfers in the two regions and due to the different eddy abundances that this mechanism increases the net kinetic energy contained in the ocean mesoscale eddy field by up to 10-15%.

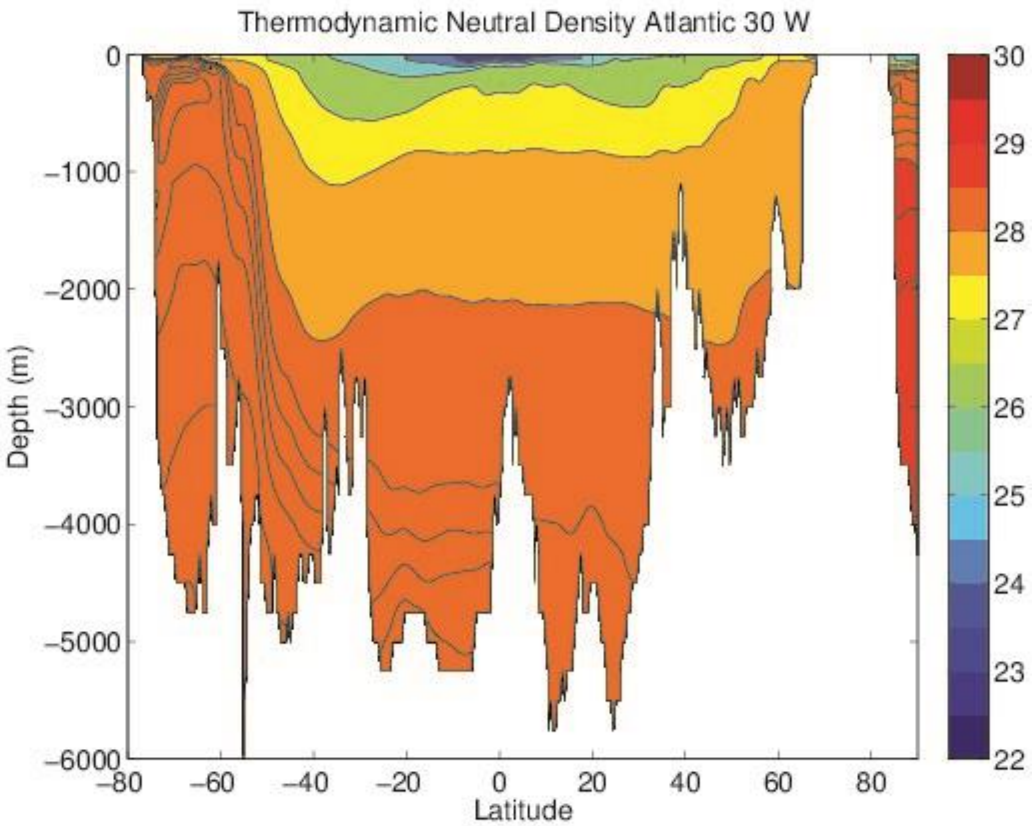
12:15 PM PO12D-08 Thermodynamic neutral density: A new physically-based, energy-constrained, materially conserved neutral density variable for quantifying mixing and tracking water masses in the ocean ***Remi Tailleux***, *University of Reading, Reading, RG6, United Kingdom*

A new materially-conserved quasi-neutral density variable has been constructed, called thermodynamic neutral density. It is composed of two parts. The first part is the Lorenz reference density entering Lorenz theory of available potential energy, which can be interpreted as the potential density of a fluid parcel referenced to the pressure it would have in Lorenz reference state of minimum potential energy. The second part is an empirical correction for pressure, which can be suitably chosen to make thermodynamic neutral density a very good approximation of Jackett and McDougall (1997) neutral density over most of the ocean water masses for which the latter is defined.

Thermodynamic neutral density possesses many advantages over the empirically constructed Jackett and McDougall (1997) neutral density: 1) it is physically-based; 2) it is easily computed using fast and efficient methods for arbitrary states of the ocean, not just the present state, using the recently developed methodology by Saenz et al. (2015); 3) it is exactly neutral in a state of rest, and approximately neutral in the present ocean; 4) it is exactly materially conserved (it is a function of salinity and potential temperature only) and not plagued by unphysical nonmaterial effects, so can be used unambiguously to define and diagnose diapycnal and isopycnal mixing; 5) it is based on available potential energy, and therefore is the most suitable variable to discuss the energy cost of adiabatic stirring; 6) it is the variable that should be used to define the isopycnal and diapycnal directions in rotated diffusion tensor, as it can be shown that using the directions defined by the local neutral tangent plane as currently done causes spurious destruction of water masses.

References:

J. A. Saenz, R. Tailleux, E.D. Butler, G.O. Hughes, and K.I.C. Oliver, 2015: Estimating Lorenz's reference state in an ocean with a nonlinear equation of state for seawater. J. Phys. Oceanogr., 45, 1242—1257



PO14G Oceanic Energy Pathways: From the Global Circulation to the Submesoscale III Posters

Monday, February 22, 2016

04:00 PM - 06:00 PM

Ernest N. Morial Convention Center

- Poster Hall

Papers

PO14G-2881 Energetics of internal wave-permitting simulations of the Macquarie Ridge region of the Southern Ocean ***Maxim Nikurashin***, *University of Tasmania, Institute for Marine and Antarctic Studies, Hobart, Australia*

Mesoscale eddies are the most energetic motions in the ocean, but the fate of their energy in the ocean remains poorly understood. Eddy generation in the Southern Ocean tends to be enhanced near prominent topographic features, creating localized hot spots of eddy stirring and turbulent mixing. In this study, realistic internal wave-permitting simulations of one of the hot spots, the Macquarie Ridge region of the Southern Ocean, are used to investigate the energy dissipation of the Antarctic Circumpolar Current fronts and eddies. The simulations are initialized and forced at open boundaries by the outputs from the Southern Ocean State Estimation (SOSE) and carried out for several years for a range of resolutions from the eddy-resolving, about 10 km, down to the submeso-scale resolving and internal wave-permitting, about 800m, horizontal resolution. The total mechanical energy budget, including inflow and outflow of kinetic energy across the boundaries, surface wind power input and energy dissipation by bottom drag and interior viscous friction, is diagnosed and closed within a few percent of the wind power input. The distribution of the viscous energy dissipation throughout the ocean and the relative contribution of the surface and deep ocean processes to the energy dissipation is quantified and discussed.

PO14G-2882 Work Done by Atmospheric Winds on Mesoscale Ocean Eddies ***Xiaoming Zhai***, *University of East Anglia, Norwich, United Kingdom and Chi Xu, South China Sea Institute of Oceanology, Guangzhou, China*

Mesoscale eddies are ubiquitous in the ocean and dominate the ocean's kinetic energy. However, physical processes influencing ocean eddy energy remains poorly understood. Mesoscale ocean eddy-wind interaction potentially provides an important energy flux into or out of the eddy field, but its effect on ocean eddies has not yet been determined. Here we examine work done by atmospheric winds on more than 1,200,000 mesoscale eddies identified from satellite altimetry data, and show that atmospheric winds significantly damp mesoscale ocean eddies, particularly in the energetic western boundary current regions and the Southern Ocean. We then show that the large-scale wind stress curl systematically injects kinetic energy into anticyclonic (cyclonic) eddies in the subtropical (subpolar) gyres, while mechanically damps anticyclonic (cyclonic) eddies in the subpolar (subtropical) gyres. We conclude that mesoscale ocean eddy-wind interaction can have a significant impact on ocean eddy energetics, with implications for the role the eddies play in ocean circulation and climate.

PO14G-2883 Impacts of far field forcing on the Southern Ocean Residual Overturning Circulation. ***Helen Burns*** *and Sybren S Drijfhout, Southampton University, Ocean and Earth Sciences, SOUTHAMPTON, United Kingdom*

The overturning circulation in the Southern Ocean consists of a residual overturning circulation (ROC) formed by opposing mean and eddy circulations. Although the ROC is part of the global overturning circulation, previous studies of the Southern Ocean ROC have explained this circulation from local surface wind and buoyancy forcing. Using a series of idealised MITgcm channel model runs we shown that the ROC cannot be maintained without incorporating a representation of diabatic processes to the north of the domain such as North Atlantic Deep Water formation. By relaxing to a set temperature profile at varying timescales in a sponge layer in the north of the domain a collapse of the ROC occurs when these processes become weaker, invoking a response in the diabatic eddy heat fluxes in order to modulate the ROC. We outline an updated Transformed Eulerian Mean scaling for the ROC to include its dependence on the stratification at the northern boundary and forcing by diabatic eddy fluxes. The robustness of this dependency on far field foricng is tested in a series of larger simulations incorporating the effects of topography, where the changes in the ACC due to far field forcing are also considered showing large changes in the baroclinic transport with changing relaxation timescales.

PO14G-2884 An Analysis of Energy Transfer Across Scales in the Leeward Intensification of a Standing Eddy

***Matthew W Hecht**, Los Alamos National Laboratory, Los Alamos, NM, United States and Hussein Aluie, University of Rochester, Rochester, NY, United States*

As the only major ocean basin that allows for fully circumpolar flow, the Southern Ocean has been identified as a region in which transient mesoscale eddies are especially important. Recent evidence indicates, however, that transient eddies alone do not generate the entire poleward heat transport that must dominate over the equatorward heat transport forced by the prevailing westerly winds. Instead, fixed meanders in the flow, which can be referred to as stationary waves or standing eddies, deliver much of the poleward heat transport. In our simplified problem a standing eddy sets up over the ridge which serves as the only bathymetry in a reentrant channel. In the lee of the ridge, the main jet becomes narrowly focussed. We apply a new analysis technique, described in Abstract id# 87364, that allows one to unambiguously quantify the energy transfer across length scales while retaining full temporal and spatial resolution, to better understand the interaction between transient eddies and the standing eddy. As it is the latter that delivers the majority of the poleward heat transport, our aim is to better understand how the transient eddies contribute to the poleward heat transport indirectly through this eddy-mean flow influence.

PO14G-2885 Ensembles of Eddying Ocean Simulations for Climate : Modeling Techniques, Diagnostics, First Results.

***Laurent Bessières**[1], Thierry Penduff[2], Stephanie Leroux[3], Jean-Marc Molines[2], Jean-Michel Brankart[2], Bernard Barnier[3] and Laurent Terray[4], (1)CERFACS-CNRS, Toulouse, France, (2)LGGE - Laboratoire de Glaciologie et Géophysique de l'Environnement, CNRS - Université Grenoble Alpes, Grenoble, France, (3)LGGE Laboratoire de Glaciologie et Géophysique de l'Environnement, Saint Martin d'Hères, France, (4)CERFACS European Centre for Research and Advanced Training in Scientific Computation, Toulouse Cedex 01, France*

Unlike laminar Ocean General Circulation Models (OGCMs), eddying OGCMs spontaneously generate a strong chaotic variability, not only at mesoscale but also up to basin- and multidecadal-scales. This component of the variability is largely sensitive to initial states and locally accounts for most of the low-frequency (interannual and slower) variance found in fully-forced oceanic hindcasts. Climate-oriented (multi-decadal) high-resolution ocean simulations therefore require ensemble approaches to disentangle the atmospherically-forced (ensemble mean) and the chaotic (ensemble spread) ocean variability components, and to quantify the uncertainty due to non-linear ocean dynamics.

The OCCIPUT project is currently performing the first 50-member ensemble of 1/4° global ocean/sea-ice hindcasts driven by the same realistic forcing over the last 57 years. The ensemble spread, produced through a stochastic

parameterization during the first year, subsequently grows and cascades toward long space and time scales. The NEMO model has been adapted to provide the following features : (1) simultaneous integration of the 50 members as one executable over several thousands of processors, so that ensemble (inter-member) statistics can be computed online as well ; (2) online production of ensemble synthetic observations allowing the use of probabilistic metrics for model assessment ; (3) flexible output archiving strategy through the use of 50 parallelized I/O servers.
We will present our modeling and processing approaches, some probabilistic products derived from this global ensemble run and from its regional (20-year 10-member North Atlantic) version, hence providing insights into the actual imprint of the atmosphere on the ocean variability.

PO14G-2886 Mechanical Energy Budgets for Regional Numerical Simulations ***Parker MacCready**, University of Washington Seattle Campus, Seattle, WA, United States*

Kinetic Energy and Available Potential Energy (KE and APE) budgets are potentially a useful way to describe the function of fluid systems. However a difficulty of using energy is that it can be hard to form closed budgets. To address this, a method is presented for calculating nearly closed energy budgets using output from ROMS. We focus on a realistic simulation of a regional coastal-estuarine domain in the NE Pacific. Another difficulty for energy budgets in regional domains such as this is the treatment of fluxes through the open boundary. For the our domain we demonstrate that these fluxes can be handled in a reasonable way by using the definition of "local" APE from Holliday and McIntyre (1981). We are able to form meaningful volume-integrated budgets over specific sub-regions, such as the continental shelf and the Salish Sea estuary. The APE may be partitioned into that due to parcels which are displaced up or down from the flattened rest state. It is found that wind-driven upwelling has a clear seasonal cycle of up-APE. In contrast, the down-APE which dominates the estuarine system has little seasonal cycle. Dividing the size of the estuarine APE reservoir by the rate at which APE is lost to advection gives a timescale of 11 months, consistent with the small seasonal variation of APE.

PO14G-2887 Dissipation and Mixing in Circulation forced by Differential Surface Heating in a Rotating Basin ***Catherine Ann Vreugdenhil**[1], Bishakhdatta Gayen[1] and Ross W Griffiths[2], (1)Australian National University, Research School of Earth Sciences, Canberra, Australia, (2)Australian National University, Research School of Earth Sciences, Canberra, ACT, Australia*

We consider the influence of rotation on circulation forced by a surface buoyancy gradient in a rectangular basin. Direct numerical simulations are reported for a rotating f-plane ocean with an applied surface temperature differential, Prandtl number $Pr=5$ and two values of the Rayleigh number which, in the absence of rotation, relate to the viscous ($Ra=7.4\times10^8$) and inertial ($Ra=7.4\times10^{11}$) regimes. The effects of rotation depend primarily on the parameter Q, the square ratio of the relative thicknesses of the thermal boundary layer to the Ekman layer. The strongly rotating regime is governed by geostrophic balance within the thermal boundary layer and causes this layer to become thicker, reducing the Nusselt number as $Nu\sim Q^{-1/3}$. At very strong rotation, the smaller Ra gives a conduction dominated regime with strong interior stratification and $Nu\sim 1$. The dynamics at larger Ra are rich, with small-scale turbulent convection in the thermal boundary layer, similar to the non-rotating case. Eddies extend through the depth of the interior outside the boundary layer over the heated region and can advect horizontally to the cooled region, thus eddy flux contributes significantly to the heat transport. The viscous dissipation remains unchanged by rotation to relatively large Q, and we attribute this to the larger Rossby numbers of small scale convection in the boundary layer. In contrast, the rate of mixing decreases throughout the geostrophic regime, scaling with Nu. Thus the global mixing efficiency $¥eta$ decreases with increasing rotation; however it remains consistent with the theoretical prediction $¥eta=1-(HNu/L)^{-1}$ (where H is height and L is length of the domain) for $HNu/L¥gg 2$. The efficiency also approaches unity in the conduction regime at extremely rapid rotation, and hence there is a trough in minimum $¥eta$ near the onset of rotational effects on turbulent dissipation scales in the boundary layer. With or without rotation, $¥eta$ approaches unity at large Nu, and therefore at large Ra.

PO14G-2888 The Latitudinal Dependence of the Oceanic Barotropic Eddy Kinetic Energy and Macro-Turbulence Energy Transport

ABSTRACT WITHDRAWN

PO14G-2889 Long-range Radiation of Barotropic Rossby Waves from an Unstable Current ***J. Thomas Farrar***[1], *Ted Durland*[2] *and Steven R Jayne*[1], *(1)Woods Hole Oceanographic Institution, Woods Hole, MA, United States, (2)Oregon State University, Corvallis, OR, United States*

The world oceans are filled with mesoscale eddies, but we do not understand how these eddies are energized. The mesoscale eddy field surely gains (and loses) energy via many mechanisms, such as instability of the local currents, local direct forcing (e.g., wind), and wave-wave interactions. One mechanism that has been advanced in recent years is local instability of the large-scale flow. Another potentially important mechanism for energizing the eddy field is nonlocal instability of the large-scale flow, in which a few of the world's most energetic currents radiate energy to the midocean gyres and other remote regions. Here, we provide an example to illustrate the potential importance of this process.

Analysis of sea-surface height (SSH) anomalies from satellite altimetry shows variability throughout the North Pacific that is coherent with Tropical Instability Waves. In the tropics (10N-20N) this variability has regular phase patterns that are consistent with barotropic Rossby waves having northward energy propagation (Farrar, J. Phys. Oceanogr., 2011). Further north, the phase patterns become confused and the variance decreases, but hot spots of coherent variability reemerge in the Gulf of Alaska and south of the Aleutian Islands. Ray-tracing calculations and comparisons with numerical simulations support the conclusion that this remote (and seemingly isolated) variability can indeed be attributed to barotropic Rossby waves generated near the equator and undergoing bathymetric refraction as they propagate northward. This sort of barotropic wave variability, coupled to mesoscale instabilities and occurring at similar space and time scales, contributes to the mesoscale variability observed in SSH.

PO14G-2890 Interior pathways to dissipation of mesoscale energy ***Balasubramanya T Nadiga***, *LANL, Los Alamos, NM, United States*

Nonlinear evolution of an unstable baroclinic wave at small Rossby and Froude numbers and in a small aspect ratio domain is considered as a setup to investigate interactions between scales that are geostrophically/hydrostatically constrained and those that are not. Both uniform and more realistic stratifications are considered and the interior submesoscale instability-related dissipation is quantified. In terms of phenomenology, mesoscale shear and strain resulting from the hydrostatic geostrophic baroclinic instability drive frontogenesis. The fronts in turn support ageostrophic secondary circulation and instabilities that cascade a small fraction of the balanced energy towards dissipation. A break is seen in the total energy (TE) spectrum at small scales: while a steep k^{-3} geostrophic scaling (where k is the three-dimensional wavenumber) is seen at intermediate scales, the smaller scales display a shallower $k^{-5/3}$ scaling, reminiscent of the atmospheric spectra of Nastrom & Gage. (For some of the details see J. Fluid Mech. (2014), vol. 756, pp. 965–1006; doi:10.1017/jfm.2014.464)

PO14G-2891 Eddy-mixing Entropy as a Measure of Mesoscale Turbulent Disorder in the Southern Ocean. ***Tomos Wyn David****, University of Oxford, Department of Physics, Oxford, United Kingdom, David Philip Marshall, University of Oxford, Oxford, United Kingdom and Laure Zanna, University of Oxford, Dept of Physics, Oxford, United Kingdom*

A novel study of Southern Ocean mesoscale turbulence is presented from a statistical mechanics perspective. An eddy-mixing entropy, a measure of turbulent disorder, is calculated for potential vorticity in coordinates of neutral density and time-mean Montgomery streamfunction. Combined with results from idealized channel models, this analysis provides a natural way of empirically investigating the geostrophic turbulence of the Southern Ocean from Bayesian statistics, or information theoretic, perspective. By considering the way the energy and enstrophy dynamics constrain the statistically steady state value of eddy-mixing entropy, progress is made towards a statistical mechanics description of a forced-dissipative channel flow. The response of eddy-mixing entropy to forcing and dissipation is investigated, examining the dependence of eddy-mixing entropy on time, longitude and neutral density in the Southern Ocean State Estimate. The concept of eddy-mixing entropy, and diagnosing its behavior in numerical ocean models, may prove valuable for developing improved stochastic parameterizations of ocean mesoscale turbulence.

PO14G-2892 Sensitivity of Horizontal Convection to Buoyancy and Wind-Stress Forcing ***Pierre-Yves Passaggia****, Varvara Zemskova, Brian L White and Alberto D Scotti, University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States*

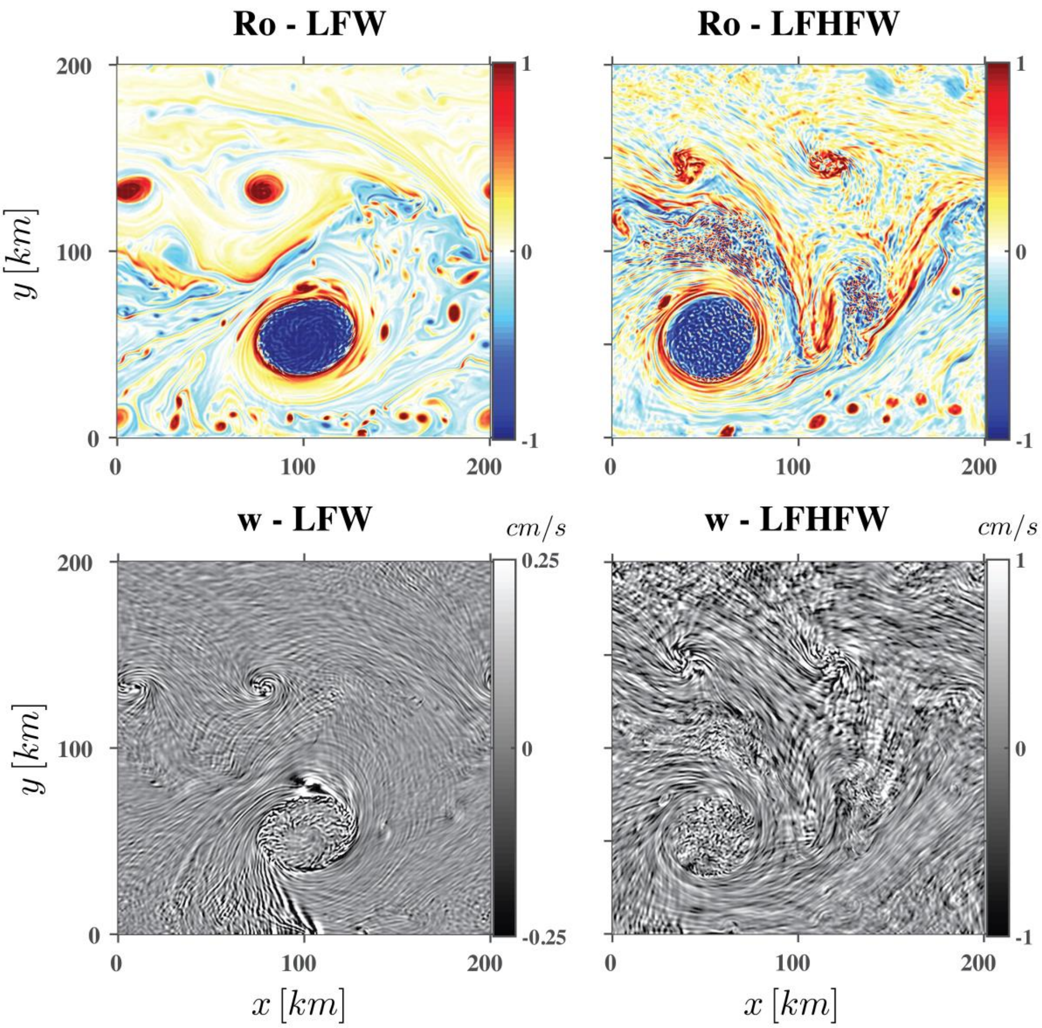
Horizontal Convection is a flow driven by differential buoyancy forcing across a horizontal surface. It has been considered as a simple model to study the influence of heating and cooling at the ocean surface on the Meridional Overturning Circulation. Here we consider the frequently-studied problem of horizontal convection driven by a step change in buoyancy, i.e. a transition from heating to cooling, along the surface.

We aim to compute the optimal buoyancy and wind stress perturbations which either maximize or minimize the overall circulation. We use the concept of local available potential energy as a measure of the circulation. The associated optimization problem is solved using the augmented Lagrangian approach. For instance this method allows for computing the sensitivity of the flow to the available potential energy flux inside the entire domain. Here the flow geometry consists of a rectangular box with an aspect ratio of 4 and the initial buoyancy distribution across the surface is given by a step function while enforcing zero wind stresses. Steady state solutions of the Navier-Stokes equations using the Boussinesq approximation at moderate Rayleigh numbers and Prandtl number close to unity have been considered.

The sensitivity analysis provides profiles for the optimal wind and buoyancy perturbations for a given Rayleigh number. We find that the response of the circulation to a small modification of the initial step profile is linear. However, further increasing the amplitude of the surface perturbation produces a nonlinear response and a dramatically increasing circulation. The impact of wind stresses and buoyancy are compared both concurrently and in isolation.

PO14G-2893 Enhancement of Mesoscale to Submesoscale Transition and the Forward Energy Cascade by High Frequency Wind Forcing ***Roy - Barkan***, *UCLA, Los Angeles, CA, United States, Kraig B Winters, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States and James C McWilliams, University of California Los Angeles, Los Angeles, CA, United States*

We study the effects of high frequency (HF) wind forcing on submesoscale dynamics and energy pathways in high-resolution numerical simulations of an idealized ‘Antarctic Circumpolar Current - like’ channel flow. We investigate three solutions: one forced by steady wind forcing (LFW) one forced by stochastic wind forcing (HFW) and one forced by both (LFHFW). We demonstrate that most of the HF wind work excites near inertial waves (NIWs) and that the frequency and wave number spectral slopes of the LFHFW solution are shallower than the LFW solution and match observations from the Southern Ocean. We show that an ~15% wind work increase, applied at high temporal frequency, results in a LFHFW solution with an ~25% increase in the conversion from available to eddy kinetic energy (EKE) and with a corresponding increase in the rate of EKE dissipation. Phenomenologically we observe amplification in the transition from mesoscales to submesoscales and enhancement of submesoscale instabilities. These results suggest that HF wind forcing and NIWs may play an important role in determining the energy pathways in the upper ocean.



Rossby number and vertical velocity at 100 m depth for the steady wind forced solution (LFW) and the steady + stochastic wind forced solution (LFHFW).

PO14G-2894 Energetics of a model ocean basin with surface buoyancy and wind forcing ***Varvara Zemskova*[1]**, *Brian L White*[1] *and Alberto D Scotti*[2], *(1)University of North Carolina at Chapel Hill, Chapel Hill, NC, United States, (2)University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States*

We present a new test case for rotating horizontal convection, where the flow is driven by differential buoyancy forcing along a horizontal surface. This simple model is used to understand and quantify the combined influence of surface heating and cooling and surface wind stress on the Meridional Overturning Circulation. The domain is a rectangular basin with cooling at both ends (to represent the poles) and warming in the middle (equatorial) region. To model the effect of the Antarctic Circumpolar Current (ACC), a zonally reentrant channel is placed near the Southern pole, where periodic boundary conditions are imposed. The model is forced by wind stress and buoyancy along the surface. The problem is solved numerically using a finite-volume Adaptive Mesh Refinement solver for the Boussinesq Navier-Stokes equations with rotation. Simulations are run at a Rayleigh number of 10^8 with different strengths and combinations of surface buoyancy and wind forcing in a domain with a relatively high aspect ratio of [5, 10, 1] in zonal, meridional and vertical directions, respectively. For each simulation, terms in the energy budget are calculated using the local Available Potential Energy framework introduce in Scotti and White

(2014, J. Fluid Mech.) to investigate the effects of surface forcing on the large-scale overturning, baroclinic eddy generation in the ACC, deep convective plumes, and diapycnal mixing.

PO14G-2895 From Internal Gravity Waves to the Mesoscale: Potential and Kinetic Energy Frequency Spectra in Global Ocean Models versus Data. ***Conrad A Luecke***[1], *Brian K Arbic*[1], *Joseph K Ansong*[1], *Steven Bassette*[1], *Maarten C Buijsman*[2], *Dimitris Menemenlis*[3], *Jim G. Richman*[4], *Jay F Shriver*[5], *Patrick G Timko*[6], *Alan J Wallcraft*[7] *and Luis Zamudio*[8], *(1)University of Michigan Ann Arbor, Ann Arbor, MI, United States, (2)University of Southern Mississippi, Stennis Space Center, MS, United States, (3)Jet Propulsion Laboratory, Pasadena, CA, United States, (4)Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL, United States, (5)Naval Research Lab, Stennis Space Center, MS, United States, (6)Bangor University, Bangor, LL59, United Kingdom, (7)Naval Research Laboratory, Stennis Space Center, MS, United States, (8)Florida State University, Tallahassee, FL, United States*

Global ocean models with spatial grids on the order of a few kilometers are on the cusp of resolving small-scale, higher-frequency motions, such as tidally generated and supertidal internal gravity waves. The question arises as to how the spatial resolution of these models changes the dynamics and energetics of motions ranging from the mesoscale to the supertidal.

We compare modeled kinetic and available potential energy frequency spectra with a global archive of historical moored instruments across periods spanning hours to years, thus encompassing a wide range of dynamic oceanic processes. We use global simulations of both the MIT General Circulation Model (MITgcm), and the HYbrid Coordinate Ocean Model (HYCOM). Both models are run at varying horizontal resolutions (1/12, 1/24, and 1/48 degree for MITgcm, and 1/12, 1/25 degree for HYCOM). In addition, all of the model runs examined are forced by both atmospheric fields and the astronomic tidal potential, thus ensuring that energy is injected across the oceanic frequency spectrum.

Examination of the impact of changing spatial resolutions on global ocean energetics helps to validate the use of high resolution general circulation models in the study of mesoscale and internal wave energy reservoirs

PO14G-2896 Interactions between inertial oscillations and geostrophic flows in the upper ocean ***Jim Thomas***, *K Shafer Smith and Oliver Buhler, New York University, New York, NY, United States*

energy transferred to the ocean by atmospheric forcing. These oscillations are superimposed on the balanced mesoscale eddy field, which acts to focus and refract the waves, speeding up their propagation into the abyss. The detailed nature of the interaction between near-inertial waves and eddies has been studied by a number of researchers, but in different parameter regimes, which can be characterized by the relative strength of the waves' dispersion: strong, weak, or very weak (depending on the relative magnitude of the Rossby number of the balanced flow and the Burger number of the baroclinic inertial waves). In the present work we formulate a unified treatment of the different regimes, and demonstrate, theoretically and numerically, their relative importance in the natural evolution of a near-inertial wave.

To illuminate the processes, we first explore the dynamics of the regimes, and demonstrate inter-regime transitions, in a one-dimensional rotating shallow water model with an imposed geostrophic flow. We follow this with a more detailed investigation, especially for the strong dispersion limit, in the hydrostatic Boussinesq equations. Our results include detailed descriptions of the waves' dynamics over three different interaction time scales and feature the formation of small-scale inertial waves trapped in the upper ocean, as well as waves that propagate vertically into the deep ocean within a few inertial periods. On even longer timescales, of the order inverse squared Rossby number, the kinetic energy of the geostrophic flow is seen to modulate these modes leading to additional vertical dispersion.

Time permitting, we will also discuss recent demonstrations of an energetic interaction between balanced flow and near inertial waves that occurs in a distinct parameter regime, applicable when the wave energy is large compared to the eddy energy. Using multiscale asymptotic analysis in the fully nonlinear shallow water equations, we derive a coupled model that captures the joint slow evolution of inertial waves and geostrophic balanced flow. The interaction is also examined by numerical simulation of an initial value problem in the shallow water equations.

PO21C The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller I

Tuesday, February 23, 2016

08:00 AM - 10:00 AM

Ernest N. Morial Convention Center

- 203-205

Papers

08:00 AM PO21C-01 NEAR-INERTIAL PROPAGATION INSIDE MESOSCALE EDDIES ***Marie-Pascale Lelong***[1], *Pascale Bouruet Aubertot*[2,3] *and Yannis Cuypers*[3], *(1)Northwest Research Associates, Redmond, WA, United States, (2)Universite Pierre et Marie Curie, Paris, France, (3)LOCEAN UPMC, Paris, France*

近慣性波の地中海高気圧性渦でのエネルギー伝搬の数値実験

Cuypers et al. 2012 の観測に対応する数値実験。

The present study was motivated by observations of intense near-inertial wave activity above and below the core of the semi-permanent anticyclonic Cyprus eddy in the Eastern Mediterranean during the BOUM field campaign.

To explain the observations, we have conducted a general numerical study of eddy/near-inertial interactions with a Boussinesq (nonhydrostatic) model. The problem is posed as an initial-value problem, with initial conditions consisting of an isolated shielded vortex in geostrophic equilibrium and surface-intensified near-inertial oscillations designed to simulate a uniform wind impulse. When ambient parameters (eddy strength and extent, mean stratification profile) are matched to the BOUM observations, our numerical results replicate quite well the wavelengths and intensity of the observed near-inertial wave field inside and below the Cyprus eddy core. The nature of near-inertial wave propagation inside an eddy is further explored as a function of initial near-inertial amplitudes at the surface and ambient stratification. Downward near-inertial propagation is most pronounced in the center of the eddy where the vortex velocity is zero (anticyclonic vorticity a maximum), and can be explained by means of a simple theoretical formulation based on transmission coefficients in a piecewise-linear approximation to the density profile. Extension to propagation within a field of several eddies is also discussed.

08:15 AM PO21C-02 Numerical Simulations of the Competition Between Restratification and Mixing Induced by Submesoscale Instabilities ***Megan A Stamper***[1], *John Ryan Taylor*[2], *Kate Adams*[3], *Scott Bachman*[2], *Phil John Hosegood*[4], *Jean-baptiste Sallee*[5] *and Ricardo Torres*[6], *(1)University of Cambridge, Department of Applied Mathematics and Theoretical Physics, Cambridge, United Kingdom, (2)University of Cambridge, Cambridge, United Kingdom, (3)Plymouth University, Plymouth, PL4, United Kingdom, (4)Plymouth University, School of Marine Science and Engineering, Plymouth, United Kingdom, (5)University Pierre and Marie Curie Paris VI, Paris, France, (6)Plymouth Marine Laboratory, Marine Ecosystem Modelling and Predictions, Plymouth, United Kingdom*

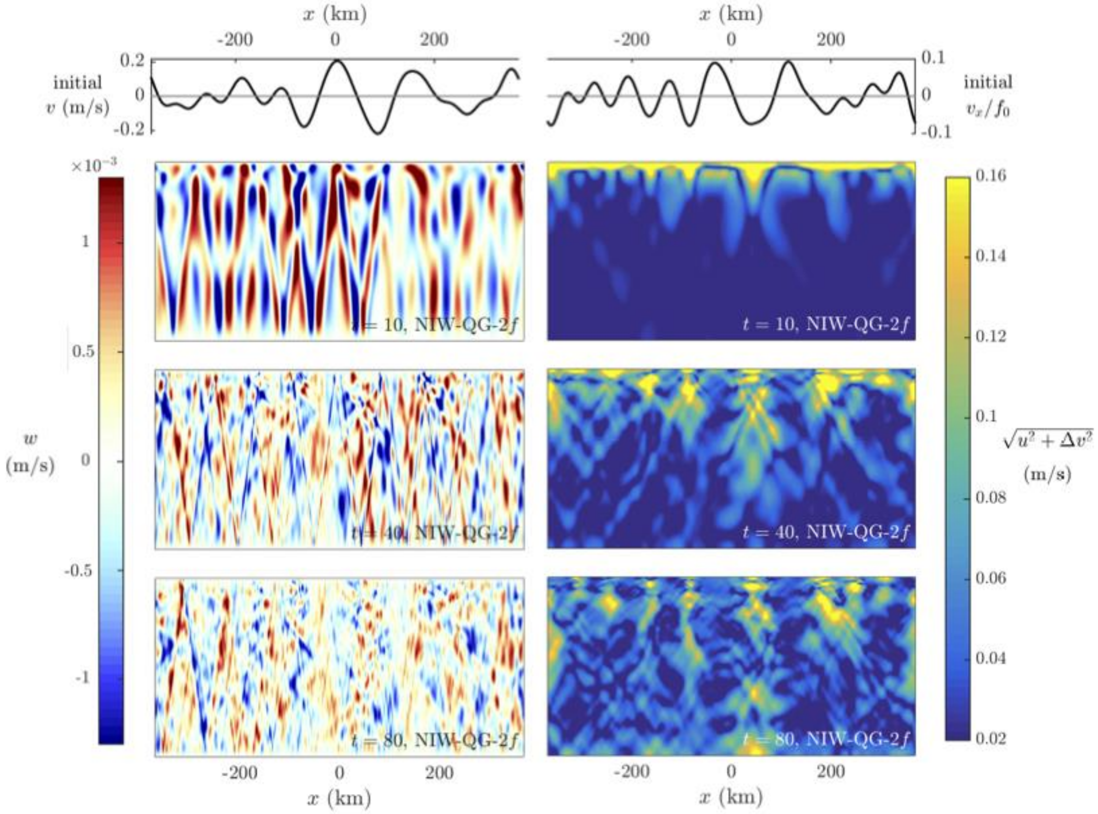
サブメソスケールの数値実験。鉛直シアを持つ基本流において生じる傾圧不安定と対象不安定を、Ri=N^2H^2/Ug^2 と定義し、高解像度計算と啓解像度計算を比較した。Ri=1 では、高解像度計算が早くから傾圧不安定渦が切離し、Ri=0.25 では３D 乱流が発生した。

Previous work has suggested that submesoscales play an important role in setting the stratification of the upper ocean; such scales are believed to be associated with large vertical velocities and therefore capable of modifying biological productivity. In this study, the feedbacks between submesoscales and small-scale turbulence are explored using very high resolution numerical simulations. Modelling an idealised domain representative of the upper mixed layer, we find submesoscale motions generated via symmetric and baroclinic instability. These, in turn, via the emergence of secondary instabilities, are able to generate significant small-scale turbulence and mixing even in the absence of surface wind and buoyancy forcing. Using comparison with lower resolution simulations in the same domain we are able to quantify the extent to which fully resolving these submesoscale features and the resulting small scale turbulence impacts on instability growth rates, mixing and dissipation, restratification of the mixed layer and vertical fluxes.

08:30 AM PO21C-03 Coupled Evolution of Near-inertial Waves and Quasigeostrophic Flow ***Gregory LeClaire Wagner***, *University of California San Diego, Mechanical and Aerospace Engineering, La Jolla, CA, United States and William R Young, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States*

近慣性波、2f の波動、準地衡流場の間のエネルギーのやり取りを、各々の方程式に成分間の相互作用項を加えた３つの方程式を導出し、３成分モデルにおいて調べたところ、元々近慣性の低鉛直波数にあったエネルギーが、地衡流場を媒介にして、2f で低鉛直波数の波動に変換され、それが PSI 機構によって、高鉛直波数の近慣性波となり、小スケールに移行することがわかった。論文は 2015JFM に出版された。

A fundamental concern of ocean circulation theory are the pathways by which kinetic energy cascades from the large scales of wind forcing, tides, and eddying mesoscale flows to the small scales of internal wave breaking. Near-inertial waves with local Coriolis frequency f_0 are likely a key participant, since they comprise half of the total kinetic energy in oceanic internal waves, have small vertical scales, and are exposed to energetic interaction with non-wave mesoscale and submesoscale flows by their low frequencies and slow propagation. Here, we present an asymptotic model which isolates the nonlinear and coupled co-evolution of near-inertial waves and quasigeostrophic flow from the Boussinesq equations. A principal result of the “NIW-QG” model implied by its two conservation laws is that near-inertial waves — which may be externally forced by winds, tides, or flow-topography interaction — can extract energy from mesoscale or submesoscale quasigeostrophic flows. A second and separate implication of the model is that this wave-flow interaction catalyzes a loss of near-inertial energy to freely propagating near-inertial second harmonic waves with frequency $2f_0$. The newly-produced $2f_0$ waves both propagate rapidly to depth and transfer energy *back* to the near-inertial wavefield at very small vertical scales. The upshot of this $2f_0$ generation is a two-step mechanism whereby quasigeostrophic flow catalyzes a nonlinear cascade of near-inertial energy to the small scales of wave breaking and mixing.



Snapshots showing near-inertial wave evolution in the NIW-QG model. The near-inertial wave evolves from a horizontally uniform, surface-concentrated initial condition in a random two-dimensional barotropic flow. The domain is periodic and 739km wide in the horizontal, and 4km deep and bounded by rigid lids in the vertical. The top panels show quasigeostrophic v-velocity (left) and Rossby number (right). The lower three panels show wavefield horizontal speed (right) and vertical velocity (left) at t=10, 40, and 80 inertial periods. The vertical velocity that fills the domain at t=10 inertial periods corresponds to freely propagating waves with $2f_0$ frequency. The two-dimensionality precludes advection of quasigeostrophic potential vorticity, such that v-velocity evolution occurs only due to changes in wave-induced mean flow.

08:45 AM PO21C-04 Effects of Submesoscale Eddies and Small-Scale Langmuir Turbulence on Multi-Scale Fluxes, Flow Instabilities, and Spectra in the Oceanic Mixed Layer ***Peter Hamlington***[1], *Katherine Smith*[1] *and Baylor Fox-Kemper*[2], *(1)Univ of Colorado, Boulder, CO, United States, (2)Brown University, Providence, RI, United States*

2014 論文有。等密度線が傾斜した混合層における対称不安定による水平スケール O(1-10km)時間スケール O(1day)のサブメソ渦と、重力不安定に伴う O(1m-1km)、O(10-100s)のシア・カングミュア乱流について、数値モデルで調べた。

Interactions between three-dimensional Langmuir turbulence and quasi two-dimensional submesoscale processes are examined in the oceanic mixed layer using large eddy simulations of the spin-down of a mesoscale temperature front. The simulations solve the Boussinesq equations both with and without Stokes drift wave forcing in a computational domain of size 20km x 20km x -160m with 5m horizontal and 1.25m vertical resolution. The enormous scale range in the simulations allows interactions between kilometer-scale submesoscale eddies and small-scale Langmuir turbulence to be studied, and also reveals the presence of a “double” spectral energy cascade consisting of a two-dimensional cascade at large scales and a three-dimensional cascade at small scales. The effects of submesoscale eddies and Langmuir turbulence on spatial and spectral properties of velocity, buoyancy, and biochemically-relevant tracers are described, and multiscale fluxes are used to show that Langmuir turbulence counters the restratifying effects of submesoscale eddies, resulting in substantially greater vertical mixing of buoyancy and tracers as well as reduced prevalence of symmetric instabilities associated with submesoscale processes. Conversely, counter-gradient tracer transport occurs co-located with regions of negative potential vorticity, suggesting that symmetric instabilities or other submesoscale phenomenon may themselves act to oppose small-scale turbulent mixing. The implications of these results for parameterizations of buoyancy, momentum, and tracer transport in the oceanic mixed layer are briefly discussed.

09:00 AM PO21C-05 The Role of the Wind and Mesoscale Eddies in Internal Wave Driven Mixing at Midlatitudes

Caitlin Whalen*, Jennifer A MacKinnon and Lynne D Talley, University of California San Diego, La Jolla, CA, United States*

渦の運動エネルギーEKE が大きいところで、大きな乱流エネルギー散逸が生じる傾向があるかどうか、中緯度 30-60N での冬季の強風による近慣性波が混合を強化する、ということを通じてか、あるいは、傾斜する等密度面に対応（Whitt & Thomas 2012; Inoue et al. 2010; Ford 1994）するのか、などを検証するために、アルゴの CTD データとストレインを用いたパラメタリゼーションを使って散逸率を算出し調べた。強度が変る季節ごとに調べると、時計周り渦が高い散逸率に対応していた。

An array of mechanisms have been suggested by previous modeling, theory, and process-scale observations that may link mesoscale dynamics and internal waves to set the mixing patterns throughout the world. Proposed processes include those where the mesoscale facilitates the dissipation of internal waves, and those where the mesoscale aids in the generation of internal waves. To evaluate whether these processes may make a noticeable impact on the energy dissipation rate at regional and global scales we employ a strain-based finescale parameterization, generating estimates of the dissipation rate using Argo float density profiles. These dissipation rate estimates are then associated with the nearest detected eddy from the Chelton eddy product and the history of the near-inertial energy flux from the winds at that location. We find evidence in support of the mesoscale modulating the wind-induced internal wave dissipation patterns and seasonal cycle. We also observe that a stronger mesoscale is correlated with an elevated dissipation rate, independent of the energy flux into the internal wave field from the winds. These results allow us to hypothesize which of the many mechanisms may be of large-scale importance.

09:15 AM PO21C-06 Mid-depth mixing under the subpolar front at the Mid-Atlantic Ridge ***Maren Walter** and Christian Mertens, University of Bremen, Bremen, Germany*

GRL2103 では、北大西洋 subpolar current(NAC)/front が mid-Atlantic Ridge（MAR）と交差する付近で大きな中層混合が生じていることを示した。NAC が深層に及び、MAR と相互作用により渦が発生し、混合を強化していると考えられた。

Finescale parameterizations of diapycnal mixing are now widely used to expand the data base of ocean mixing observations for a better spatial coverage than direct microstructure measurements. Further, they are also a useful tool to assess temporal changes of the strength and distribution of internal wave energy and mixing in the ocean, and thereby identify the processes responsible for these distributions. Here, we use an 8 year data set to examine the temporal variability of mixing estimated from internal wave finestructure at the part of the Mid Atlantic Ridge (MAR) where the subpolar front crosses the ridge from west to east Atlantic. Earlier estimates of finescale mixing at this location (based on 3 realizations) revealed a temporal variability of mixing strength at mid-depth below the NAC. The observed mixing strength was linked to the presence of an NAC core, and the pattern of energy dissipation depended on the position of the subpolar front. The extended data set now covers the years from 2008 to 2015, with seven repeats of a hydrographic section reaching roughly from 47° N to 53° N along the MAR, west of the ridge crest, and confirms the presence of enhanced mixing below the NAC/subpolar front. The coverage of years with strong negative (2010) as well as positive (2012) winter North Atlantic Oscillation indices and associated fluctuations in NAC position and volume transport allows to examine the effects of variations in external parameters like strength (volume transport) and structure of NAC interacting with the topography, stratification, presence of eddies and surface eddy kinetic energy on the distribution of mixing in the water column, especially at mid-depth where it potentially impacts deep water transformation.

09:30 AM PO21C-07 Upper Ocean Turbulent Processes in the Antarctic Frontal Zones ***Sophia Merrifield***[1,2], *Louis St Laurent*[2], *Andreas Thurherr*[3], *John Merrill Toole*[2] *and Breck Owens*[2], *(1)Massachusetts Institute of Technology, Cambridge, MA, United States, (2)Woods Hole Oceanographic Institution, Woods Hole, MA, United States, (3)Lamont-Doherty Earth Observatory of Columbia University, NY, United States*

ファインスケールパラメタリゼーションを用いた散逸率推定は、変動の大きな前線域躍層付近では VMP で計測したものよりも、1-2 オーダー過大評価している可能性がある。

A number of processes in the Southern Ocean are thought to support high levels of mixing relative to other regions of the global ocean. At the surface, strong winds and storms force the ocean at near-inertial frequencies, generating internal waves that can propagate downward and break. Deep reaching currents associated with density fronts flow over rough topography generating internal lee-waves which radiate energy and provide power for turbulence in the stratified ocean interior. Watermass variability and strong mesoscale activity also precondition the water column for double-diffusive instability. Due to the remote location and harsh conditions, few direct measurements of turbulence have been collected in the Southern Ocean. Direct measurements of oceanic turbulent parameters were taken upstream of and across Drake Passage, in the region of the Subantarctic and Polar Fronts. Values of turbulent kinetic energy dissipation rate, estimated by microstructure are up to two orders of magnitude lower than previously reported fine-structure derived estimates in the upper 1000m. Despite the prevalence of wind forcing, turbulence driven by near-inertial shear is weak. The dissipation rate of thermal variance is enhanced in the upper 1000m, with the highest values found in northern Drake Passage where water mass variability is the most pronounced. Using the density ratio, evidence for mixing by double-diffusive instability is presented, and implications for the mixing efficiency are also discussed.

09:45 AM PO21C-08 Energy Cascade from Internal Modes in Non-uniformly Stratified Fluid through Excitation of Superharmonic Disturbances ***Bruce R Sutherland***, *University of Alberta, Edmonton, AB, Canada*

Mackinnon & Winters 2005GRL の PSI による臨界緯度での乱流強化は、一様成層モデルの結果であり、実際の海洋観測からは明確になっていない。Hazewinkel & Winters (2011JPO)。PSI は N が鉛直方向に変化するときには、明確にならないことが示唆された。

It is well established that two-dimensional internal plane waves and modes in uniformly stratified fluid efficiently transfer energy to smaller scale waves and ultimately turbulent mixing through parametric subharmonic instability

(PSI). The numerical simulations of MacKinnon & Winters (GRL 2005) predicted PSI should act efficiently to disrupt the internal tide. However, while in situ observations showed the presence of PSI, it was not found to be appreciable. One reason for the discrepancy between simulations and observations is that the former examined an internal mode in uniformly stratified fluid whereas, in reality, the internal tide exists in non-uniform stratification and is manifest as sinusoidal oscillations of the thermocline.

Through theory supported by numerical simulations, it is shown that internal modes in non-uniform stratification immediately excite superharmonics, not subharmonic disturbances. These have double the horizontal wavenumber and double the frequency of the parent mode and hence move with the same horizontal phase speed of the parent mode. As the disturbances grow in amplitude, however, they interact with the parent mode generating small-scale vertically propagating internal waves within the strongly stratified layer. The occurrence of PSI over very long times can occur, as in the simulations of Hazewinkel and Winters (JPO 2011). However, a comprehensive understanding of the energy cascade from the internal tide to small scales must consider the evolution of excited superharmonic disturbances.

PO23C The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller II

Tuesday, February 23, 2016

02:00 PM - 04:00 PM

Papers

02:00 PM PO23C-01 Deep Cycle Turbulence and Oceanic Heat Uptake in the Eastern Equatorial Pacific ***William Smyth***, *Oregon State University, Corvallis, OR, United States and Jim Moum, Oregon State University*

散逸率 ε＝2.7*10^-3*(**τ・S**/密度)^3/Jb^2　τは日平均風応力、Sは流速鉛直シア、Jbは日平均浮力フラックス、とχポッドのデータを用いて校正し、エルニーニョEとラニーニャLで平均の散逸率がEが大きいが、ピーク値はLが大きいことなどを示した。

The eastern Pacific cold tongue is a prime location for heat transfer into the ocean. The effect of this heat uptake on climate is determined in part by vertical transport: heat remaining near the surface can be returned to the atmosphere on a timescale of days, whereas heat transferred into the thermocline by turbulent mixing may not contact the surface again for centuries. Below the surface mixed layer, the so-called "deep cycle" turbulence dominates vertical transport. The mechanism of the deep cyce is not fully understood, but it depends on a combination of the stratified, parallel shear flow on the upper flank of the equatorial undercurrent and nonlocal forcing due to diurnally varying surface fluxes. In this presentation I will use data from the TOGA-TAO mooring array in combination with a new parameterization of deep cycle turbulence to estimate the strength of the turbulent heat flux over a period of 20 years and to show how it varies over diurnal, seasonal and ENSO cycles.

02:15 PM PO23C-02 Enhanced Energy Dissipation in the Equatorial Pycnocline in a Simple Model of a Tropical Ocean ***Andrei Natarov***, *IPRC/SOEST Univ Hawaii, Honolulu, HI, United States*

運動エネルギーの散逸が強化されることを簡素化したモデルで示した。

Numerical experiments show that in a zonally symmetric model of a tropical ocean forced by transient wind stress both inertia-gravity wave (IGW) activity and the energy dissipation rate have a pronounced maximum in the pycnocline close to the equator regardless of the latitudinal distribution of the energy input into the ocean's mixed layer by the wind. We show that this equatorial enhancement is due to a combination of three factors: a stronger superinertial component of the wind forcing close to the equator, wave action convergence at turning latitudes for various equatorially trapped waves, and nonlinear wave-wave interactions between equatorially trapped waves. Another possible mechanism is wave-breaking during refraction of IGWs at the top of the pycnocline. We show that the latter mechanism can operate at any latitude, but is limited in its capacity to amplify the Froude number associated with propagating IGW packets and requires short (shorter than the local inertial period) energetic wind bursts to produce enhanced mixing.

02:30 PM PO23C-03 Internal Waves, Shear, and Mixing at the Equator ***Jerome A Smith*** *and San T Nguyen, Scripps Institution of Oceanography, La Jolla, CA, United States*

Data from a month long expedition at the equator in October-November 2012 ("EquatorMix," near 140W) are used to examine relations between high-frequency internal waves, strong shears, and mixing in the upper 200 m. During this time, the Equatorial Undercurrent was unusually strong, peaking over 1.5 m/s relative to the surface at about 120 m depth. This corresponds to a mean shear of order 0.0125 s^-1 (1/80s)! A turbulent eddy rotating at the same rate would have a turn-over time of pi*80s, a little over 4 minutes. This is quite close to the buoyancy frequency over the same depth range, so there exists the possibility of direct interactions between such eddies and internal waves. The mean Richardson number over this depth range is often under 0.5; with such a low mean Richardson number, almost any perturbation can excite turbulence and mixing. One analysis issue in the presence of such strong shear is to separate the effects of vertical advection of the mean shear from the horizontal velocity perturbations due to high-frequency internal waves. With a Phased-Array Doppler Sonar (PADS) looking at a vertical slice on a vertical plane parallel to the ship's track, we get robust estimates of the vertical velocity that are not subject to the troubles of beam-separation becoming comparable to the internal waves' length; integrating this to obtain vertical displacements over a narrow frequency band proves fairly effective at making the above distinction; this also helps us to refine our estimate of the temporal offset between isopycnal depths and the HDSS-based horizontal velocities (due mainly to being measured at different locations along the ship). We find that "packets" of high-frequency internal waves often occur near times of "shear events" associated with mixing, though we can't say whether there is a causal relation (or, if so, in which direction).

02:45 PM PO23C-04 BUOYANT GRAVITY CURRENTS RELEASED FROM TROPICAL INSTABILITY WAVES ***Sally J Warner***[1], *Ryan Holmes*[2], *Jim N Moum*[3] *and Elizabeth H McHugh Hawkins*[1], *(1)Oregon State University, CEOAS, Corvallis, OR, United States, (2)Stanford University, Stanford, CA, United States, (3)Oregon State Univ, Corvallis, OR, United States*

太平洋赤道域には、衛星では捉えきれない小スケールのフロントが存在。このフロントの暖かい側では、冷たい側に比べて、3 倍大きな散逸率を観測（注意：下記要旨を見ると 1000 倍とあるので、3 倍は Factor 3 という事だったのかもしれない）。暖かい水塊は、重力流として移動し、この移動速度は、赤道不安定波の伝播速度と一致。

Extremely sharp fronts with a 0.5°C sea surface temperature change over lateral distances of ~2m were observed in the equatorial Pacific on two occasions at 0°, 140°W and at 0.75°N, 110°W. In both cases, relatively warm and fresh water extending to 50m depth propagated to the southwest as a buoyant gravity current. This is confirmed by comparing estimates of front propagation velocity, calculated from a variety of shipboard and moored instruments, to theoretical gravity current models. Turbulent kinetic energy dissipation rates exceeding 10^{-4} W kg^{-1} were measured with a microstructure profiler on the warm/fresh side behind the leading edge of the front — 1000 times greater than dissipation rates found on the quiescent side. From satellite images, these gravity currents were observed to propagate ahead of the trailing edge of a tropical instability wave (TIW) cold cusp. The observations are compared to a numerical model of the equatorial Pacific with 6km horizontal resolution. The model results suggest that TIW fronts may release gravity currents through frontogenesis and loss-of-balance as the fronts approach the equator. While the lateral scale of the modeled fronts is many times larger than the observed fronts, they appear to obey a similar dynamical balance between pressure gradient and across-front acceleration.

03:00 PM PO23C-05 The Tasman Tidal Dissipation Experiment: Tidal Mixing, Scattering, and Reflection on the East Tasman Slope ***Robert Pinkel***[1], *Matthew H Alford*[2], *Andrew Lucas*[3], *Shaun Johnston*[1], *Nicole L Jones*[4], *Sam Kelly*[5], *Jody M Klymak*[6], *Jennifer A MacKinnon*[1], *Jonathan D Nash*[7], *Luc Rainville*[8], *Harper L Simmons*[9], *Peter G Strutton*[10], *Amy Frances Waterhouse*[1] *and Zhongxiang Zhao*[11], *(1)University of California San Diego, La Jolla, CA, United States, (2)Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United*

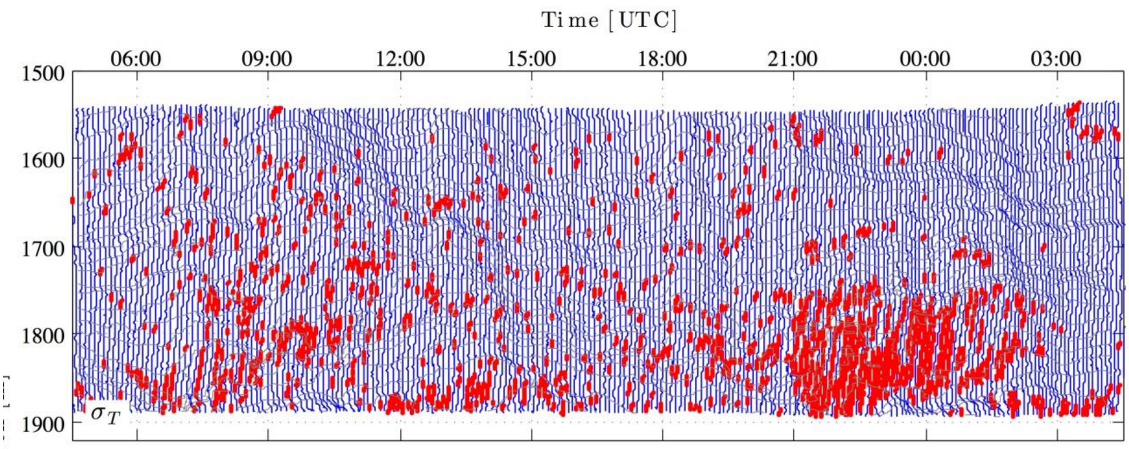
States, (3)Scripps Institution of Oceanography, La Jolla, CA, United States, (4)University of Western Australia, Crawley, WA, Australia, (5)University of Minnesota Duluth, Duluth, MN, United States, (6)University of Victoria, Victoria, BC, Canada, (7)Oregon State Univ, Corvallis, OR, United States, (8)University of Washington, Applied Physics Laboratory, Seattle, WA, United States, (9)University of Alaska Fairbanks, Fairbanks, AK, United States, (10)University of Tasmania, Hobart, TAS, Australia, (11)Applied Physics Laboratory University of Washington, Seattle, WA, United States

T-Tide プロジェクトについて。タスマニア海南東の海嶺で発生した半日周潮内部潮汐が、タスマニア沖の斜面にぶつかった時の反射・混合過程について研究。船舶のほかグライダーも用いて、入射波と反射波による定在波の形成などを明らかにしている。入射波の 6-9 割のエネルギーが、タスマニア南から反射。

To maintain the thermohaline circulation of the ocean in steady state, the sinking of dense waters at high latitude must be balanced by mixing processes in the deep sea. Such mixing is anticipated at sites where baroclinic tides dissipate, among other places. To date, however, the primary observational focus has been on baroclinic generation, not dissipation, sites.

During January-March 2015, the NSF TTIDE Experiment investigated deep-mixing processes on the eastern slope of Tasmania. A well-focused semi-diurnal baroclinic tidal beam generated on the Macquarie Ridge south of New Zealand transits the Tasman Sea and impinges on this slope. The objective of TTIDE is to identify the various small-scale processes associated with tidal shoaling, dissipation, and reflection on the slope and to assess the potential role of such processes in the general circulation of the ocean.

Guided by initial glider reconnaissance and numerical simulations, arrays of moorings were deployed at a southern (reflective-supercritical) site and a northern (dissipative-critical) region. Supplemental experiments T-BEAM and T-SHELF mapped the incoming tidal beam and quantified its signature on the continental shelf. Shipboard surveys using LADCPs and a fast-profiling CTD indicate elevated mixing regions 1-300 m above the slope at depths of 500-2200 m, with high-mode wave-beams in mid-water and near-bottom bores. These intense deep-mixing events occur even though the majority of the incoming tidal energy appears to be reflected northeastward, back into the Tasman Sea. Locally generated semi-diurnal and topographically-trapped diurnal tides are also dissipating on the slope. A more complete picture of this tidally forced slope and shelf will emerge as TTIDE data are synthesized.



03:15 PM PO23C-06 [Diffraction and Reflection of the Internal Tide on the Tasman Continental Slope](#) *Jody M Klymak, University of Victoria, Victoria, BC, Canada and* ***Harper L Simmons****, University of Alaska Fairbanks,*

Fairbanks, AK, United States
MITgcm による、タスマニア沖斜面での反射過程を解析。外力として、M2 第一モードを与えた。入射波のエネルギーの大半が反射。入射波は、斜面に入射する前にタスマニア Rise にぶつかって、回折しているのが見られた。
An internal tide impacts the region of the Tasman continental slope, as evidenced by numerical simulations and satellite altimetry. The character of its reflection is discussed here using a suite of observations and simulations. A pair of glider antennae find compelling evidence of a standing wave pattern along the slope, with at least 70% of the incoming energy being reflected. They also find stronger reflectance at southern end of the slope. Standing patterns are also found by fitting plane waves to satellite altimetry. A wide lateral beam (>500 km) impacts the region. Intriguingly, the response is split into two reflected beams. 1-km resolution numerical simulations bolster these observations. The incoming beam is prescribed in the model. It diffracts around the Tasman Rise, a 100-km radius and 1000-m high plateau just upstream of the continental slope. The diffraction leads to two peaks of internal tide energy reaching the continental slope, one directly downstream of the incoming beam, and a second lobe projected further north. These two lobes explain the reflected pattern seen in the altimetry. The peaks of the diffraction pattern are about 200-km wide, so mooring arrays and large-scale plane wave fits are challenged to resolve it.
03:30 PM PO23C-07 Internal tide breaking processes at the Tasman Continental Slope ***Matthew H Alford***, *University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States and The TTIDE Team*
The Tasman Tidal Dissipation Experiment (TTIDE) sought to measure and understand the reflection and dissipation of internal tides at the Tasman continental slope, which is irradiated by a strong collimated beam generated at the McQuarie Ridge south of New Zealand. Because the strongest part of the beam impacts the most reflective part of the slope, the dissipative processes and reflective fraction differ from the northern flank of the beam which impacts a more critical slope. At northern sites, dissipation occurs primarily via lee wave breaking over a deep 3D bump and atop a nearly critical portion of the slope near 1500 m depth. At the southern slope, dissipation is due to along-ridge flow over corrugations superimposed on the supercritical slope. In this talk we describe towed and moored observations of these two types of dissipation physics.
03:45 PM PO23C-08 Pathway from tides to turbulence: fission of internal solitary waves over rough topography
Zhiyu Liu[1], *Xiaolin Bai*[1] *and Tom Philip Rippeth*[2], *(1)Xiamen University, Xiamen, China, (2)Bangor University, School of Ocean Sciences, Bangor, Wales, United Kingdom*
The tides are a major energy source of small-scale turbulence, and therefore diapycnal mixing, in the world's oceans. An understanding of the processes responsible for the cascade of energy from tides to turbulence is important in identifying when and where this mixing will take place. Internal solitary waves (ISWs) generated by tide-topography interactions are ubiquitous in the world's oceans and thought to be important sources of mixing. Whilst the understanding of the dynamics and energetics of ISWs have been greatly advanced in the past a few decades, identification of the processes and mechanisms responsible for their dissipation is limited. Here we present velocity and turbulence measurements from the northeastern South China Sea, together with process-orientated numerical simulations, to demonstrate the key role of ISW fission, into groups of high-frequency internal waves

over rough topography, in the dissipation of tidal energy. These new results show that, as a result of the fission, wave-induced velocity shear is elevated over significant time periods coincident with a period of enhanced turbulent dissipation. It is suggested that the enhanced dissipation is a result of instability and breaking of the high-frequency internal waves.

PO24E The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller III Posters

Tuesday, February 23, 2016

04:00 PM - 06:00 PM

Papers

PO24E-2993 A Discussion on Diapycnal Mixing Efficiency in Stably Stratified Geophysical Flows *Subhas Karan Venayagamoorthy[1], **Amrapalli Garanaik**[1], Louis St Laurent[2] and Derek D Stretch[3], (1)Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO, United States, (2)Woods Hole Oceanographic Institution, Physical Oceanography, Woods Hole, MA, United States, (3)University of KwaZulu-Natal, Civil Engineering, Durban, South Africa*

The diapycnal mixing efficiency is a measure of the amount of turbulent kinetic energy that is irreversibly converted into background potential energy in stably stratified flows. Despite the prevalence of a number of studies on mixing efficiency, no unifying parameterization of the mixing efficiency exists to date primarily due to the variability of geophysical flows and ambiguous use of certain parameters such as the buoyancy Reynolds number (Re_b). In particular, there is an ongoing debate in the oceanographic mixing community regarding the utility of Re_b, particularly with regard to how mixing efficiency varies with this parameter. Specifically, is there a robust and universal relationship between the intensity of turbulence (which is given by the turbulent Reynolds number Re_L) and the strength of the stratification that can support an unbiased description of mixing efficiency based on Re_b? This is an important question to consider when parameterizations developed from low Re_L simulations or laboratory experiments are used to describe geophysical turbulence. In such low Re_L studies, high Re_b is readily achieved with weak stratification despite low turbulent Reynolds number Re_L. However, oceanic and atmospheric turbulence can be sustained in the presence of strong stratification at much higher turbulence Reynolds numbers. In this talk, a discussion on the mixing efficiency and implications for estimates of diapycnal mixing in the ocean will be presented using data from direct numerical simulations, laboratory experiments, and field observations.

PO24E-2994 Internal Solitary Waves off the Amazon River Mouth: coherence crestlengths and generation mechanism

ABSTRACT WITHDRAWN

PO24E-2995 A spectral multidomain penalty method model for the simulation of internal solitary wave shoaling and breaking over gentle slopes ***Peter Diamessis**[1], Sumedh M Joshi[1], Greg Thomsen[2] and Gustavo Rivera[1], (1)Cornell University, Ithaca, NY, United States, (2)Applied Research Laboratories, U. of Texas, Austin, TX, United States*

This presentation outlines the basic components of an MPI-parallelized high-accuracy/resolution fully nonlinear and non-hydrostatic spectral multidomain penalty method solver designed to simulate the shoaling and potential breaking of internal solitary waves (ISWs) over long distances along gentle slopes. The solver employs deformed quadrilateral 2-D Legendre-polynomial based subdomains in the along-wave propagation direction. A Fourier discretization in the transverse direction, allows for the simulation of turbulence under the assumption that ISWs propagate normal to the isobaths, as is the case in the South China Sea (SCS). The use of high-order element-based techniques minimizes spurious dissipation/mixing at the smallest-resolved scales, enables wave propagation over

long distances free of numerical dispersion and permits flexibility in resolving localized dynamics within an ISW. Particular emphasis is placed on an efficient pressure Poisson equation (PPE) solver designed to efficiently capture the strongly non-hydrostatic dynamics of shoaling ISWs on highly leptic grids. To minimize the number of iterations in the PPE solver, an iterative substructuring approach is employed to assemble and solve the Schur problem of the Poisson matrix. For high-order methods, this Schur problem is far smaller and better conditioned than the original operator. Then, a block-diagonal preconditioner is used to mitigate the effects of domain aspect ratio, and a deflation technique bounds the number of GMRES iterations required in the iterative solution as the number of subdomains grows. The performance and accuracy of the preconditioned iterative substructuring are evaluated as is also the scalability of these methods in a practical distributed parallel computing environment.

The remaining numerical discussion focuses on validation of the code through specific ISW-based flow benchmarks. Select results will be shown for ISWs shoaling over actual SCS bathymetry with realistic background stratification and currents. Some first 3-D snapshots of the transition of turbulence in a convectively breaking wave will be shown. Finally, preliminary results on Lagrangian particle tracking in the associated trapped cores will be presented.

PO24E-2996 A NATURAL LABORATORY TO STUDY SHEAR-GENERATED TURBULENCE: THE WESTERN EQUATORIAL PACIFIC ***Kelvin John Richards**, Univ Hawaii, Honolulu, HI, United States*

Shear-generated turbulence is an important source of mixing in the ocean ending the cascade of energy from larger scales. Often because of sampling difficulties we are limited to deriving statistical relationships between the turbulence activity and the larger scale properties of the fluid flow. The Western Equatorial Pacific proves to be an ideal natural laboratory to study shear-generated turbulence. Here turbulent production is dominated by the shear associated with relatively long-lived flow structures in the form of high vertical mode inertia-gravity waves and flow instabilities. With enough vertical resolution we can directly measure the characteristics of these flow features. We find a strong relationship between the vertical shear and stratification and the turbulent dissipation. Using this relationship we can deduce the vertical mixing length scale and derive a parameterization scheme that is shown to work well when applied to flows with similar characteristics. An important lesson from this work is the need to resolve adequately the flow features generating the turbulence in both observations and models.

PO24E-2997 Estimation of vertical mixing with Thorpe scale on the continental slope of the southwestern East Sea

***Seongbong Seo**[1,2], Young-Gyu Park[1,2], Jae-Hun Park[3] and Hee-Dong Jeong[4], (1)KIOST, Ocean Circulation and Climate Research Center, Ansan, South Korea, (2)Korea University of Science and Technology, Integrated Ocean Sciences, Daejeon, South Korea, (3)Inha University, Department of Ocean Sciences, Incheon, South Korea, (4)NFRDI, Fisheries Resources and Environment Division, Gangneung, South Korea*

Internal tide of about 30 m amplitude was observed from two sets of 25-hour-long hourly CTD data obtained on the continental slope of the southwestern East Sea. To quantify the mixing that may have induced by the internal tide we conducted Thorpe scale (L_T) analysis using the raw CTD data. The data were processed carefully to reduce instrument noises and measurement errors. In each profile, segments with low fall speed (<0.25 *m/s*) or pressure inversion were removed without introducing artificial inversions. In each density inversion, the sum of the positive displacement is compared to that of the negative one. Only when the two values are comparable the inversion is considered as a physical one. The value of below the main thermocline estimated with the Osborn parameterization ($K_{z\text{-}os}=\alpha\varepsilon/N^2\approx0.128NL^2{}_T$) was $5.3\times10^{-4}(1.1\times10^{-4})$ m^2/s and that with the Shih parameterization ($K_{z\text{-}sh}=2\nu(\varepsilon/\nu N^2)^{1/2}\approx1.6\nu^{1/2}L_TN^{1/2}$) was $5.9\times10^{-5}(2.4\times10^{-5})$ m^2/s during the spring (neap) tidal period. Here ν is molecular viscosity, ε dissipation rate, and N^2 the buoyancy frequency. The Richardson numbers were low (0−0.25) in layers where the value of Kz is large. These results suggest that internal tides can enhance vertical mixing in the observation region.

PO24E-2998 Local vs. Bulk Measures of the Mixing Efficiency in Breaking Internal Waves on Slopes ***Robert S Arthur***[1]*, Jeffrey R Koseff*[1] *and Oliver B Fringer*[2]*, (1)Stanford University, Stanford, CA, United States, (2)Stanford University, Dept. of Civil and Environmental Engineering, Stanford, CA, United States*

Using direct numerical simulations, we explore local and bulk measures of the mixing efficiency in breaking internal waves on slopes. In a laboratory-scale domain, we consider eight breaking wave cases with a range of initial pycnocline thicknesses kδ, where k is the horizontal wavenumber and δ is the pycnocline thickness, but with similar incoming wave properties. The energetics of wave breaking is quantified in terms of local turbulent dissipation and irreversible mixing using the method of Scotti & White (2014). Local turbulent mixing efficiencies are calculated using the irreversible flux Richardson number R_f^* and are found to follow a representative function of the turbulent Froude number Fr_k. Comparisons are made to local mixing efficiencies calculated using the traditional flux Richardson number R_f. Because the local mixing efficiency is found to be a weak function of kδ, integrated measures of the turbulent mixing efficiency over the turbulent patch created by wave breaking are also made, and are found to be strong functions of kδ. The bulk patch-integrated turbulent mixing efficiency ranges from 0.25-0.37 and is maximized when kδ≈1, which corresponds to the optimal scale of billows at the interface during breaking, and to the highest occurrence of optimal turbulent Froude numbers Fr_k. Our results suggest that local mixing efficiencies measured during breaking internal wave events in the ocean may not be representative of the bulk mixing efficiency of the event as a whole.

PO24E-2999 Accuracy of Thorpe scale dissipation estimates during mixing driven by internal tide breaking ***Vamsi Krishna Chalamalla****, Masoud Jalali and Sutanu Sarkar, University of California San Diego, La Jolla, CA, United States*

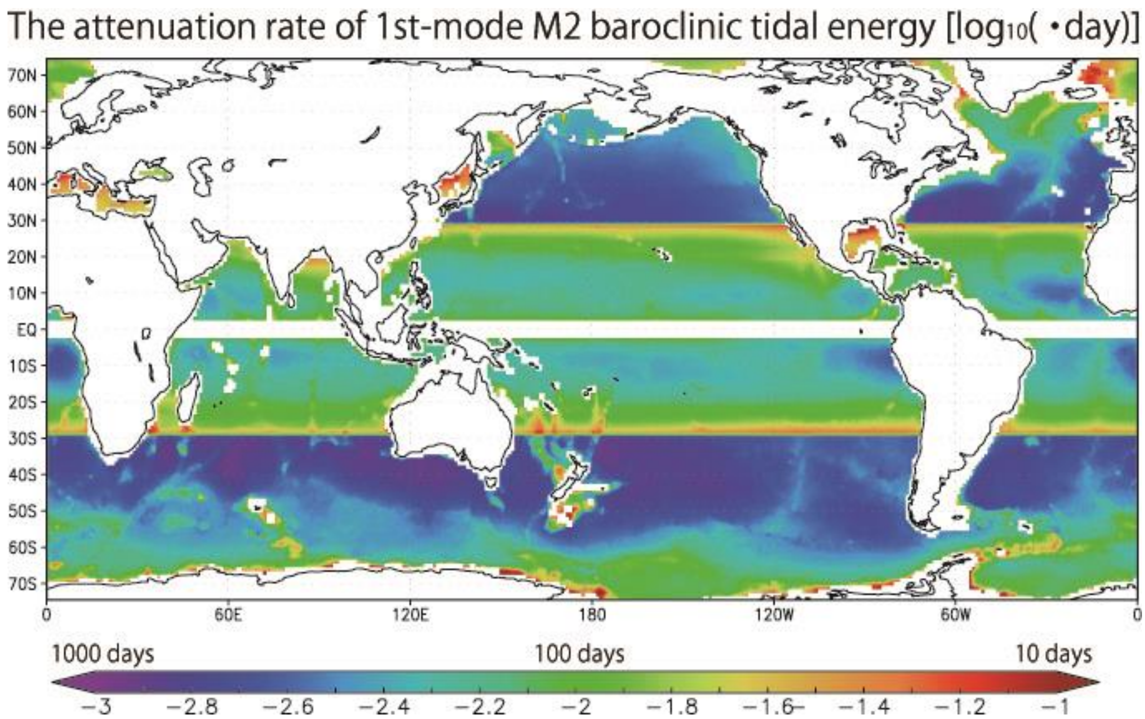
Direct numerical simulation (DNS) and large eddy simulation (LES) are employed to study the mixing brought about by convective overturns in a stratified, oscillatory bottom layer underneath internal tides. The Thorpe (overturn) length scale is often used as a proxy for the Ozmidov length scale and thus infer turbulent dissipation rate from overturns. The accuracy of overturn-based estimates of the dissipation rate is assessed for this flow using two different methods (modified and conventional) of detecting an overturn. The modified method is based on detecting inversions through statical instability.The Ozmidov length scale, L_O, and Thorpe length scale, L_T, are found to behave differently during a tidal cycle: L_T decreases during the convective instability while L_O increases, there is a phase lag ($¥approx 1/N$) between the maxima of Thorpe inferred dissipation and the model dissipation. Thus, the instantaneous values of overturn-inferred dissipation rates from both Thorpe and modified overturn methods are quite different from the actual values. Interestingly, the ratio of their cycle-averaged values is found to be O(1) in the case of the modified overturn scale method, a result explained on the basis of available potential energy. On the other hand, conventional Thorpe scale method is found to overestimate the cycle averaged dissipation by one to two orders magnitude. Comparison of time series of dissipation rates show that conventional Thorpe scale method highly overestimate the dissipation during the breaking of large density overturns, however it compares well with the model dissipation during shear driven turbulence.

PO24E-3000 Estimates of the Attenuation Rates of Baroclinic Tidal Energy Caused by Resonant Interactions Among Internal Waves based on the Weak Turbulence Theory ***Yohei Onuki*** *and Toshiyuki Hibiya, The University of Tokyo, Department of Earth and Planetary Science, Graduate School of Science, Tokyo, Japan*

The baroclinic tides are thought to be the dominant energy source for turbulent mixing in the ocean interior. In contrast to the geography of the energy conversion rates from the barotropic to baroclinic tides, which has been clarified in recent numerical studies, the global distribution of the energy sink for the resulting low-mode baroclinic tides remains obscure. A key to resolve this issue is the resonant wave-wave interactions, which transfer part of the baroclinic tidal energy to the background internal wave field enhancing the local energy dissipation rates. Recent field observations and numerical studies have pointed out that parametric subharmonic instability (PSI), one of the resonant interactions, causes significant energy sink of baroclinic tidal energy at mid-latitudes. The purpose of this study is to analyze the quantitative aspect of PSI to demonstrate the global distribution of the intensity of resonant wave interactions, namely, the attenuation rate of low-mode baroclinic tidal energy.

Our approach is basically following the weak turbulence theory, which is the standard theory for resonant wave-wave interactions, where techniques of singular perturbation and statistical physics are employed. This study is, however, different from the classical theory in some points; we have reformulated the weak turbulence theory to be applicable to low-mode internal waves and also developed its numerical calculation method so that the effects of stratification profile and oceanic total depth can be taken into account.

We have calculated the attenuation rate of low-mode baroclinic tidal waves interacting with the background Garrett-Munk internal wave field. The calculated results clearly show the rapid attenuation of baroclinic tidal energy at mid-latitudes, in agreement with the results from field observations and also show the zonal inhomogeneity of the attenuation rate caused by the density structures associated with the subtropical gyre. This study is expected to contribute to clarify the global distribution of the dissipation rates of baroclinic tidal energy.



PO24E-3001 Energetics of Wind-Induced Internal Wave Radiation from the Base of the Mixed Layer in the North Atlantic ***Georg Sebastian Voelker***[1,2], *Christian Mertens*[1], *Paul Glen Myers*[3], *Dirk J Olbers*[4] *and Maren Walter*[1], *(1)University of Bremen, Bremen, Germany, (2)MARUM – Center for Marine Environmental Sciences, Bremen, Germany, (3)University of Alberta, Edmonton, AB, Canada, (4)Alfred-Wegener-Institute, Bremerhaven, Germany*

Energy transfer mechanisms between atmosphere and the deep ocean have been studied for many years. Their importance to the ocean's energy balance and possible implications on mixing are widely accepted. The slab model is a well-established simulation of near-inertial motion and energy inferred through wind-ocean interaction. However, temporally coarse resolution wind forcing data in combination with rough internal wave energy flux assumptions are mainly used.

A slab model using hourly wind forcing from the NCEP-CFSR reanalysis allowing computations up to high latitudes without loss of resonance was set up. It was validated with buoy data from 44 sites in the Atlantic, Indian and Pacific Oceans and the Mediterranean Sea. Augmenting the one-dimensional model by the horizontal divergence of the near-inertial current field at the mixed layer base led to direct estimates of energy transfer spectra of radiation of internal waves into the ocean interior. No crucial assumptions on transfer physics were made.

Results of the hybrid model indicated the presence of internal wave modes at the base of the mixed layer. Spatially-advancing wind stress fronts were identified as their main driver and thus they acted as the major source for internal wave radiation into the deep ocean. Accordingly, mid-latitude storms with a strong seasonal cycle as well as isolated tropical storm tracks are dominant in energy fluxes in the North Atlantic.

PO24E-3002 Soliton Arrival Patterns Over the Chinese Upper Continental Slope During June 2014: Reaffirmations and Exploded Myths ***Steven Ramp***[1], *Yiing Jang Yang*[2], *D. Benjamin Benjamin Reeder*[3], *Ching-Sang Chiu*[3] *and Fred Bahr*[4], *(1)Soliton Ocean Services, Inc., Carmel Valley, CA, United States, (2)National Taiwan University, Taipei, Taiwan, (3)Naval Postgraduate School, Monterey, CA, United States, (4)MBARI, Moss Landing, CA, United States*

A very dense array of sensors measuring temperature, salinity, and velocity was deployed between the 386 m – 266 m isobaths northeast of Dongsha Island in the South China Sea. One complete fortnight was sampled at 90 s or faster intervals, which allowed nonlinear internal waves (NLIW) generated by a wide range of tidal forcing to be observed. Two "families" of waves were observed, the now familiar a-waves and b-waves. The correct way to categorize these waves is by their generation mechanism since their amplitudes and packet structures overlap. The a-waves were generated on the larger of the two ebb tides in the Luzon Strait and the b-waves on the flood tide that immediately preceded it. Details such as the amplitudes and arrival times of the incoming waves very closely tracked the details of the Luzon Strait forcing. Almost all the a-waves were present by the time the waves reached the 386m isobath, however many of the b-waves were formed locally by steepening and breaking of the leading edge of the upslope internal tide. This phenomenon commonly took place between the 342 m and 266 m isobaths. Breaking of individual NLIW was not observed since the orbital speed did not exceed the local propagation speed of 1.69 – 1.87 m/s in this depth range. The increasing number of waves per packet shoreward was instead consistent with the formation of a dispersive "tail" over gently sloping topography. Huge double a-waves two hours apart were observed near spring tide. The origin of these waves is unknown and deserves further study.

PO24E-3003 Measurements of the Rate of Dissipation of Turbulent Kinetic Energy in a High Reynolds Number Tidal Channel ***Justine McMillan***[1], *Alex E Hay*[1], *Rolf G Lueck*[2] *and Fabian Wolk*[3], *(1)Dalhousie University, Halifax, NS, Canada, (2)Rockland Scientific International Inc., Victoria, BC, Canada, (3)Rockland Scientific Inc, Victoria, BC, Canada*

The rate of dissipation (ε) of turbulent kinetic energy at mid-depth in a high speed tidal channel is estimated using measurements from both a standard acoustic Doppler current profiler (ADCP) and shear probes mounted on an underwater, streamlined buoy. The investigation was carried out in Grand Passage, Nova Scotia where the depth-averaged flow speed reached 2 m/s and the Reynolds number was 4 x 10^7. The dissipation rates estimated from the ADCP data agree with the shear probe data to within a factor of two, with some of the discrepancy attributed to the 40 m separation of the instrument platforms. Both the ADCP and the shear probe measurements indicate a linear dependence of ε on the cube of the flow speed during flood tide with maximum values reaching 5 x 10^{-5} W/kg. Much lower dissipation rates were observed on the ebb tide when the convergence of the flow in the narrowing channel suppresses the turbulent fluctuations. Two significant limitations of ADCPs in measurements of turbulence will be discussed: (1) the calculated dissipation rates are highly sensitive to the choice of Doppler noise level, and (2) the ADCP measurements do not capture the intermittency in the flow.

PO24E-3004 Quantification of Internal Wave Energy

ABSTRACT WITHDRAWN

PO24E-3005 Wave-Induced Pressure Under an Internal Solitary Wave and Its Impact at the Bed ***Gustavo Rivera***[1], *Peter Diamessis*[2] *and James Jenkins*[1], *(1)Cornell University, Civil and Environmental Engineering, Ithaca, NY, United States, (2)Cornell University, Ithaca, NY, United States*

Internal Solitary Waves (ISW) of depression are known to cause significant resuspension and bed deformation during their passage. The underlying interplay between wave-driven hydrodynamics in the water column and the bed are yet to be fully understood. Given a characteristic stratification profile, observations of the induced-pressure hint at a potential bed failure during a wave episode. Employing a Fourier- nodal Galerkin method, we solve for the

diffusion of the wave-induced pressure and assess the critical bed-normal pressure gradient responsible for particle movement. Likewise, we can also assess the induced shear stress as a possible mechanism for failure. In a similar context, we also examine the near-bed turbulent wake in the separating region in the lee of the wave. At sufficiently high ISW amplitude, the wave-induced BBL undergoes a global instability which produces intermittent vortex shedding from within the separation bubble. Using a 2D spectral multidomain penalty method with Re O(10^5), we resolve for the vortex shedding episode expanding the scope of the induced-pressure and shear stress and characterizing their subsequent development. It can be argued that the resuspension of bottom particulate upon the passage of the ISW trough and BBL separation directly relates to the potential for bed failure. We aim to link both events under the context of a specific sediment transport model capable of describing a range of ISW environments studied in the field.

PO24E-3006 Turbulence in the Pycnocline: Temporal and Spatial Scales *Holly Pelling, Bangor University, Menai Bridge, United Kingdom,* ***Matthew R Palmer****, NOCL, Matthew Toberman, SAMS, Jeff Polton, National Oceanography Center, Liverpool, United Kingdom, Mark Inall, Scottish Association for Marine Science, Oban, United Kingdom and Tom Philip Rippeth, Bangor University, School of Ocean Sciences, Bangor, Wales, United Kingdom*

Vertical exchange of nutrients facilitated by small amounts of vertical mixing across the pycnocline in continental shelf seas sustains a substantial proportion of the total oceanic primary production (15-30%). Mixing at this critical interface is sporadic and highly variable, both spatially and temporally, which makes its observation and prediction very difficult. We present preliminary results from a new project PycnMix, which aims to produce a ‘step change’ in the representation of pycnocline mixing processes in regional scale shelf sea models. We present results from the reanalysis of over 20 years of microstructure measurements from across the seasonally stratified North West European Shelf Seas, forming the world’s largest observational database of shelf sea pycnocline turbulence measurements.

We find that the distribution of pycnocline turbulence data relative to proposed stability criteria is highly dependent on the large range of representative turbulent length and timescales observed. Instrument separation and resolution is likely a key factor in the observed distribution of data. Here we present the potential impacts of under resolving turbulence and mixing in the pycnocline and show how this can give a skewed impression of the mechanisms involved. We employ theoretical frameworks of turbulent behaviour to reanalyse data over suitable length scales to assess the impact on empirical solutions. The results from a high-resolution non-hydrostatic model are used to validate methods and to assess the broader impact of our findings.

PO24E-3007 Theoretical analysis of vertical mode internal waves affected by a vortex. ***Kaoru Ito*** *and Tomohiro Nakamura, Hokkaido Univ, Sapporo, Japan*

Interaction between vortices and internal waves plays important roles in mixing and the formation of local internal wave spectra. This interaction has attracted attention, and remarkable theories have been achieved in the parameter range of weak meso-scale eddies with relatively short internal waves, which allows WKB like approach.

However, processes outside of the above parameter range are not well known; for example, universally located sub-mesoscale vortices and tide-induced internal gravity waves of various wavelengths. In such a parameter range incident wavelength is sometimes comparable to spatial scale of a vortex. This requires a non-WKB like method. Here, we investigated the interaction between a single vortex and incident internal waves by a perturbation method. We obtained scattered wave solutions for azimuthal modes, whose sum gives the total scattered wave field. In the analysis, a useful non-dimensional parameter arose. This parameter represents a product of ratios of length and nonlinearity scales, and is available for classifing the interaction dynamics.

PO24E-3008 The Impact of Oscillatory Currents and Stratification on Turbulent Dissipation in the Marginally Stratified Celtic Sea, U.K. ***Marcus Zanacchi**, Plymouth University, School of Marine Science and Engineering, Plymouth, United Kingdom, Phil John Hosegood, University of Plymouth, School of Marine Science and Engineering, Plymouth, United Kingdom and Ricardo Torres, Plymouth Marine Laboratory, Marine Ecosystem Modelling and Predictions, Plymouth, United Kingdom*

We present full water column observations of turbulence microstructure, associated water properties and current velocities during eight tidal cycles at a marginally stratified shelf sea front in the southern Celtic Sea, U.K. The aim of the fieldwork, conducted at two sites (depth: 35m & 65m) in spring and late summer of 2012 and during both spring and neap tides, was to investigate the effect of stratification on the phase-dependent properties of turbulent dissipation within an oscillatory tidal regime. The results of this study demonstrate that, as opposed to tidal fronts that are governed by competition between restratification and mixing arising from tidal friction alone, second-order mixing processes are of importance in regulating the mixing regime in marginally stratified frontal regions. Dissipation profiles showed strong tidal asymmetry between the flood and ebb tides. Bottom boundary layer (BBL) growth was strongly limited by stratification both during the weakly stratified spring regime ($N^2_{max} = 3\times10^{-5}$ s^{-2}) and more pronounced during the strongly stratified summer regime ($N^2_{max} = 2\times10^{-4}$ s^{-2}). In accordance with numerical simulations of a stratified flow under an oscillatory current, stratification did not substantially affect dissipation rates within the BBL (~10^{-5} Wkg^{-1}) but strongly supressed them above, forming regions of the lowest dissipation rates in the water column (~10^{-9} Wkg^{-1}). Furthermore, a phase lag between maximum dissipation rates and currents was observed to increase with the strength of the stratification. Analysis of the Richardson number reveal a weak dependence of dissipation on local shear instability based on an assessment of the MacKinnon & Gregg scaling for mixing in stably stratified conditions. In addition to the modulation of bottom mixing due to the effects of stratification, we examine the tidal-phase dependence of surface mixed layer deepening associated with the opposing orientation of surface forcing versus tidal flow.

PO24E-3009 Turbulent properties of a deep-sea hydrothermal plume in a time-variable cross flow using anisotropic mixing parameterizations in LES *Daniela Di Iorio[1], J William Lavelle[2] and **Ian Gregory Adams**[1], (1)University of Georgia, Athens, GA, United States, (2)NOAA, Seattle, WA, United States*

A large eddy simulation of a deep-sea hydrothermal plume in a time-variable cross flow, parameterized with anisotropic eddy viscosities and diffusivities, is developed to simulate turbulent flow characteristics. The turbulent dissipation rates for kinetic energy (ε) and thermal variance (ε_θ) is approximated by computing the Reynolds averaged sub-grid scale turbulent production from shear and buoyancy (ε=P-B) and from temperature fluxes ($\varepsilon_\theta = P_\theta$) respectively. The model is tuned to represent the mean flow and turbulent observations of the hydrothermal plume properties at Dante within the Main Endeavour vent field (MEF) at the Endeavour segment of the Juan de Fuca

Ridge using specialized acoustic instrumentation. The model takes into account realistic background stratification, and vent exit fluid heat and flow transport. The turbulent kinetic energy and thermal dissipation rates reach their maximum near the vent. Shear production dominates over buoyancy production of turbulent kinetic energy. The model is used to derive several important scalings with cross flows that are relevant to understanding plume impact on the ocean. These scalings include maximum plume rise height and turbulent diffusivity and their variability with cross flow speeds.

PO24E-3010 Nonlinear interaction of internal solitary-like waves in three-dimensional simulations ***Kenji Shimizu***, *CSIRO Oceans and Atmosphere Flagship, Floreat, Australia and Keisuke Nakayama, Kobe University, Kobe, Japan*

Internal solitary-like waves (ISWs) are nonlinear and nonhydrostatic waves with short wavelengths (~1 km) and short periods (~10 min). ISWs provide a pathway of energy from internal tides to shear instability, boundary layer turbulence, and mixing. They are also an essential factor for structural design in offshore engineering. For example, on the Australian Northwest Shelf, ISWs can induce stronger extreme near-bottom currents than tropical cyclones. However, the dynamics of ISWs have not been well understood partly because of the complexity of the physics and partly because of high computational demand for realistic three-dimensional simulations.

Here we investigate the nonlinear interaction of ISWs using three-dimensional MITgcm simulations in the presence of Coriolis effects. Previous studies of barotropic solitons show that solitons intersecting at oblique angles cause nonlinear interaction; however, such effects have not been well investigated for ISWs. To understand the relevance of such a process to ISWs in realistic conditions, we conduct idealized and realistic simulations. In the idealized simulations, we consider the interaction of radially spreading ISWs from two sources for two purposes: 1) to illustrate the nonlinear interaction of ISWs with full nonlinear and nonhydrostatic effects but in simplified settings; and 2) to compare the results against some previous theoretical work. In the realistic simulations, we use realistic bathymetry, stratification, and barotropic tides from the Australian Northwest Shelf. ISWs are generated by topographic generation of internal tides and subsequent nonlinear steepening. We show that the nonlinear interaction of ISWs is essential to understand the complicated interference pattern of internal wave fields in the realistic simulations. This in turn suggests the importance of the process to the interpretation of observations.

PO24E-3011 Nonlinear interaction of internal and acoustic-gravity waves in continuously-stratified ocean ***Usama Kadri***, *University of Haifa, The Hatter Department of Marine Technologies, Haifa, Israel, Miao Tian, Woods Hole Oceanographic Institute, Physical Oceanography, Woods Hole, MA, United States and Karl Richard Helfrich, WHOI, Woods Hole, MA, United States*

Acoustic and gravity modes are two fundamental solutions of waves induced by oscillations of seafloor in a compressible ocean. Studies of acoustic-gravity waves (AGW) can benefit the early detection of tsunamis because AGW propagate significantly faster than tsunami (the gravity modes), and are expected to be detectable on bottom-pressure records (Stiassnie, 2010).

This work investigates the potential nonlinear interaction between internal waves (IW) and acoustic-gravity waves (AGW) in deep ocean. The goal is to formulate the theoretical framework for AGW-generated IW in continuously-stratified fluid over finite depth. The linear dispersion relationship that contains the effects of stratification (for IW) as well as compressibility (for AGW) has been derived. Current effort focuses on the development of nonlinear evolution equation and its numerical implementation.

PO24E-3012 Instability and Mixing of Stratified Shear Layers Forced by Internal Wave Strain ***Alexis Kaminski** and John Ryan Taylor, University of Cambridge, Cambridge, United Kingdom*

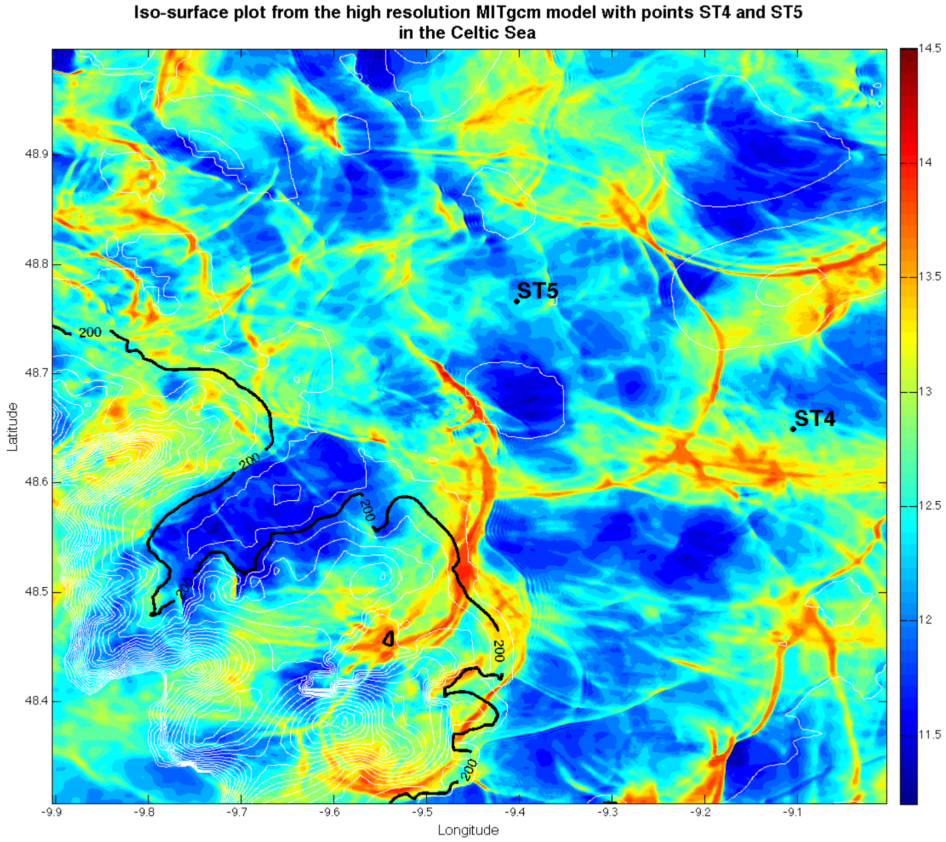
Turbulence generated by breaking internal waves is an important source of mixing in the ocean interior. This is often interpreted in terms of vertical shear and associated shear instabilities; however, observations suggest that the vertical strain caused by internal waves may also impact the stability and subsequent mixing of the flows through which they propagate (e.g.~Alford and Pinkel, JPO, 2000). Here, we idealize this process by imposing a background wave which is spatially and temporally periodic onto a stably-stratified shear flow. We examine the stability of this complicated, time-dependent base flow over a range of parameters in order to identify and quantify the effect of the internal wave strain on the overall flow stability. Using a direct-adjoint looping method, we find the most unstable linear perturbations over a finite time interval. Direct numerical simulations are then used to examine the nonlinear evolution and subsequent mixing. These results could be useful when developing parameterizations of ocean mixing which include the effects of vertical strain.

PO24E-3013 The Life-Cycle of High Frequency Internal Waves in a Continental Shelf Sea: Generation, Propagation and Dissipation". ***Anastasiia Domina**, University of Liverpool, School of Environmental Sciences, Liverpool, United Kingdom, Matthew Palmer, National Oceanography Center, Liverpool, United Kingdom, Jonathan Sharples, University of Liverpool, Liverpool, L69, United Kingdom, Vasyl Vlasenko, Plymouth University and Mattias Green, Bangor University, Glan Conwy, United Kingdom*

High-frequency internal waves (HFIW) are particularly important to internal mixing in the shelf seas, where they contain an enhanced fraction of the available baroclinic energy. The origin, generation mechanism, propagation and spatial distribution of these waves are unfortunately still poorly understood since they are difficult to measure and simulate, and are therefore not represented in the vast majority of ocean and climate models.

In this study we aim to increase our understanding of HFIW dynamics in shelf seas through a combination of observational (moorings, gliders, OMGs) and modelling methods (MITgcm), and test the hypothesis that "Solitary waves are responsible for driving a large fraction of the vertical diffusivity at the shelf edge and adjacent shelf region". Our analysis of two separate sites, both situated ~20km from the continental shelf break, shows that the energetics (KE and APE) of low frequency internal waves (IWs) are of similar magnitude with subtle differences explained through variable local and remote forcing. Baroclinic energy distribution at high frequencies is shown to be near constant at both sites, independent of low frequency forcing. There is however a significant difference in energy levels between sites, one being enhanced by ~60%.

A new high-resolution (50m horizontal) MITgcm configuration is validated using the observed IW characteristics and employed to identify the generation and propagation of IWs in the Celtic Sea. We identify how energy is transferred to higher frequencies and subsequently identify likely mixing hotspots on the Celtic Sea. These predictions are then compared to turbulence data collected using an Ocean Microstructure Glider and VMP to assess the impact of the identified IW characteristics on internal mixing. Lastly, we force the model with different density structures to assess the likely impact of changing climate forcing scenarios on IW generation and internal mixing on the continental shelf.



Iso-surface plot of results from new high-resolution (50m in horizonthal scale) non-hydrostatic MITgcm model at the depth of 40m, which shows the spatial distribution of internal waves in the Celtic Sea. Points, ST4 and ST5, with in-situ data have been used for the model validation. Colorbar shows the temperature in degrees. White lines indicates the topography of the region, whereas black lines indicates the shelf break.

PO24E-3014 Why is no Near-Inertial Peak Observed in the Luzon Strait, a Major Internal Tide Generation Region?

Arnaud Le Boyer, *Scripps Institut of Oceanography, MPL, San Diego, CA, United States*, *Matthew H Alford, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States and Andy Pickering, Universiy of Washington, APL, Seattle, WA, United States*

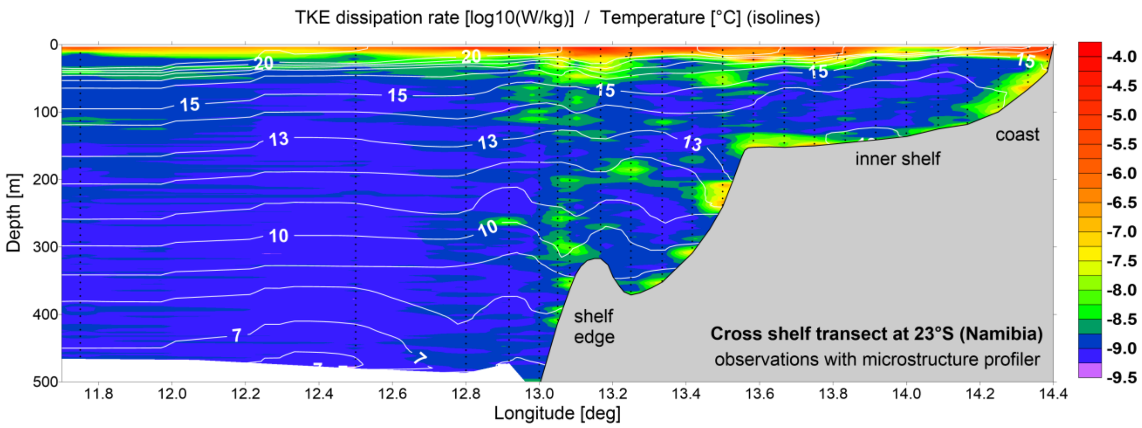
The Luzon Strait, a double submarine ridge between Taiwan and the Philippines, is home to the largest internal tides observed in the world oceans. Yet, the usually-ubiquitous near-inertial spectral peak is absent in spite of strong wind forcing during much of the observational period. Observations were collected during the southwestern monsoon season (Summer 2011) along northern and southern transects. Each of these transects was instrumented with 4 moorings with ADCP (Acoustic Doppler Current Profilers) and McLane moored profilers. Over the first 500 meters, in the north, there is no measurable energy in the near inertial band and, in the south, we observe near-inertial kinetic energy peaks 10 times weaker than the tidal peaks. These observations differ from other parts of the global ocean where inertial current forced by fluctuations in the local wind stress dominates the upper ocean circulation. Here, the strong monsoon winds (≈ 15 m s^{-1}) should generate mixed layer inertial currents which, after propagating downward, should also excite near-inertial waves beneath the mixed layer. The presence of these currents depends of the scales of the wind stress, the background stratification and the surrounding oceanic motions, among other factors. We hypothesize that the presence of the northern branch of the Kuroshio and/or Doppler shifting by the extreme internal tides in the area may be responsible, and present evidence for each scenario.

PO24E-3015 Horizontal Structure of Turbulence on Decimeter to 10m Scales in Fast Tidal Flows ***Rachel Horwitz** and Alex E Hay, Dalhousie University, Halifax, NS, Canada*

We characterize the structure of turbulence in a very fast tidal channel in the Bay of Fundy, Nova Scotia that has been identified for development as a commercial tidal power resource. A subsurface mooring that orients into the flow was equipped with a horizontally-aimed AD2CP, and upward- and downward-looking ADCPs. Two week-long deployments provide velocity measurements of tidal flows up to 4 m/s that are used to describe the spatial (lateral) and temporal structure of turbulent fluctuations on decimeter to 10m scales. The spatial scales and temporal intermittency vary with both speed of the flow and the effects of upstream topography.

PO24E-3016 Distribution of TKE dissipation and turbulent mixing across at the central Namibian shelf ***Volker Mohrholz**[1], Toralf Heene[1] and Anja van der Plas[2], (1)Leibniz-Institute for Baltic Sea Research Warnemünde, Physical Oceanography and Instrumentation, Rostock-Warnemünde, Germany, (2)Ministry of Fisheries & Marine Resources, Subdivision Environment, Swakopmund, Namibia*

Shelf areas are hot spots of turbulent mixing in the Ocean. A number of smaller scale processes like breaking internal tides at the shelf edge, generation of nonlinear internal waves, shoaling of swell, and current shear causes enhanced vertical mixing at particular locations across the continental shelf. Most of these processes are not well represented in numerical models, and need an improved parameterization. In frame of the GENUS project a series of field observations were carried out off the central Namibian coast, to gather detailed information on the distribution of turbulent kinetic energy (TKE) dissipation and turbulent mixing across at the Namibian shelf. Hot spots and shadow zones were identified. The Interaction of internal tide with the bottom topography leads to enhanced TKE levels at critical slope angles, mainly located at the shelf edge. Here the bottom mixed layer can reach up to 100m thickness, characterized by high suspended matter concentration. Patches with enhanced TKE dissipation rates of about 10^{-8} to 10^{-7} Wkg^{-1} were observed throughout the water column. At the shelf edge nonlinear internal waves are generated frequently. A statistical analysis of satellite images revealed a region of enhanced NLIW generation near the Walvis Ridge. In contrast to the shelf edge the inner shelf off Namibia depict low TKE dissipation rates outside the boundary layers. Based on time series observations with moored instruments it is shown, that near bottom the eddy viscosity is mainly controlled by the mean currents and the law of the wall. Off the Namibian coast the locations of hot spots and shadow zones of TKE correlate with the distribution of carbon rich surface sediments, which points to a high impact of enhanced TKE near sea bed on resuspension of particulate matter.



PO24E-3017 Multiscale modeling of internal waves and turbulence at rough, realistic topography with SOMAR-LES ***Edward Santilli***, *University of North Carolina at Chapel Hill, Chapel Hill, NC, United States; Philadelphia University, Dept. of Sciences, Philadephia, PA, United States, Vamsi K Chalamalla, University of California at San Diego, Aerospace and Mechanical Engineering, San Diego, CA, Alberto D Scotti, University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States and Sutanu Sarkar, University of California San Diego, La Jolla, CA, United States*

The Stratified Ocean Model with Adaptive Refinement (SOMAR) is a modeling framework with the flexibility of adaptive mesh refinement at localized regions with high gradients. Several test cases including the lock-exchange problem, solitary wave propagation and internal tide generation have been previously considered to validate the method. Local refinement of the

grid allows the solver to achieve highly accurate results with substantial reduction in computational cost. Recently, SOMAR-LES has been developed wherein a three-dimensional, body-conforming Large Eddy Simulation (LES) model that resolves turbulence scales is coupled with SOMAR to accurately represent small scale turbulence as well as its effect on flow evolution at large scale. The coupling is two-way: LES is driven with large scale forcing, and SOMAR receives feedback in the form of eddy viscosity, diffusivity and sub-grid scale fluxes. This novel multi-scale modeling technique is applied to study the near- and far-field baroclinic response when the oscillating barotropic tide interacts with underwater topography. Numerical simulations are performed with SOMAR-LES to examine the flow at Kaena ridge, a steep supercritical generation site, where the topographic length scales are of O(100 km), and the barotropic forcing corresponds to a small outer excursion number ($Ex = U_0/\omega \approx 0.01$) and small Froude number ($Fr = U_0/N\, h_0 \approx 0.006$). Results are compared against high-resolution LES of the flow at the ridge in a scaled-down LES to assess turbulence representation in the coupled model. The SOMAR-LES results are compared with HOME data, and used to quantify baroclinic energy conversion and internal wave properties such as the radiated wave flux and modal composition.

PO24E-3018 Near-surface energy transfers from internal tide beams to smaller vertical scale motions ***Sherry Chou***[1], *Chantal Staquet*[2], *Glenn S Carter*[3] *and Douglas S Luther*[3], *(1)University of Hawaii, Oceanography, Honolulu, HI, United States, (2)Laboratoire des Écoulements Géophysiques et Industriels, Grenoble, France, (3)University of Hawaii at Manoa, Honolulu, HI, United States*

Mechanical energy capable of causing diapycnal mixing in the ocean is transferred to the internal wave field when barotropic tides pass over underwater topography and generate internal tides. The resulting internal tide energy is confined in vertically limited structures, or beams. As internal tide beams (ITBs) propagate through regions of non-uniform stratification in the upper ocean, wave energy can be scattered through multiple reflections and refractions, be vertically trapped, or transferred to non-tidal frequencies through different nonlinear processes. Various observations have shown that ITBs are no longer detectable in horizontal kinetic energy beyond the first surface reflection. Importantly, this implies that some of the internal tide energy no longer propagates in to the abyssal ocean and consequently will not be available to maintain the density stratification.

Using the NHM, a nonlinear and nonhydrostatic model based on the MITgcm, simulations of an ITB propagating up to the sea surface are examined in order to quantify the transformation of ITB energy to other motions. We compare and contrast the transformations enabled by idealized, smoothly-varying stratification with transformations enabled by realistic stratification containing a broad-band vertical wavenumber spectrum of variations. Preliminary two-dimensional results show that scattering due to small-scale structure in realistic stratification profiles from Hawaii can lead to energy being vertically trapped near the surface. Idealized simulations of "locally" generated internal solitary waves are analyzed in terms of energy flux transfers from the ITB to solitary waves, higher harmonics, and mean flow. The amount of internal tide energy which propagates back down after near-surface reflection of the ITB in different environments is quantified.

PO31C The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller IV

Wednesday, February 24, 2016

08:00 AM - 10:00 AM

Ernest N. Morial Convention Center

- 203-205

Papers

08:00 AM PO31C-01 Observations of an internal tide beam in the Tasman Sea ***Amy Frances Waterhouse**[1], Samuel Maurice Kelly[2], Jennifer A MacKinnon[3], Jonathan D Nash[4], Shaun Johnston[3], Zhongxiang Zhao[5], Luc Rainville[5], Harper L Simmons[6], Dmitry Brazhnikov[7] and Daniel L Rudnick[8], (1)Scripps Institution of Oceanography, CA, United States, (2)University of Minnesota Duluth, Duluth, MN, United States, (3)University of California San Diego, La Jolla, CA, United States, (4)Oregon State Univ, Corvallis, OR, United States, (5)Applied Physics Laboratory University of Washington, Seattle, WA, United States, (6)University of Alaska Fairbanks, Fairbanks, AK, United States, (7)University of Alaska Fairbanks, Anchorage, AK, United States, (8)Scripps Institution of Oceanography, La Jolla, CA, United States*

タスマン海での内部潮汐ビームでの観測(係留や 24-30 時間繰り返し定点観測、衛星高度計観測)を行い、内部潮汐エネルギーフラックスやエネルギー散逸を求めた。高度計観測からは、ビーム内で 0.1W/m^2 で、背景場（0.004W/m^2, Kunze による）に比べて 1 桁以上強化されていた。

Internal-tide energy can propagate away from generation regions in the form of low-mode internal tides. The ultimate fate of this energy is unknown and has a large impact on the global geography of turbulent mixing rates. Previous studies of low-mode internal tide propagation have observed regions where the internal tide was diffuse and exhibited complex interference patterns. As a result, direct comparisons of observed energy-flux divergence and dissipation rates have been inconclusive. A well-defined beam of internal tide energy originates from the Macquarie Ridge southwest of New Zealand and propagates across the Tasman Sea towards Tasmania, dominating the internal wave field found in the region. Numerical simulations have shown that the internal tide focuses into a “beam” as it propagates northwest across the Tasman Sea before it eventually impinges on the Tasmanian continental slope. During January-February 2015, field observations mapped the structure and variability of this internal-tide beam in the deep ocean before it reached the continental slope using moored, ship-based and glider observations. In-situ observations from the Tasman Sea captured synoptic measurements of incident internal-tide energy flux that are comparable to those inferred from altimetric estimates. As the region is known to have a strong mesoscale which can bias altimetric estimates, comparisons made here can document the extent of this bias. Estimates on how variability of the internal beam as it crosses through an active mesoscale are made using both observational and numerical results.

08:15 AM PO31C-02 Global Internal Tide Energy Flux and Dissipation from Satellite Altimetry ***Zhongxiang Zhao**[1], Matthew H Alford[2], James B Girton[1], Luc Rainville[1], Harper L Simmons[3], Amy Frances Waterhouse[2] and Caitlin Whalen[2], (1)Applied Physics Laboratory University of Washington, Seattle, WA, United States, (2)Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States, (3)University of*

Alaska Fairbanks, Fairbanks, AK, United States

通常の調和解析だとデータが少ないが、Zhao et al. 2012 の平面波を当てはめる手法を使いデータを増やして解析することによって、３つの波動、特に南北方向の向きなどがわかり、ルソン海峡で、日周期のエネルギーフラックスが曲率を持って伝搬することをわかった。zzhao@apl.uw.edu　で質問を受け付ける。有力な手法と感じた。

We aim to quantify the internal tide's contribution to deep-ocean mixing, as opposed to the wind's contribution via near-inertial internal waves. We construct a global internal tide model consisting of M2, S2, O1 and K1, using 50 satellite-years of altimeter sea-surface height (SSH) measurements. Two-dimensional plane wave fits are employed to (1) suppress mesoscale contamination by extracting internal tides with both spatial and temporal coherence, and (2) separately resolve internal tides in multiple propagation directions. Energy and flux are computed from the internal tide's SSH amplitude, using transfer functions derived from the climatological hydrographic profiles in the WOA 2013. The satellite products represent multiyear coherent internal tide fields, neglecting the incoherent component. M2 is the dominant constituent; however the contribution of S2, O1 and K1 is greater in a few regions (e.g., the western Pacific). M2 and S2 have similar, but different, geographic patterns. O1 and K1 internal tides mainly occur in the Pacific and Indian oceans. Global integration of the mode-1 M2 internal tide gives a lower bound energy of 36 PJ. Its residence time is estimated to be 1~1.4 days, equivalent to an average propagation distance of 400 km from its generation sources (compared to the longest propagation distance >3500 km). M2 internal tidal beams propagate across critical latitudes for PSI (28.8 S/N) with little energy loss. In the eastern Pacific Ocean, M2 internal tides lose significant energy in propagating across the Equator, likely due to the loss of coherence in the varying equatorial jets. In contrast, little energy loss is observed in the equatorial zones in the Atlantic, Indian, and western Pacific oceans. The dissipation rate (which includes the likely loss of coherence) is estimated from the divergence of energy flux and compared with recent observations using historical microstructure profiles and Argo float profiles, and a global numerical model GOLD.

08:30 AM PO31C-03 Tidally driven mixing and dissipation in the stratified boundary layer above steep submarine topography ***Kraig B Winters****, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States*

沖から sub-critical の緩やかな海底に内部波が到達すると、前（岸）向きにエネルギー前方反射し、super-critical になったところでは後方に反射するため、緩やかな地形が続くと沿向きにエネルギーは伝搬する。Pinkel et al. 2016EOS, vanHaren et al. 2015GRL では、super-critical および critical の斜面で散逸率が 2*10^-7、sub-criticaol で 2*10^-9 と前 2 者で大きいとした。また、Martini et al. 2012JPO は、散逸強化につながるボアが super-critical のみで観測されると述べている。この現象をオズミドフスケールとコルモゴロフスケールの間まで分解する高解像度計算を行い、上記の現象が生じることを示した。

ウルップ海峡での係留観測と対応しているような気がした。

A tidally driven, stratified boundary layer over supercritical topography is simulated numerically (Winters, 2015). The near-boundary flow is characterized by quasi-periodic, bore-like motions and episodic expulsion events where fluid is ejected into the stratified interior. The character of the bores is compared to the high-resolution ocean mooring data of van Haren (2006). The diffusivity of the flow near the boundary is estimated by means of a synthetic dye tracer experiment. The average dissipation rate within the dye cloud is computed and combined with the diffusivity estimate to yield an overall mixing efficiency of 0.15. Both the estimated diffusivity and dissipation rates are in reasonable agreement with the microstructure observations of Kunze at al (2012) when scaled to the environmental conditions at the Monterey and Soquel Canyons and to the values estimated by van Haren and Gostiaux (2012) above the sloping bottom of the Great Meteor Seamount in the Canary Basin.

08:45 AM PO31C-04 Evaluating the role of inertial and tidal internal wave dynamics on a narrow continental shelf: An assessment of the dominant physical dynamics influencing mixing and the energy budget ***Tamara Lillian Schlosser**[1], Cynthia Bluteau[1], Nicole L Jones[1], Andrew Lucas[2], Jonathan D Nash[3] and Gregory N Ivey[1], (1)University of Western Australia, Crawley, WA, Australia, (2)Scripps Institution of Oceanography, La Jolla, CA, United States, (3)Oregon State University, Corvallis, OR, United States*

タスマン海での亜慣性の日周期内部潮汐波の作用について、ボアの関与などについて調べた。

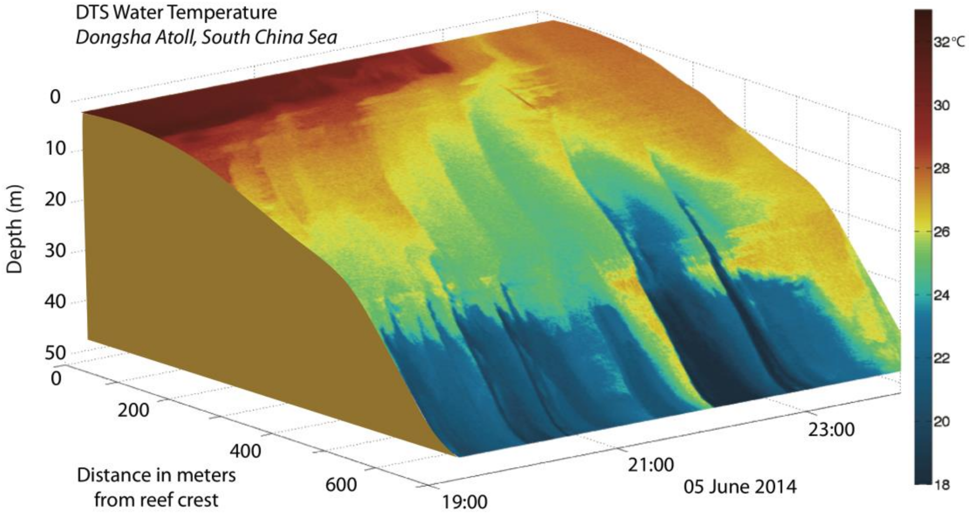
A tidally driven, stratified boundary layer over supercritical topography is simulated numerically (Winters, 2015). The near-boundary flow is characterized by quasi-periodic, bore-like motions and episodic expulsion events where fluid is ejected into the stratified interior. The character of the bores is compared to the high-resolution ocean mooring data of van Haren (2006). The diffusivity of the flow near the boundary is estimated by means of a synthetic dye tracer experiment. The average dissipation rate within the dye cloud is computed and combined with the diffusivity estimate to yield an overall mixing efficiency of 0.15. Both the estimated diffusivity and dissipation rates are in reasonable agreement with the microstructure observations of Kunze at al (2012) when scaled to the environmental conditions at the Monterey and Soquel Canyons and to the values estimated by van Haren and Gostiaux (2012) above the sloping bottom of the Great Meteor Seamount in the Canary Basin.

09:00 AM PO31C-05 Nonlinear Internal Waves on the Inner Shelf: Observations Using a Distributed Temperature Sensing (DTS) System. ***Kristen A Davis**[1], Emma Catherine Reid[1] and Anne L Cohen[2], (1)University of California Irvine, Irvine, CA, United States, (2)Woods Hole Oceanographic Institution, Woods Hole, MA, United States*

ケーブルを海底に敷設して、2m の水平解像度で海底水温が連続モニタできるシステム（DTS）を南シナ海 Donsha　Atoll というサンゴ礁の斜面での水温変化を調べた。Super-critical slope となるところで、内部波の後方反射が捉えられた。

新しい観測システム、おもしろかった

Internal waves propagating across the continental slope and shelf are transformed by the competing effects of nonlinear steepening and dispersive spreading, forming nonlinear internal waves (NLIWs) that can penetrate onto the shallow inner shelf, often appearing in the form of bottom-propagating nonlinear internal bores or boluses. NLIWs play a significant role in nearshore dynamics with baroclinic current amplitudes on the order of that of wind- and surface wave-driven flows and rapid temperature changes on the order of annual ranges. In June 2014 we used a Distributed Temperature Sensing (DTS) system to give a continuous cross-shelf view of nonlinear internal wave dynamics on the forereef of Dongsha Atoll, a coral reef in the northern South China Sea. A DTS system measures temperature continuously along the length of an optical fiber, resolving meter-to-kilometer spatial scales. This unique view of cross-shelf temperature structure made it possible to observe internal wave reflection, variable propagation speed across the shelf, bolus formation and dissipation. Additionally, we used the DTS data to track internal waves across the shallow fore reef and onto the reef flat and to quantify spatial patterns in temperature variability. Shoaling internal waves are an important process affecting physical variability and water properties on the reef.



09:15 AM PO31C-06 Turbulence and Mixing in a Rotating Shallow Bottom Gravity Current ***Lars Umlauf***, *Chris Lappe and Peter Holtermann, Leibniz Institute for Baltic Sea Research, Rostock, Germany*

摩擦が効くバルト海での海底 gravity current を昇降式係留系観測等を使って調べた。

Angle of descent tanβ=Ek =cd*U/(fH) Ameborg et al. 2007

Entrainment parameter E=we/U Umlauf and Ameborg (2009)

Mesoscale, wind, inertial, tide and internal tide dynamics determine the vertical mixing, horizontal transport of mass and energy, and dissipation of energy on the continental shelf. We investigate the relative contribution of each of these processes, with emphasis on the internal wave dynamics in particular, to shelf mixing and to the cross- and along-shelf energy budgets on the Tasmanian Eastern Shelf, Australia. We deployed three traditional moorings and two autonomous profilers (WireWalkers) along a transect on this relatively narrow shelf. Estimates of mixing rates were derived from both high-frequency temperature measurements (chi-pods) on the WireWalkers and near-bed continuous measurements of temperature and velocity. The region is unique with a locally generated sub-inertial diurnal internal tide and a super-inertial semidiurnal internal tide, the potential for remotely generated energetic internal tides to be scattered onto the shelf, strong winds that force inertial waves and a persistent along-shore current. Although the diurnal internal tide is sub-inertial, the total horizontal kinetic energy (HKE) is the same order of magnitude as the super-inertial internal semidiurnal tide at $O(10\ \mathrm{Jm}^{-3})$. In comparison, the near-inertial HKE is $O(100\ \mathrm{Jm}^{-3})$ and dominates the baroclinic tides. Frequent but irregular bore-like nonlinear waves with amplitudes $O(10\ \mathrm{m})$ are measured at the shelf-break, but do not propagate to the mid-shelf moorings (~10 km west). Estimated turbulent dissipation rates ε varied from 1e-9 to 1e-6 W kg^{-1} near the seabed with increased values near the surface following large wind events (>0.6 N m^{-2}). Mixing rates were often in excess of $10^{-4}\ \mathrm{m}^2\mathrm{s}^{-1}$. The implications of the topographically trapped internal diurnal tide for local dissipation of energy will be discussed.

09:30 AM PO31C-07 Near-Bottom Turbulence in the Deep Hypolimnetic Waters of a Large Stratified Basin *Cary David Troy, Purdue University, Civil and Environmental Engineering, West Lafayette, IN, United States and* ***David Cannon****, Purdue University, Lyles School of Civil Engineering, West Lafayette, IN, United States*
Troy et al. 2016JGR に出版
良くできた観測
The Baltic Sea consists of a system of shallow brackish basins, connected to the salty waters of the North Sea by a system of narrow straights. The strong lateral density gradient across the connecting region intermittently triggers bottom gravity currents that may travel over hundreds of kilometers along the bottom topography towards the deep central basins of the Baltic Sea. This configuration, and the relatively easy accessibility with oceanic instrumentation, makes the Baltic Sea an ideal natural laboratory for the study of rotationally influenced bottom gravity currents. Here, we discuss recent data from an extensive field campaign that took place in spring 2015, when one of the largest inflows of dense bottom waters ever recorded arrived in the central parts of the Baltic Sea. Measurements from this exceptional event include densely-spaced simultaneous turbulence microstructure and velocity (ADCP) transects across the gravity current as well as high-resolution moorings positioned along its pathway. These data reveal a vigorously turbulent dense bottom layer of 10-20 m thickness that travels, strongly affected by rotation, along the lateral slopes of the basin, and merges with its lower flank into a pool of dense bottom water. We use these data to analyze the mixing parameters and dynamics of this flow, compare them to the large-scale oceanic overflows, and briefly discuss the bio-geochemical implications of the oxic waters transported and mixed by the gravity current into the otherwise sulfidic deep layers of the central Baltic Sea.

09:45 AM PO31C-08 Horizontal distribution of near-inertial waves in the western Gulf of Mexico: Eulerian vs Lagrangian. ***Enric Pallas Sanz***[1]*, Paula García-Carrillo*[1]*, Beatriz Ixetl Garcia Gomez*[1]*, Jonathan M Lilly*[2] *and Paula Perez-Brunius*[1]*, (1)CICESE, Ensenada, Mexico, (2)NorthWest Research Associates, Inc, Socorro, NM, United States*
メキシコ湾の drifter や係留上向き ADCP を使って、(0.75〜1.25)*f の NIW を、Demodulation と Butterworth の手法で取り出し、分布パターンは良く一致するが、大きさはドリフタが大きい。差は冬季に大きく、北風によって高気圧性渦の表層に NIW が捕捉され、深いところを含む係留 ADCP と表面付近の drifter で差がでていた。
The time-average horizontal distribution of the near-inertial waves (NIWs) on the western Gulf of Mexico (GoM) is investigated using horizontal velocity data obtained from Lagrangian trajectories of ~200 surface drifters drogued at ~50m and deployed between September 2008 and September 2012. Preliminary results suggest maximum time-averaged near-inertial circle radius of 2.6km located in the southern Campeche bay near [22N,95W]; implying an inertial velocity of about 0.14m/s. Similar conclusions are delineated using horizontal velocity data obtained from 21 moorings deployed in the western GoM during the same time period. Maximum near-inertial kinetic energy and clockwise spectral energy is found in the mooring LNK3500 located at 21.850N and 94.028W. Maximum inertial circles measured with mooring data, however, are of about 1.6km leading to inertial currents of

0.087m/s, approximately a 40% smaller. This discrepancy seems to be due to the different depth level of the measurements and the bandwidth used to extract the near-inertial oscillations from the total flow. The time-average horizontal distributions of wind work computed from Lagrangian and Eulerian data are compared and they are not consistent with the time-averaged NIW field. The differences are not well understood but we speculate they may be due to the different time scales of wind fluctuations in the northwestern GoM compared to those observed in the Bay of Campeche, together with the change of sign of the background vorticity in the region; being negative (anticyclonic) in the northern GoM and positive (cyclonic) in the Bay of Campeche.

PO33B The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller V

Wednesday, February 24, 2016

02:00 PM - 04:00 PM

Ernest N. Morial Convention Center

- 203-205

Papers

02:00 PM PO33B-01 On Turbulence Losses at Rough Topography: LES results ***Sutanu Sarkar**, Masoud Jalali and Vamsi K Chalamalla, University of California San Diego, La Jolla, CA, United States*

斜面での乱流は、斜面傾斜が 1) sub-critical, 2) subcritical + critical, 3) super-critical, 及び、excursion parameter Ex=(定義？)の大小で、1 小) 線形内部潮汐、1 大)風下波（Lee）、2 小）IW のビーム、2 大）Advected Lee 波、3 小）ビーム＋harmonics + Jet、３大）Jet＋Lee 砕波、と整理される。Jalali, Rapaka & Sarkar JFM 2014 Excursion parameter の定義？で整地されて面白い。

With increasing slope steepness, conversion from the barotropic tide to internal waves increases in linear theory prediction. However, dissipative nonlinear features also become increasingly evident in observational studies and numerical simulations of wave generation at steep topography. High-resolution, three-dimensional LES have been performed to resolve turbulence, compute a closed baroclinic energy budget and quantify the local baroclinic energy loss, q. The tidal amplitude is varied for a model triangular ridge with different slope angles spanning sub- to supercritical topography. The LES results are used to extract the dependence of cycle-averaged q on the governing non-dimensional parameters as a step towards parameterization of internal tides in ocean models. Comparisons are made with observations and previous model studies at Luzon Strait and Kanea Ridge. The spatial distribution of cycle-averaged q, turbulent viscosity and turbulent diffusivity varies qualitatively among cases. Changes in q are linked to changes in the features responsible for turbulence which include one or more of the following: unstable wave shear, lee wave breaking, boundary layer shear, boundary layer inversions, downslope jets, and upslope bores.

02:15 PM PO33B-02 Highly efficient boundary mixing near sloping topography in a non-tidal basin ***Chris Lappe** and Lars Umlauf, Leibniz Institute for Baltic Sea Research, Rostock, Germany*

バルト海斜面海底付近での混合(boundary mixing)についての観測。海盆内部では、halocline 中で KH 不安定による散逸率の強化が起こるのに対して、斜面海底付近では、halocline が斜面にぶつかる深度以外の場所で、散逸率が強化。Halocline が斜面にぶつかる場所では、流速が遅かった。（内部波の流速構造と対応しているというような事を言っていた気がするが、ちゃんと聞き取れなかった）

Recent results from a tracer experiment in the deepest layers of the central Baltic Sea suggest that boundary mixing plays an essential role for the net vertical transport of dissolved substances. Here, we discuss results from an extensive field campaign, aimed at clarifying the relevance of boundary mixing in strongly stratified, non-tidal basins, taking the Baltic Sea as an example. The dataset includes high-resolution turbulence microstructure and velocity data from seven cross-slope transects, providing a detailed view of the temporal and cross-slope variability of mixing. Basin-scale motions are found to be dominated by near-inertial waves with velocities reaching 0.2 m s^{-1}.

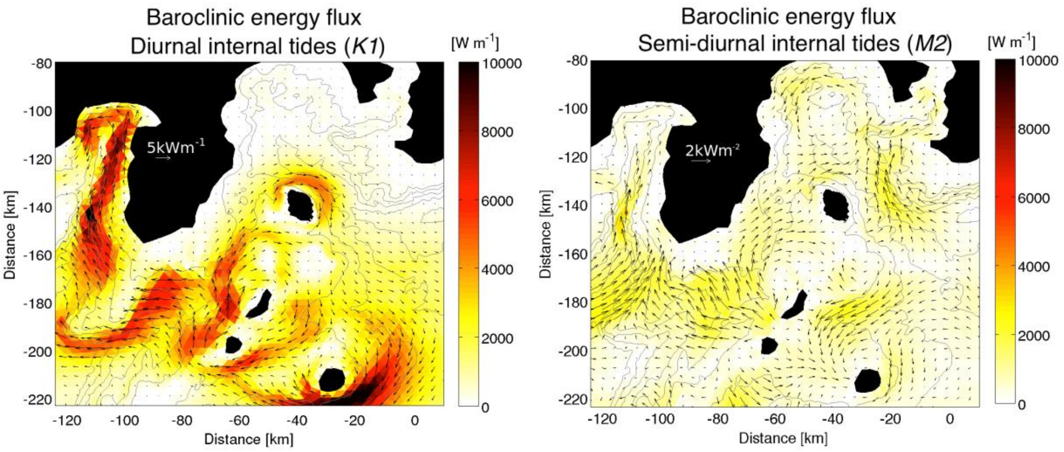
The near-bottom currents associated with these motions generate a vigorously turbulent bottom boundary layer (BBL) with a thickness of several meters, where bottom friction rather than the critical reflection of the near-inertial waves acts as the main energy source for turbulence. Most of the BBL is stably stratified, and characterized by Ozmidov scales smaller than the distance to the bottom, suggesting that near-bottom turbulence is generally not controlled by law-of-the-wall dynamics. As a consequence, the buoyancy Reynolds number is relatively small, and mixing efficiencies are high. This suggests that boundary mixing near sloping topography is more efficient than generally assumed.

02:30 PM PO33B-03 Effects of Anisotropy on Observation of Turbulent Dissipation in Bottom Boundary Layers
***Leon Boegman**, Aidin Jabbari and Ugo Piomelli, Queen's University, Civil Engineering, Kingston, ON, Canada*
発表者が会場に来ない。聴講者の一人が急遽代理で発表した。
When internal waves interact with topography, such as continental slopes, they can deposit their energy to local dissipation and diapycnal mixing. Submarine canyons comprise approximately ten percent of global continental slopes, and can enhance the local dissipation of internal wave energy, yet parameterizations of canyon mixing processes are currently missing from large-scale ocean models. As a first step in the development of such parameterizations, we conduct a parameter space study of M2 tidal-frequency, low-mode internal waves interacting with idealized V-shaped canyon topographies. Specifically, we employ a two-pronged approach: a suite of numerical simulations using the MITgcm, as well as a theoretical ray-tracing algorithm, in which we vary the mouth width and sidewall slope (i.e. flat bottom or critical slope) of the canyon. At intermediate canyon widths, we observe multiple wave reflections, leading to increased vertical wavenumber, and thus decreased Richardson number. The instability that results leads to increased dissipation. Relative to a supercritical continental slope without a canyon, we find that V-shaped flat bottom canyons always dissipate more energy and are an effective geometry for wave trapping and subsequent energy loss. When both flat bottom canyons and critical slope canyons are made narrower, less wave energy enters the canyon, but a larger fraction of that energy is lost to dissipation due to subsequent reflections and wave trapping. The relative important of convective and shear-driven instability can be deduced from examination of the Richardson. As a next step, we seek to expand this parameter-space study to realistic topographies, such as Atlantis and Veatch Canyons, in order to validate our wave reflection and dissipation theory.

02:45 PM PO33B-04 Internal Wave Scattering in Continental Slope Canyons: A Parameter Space Study ***Robert Nazarian** and Sonya Legg, Princeton University, Princeton, NJ, United States*
海底谷でのエネルギー散逸は全球の１５%に及ぶことが示唆されている。３次元の反射理論
When internal waves interact with topography, such as continental slopes, they can deposit their energy to local dissipation and diapycnal mixing. Submarine canyons comprise approximately ten percent of global continental slopes, and can enhance the local dissipation of internal wave energy, yet parameterizations of canyon mixing processes are currently missing from large-scale ocean models. As a first step in the development of such parameterizations, we conduct a parameter space study of M2 tidal-frequency, low-mode internal waves interacting with idealized V-shaped canyon topographies. Specifically, we employ a two-pronged approach: a suite of

numerical simulations using the MITgcm, as well as a theoretical ray-tracing algorithm, in which we vary the mouth width and sidewall slope (i.e. flat bottom or critical slope) of the canyon. At intermediate canyon widths, we observe multiple wave reflections, leading to increased vertical wavenumber, and thus decreased Richardson number. The instability that results leads to increased dissipation. Relative to a supercritical continental slope without a canyon, we find that V-shaped flat bottom canyons always dissipate more energy and are an effective geometry for wave trapping and subsequent energy loss. When both flat bottom canyons and critical slope canyons are made narrower, less wave energy enters the canyon, but a larger fraction of that energy is lost to dissipation due to subsequent reflections and wave trapping. The relative important of convective and shear-driven instability can be deduced from examination of the Richardson. As a next step, we seek to expand this parameter-space study to realistic topographies, such as Atlantis and Veatch Canyons, in order to validate our wave reflection and dissipation theory.

03:00 PM PO33B-05 Generation mechanisms and energetics of internal waves around an island ***Eiji Masunaga***[1], *Oliver B Fringer*[2] *and Hidekatsu Yamazaki*[1], *(1)Tokyo University of Marine Science and Technology, Tokyo, Japan, (2)Stanford University, Dept. of Civil and Environmental Engineering, Stanford, CA, United States*
Masunaga et al. 2015CSR
Shallow ridges, seamounts and islands have been known as generation site of strong baroclinic internal tides in coastal oceans. However, details of generation and propagation processes of such internal waves/tides have not been investigated well. In this study, generation processes of internal tides around islands were investigated by using numerical simulation performed by Stanford Unstructured Nonhydrostatic Terrain-Following Navier-Stokes Similator (SUNTANS). This study focuses on Izu-Oshima Island located off Sagami Bay, Japan. The barotropic tides generated strong baroclinic internal waves around the study site. The diurnal tidal frequency (~ *K1*) is lower than the inertial frequency (*f*) in the mid latitude, which results in strongly enhanced Kelvin trapped internal tides around the island. The isothermal displacement due to diurnal internal tides reached 50 m in the model. The internal wave energy generated by diurnal tides was resonated around the island and was much higher than that of semi-diurnal (~ *M2*) internal tides. Shallow ridges near the island enhanced non-linearity of internal waves, which induces high frequency internal waves. Such high frequency waves cannot be trapped around the island, because their frequency is higher than the inertial frequency. These high frequency waves were released from the island and propagated to the offshore, like nonlinear solitary waves. In addition, numerical results showed good consistencies with observed results taken near the island.



03:15 PM PO33B-06 [Global Patterns of Turbulence and Diapycnal Mixing from CTD-Chipods on the Global Repeat Hydrography Program] ***Andrew Pickering***[1], *Jonathan D Nash*[2], *Jim N Moum*[2] *and Jennifer A MacKinnon*[3], *(1)Oregon State University, Corvallis, OR, United States, (2)Oregon State Univ, Corvallis, OR, United States, (3)University of California San Diego, La Jolla, CA, United States*

Moum が代理講演した。Xpod は 100Hz、詳細な解析手法は不明、結果は妥当に見えた。海底付近での強化が示されているが、悪いデータをどのように外し、補正したかなど不明

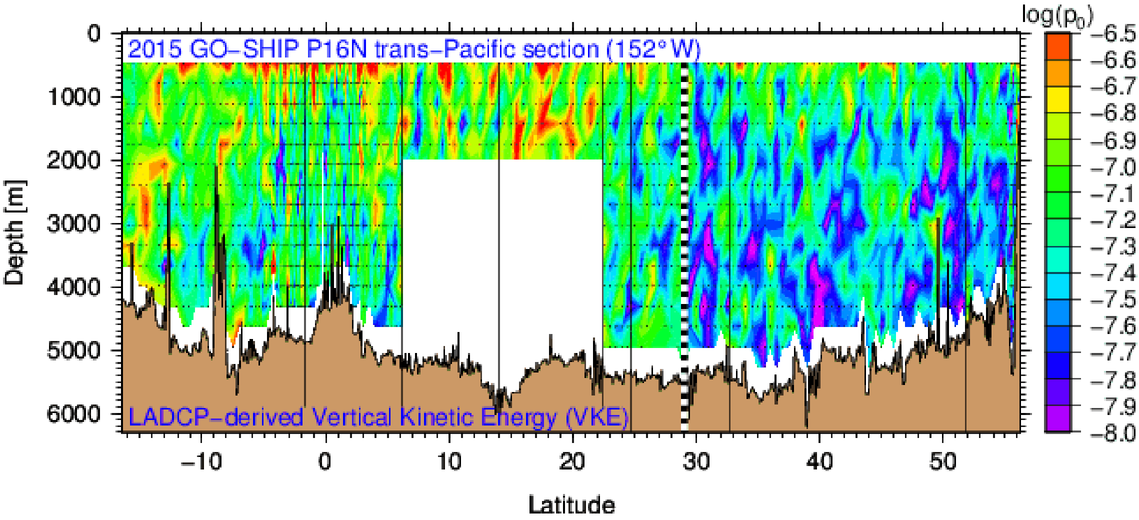
With an aim to quantify global patterns of ocean mixing, we have developed the CTD-chipod, an instrument that measures the turbulent dissipation rate of temperature variance from standard shipboard CTD. First, turbulent diffusivities and turbulent dissipation rate inferred from the CTD-chipod are compared to that from traditional turbulence profilers with shear probes, suggesting the method does not suffer from significant bias. CTD-chipods have now been deployed on several of the global repeat hydrography program cruises, including the complete P16 line from 60S to 55N in the Pacific. Here we discuss broad patterns of mixing from these observations, as well as focusing on some specific interesting features. In particular, a section of higher resolution sampling across the equator from 5S to 5N in the Pacific suggests elevated abyssal mixing in that region. This and other patterns will be examined in relation to large-scale patterns of stratification, velocity, and shear. The observations will also be compared to other common parameterizations of mixing from shear and strain. These chipod measurements are a step towards constraining the spatial and temporal patterns of turbulent mixing across the world's oceans, in order to better understand dissipative mechanisms and their role in ocean dynamics.

03:30 PM PO33B-07 [Vertical Kinetic Energy Observed With LADCP/CTD Systems] ***Andreas M Thurnherr***, *Lamont-Doherty Earth Observatory, Palisades, NY, United States*

LADCP から w を求め、鉛直流速エネルギーのスペクトルを用いて、慣性領域を使って散逸率を求め、VMP の結果と比較したところ、緯度の補正無でもファクタ２で整合した(Thurnherr et al., GRL 2015)。w の求め方は、www.ldeo.columbia.edu/LADCP

Away from the boundaries, vertical motion in the ocean is dominated by high-frequency internal waves, which are very closely linked to turbulence (Thurnherr et al., GRL 2015). Conveniently, there is a very large available data base of vertical kinetic energy (VKE) observations, collected with conventional LADCP/CTD systems, from many

regions of the ocean. The data base includes the profiles from many WOCE and almost all CLIVAR repeat hydrography cruises, as well as from numerous process studies carried out since the 1990s. Here, observations of vertical velocity, VKE, and VKE-parameterized dissipation from several example data sets are presented. The data include profiles from dynamically active regions, where w commonly reaches several cm/s, such as overflows, gravity currents, regions of strong internal-tide generation, as well as a time series from the outflow of a sub-glacial cavity on the West Antarctic Ice Sheet. Also included is a recent meridional GO-SHIP (CLIVAR repeat hydrography) section across the Pacific along 152W, where rms vertical velocities <1cm/s are near the noise level of the instrumentation, but where a clear poleward drop of VKE across the critical latitude for semi-diurnal PSI was nevertheless observed.



03:45 PM PO33B-08 Nine years of temporal and spatial low-mode internal wave variability in the Atlantic Basin at 26N ***Kim I Martini***, *University of Washington Seattle Campus, Seattle, WA, United States and Zoltan B Szuts, Applied Physics Laboratory University of Washington, Seattle, WA, United States*

Rapid の MOC 観測で、26N まで北大西洋を伝搬する内部潮汐波を検出し、台風応答を調べた。

Although internal waves have been studied in numerous process studies, there are few observations of their long-term variability at seasonal and longer time scales. The collaborative US/UK Atlantic Meridional Overturning Circulation (AMOC) moored array (MOCHA/WBTS/Rapid_MOC projects) has been deployed across the south Atlantic basin at 26 N for over 9 years and is a unique platform which is leveraged here to examine this low-frequency variability. Hourly full-depth measurements at 8 moorings are used to examine the wind and tidally generated internal wave field. Variability at weather, seasonal and longer time scales will be discussed, as well as cross-basin propagation. Particular attention will paid to the Western Boundary, the Mid-Atlantic Ridge and the Eastern Boundary and potential internal wave sources and sinks will be identified.

PO34C The Ocean's Energy Cascade: Measuring and Modeling of Instabilities, Internal Waves, and Turbulence at the Submesoscale and Smaller VI Posters

Wednesday, February 24, 2016

04:00 PM - 06:00 PM

Ernest N. Morial Convention Center

- Poster Hall

Papers

PO34C-3065 Tidal Mixing over Rough Topography: Sensitivity to Topographic Length Scale and Steepness ***Young Ro Yi***[1], *Sonya Legg*[2] *and Robert Nazarian*[2], *(1)Princeton University, Geosciences, Princeton, NJ, United States, (2)Princeton University, Princeton, NJ, United States*

Tidal flow over topography generates internal waves at the tidal frequency known as internal tides and the breaking of these waves leads to enhanced dissipation and diapycnal mixing over topography. This tidally driven mixing influences the large-scale circulation, affecting ocean heat and salt distribution, carbon uptake and sea level. Developing improved parameterizations of tidal mixing for general circulation models is therefore crucial. Climate model simulations are sensitive to the vertical profile of dissipation (Melet et al., 2013), an unknown in current parameterizations. At rough abyssal topography, the dominant process leading to internal wave breaking appears to be nonlinear wave-wave interactions which transfer energy to smaller vertical scales (Nikurashin and Legg, 2011). Here a parameter space study of tidal mixing over rough topography, focusing on the dependence of the vertical profile of dissipation to Coriolis frequency and the topographic wavelength, is conducted using two-dimensional MITgcm numerical simulations. Four different Coriolis frequencies are considered for six different topographic wavelengths, encompassing both subcritical and supercritical topographies. Existing parameterizations are shown to incorrectly reproduce the simulated vertical structure of the enhanced dissipation over topography. In addition, although wave-wave interactions leading to dissipation are known to peak at the critical latitude before decreasing once again towards the poles, a peak in dissipation at the critical latitude is observed for only some of the six topographic wavelengths. Further simulations attempt to distinguish the effects of topographic steepness on the wave breaking and dissipation from that of topographic wavelength. The effects of Coriolis frequency, topographic wavelength and topographic steepness need to be included in parameterizations of tidal mixing over rough topography to more accurately simulate climate states.

PO34C-3066 Structure Function Statistics to Detect Submesoscale Cascades ***Jenna Lynn Palmer***, *Brown University, Earth, Environmental and Planetary Sciences, Providence, RI, United States and Baylor Fox-Kemper, Brown University, Providence, RI, United States*

Lagrangian trajectories coupled with pairwise velocity and tracer statistics are an important piece in unraveling the complexities of mesoscale, submesoscale and boundary layer turbulence. Typical characterizations of turbulence are often theoretically attainable under certain simplified assumptions and conditions, but they are often hard to apply with current methods because of gaps or irregularities in observations. Many observational platforms provide measurements at separated, random locations within a turbulent flow. This presentation analyzes the structure function statistics obtained from these measurements toward identifying classes of turbulence.In varying

submesoscale models where forward and inverse kinetic and potential energy cascades, vigorous internal gravity waves, fronts, filaments, and mixed layer eddies are directly diagnosed, we simulate drifter observations of velocity and tracers. Through this analysis, optimization of array size, sampling, and uncertainty can be made rigorous. Different classes of turbulence (3d, 2d, quasigeostrophic, wave, and Langmuir) can be distinguished using these techniques with sufficient numbers of pairs at varying scales. General scaling laws, such as the Richardson scaling, tend to arise under certain types of averaging for many distinct classes of turbulence. Future work will refine the use of higher order structure functions and turbulence characterizations in anisotropic and heterogeneous settings.

PO34C-3067 Uncertainties in Internal Tide Generation and Energy Flux in the Tasman Sea ***Samuel Maurice Kelly***, *University of Minnesota Duluth, Duluth, MN, United States*

Macquarie Ridge, southwest of New Zealand, is a site of enhanced internal-tide generation, which produces a horizontal internal tide beam that propagates northwest across the Tasman Sea. This beam has been identified in satellite altimetry, gliders, and in situ measurements. Here, we use numerical models to estimate internal-tide generation and energy fluxes, and their associated uncertainties, at Macquarie Ridge. First, we compare realistic simulations from fully-nonlinear and quasi-linear models with in situ measurements to determine best estimates of internal tide generation and energy flux. Next, we use the quasi-linear model (CSW) to conduct numerous sensitivity experiments that quantify the uncertainties in internal-tide generation due to numerical approximations (e.g., grid resolution) and unknown environmental conditions (e.g., local stratification anomalies). Lastly, we use CSW, in conjunction with estimates of mesoscale currents and stratification, to quantify uncertainties in energy flux due to internal-tide interactions with mean flows at a range of time and length scales. These analyses provide context for analyzing observations and more sophisticated numerical simulations of the Tasman Sea.

PO34C-3068 Impact of the North Atlantic Subpolar Front on Near-Inertial Wave Propagation ***Janna Köhler***[1], *Maren Walter*[1], *Christian Mertens*[1], *Birgit A Klein*[2] *and Monika Rhein*[1], *(1)University of Bremen, Bremen, Germany, (2)BSH Federal Maritime and Hydrographic Agency, Hamburg, Germany*

Recent studies emphasize the strong influence of oceanic fronts on the strength of diapycnal mixing and on the generation and propagation of near-inertial waves. Here we analyze the temporal variability of near-inertial wave energy in relation to changes in flow speed, the presence of eddies and the wind field at the North Atlantic subpolar front using three-year velocity timeseries at three moorings covering the depth range from 240m to 3000m. Along the mooring array the influence of the North Atlantic Current (NAC) is decreasing northward, inducing pronounced differences in the internal wave field. Other studies e.g. at the Subtropical Front in the North Pacific showed that near-inertial waves radiate off the front. In the region of the NAC however, near-inertial waves are most energetic at the northernmost mooring (least influenced by the NAC) whereas the energy level at the southern moorings is lower. Thereby variability in near-inertial wave energy is dominantly induced by changes in the wind field.

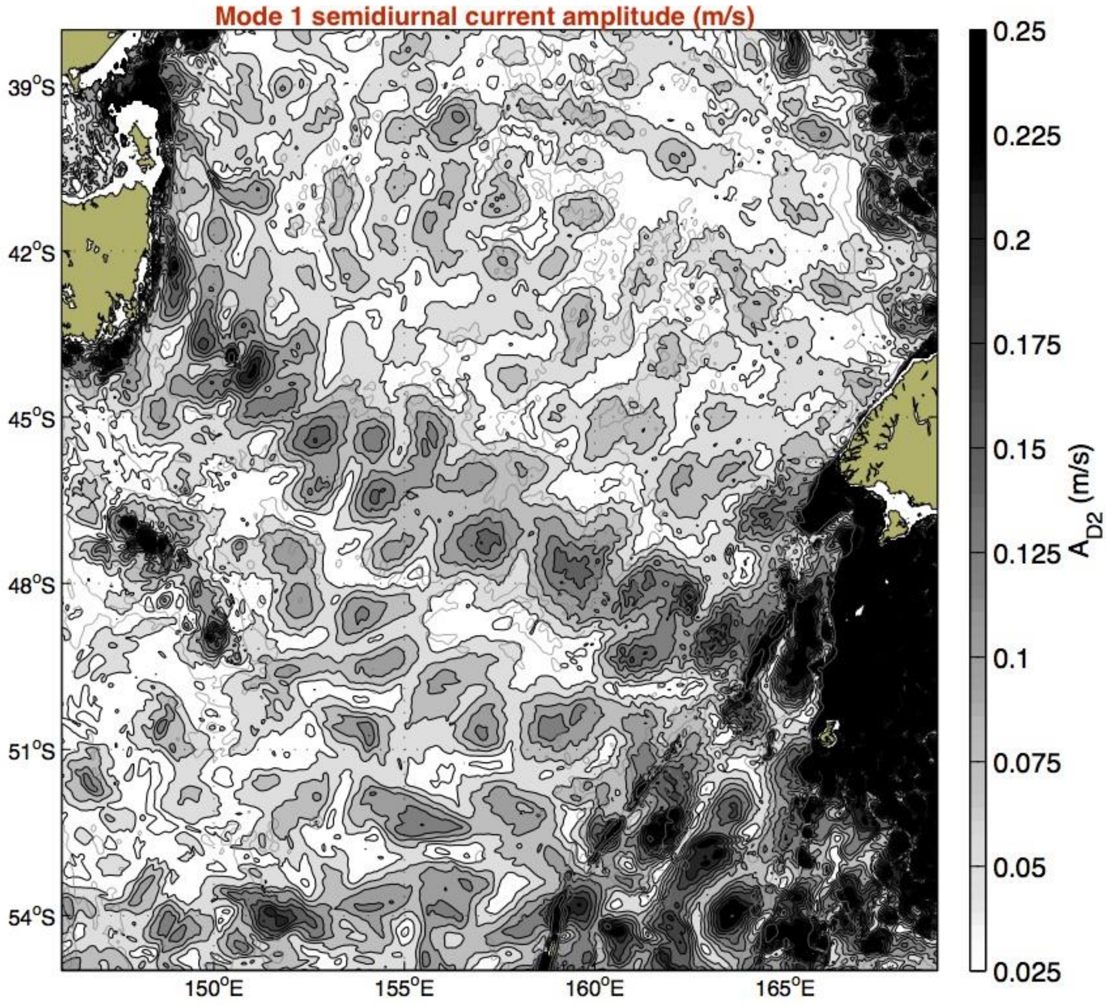
Within the upper part of the NAC data are consistent with low Richardson numbers, likely inducing enhanced internal wave breaking. Additionally a stronger stratification within the lower part of the NAC compared to north of the front results in a shift of wavenumber aspect ratio and a longer residence time of the internal waves in the upper water column. Both processes would result in the observed reduction of near-inertial internal wave energy at greater depths within the region of the NAC.

PO34C-3069 Observed Internal Tide Energy Fluxes in the Tasman Tidal Dissipation Experiment ***Olavo Badaro Marques***, *Scripps Institution of Oceanography, La Jolla, CA, United States and Matthew H Alford, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States*

Low mode internal tides propagate across long distances in the ocean and the location of their energy dissipation has important
consequences for ocean circulation. The Tasman Tidal Dissipation Experiment (TTIDE) was designed to evaluate the fate of the internal
tide as it approaches a continental slope and the involved dissipation mechanisms. The observational component of TTIDE included mooring,
glider and ship-based observations for over 2 months off Tasmania, where strong internal tides are expected to impinge on the continental
slope. Observed amplitudes of internal semidiurnal and diurnal tidal currents are of 0.3 m s^{-1}. Results from CTD and LADCP casts over a
tidal cycle in 2500 meters of water column show an onshore energy flux of 3 kW m^{-1}. Tidal energy fluxes results of ongoing analysis of mooring
and ship-based data on the Tasman slope and the deep ocean will be presented.

PO34C-3070 The Internal Tide Of The Tasman Sea ***Harper L Simmons***, *University of Alaska Fairbanks, Fairbanks, AK, United States, Dmitry Brazhnikov, University of Alaska Fairbanks, Anchorage, AK, United States, Sam Kelly, University of Minnesota Duluth, Duluth, MN, United States, Jody M Klymak, University of Victoria, Victoria, BC, Canada and Amy Frances Waterhouse, University of California San Diego, La Jolla, CA, United States*

The Tasman Sea internal tides feature a relatively narrow beam of low mode energy flux that has been observed to cross the basin from the Macquarie Ridge and impinge upon the continental slope of Tasmania. A series of regional hindcast simulations of the tides and general circulation reveal that the beam is formed when semidiurnal barotropic tidal current ellipses cross submarine features South of New Zealand. The beam generation sites are along the Macquarie Ridge, which extends Southeast from New Zealand, and the shelf break on the Western edge of the Campbell plateau. The simulated basin scale barotropic and low mode baroclinic tides are described, with attention to the generation, propagation, reflection and scattering of the beam. Interannual variability in the circulation and stratification is described, along with changes of the surface tides, the baroclinic generation and the beam. Comparisons are made to in-situ measurements collected during the TTIDE/TBEAM/TSHELF experiments as well as to historical glider measurements and altimetric inferences of surface and baroclinic tides.



PO34C-3071 Observations of internal tidal reflection from a supercritical corrugated slope

ABSTRACT WITHDRAWN

PO34C-3072

Local turbulence and baroclinic energy balance in a Luzon Strait model ***Masoud Jalali***[1]*, Sutanu Sarkar*[1] *and Vamsi K Chalamalla*[2]*, (1)University of California San Diego, La Jolla, CA, United States, (2)University of California at San Diego, Aerospace and Mechanical Engineering, San Diego, CA*

Generation sites for topographic internal gravity waves can also be sites of intense turbulence. The present work uses high resolution 3D LES to simulate flow over a model with topography patterned after a cross-section of Luzon Strait at latitude of $20.6^{¥circ}$, double-ridge generation site which was the subject of the recent IWISE experiment. The west ridge has been modeled in isolation, and at 1:100 length scale using environmental parameters that match important nondimensional numbers such as the slope criticality, Froude number, and Excursion number. Comparison with observations at measurement station N2 shows generally good agreement with the amplitude and phasing of velocity, overturns and turbulent dissipation except for the lack of resonance with the east ridge at a specific tidal phase. Bc-Bt energy conversion equation terms are calculated and the budget is closed. The results emphasize the importance of turbulent processes with the local energy loss, $q ¥simeq 35¥%$.

Several turbulent mechanisms are found to be responsible for turbulence including breaking lee waves during flow reversal and downslope jets that have been observed (Alford et al. (2011), Alford et al. (2015)) as well as critical slope boundary layer, internal wave beams, off-slope lee wave breaking and valley flows. Wave breaking and turbulence at these sub-ridges are governed by an inner Excursion number (Ex_{in}) and exhibit similarity with the regimes identified by DNS of Jalali et al. (2014).

PO34C-3073 Application of Directional Wave Spectra Method to Numerical Investigations of Internal Tide Reflection ***Dmitry Brazhnikov***[1]*, Harper L Simmons*[1]*, Jody M Klymak*[2] *and Zhongxiang Zhao*[3]*, (1)School of Fisheries and Ocean Sciences, Fairbanks, AK, United States, (2)University of Victoria, Victoria, BC, Canada, (3)Applied Physics Laboratory University of Washington, Seattle, WA, United States*

Internal tides can interfere creating complex patterns of standing waves with nodes and antinodes in energy density. The interference picture becomes more complicated for cases when the field is composed of forward and reflected waves. Such phenomena mask important physical process occurring near steep continental slopes, both in observations and in simulations. Here we propose a method of directional wave spectra decomposition for the analysis of tidal interference. The method is based on fitting plane waves to the spectral representation of numerical observations. The cross-spectra and quad-spectra are linearly regressed to a “kernel matrix” describing interactions of elementary directionally different components. Such an approach, in comparison to regular plane wave fits, has advantage of distinctly defining wave propagation and energies involved. However, the interference picture cannot be perfectly reconstructed since the wave phases are not retained. To test the method’s validity idealized simulations with simplified bathymetric features were carried out. In these experiments the scattered waves can be easily identified and compared with the spectral analysis. Further, we present application of the approach to comprehensive numerical simulations: the propagation of internal tides in Tasman Sea and subsequent reflection from the Tasmanian shelf break. The simulations include mesoscale ocean dynamics which complicate the analysis due to interaction of the tidal signal with the background fields as well as complicated bottom bathymetry that scatter low mode internal tides into higher modes. In both cases the method of wave spectra decomposition proves to give satisfactory results and can be used for investigations of large scale internal tide energy pathways.

PO34C-3074 Observations of arrested internal lee waves at a tall, steep submarine ridge ***Celia Yun Ou****, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States and Shaun Johnston, University of California San Diego, La Jolla, CA, United States*

Steady ocean currents flowing over topography produce arrested internal lee waves, which have phase speeds equal to the steady current speed. Models suggest these waves may be an energy sink for the general circulation. Recent interest in these lee waves has been focused on abyssal hill topography in the Southern Ocean, where half of the global energy flux from geostrophic flow into lee waves may occur according to models. Other areas of possible lee wave generation include the western Pacific, where strong, surface-intensified currents flow over tall, steep topography. As part of ONR’s Flow Encountering Abrupt Topography (FLEAT) program, spatial surveys with shipboard ADCP and a towed CTD (SeaSoar) were conducted over a submarine ridge near Merir Island in the midst of the North Equatorial Countercurrent (NECC). We observed a strong mean flow in the NECC ranging from 0.3 to 1.0 m/s in the upper 400 m upstream of Merir Island. Arrested internal lee waves were found. Oscillations in density and velocity had horizontal wavelengths of roughly 20 km, had intrinsic periods of O(0.1-1 days), and were

persistent over the 2 days of the survey. The waves carried a westward and upward energy flux and exerted a drag on the mean current.

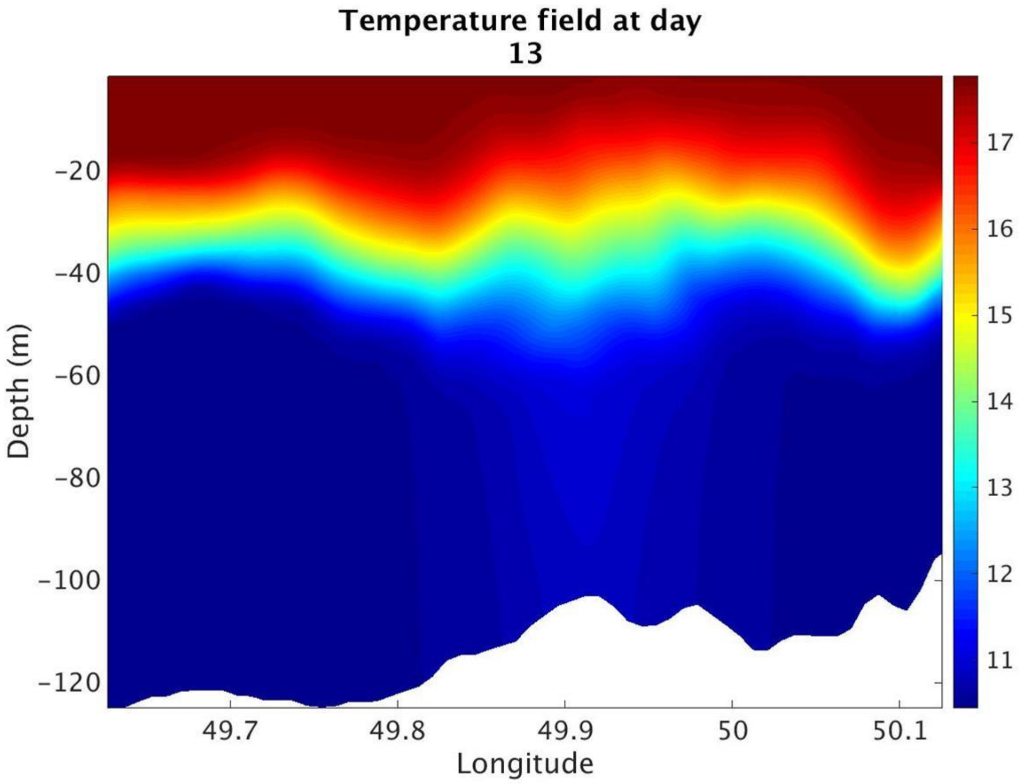
PO34C-3075 Internal tides variability at steep topographies: Interactions and probabilistic global dynamical analysis ***Sydney Sroka***, *Pierre F J Lermusiaux and Patrick J Haley Jr, Massachusetts Institute of Technology, Cambridge, MA, United States*

Internal tides and waves are important drivers of mixing and transport in the coastal ocean. In this work, we investigate the spatial variability, temporal variability, and intermittency of internal tides using non-hydrostatic simulations at idealized steep topographies. In particular, we study the sensitivity of internal tide generation and propagation to variability in the external forcing and background state. Examples of such variability include variations in the remote barotropic and internal tides forcing, background stratification, background flow, and surface wave forcing. To complete such studies, we employ a novel probabilistic global dynamical analysis using the stochastic Dynamically Orthogonal (DO) non-hydrostatic Boussinesq equations. These equations, where the stochasticity is introduced through the remote forcing, surface forcing, and background state, evolve in a fully coupled way the mean flow, density, and waves, as well as the statistical, spatial, and temporal characteristics of the stochastic fluctuations. The resulting global analysis also allows the study of nonlinear energy transfers and of the degree to which internal tides respond to specific variable forcing.

PO34C-3076 Looking Inside Internal Tides – A High Resolution Modelling Study ***Ashley Brereton***[1], *Jeff Polton*[1] *and Andres E Tejada-Martinez*[2], *(1)National Oceanography Centre, Liverpool, United Kingdom, (2)University of South Florida*

Shelf-sea models have progressed substantially in the last couple of decades in terms of their predictive capabilities and are now at the point where mesoscale features, such as internal tides, can be resolved. Internal waves are of particular importance as they include mechanisms for transferring matter, such as nutrients for phytoplankton and CO2, between deep water and the surface mixed layer. However, there is still disparity between the small-scale turbulent mixing processes and the large scale driving forces, a link which is vital to understanding the underlying mechanisms behind this exchange of matter. The aspiration of this project, PycnMix, is to simulate (in fine detail) the mixing processes that are observed in the field, to help optimise parameterisations in shelf-sea models.

To bridge this scale gap, a large-eddy simulation (LES) model has been utilised to focus in on the fine-scale (<1m) detail of the flow field, whilst using a novel technique to retain the large scale driving forces. This method permits the simulation of tidally driven turbulent mixing processes. In particular we investigate the turbulent mixing processes due to (i) tides rubbing over a rough sea bed, which result in elevated levels of shear and mixing in the bottom boundary layer, and (ii) the internal tides, generated non locally by interaction between the barotropic tide and bathymetric features, which result in elevated levels of mixing across the pycnocline.



PO34C-3077 Measurements of a Lee Wave in the Southern Ocean: Energy and Momentum Fluxes and Mixing

***Jesse Martin Cusack**, University of Southampton, United Kingdom; National Oceanography Centre, Southampton, United Kingdom, Alberto Naveira Garabato, University of Southampton, Southampton, SO14, United Kingdom, David Smeed, National Oceanography Center, Soton, Southampton, United Kingdom and James B Girton, Applied Physics Laboratory University of Washington, Seattle, WA, United States*

Lee waves, internal waves generated by stratified flow over topographic features are thought to break and generate a significant proportion of the turbulent mixing required to close the abyssal overturning circulation. A lack of observations means that there is large uncertainty in the magnitude of contribution that lee waves make to turbulent transformations, as well as their importance in local and global momentum and energy budgets. Two EM-APEX profiling floats deployed in the Drake Passage during the Diapycnal and Isopycnal Mixing Experiment (DIMES) independently measured a large lee wave over the Shackleton Fracture Zone. A model for steady EM-APEX motion is presented and used to calculate absolute vertical water velocity in addition to horizontal velocity measurements made by the floats. The wave is observed to have velocity fluctuations in all three directions of over 15 cm s^{-1} and a frequency close to the local buoyancy frequency. Furthermore, the wave has a measured peak vertical flux of horizontal momentum of 6 N m^{-2}, a value that is two orders of magnitude larger than the time mean wind forcing on the Southern Ocean. Linear internal wave theory was used to estimate wave energy density and fluxes, while a mixing parameterisation was used to estimate the magnitude of turbulent kinetic energy dissipation, which was found to be elevated above typical background levels by two orders of magnitude. This work provides the first direct measurement of a lee wave generated by ACC flow over topography with simultaneous estimates of energy fluxes and mixing.

PO34C-3078 How to Improve Surface and Internal Tides in a Global Ocean Model? Use a Linear Wave Drag Parameterization! ***Maarten C Buijsman***[1], *Joseph K Ansong*[2], *Brian K Arbic*[2], *James G Richman*[3], *Jay F Shriver*[4], *Patrick G Timko*[5], *Alan J Wallcraft*[6], *Caitlin Whalen*[7] *and Zhongxiang Zhao*[8], *(1)University of Southern Mississippi, Stennis Space Center, MS, United States, (2)University of Michigan Ann Arbor, Ann Arbor, MI, United States, (3)Florida State University, Tallahassee, FL, United States, (4)Naval Research Lab Stennis Space Center, Stennis Space Center, MS, United States, (5)Bangor University, Bangor, LL59, United Kingdom, (6)Naval Research Laboratory, Stennis Space Center, MS, United States, (7)University of California San Diego, La Jolla, CA, United States, (8)Applied Physics Laboratory University of Washington, Seattle, WA, United States*

The effects of a parameterized linear internal wave drag on the semidiurnal barotropic and baroclinic energetics of realistically forced three-dimensional global ocean models with 4 and 8 km horizontal resolutions are analyzed. Although the main purpose of the parameterization is to improve the surface tides, it also influences the internal tides. The coarse resolution of global ocean models only permits the generation and propagation of the lowest vertical modes. Hence, the wave drag parameterization represents the energy conversion to and the subsequent breaking of the unresolved high modes. We will discuss the impact of the horizontal resolution on the energetics, the generation of the vertical modes, and the wave drag strength.

Findings for the 8-km model indicate a reasonable agreement of the surface and internal tide energetics with TPXO, an accurate satellite-altimetry constrained model, Argo floats, and satellite altimetry. In addition to the surface tides, the wave drag also damps the low-mode internal tides as they propagate away from their generation sites. Hence, it can be considered a scattering parameterization, causing more than 50% of the deep water dissipation of the internal tides in the 8-km model. The good agreement between the internal tide predictions in the 8-km model and satellite altimetry confirms that a wave-drag parameterization is required to prevent overly energetic internal tides. We use a plane-wave fitting technique to estimate the amount of low-mode energy that reaches the shelves. Realistically forced global ocean models with accurate internal tides may provide crucial input for climate models on the amount and location of internal tide dissipation.

PO34C-3079 The ARCtic Tracer Release EXperiment (ARCTREX): Initial results from the release of passive tracers in the Chukchi Sea. ***Elias J Hunter***[1], *Robert J Chant*[2], *Peter Winsor*[3], *Harper L Simmons*[4] *and Hank Statscewich*[4], *(1)Rutgers University, New Brunswick, NJ, United States, (2)Institute of Marine and Coastal Science, New Brunswick, NJ, United States, (3)University of Alaska Fairbanks, Anchorage, AK, United States, (4)University of Alaska Fairbanks, Fairbanks, AK, United States*

The initial results of three passive tracer experiments in the Chukchi Sea are presented to characterize and quantify advective processes and diapycnal mixing in the Chukchi Sea. 55 kg of Rhodamine dye was injected in the surface layer of on three occasions, September 10, 2014 (release 1), September 15, 2014(release 2), and September 9, 2015(release 3). The dye was subsequently tracked using a shipboard flow through system and a towed undulating vehicle equipped with Rhodamine fluorometers. Release 1 was carried out in a moderately quiescent, highly stratified region and quickly dispersed throughout the mixed layer to a depth of ~15m. Over the next 3-4 days variability in the patch was characterized by weak advection and mixing by weak (~0.1 PSU) horizontal frontal

features that steered and strained the dye patch. In contrast to release 1, a highly energetic region near a strong (1 PSU) frontal feature was chosen for release 2. Release 2 also quickly mixed to 15-20m, then advected north at 30 cm/s. After approximately 4.5 hours it vanished from the surface layer and subducted along downward sloping isohalines. Release 2 was subsequently strained into a thin subsurface layer between the 31 and 31.2 PSU isohalines. It remained subsurface for the next 1.5 days. Release 3 was also injected near a front, albeit less energetic than release 2 and was tracked for 2 days. As in release 1 the dye mixed across a weak persistent front for the duration it was tracked. While the patch advected slowly initially, a wind event strained the dye patch horizontally and quickly advected it to the southwest. The salinity of the dye increased by ~.1 PSU over the course of release 1. These results suggest dispersion due horizontal advection/stirring processes are important in addition to vertical shear processes.

PO34C-3080 Tidally induced turbulence in the Bermuda underwater cave-system ***Sergey Molodtsov***[1], *Ayal Anis*[2] *and Thomas M. Iliffe*[2], *(1)Texas A & M University College Station, College Station, TX, United States, (2)Texas A & M University at Galveston, Galveston, TX, United States*

This study presents results from field measurements of turbulence made in Bermuda's underwater cave-system. To the best of our knowledge, this is the first time that turbulence velocity measurements have been taken in an underwater cave-system. Water currents in caves are unaffected by surface waves and thus provide a unique opportunity to obtain clear signals of tidally induced turbulence. An acoustic Doppler velocimeter and acoustic Doppler current profiler were deployed in several cave locations during a period of six days. Power spectral density (PSD) of velocity fluctuations was estimated using the multitaper power spectral method. Turbulence kinetic energy dissipation rates, ε, were calculated based on the PSD and were found to exhibit a clear -5/3 slope within the inertial subrange. Measurement periods covered full diurnal cycles and estimates of ε showed a strong correlation with the tide phase with values up to 10^{-3} W/kg during peak ebb and flood (horizontal velocities up to 0.35 m/s). Furthermore, ε was found to closely follow the wall boundary layer parametrization, $\varepsilon = u_*^3/(\kappa z)$, where u_* is the friction velocity, κ is von Karman's constant, and z is the height above the bed.

PO34C-3081 Downward lee wave radiation from tropical instability waves in the central equatorial Pacific Ocean: a possible energy pathway to turbulent mixing ***Yuki Tanaka***, *The University of Tokyo, Department of Earth and Planetary Science, Graduate School of Science, Tokyo, Japan, Toshiyuki Hibiya, University of Tokyo, Department of Earth and Planetary Science, Bunkyo-ku, Japan and Hideharu Sasaki, JAMSTEC Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan*

Turbulent mixing in the equatorial Pacific Ocean is an important process that controls diapycnal heat transport and hence affects the intensity of air-sea interactions related to the global climate. It is recently shown that, in the eastern equatorial Pacific, strong mixing is induced in the thermocline by enhanced vertical shear associated with tropical instability waves (TIWs), which propagate westward along the equator at a speed of ~0.5 m s^{-1} with a wavelength of ~1000 km.

In this study, using a high-resolution ocean general circulation model, we show that the TIWs can play an important role in inducing turbulent mixing in the thermocline also in the central equatorial Pacific, although the thermocline is too deep to be directly affected by the vertical shear of the TIWs. The front of the TIW is clearly manifested as a narrow strip of strong convergence of horizontal surface flow, from which area downward and westward propagating internal waves are intermittently emanated. These internal waves can be interpreted as lee waves generated by the surface-flow convergence zone, which acts like an inverted obstacle moving along the stratified ocean surface by inducing downward flow. The associated downward energy flux below the surface mixed layer increases as the TIW structure becomes deeper toward the central equatorial Pacific, so that the energy pathway to turbulent mixing in the thermocline can be created. The downward energy flux integrated over the entire equatorial Pacific and averaged during January 2011 amounts to ~8.1 GW, occupying a significant fraction of the energy input to the TIWs.

PO34C-3082 Impacts of tidal-mixing parameterization on the simulation of the South China Sea circulations
Shiqiu Peng, *SCSIO South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China*
A parameterization of three-dimensional climatologically vertical diffusivity driven by internal tides is implemented in a regional ocean model to simulate the circulations of the SCS. This new tidal-mixing parameterization scheme takes into account the local and non-local energy dissipation of internal tides in the South China Sea (SCS) and Luzon Strait (LS) and thus enhances vertical mixing in the SCS basin significantly compared to the scheme of St. Laurent et al. (LSJ02) that only takes into account the local energy dissipation of internal tides. Results from experiments with different vertical diffusivity parameterization schemes show that the simulated stratification of the deep SCS and water transport of the LS by the new tidal mixing scheme are more stable and much closer to the previous observation reports, which suggests that the non-local dissipation of internal tides is a non-negligible energy source for the vertical mixing in the SCS and thus is important for the maintenance of the deep water transport in the LS and the circulations in the SCS. Moreover, obvious differences between the new scheme and the LSJ02 scheme are seen in the deep currents and meridional overturning circulation in the SCS, which needs further verification against observations in the future.

PO34C-3083 Seismic Oceanography of the Gulf of Mexico ***Alex Dickinson***, *University of Cambridge, Department of Earth Sciences, Cambridge, United Kingdom, Nicky White, University of Cambridge, Earth Sciences (Bullard Laboratories), Cambridge, United Kingdom, Colm-cille Patrick Caulfield, University of Cambridge, Department of Applied Mathematics and Theoretical Physics, Cambridge, United Kingdom and Matthew Falder, University of Birmingham, School of Geography, Earth and Environmental Sciences, Birmingham, United Kingdom*
Near-surface circulation within the Gulf of Mexico is dominated by the Loop Current and its generation of anticyclonic eddies, which periodically detach and migrate westward. The interaction of these eddies with the continental slope may play a significant role in transporting near-surface shelf waters into the central Gulf. Here, a 180 km long seismic profile acquired by ION Geophysical in July 2002 is analyzed. This profile crosses the Sigsbee Escarpment, starting in water depths of ~ 80 m and culminating in water depths of ~ 3000 m. It traverses a prominent anticyclonic eddy visible on altimetric surveys. The source consisted of a tuned airgun array (volume = 4800 cubic inches, pressure = 2000 psi). Reflections were recorded on a 9 km streamer towed at 9 m depth with 360 hydrophones spaced every 25 m. Shots were fired every 50 m yielding a fold of cover of 90. These data were

processed using a standard workflow (e.g. band-pass filtering, direct wave removal, accurate velocity picking, stacking, migration). By changing the length of the streamer during processing, the `imaging time' of a single location can be varied between 3 and 30 minutes. The stacked image compares well with legacy hydrographic measurements. The top kilometer is characterized by bright, undulatory reflectivity associated with Subtropical Undercurrent and Antarctic Intermediate Water layers. At greater depths, the profile is acoustically transparent due to the nearly constant temperature and salinity of deeper Gulf waters. This hydrographic structure suggests that double diffusion may occur. However, thermohaline staircases are not observed, suggesting the presence of turbulent mixing. Diapycnal diffusivity will be calculated using spectral analysis of tracked seismic reflections. Temporal evolution of thermohaline structure will also be investigated.

PO34C-3084 Observations of internal tides and associated turbulent mixing in a shallow estuary

ABSTRACT WITHDRAWN

PO34C-3085 Characteristic and Variation of the High Frequency Variability (HFV) in the South China Sea (SCS)

***Hiu Suet Kung**, Hong Kong University of Science and Technology, Division of Environment & Department of Mathematics, Hong Kong, Hong Kong, Gan Jianping, Hong Kong University of Science and Technology, Hong Kong, Hong Kong and Tswen-Yung Tang, Institute of Oceanography, National Taiwan University, Taipei, Taiwan*

Near-inertial oscillations (NIOs) and internal tides (ITs) have been observed in multiple locations in the SCS and are often considered to provide a crucial energy pathway for influencing the circulation in the SCS. In this study, a series of one-year current, temperature, and salinity mooring measurements at the northern, middle, and southern parts of the central SCS basin (NCB, MCB, SCB) during the South China Sea Monsoon Experiment (SCSMEX) are used to examine the spatial variation of the HFV in the upper ocean spanning the summer and winter monsoon periods (SMP, WMP). NIOs, diurnal and semi-diurnal tides are the most pronounced components in energy and vertical shear spectra at these three locations for both SMP and WMP. The tidal signals are relatively distinct in the temperature spectra and NIOs display a larger asymmetry in vertical wavenumber spectra. All these spectra agree reasonably well with the canonical internal wave spectrum, but with a larger deviation at the MCB due to local topography effects and wave-wave interaction. HFV accounts for 10-15% of the total kinetic energy (KE) in the SCS circulation, while velocity vertical shear arising from HFV is 2-3 factors larger than that from the quasi-geostrophic currents in the upper ocean. In general, NIOs are highly intermittent with stronger seasonal mean magnitude during WMP. Analyses on the coherence between wind burst and NIO episodes, accompanied with the estimate of KE budget, shows that the local wind work accounts for ~ 20-40% of the NIO generation, while energy by wave propagation and Parametric Subharmonic Instability (PSI) act as the additional sources. Seasonal mean diurnal tidal energy decreases from NCB to SCB, and larger southeastward energy fluxes occur between NCB and MCB. Both KE budget and time series of energy fluxes indicate a significant remote influence on the tidal energy through background current advection.

PO34C-3086 Internal wave shoaling in Mamala Bay, Oahu, Hawaii

ABSTRACT WITHDRAWN

PO34C-3087 Near-Inertial Waves on the Continental Shelf: Physics Based on Observations off the West Florida.

***Ekaterina V Maksimova**, Florida State University, Tallahassee, FL, United States; University of South Florida St. Petersburg, St Petersburg, FL, United States and Robert H Weisberg, University of South Florida Tampa, Tampa, FL, United States*
Oscillations and waves of near-inertial frequency on the West Florida continental shelf in the eastern Gulf of Mexico are thought to be seasonally important for mixing the shelf waters because of their tendency to have large vertical shear and to be quite energetic. Such motions are also thought to seasonally affect the ecology of the region via daily vertical thermocline migration. The unique multiyear observations off the West Florida coast allow the understanding of physics underlying the processes. The presentation will discuss the key findings on near-inertial motions in the region, including observed energetics, spatial and temporal variability, and mechanisms of generation and dissipation. This work was supported by the National Science Foundation Ocean Sciences Postdoctoral Research Fellowship under Grant OCE-1421180 (E. V. Maksimova).

PO34C-3088 Propagation and Dissipation of Internal Tides on the Northwest Shelf of Australia from Microstructure Observations and Numerical Simulations ***Ana E Rice**[1], Jeffrey W Book[2], Nicole L Jones[3], Cynthia Bluteau[4], Gregory N Ivey[3] and Scott R Smith[5], (1)Naval Research Laboratory, Oceanography Division, Stennis Space Center, MS, United States, (2)US Naval Research Laboratory, Washington, DC, United States, (3)University of Western Australia, Crawley, WA, Australia, (4)University Western Australia, Crawley, WA, Australia, (5)Naval Research Laboratory, Stennis Space Center, MS, United States*
The coastal shelf in Northwest Australia is a region of strong nonlinear internal wave generation and dissipation that results from strong tidal flows. This study focuses on the analysis of direct dissipation measurements from the first ever microstructure profile observations collected in the region. We are assessing the propagation, energy, evolution and mixing rates of internal tide wave packets crossing the shelf. A total of 309 microstructure profiles were collected between April 5-11, 2012 in a domain spanning both offshore and inshore locations and on both broad and narrow parts of the shelf, where internal tide energy ranges from strong to moderate. On the broad central portion of the shelf, where internal tide energy is stronger, microstructure observations from a 24 hour station show the passage of two internal tide packets that are out of phase with the local barotropic tidal oscillations in the region. The passing of the waves first produce thermocline deepening and high dissipation regions near the surface and subsequently the transport of cold water to the surface as the thermocline is shallowed. In a southern location with weaker internal tide energy, a microstructure section survey reveals that changes in the pycnocline slope are associated with a gap in internal tide packet propagation onshore. Concurrent observations of low-frequency flow in the area show that strengthening and weakening of a southward flowing coastal current is associated with these changes and thus demonstrates the control that mesoscale phenomena exhibits on shelf propagation of internal tides in the region. Model results from the relocatable-Navy Coastal Ocean Model (RELO-NCOM) for the microstructure study period will be analyzed both to provide context to the microstructure observations and to evaluate model turbulence closure solutions.

PO34C-3089 Observations of Nonlinear Internal Tides and Turbulence in a Steep Submarine Canyon ***Madeleine Marie Hamann**[1], Veronica Margaret Tamsitt[1], Celia Yun Ou[2], Marion S Alberty[3], Sam Billheimer[4], Matthew H*

Alford[5] and Andrew Lucas[3], (1)Scripps Institution of Oceanography, Physical Oceanography, La Jolla, CA, United States, (2)University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States, (3)Scripps Institution of Oceanography, La Jolla, CA, United States, (4)Scripps Institution of Oceanography, San Deigo, CA, United States, (5)Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, United States
Submarine canyons connect the open ocean to coastal waters. Their complex topography can focus internal waves and enhance mixing over continental slopes and shelves. To better understand how internal waves dissipate their energy within a canyon smaller and steeper than most observed to date, a process study was conducted off the coast of La Jolla, CA in the La Jolla Canyon (LJC). 54-hour time series from a moored wave-powered profiler and bottom-mounted Acoustic Doppler Current Profiler (ADCP) were collected at the head of the canyon and supplemented with concurrent 25-hr time series of density, velocity, and temperature microstructure profiles from two shipboard stations further offshore. Isopycnal displacements are large (up to 50m in 100m water depth). High strain events occur twice per M2 tidal cycle alternating between two distinct mid-water column depths. KE turbulent dissipation rates are enhanced O(10^{-7} to 10^{-5} $m^2\,s^{-3}$) in these mid-depth regions of high strain. Harmonic analysis reveals that variance is dominated by semi-diurnal (M2) tide. Moving up-canyon, relative importance of M2 decreases and its higher harmonics (2M2 and 3M2) are needed to account for a majority of the observed variance, indicating steepening. Baroclinic energy flux is oriented up-canyon and decreases from 182±18 W m^{-1} at the canyon mouth to 46±5 W m^{-1} near the head, and is smaller than that expected for a free wave, indicating reflection. Flux divergence between stations balances the measured dissipation of kinetic energy to within a factor of 2. Despite its size and reflective character, the LJC dissipates incoming internal wave energy significantly, suggesting that it and other small, steep canyons may be under-represented in mixing parameterizations for large-scale ocean models.

PC21A Midlatitude Climate Dynamics and the Role of the Ocean I

Tuesday, February 23, 2016

08:00 AM - 10:00 AM

Ernest N. Morial Convention Center

- 211-213

Papers

08:00 AM PC21A-01 Role of Mid-latitude Oceanic Front Zones in the Ozone-induced Climate Change over the Southern Hemisphere as Revealed in Aqua Planet Experiments ***Hisashi Nakamura***[1], *Fumiaki Ogawa*[2], *Nour-Eddine Omrani*[2], *Kazuaki Nishii*[3] *and Noel S Keenlyside*[4], *(1)University of Tokyo, Bunkyo-ku, Japan, (2)University of Bergen, Geophysical Institute, Bergen, Norway, (3)The University of Tokyo, RCAST, Tokyo, Japan, (4)Geophysical Institute Bergen, Bergen, Norway*

08:15 AM PC21A-02 Simulated and observed atmospheric response to oceanic mesoscale eddies in the Gulf Stream region

ABSTRACT WITHDRAWN

08:30 AM PC21A-03 The influence of the Gulf Stream on Wintertime European blocking ***Shoshiro Minobe***[1], *Christopher H. O'Reilly*[1] *and Akira Kuwano-Yoshida*[2], *(1)Hokkaido Univ-Grad. School Sci, Sapporo, Japan, (2)Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan*

08:45 AM PC21A-04 Predominant nonlinear atmospheric response to meridional shift of the Gulf Stream path from the WRF atmospheric model simulations ***Hyodae Seo***[1], *Young-Oh Kwon*[2] *and Terrence M Joyce*[1], *(1)Woods Hole Oceanographic Institution, Woods Hole, MA, United States, (2)WHOI, Woods Hole, MA, United States*

09:00 AM PC21A-05 Influence of Kuroshio Oceanic Eddies on North Pacific Weather Patterns ***Xiaohui Ma***[1], *Ping Chang*[1], *Ramalingam Saravanan*[1], *Raffaele Montuoro*[1], *Jen-Shan Hsieh*[1], *Dexing Wu*[2], *Xiaopei Lin*[2], *Lixin Wu*[2] *and Zhao Jing*[1], *(1)Texas A & M University, College Station, TX, United States, (2)Ocean University of China, Qingdao, China*

09:15 AM PC21A-06 Wintertime atmospheric response to decadal SST anomalies in the North Pacific frontal zone and its relationship to dominant atmospheric internal variability ***Satoru Okajima***[1], *Hisashi Nakamura*[2], *Kazuaki Nishii*[3], *Takafumi Miyasaka*[2], *Akira Kuwano-Yoshida*[4] *and Bunmei Taguchi*[5], *(1)Reserch Center for Advanced Science and Technology, Japan, (2)University of Tokyo, Bunkyo-ku, Japan, (3)The University of Tokyo, RCAST, Tokyo, Japan, (4)Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan, (5)JAMSTEC Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan*

09:30 AM PC21A-07 Distinguishing Between the Atmospheric Response to the Variability of the Kuroshio and the Oyashio Extensions in the Cold Season and the Impact of the Main Extratropical and Tropical SST Modes, and Sea-Ice Concentration Changes ***Claude Frankignoul***, *Sorbonnes Universités LOCEAN, Paris, France, Adele Revelard, Sorbonne Universités, UPMC, LOCEAN/IPSL, Paris, France and Young-Oh Kwon, Woods Hole Oceanographic Institution, Woods Hole, MA, United States*

09:45 AM PC21A-08 State-Dependence of Atmospheric Response to Extratropical North Pacific SST Anomalies *Guidi Zhou*, ***Mojib Latif***, *Richard John Greatbatch and Wonsun Park, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany*

PC23A Midlatitude Climate Dynamics and the Role of the Ocean II

Tuesday, February 23, 2016

02:00 PM - 04:00 PM

Ernest N. Morial Convention Center

- 211-213

Papers

02:00 PM PC23A-01 Factors shaping the global warming atmospheric response in the North Atlantic Sector ***Noel S Keenlyside***, *Geophysical Institute Bergen, Bergen, Norway, Ralf Hand, Max Planck Institute for Meteorology, Germany, Nour-Eddine Omrani, University of Bergen and Bjerknes Centre, Geophysical Institute, Bergen, Norway, Juergen Bader, Max Planck Institute for Meteorology, Hamburg, Germany and Richard John Greatbatch, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany*

02:15 PM PC23A-02 Extreme Conditions Over Europe and North America: Role of the Atlantic Multidecadal Variability ***Yohan Ruprich-Robert***[1,2], *Rym Msadek*[2,3] *and Thomas L Delworth*[2], *(1)Princeton University, AOS, Princeton, NJ, United States, (2)NOAA, GFDL, Princeton, NJ, United States, (3)CNRS/CERFACS, Toulouse, France*

02:30 PM PC23A-03 Regional and Global Ramifications of Boundary Current Upwelling ***Enrique N Curchitser***[1], *Justin Small*[2], *Katherine Hedstrom*[3], *Brian Kauffman*[2], *William Large*[4] *and Michael A Alexander*[5], *(1)Rutgers University New Brunswick, Department of Environmental Sciences, New Brunswick, NJ, United States, (2)National Center for Atmospheric Research, Boulder, CO, United States, (3)Arctic Region Supercomputing Center, Fairbanks, AK, United States, (4)NCAR, Boulder, CO, United States, (5)NOAA Denver, DENVER, CO, United States*

02:45 PM PC23A-04 Role of Antarctic Circumpolar Current in Decadal Climate Variability over Southern Africa ***Yushi Morioka***[1], *Francois Engelbrecht*[2] *and Swadhin K Behera*[1], *(1)JAMSTEC, Yokohama, Japan, (2)CSIR, Pretoria, South Africa*

03:00 PM PC23A-05 Eurasian winter cooling in the warming hiatus of 1998-2012 ***Chao Li***[1], *Bjorn B Stevens*[2] *and Jochem Marotzke*[1], *(1)Max Planck Institute for Meteorology, The Ocean in the Earth System, Hamburg, Germany, (2)Max Planck Institute for Meteorology, Hamburg, Germany*

03:15 PM PC23A-06 Connections of Arctic Oscillation and warm pool SST variations during boreal winter ***Sang-Wook Yeh*** *and Hyun-Su Jo, Hanyang University, Marine Sciences and Convergent Technology, Seoul, South Korea*

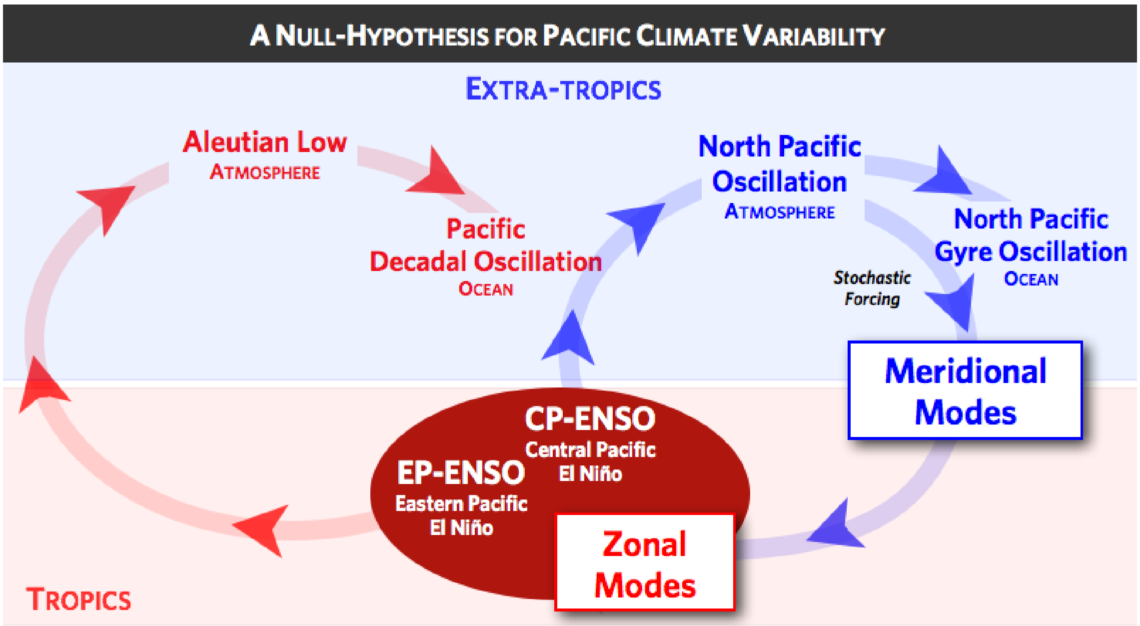
03:30 PM PC23A-07 The Pacific Decadal Oscillation, Revisited *Matthew Newman*[1], ***Arthur J Miller***[2], *Michael A Alexander*[3], *Toby Ault*[4], *Kim M Cobb*[5], *Clara Deser*[6], *Emanuele Di Lorenzo*[7], *Nathan J Mantua*[8], *Shoshiro Minobe*[9], *Hisashi Nakamura*[10], *Niklas Schneider*[11], *Daniel Vimont*[12], *Adam Phillips*[6], *Catherine Anne Smith*[13] *and James D Scott*[14], *(1)University of Colorado at Boulder, Boulder, CO, United States, (2)University of California San Diego, La Jolla, CA, United States, (3)NOAA Denver, DENVER, CO, United States, (4)Cornell University, Department of Earth and Atmospheric Science, Ithaca, NY, United States, (5)Georgia Institute of Technology Main Campus, Earth and Atmospheric Sciences, Atlanta, GA, United States, (6)NCAR, Boulder, CO, United States, (7)Georgia Institute of Technology Main Campus, Atlanta, GA, United States, (8)NOAA Southwest Fisheries Science Center, Fisheries Ecology Division, La Jolla, CA, United States, (9)Hokkaido University, Sapporo, Japan, (10)University of Tokyo,*

Bunkyo-ku, Japan, (11)University of Hawaii at Manoa, Honolulu, HI, United States, (12)University of Wisconsin Madison, Madison, WI, United States, (13)NOAA Earth System Research Laboratory, Boulder, CO, United States, (14)Cooperative Institute for Research in Environmental Sciences, Boulder, CO, United States

Since its identification in the late 1990's as the dominant pattern of North Pacific sea surface temperature (SST) variability, the Pacific decadal oscillation (PDO) has been connected both to other parts of the climate system and to impacts on natural resources and marine and terrestrial ecosystems. Variability associated with the PDO has often been confused with externally forced climate change including anthropogenic effects. Subsequent research, however, has found that the PDO is not a single physical mode of climate variability but instead largely represents the combination of three groups of processes: (1) changes in ocean surface heat fluxes and Ekman (wind-driven) transport related to the Aleutian low, due to both local, rapidly decorrelating, unpredictable weather noise and to remote forcing from interannual to decadal tropical variability (largely El Nino) via the "atmospheric bridge"; (2) ocean memory, or processes determining oceanic thermal inertia including "re-emergence" and oceanic Rossby waves, that act to integrate this forcing and thus generate added PDO variability on decadal time scales; and (3) decadal changes in the Kuroshio-Oyashio current system forced by the multi-year history of basin-wide Ekman pumping, manifested as SST anomalies along the subarctic front at about 40N in the western Pacific ocean. Thus, the PDO represents the effects of different processes operating on different timescales, with few of its apparent impacts due to extratropical SST anomalies. This talk presents a synthesis of this current view of the PDO, and discusses corresponding implications for climate diagnosis, including of PDO climate impacts and predictability (both oceanographic and atmospheric); potential decadal regime-like behavior; simulations of the PDO in climate models; the interpretation of paleoclimate multicentennial reconstructions of the PDO; and its impacts on marine ecosystems. We conclude with some suggested "best practices" for future PDO diagnosis and forecasts including investigating the potential role of the PDO in the global temperature hiatus.

03:45 PM PC23A-08 A Null-hypothesis to explain the El Niño-like Pacific Decadal Variability ***Emanuele Di Lorenzo**, Georgia Institute of Technology Main Campus, Atlanta, GA, United States*

Pacific low-frequency variability (timescale > 8 year) exhibits a well-known El Niño-like pattern of basin-scale sea surface temperature, which is found in all the major modes of Pacific decadal climate. Using a set of climate model experiments and observations, we decompose the mechanisms contributing to the growth, peak and decay of the Pacific low-frequency spatial variance. We find that the El-Niño-like inter-decadal pattern is established through the combined actions of Pacific Meridional Modes (MM) and the El Niño Southern Oscillation (ENSO). Specifically, in the growing phase of the pattern, sub-tropical stochastic excitation of the MM, and its ENSO-precursor dynamics, becomes an important source of tropical low-frequency variance (e.g. red noise). Once in the tropics, ENSO amplifies and distributes this low-frequency energy in the extra-tropics through global teleconnections in the peak and decaying phases. In this stochastic red noise model of Pacific climate, the timescale of the MM/ENSO progression and extra-tropical decay (1-2 year) enhances the spatial memory of the decadal and inter-decadal El-Niño-like pattern.



2 <u>**ENSO Amplification & Teleconnections**</u>: in the tropics positive feedbacks of zonal modes (e.g. ENSO) amplify the MM anomalies and excite teleconnections that project the decadal-scale variance into extra-tropics.

1 <u>**Extra-tropical Stochastic Forcing**</u> by the NPO excites Meridional Modes (MM) in the sub-tropics, which inject low-frequency variance into the tropical system. The MM is consistent with red noise process.

PC24A Midlatitude Climate Dynamics and the Role of the Ocean III Posters

Tuesday, February 23, 2016

04:00 PM - 06:00 PM

Ernest N. Morial Convention Center

- Poster Hall

Papers

PC24A-2109 Feedbacks of Sea Surface Temperature to Wintertime Storm Tracks in the North Atlantic ***Bolan Gan*** *and Lixin Wu, Ocean University of China, Qingdao, China*

PC24A-2110 How European Climate Changes When You Include Ocean Tides in Regionally Coupled Ocean-Atmosphere Model Simulations. ***Nikolay V. Koldunov****, Climate Service Center Germany, Climate System, Hamburg, Germany, Dmitry Sein, Alfred Wegener Institute Helmholtz-Center for Polar and Marine Research Bremerhaven, Bremerhaven, Germany, Alfredo Izquierdo, Universidad de Cádiz, Applied Physics, Cadiz, Spain and Jacob Daniela, Climate Service Center Germany, Hamburg, Germany*

PC24A-2111 The Surface Storm Tracks in Three CMIP5 Global Climate Models *James F Booth[1],* ***Young-Oh Kwon****[2], Justin Small[3], Rym Msadek[4] and Stanley Ko[1], (1)CUNY City College of New York, New York, NY, United States, (2)Woods Hole Oceanographic Institution, Woods Hole, MA, United States, (3)National Center for Atmospheric Research, Boulder, CO, United States, (4)GFDL/NOAA Princeton University, Princeton, NJ, United States*

PC24A-2112 Atmospheric Response to Mesoscale Ocean Eddies and Its Feedback onto the Ocean ***Xue Liu****, Texas A&M University, Department of Oceanography, College Station, TX, United States, Ping Chang, Texas A & M University College Station, College Station, TX, United States, Jaison Kurian, Texas A & M University, College Station, TX, United States and Xiaohui Ma, Texas A&M university, College Station, TX, United States*

PC24A-2113 Impact of oceanic front on the northern hemispheric coupled stratosphere/troposphere-system ***Nour-Eddine Omrani****, University of Bergen and Bjerknes Centre, Geophysical Institute, Bergen, Norway, Fumiaki Ogawa, University of Bergen, Geophysical Institute, Bergen, Norway, Hisashi Nakamura, University of Tokyo, Bunkyo-ku, Japan, Noel S Keenlyside, Geophysical Institute Bergen, Bergen, Norway and Katja Bettina Matthes, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany*

PC24A-2114 Investigation of model SST biases in southeastern tropical Atlantic through high-resolution regional climate simulations

ABSTRACT WITHDRAWN

PC24A-2115 Seasonal to Inter-annual Variability of the Advection along the Southwest African Coast ***Tim Junker****, Volker Mohrholz and Lydia Siegfried, Leibniz-Institute for Baltic Sea Research Warnemünde, Physical Oceanography and Instrumentation, Rostock-Warnemünde, Germany*

PC24A-2116 Multi-decadal Variability of Large-scale Circulation and its Contribution to Extreme Hydroclimate in the Mediterranean region.

ABSTRACT WITHDRAWN

PC24A-2117 Interdecadal Changes in Mediterranean Evaporation Variability and its Links to Regional

Teleconnections **Igor I Zveryaev**, *Shirshov Institute of Oceanology, Moscow, Russia and Abdelwaheb B A Hannachi, Stockholm University, Department of Meteorology, Stockholm, Sweden*

PC24A-2118 The absence of an Atlantic imprint on the multidecadal variability of wintertime European temperature **Jaime B Palter**, *McGill University, Montreal, QC, Canada; University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, United States and Ayako Yamamoto, McGill University, Atmospheric and Oceanic Sciences, Montreal, QC, Canada*

PC24A-2119 Impact of sea surface temperature anomalies on the Jet Variability and Atmospheric Blocking over the South America Sector **Regina Rodrigues**, *UFSC Federal University of Santa Catarina, Florianópolis, Brazil and Tim Woollings, University of Oxford, Dept. of Physics, Oxford, United Kingdom*

PC24A-2120 A Regional Climate Mode Discovered in the North Atlantic: Dakar Niño/Niña **Pascal Oettli**, *Yushi Morioka and Toshio Yamagata, JAMSTEC, Yokohama, Japan*

PC24A-2121 Intrinsic interannual oceanic variability and its impact on decadal predictability **Christopher Wolfe**, *Stony Brook University, SoMAS, Stony Brook, NY, United States and Paola Cessi, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States*

PC24A-2122 Indian Ocean Dipole Effects on the Wave Climate of New Zealand **Victor A Godoi**, *University of Waikato, Earth Sciences, Hamilton, New Zealand, Karin R Bryan, University of Waikato, Hamilton, New Zealand and Richard M Gorman, NIWA, Hamilton, New Zealand*

PC24A-2123 On the Mechanisms of Decadal Variability of the North Pacific Gyre Oscillation Over the 20th Century **Daling Li Yi**[1,2], *Liping Zhang*[3] *and Lixin Wu*[2], *(1)Ocean University of China, Physical Oceanography Laboratory, Qingdao, China, (2)Ocean University of China, Qingdao, China, (3)Princeton University, Princeton, NJ, United States*

PC24A-2124 "Intrinsic" correlation and its temporal evolution between winter-time PNA/EPW and winter drought in the west United States **Lin Piao**[1], *Zuntao Fu*[1] *and Naiming Yuan*[1,2], *(1)Peking University, Beijing, China, (2)Chinese Academy of Meteorological Ssecience, BeiJing, China*

PC24A-2125 Determining the Effect of the Lunar Nodal Cycle on Tidal Mixing and North Pacific Climate Variability **David J Ullman**[1], *Andreas Schmittner*[1], *Gokhan Danabasoglu*[2], *Nancy J Norton*[2] *and Malte Müller*[3], *(1)Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR, United States, (2)National Center for Atmospheric Research, Boulder, CO, United States, (3)Norwegian Meteorological Institute, Norway*

Oscillations in the moon's orbit around the earth modulate regional tidal dissipation with a periodicity of ~18.6 years. In regions where the diurnal tidal constituents dominate diapycnal mixing, this Lunar Nodal Cycle (LNC) may be significant enough to influence ocean circulation, sea surface temperature, and climate variability. Such periodicity in the LNC as an external forcing may provide a mechanistic source for Pacific decadal variability (i.e. Pacific Decadal Oscillation, PDO) where diurnal tidal constituents are strong. We have introduced three enhancements to the latest version of the Community Earth System Model (CESM) to better simulate tidal-forced mixing. First, we have produced a sub-grid scale bathymetry scheme that better resolves the vertical distribution of the barotropic energy flux in regions where the native CESM grid does not resolve high spatial-scale bathymetric features. Second, we test a number of alternative barotropic tidal constituent energy flux fields that are derived from various satellite altimeter observations and tidal models. Third, we introduce modulations of the individual diurnal and semi-diurnal tidal constituents, ranging from monthly to decadal periods, as derived from the full lunisolar tidal potential. Using both ocean-only and fully-coupled configurations, we test the influence of these enhancements, particularly the LNC modulations, on ocean mixing and bidecadal climate variability in CESM.

PC24A-2126 Dynamics and Mechanisms of Decadal Variability of the Pacific-South America Mode over the 20th Century ***Li Zhang***, *Ocean University of China, China*

PC24A-2127 Oceanic Influences on Pacific Storm Track Activity and Southwest United States Precipitation from 1915-2011 ***Richard Bateman***, *University of Colorado at Boulder, Boulder, CO, United States and Weiqing Han, Univ of Colorado, Boulder, CO, United States*

PC24A-2128 The Effect of Jet Stream Position on Wind Relaxations off Central and Southern California, U.S.A. ***Melanie R Fewings***, *University of Connecticut, Department of Marine Sciences, Groton, CT, United States, Libe Washburn, University of California Santa Barbara, Marine Science Institute and Department of Geography, Santa Barbara, CA, United States, Clive Dorman, University of California, San Diego, Scripps Institution of Oceanography, San Diego, CA, United States, Chris Gotschalk, University of California Santa Barbara, Santa Barbara, CA, United States, Kevin S Brown, University of Connecticut, Department of Biomedical Engineering, Groton, CT, United States, Ke Chen, Woods Hole Oceanographic Institution, Woods Hole, MA, United States and John Bane, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States*

PC24A-2129 Interannual-decadal variability of wintertime mixed layer depthsin the North Pacific detected by an ensemble of ocean syntheses ***Takahiro Toyoda***[1], *Yosuke Fujii*[2], *Tsurane Kuragano*[2], *Naohiro Kosugi*[3], *Daisuke Sasano*[3], *Masafumi Kamachi*[2], *Yoichi Ishikawa*[4], *Shuhei Masuda*[4], *Kanako Sato*[5], *Toshiyuki Awaji*[6], *Fabrice Hernandez*[7], *Nicolas Ferry*[8], *Stéphanie Guinehut*[9], *Matthew Martin*[10], *Andrew Peterson*[11], *Simon A Good*[10], *Maria Valdivieso*[12], *Keith Haines*[13], *Andrea Storto*[14], *Simona Masina*[15], *Armin Koehl*[16], *Yonghong Yin*[17], *Li Shi*[17], *Oscar Alves*[18], *Gregory C Smith*[19], *You-Soon Chang*[20], *Guillaume Vernieres*[21], *Xiaochun Wang*[22], *Gaël Forget*[23], *Patrick Heimbach*[24], *Ou Wang*[25], *Ichiro Fukumori*[22], *Tong Lee*[22], *Hao Zuo*[26] *and Magdalena Balmaseda*[26], *(1)Meteorological Research Institute, Japan Meteorological Agency, Oceanography and Geochemistry Research Department, Tsukuba, Japan, (2)Meteorological Research Institute, Ibaraki, Japan, (3)Meteorological Research Institute, Oceanography and Geochemistry Research Department, Tsukuba, Japan, (4)JAMSTEC Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan, (5)JAMSTEC, Yokosuka, Japan, (6)Kyoto University, Kyoto, Japan, (7)IRD/Mercator Ocean, Ramonville St Agne, France, (8)Mercator Ocean, Ramonville St Agne, France, (9)Collecte Localisation Satellites (CLS), Ramonville Saint-Agne, France, (10)Met Office, Exeter, United Kingdom, (11)UK MetOffice, Exeter, United Kingdom, (12)University of Reading, Department of Meteorology, Reading, United Kingdom, (13)Reading University, Reading, United Kingdom, (14)CMCC, Bologna, Italy, (15)National Institute of Geophysics and Volcanology, Rome, Italy, (16)Universität Hamburg, Hamburg, Germany, (17)Centre for Australian Weather and Climate Research, Bureau of Meteorology, Melbourne, Australia, (18)Australian Bureau of Meteorology, Research & Development, Melbourne, Australia, (19)Environment Canada, Meteorological Research Division, Quebec, QC, Canada, (20)Kongju National University, Gongju, South Korea, (21)NASA GSFC, (22)NASA Jet Propulsion Laboratory, Pasadena, CA, United States, (23)Massachusetts Institute of Technology, Cambridge, MA, United States, (24)University of Texas at Austin, Institute for Computational*

Engineering and Sciences & Jackson School of Geosciences, Austin, TX, United States, (25)Jet Propulsion Lab, Pasadena, CA, United States, (26)ECMWF, Reading, United Kingdom

PC24A-2130 Downward Heat Penetration below Seasonal Thermocline and its Impact on Sea Surface Temperature Variation Affected by Net Heat Flux during Summer Season ***Shigeki Hosoda***[1], *Masami Nonaka*[2], *Tomohiko Tomita*[3], *Bunmei Taguchi*[2], *Hiroyuki Tomita*[4] *and Naoto Iwasaka*[5], *(1)JAMSTEC, Yokosuka, Japan, (2)JAMSTEC Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan, (3)Kumamoto University, Kumamoto, Japan, (4)Nagoya University, HyARC, Nagoya, Japan, (5)Tokyo University of Marine Science and Technology, Tokyo, Japan*

PC24A-2131 Relationship between the Southeast Pacific Anticyclone and the upwelling favorable winds along the west coast of South America ***Catalina Aguirre***, *Universidad de Chile, Geophysics Department, Santiago, Chile*

PC24A-2132 Influence of ENSO Decadal Variations on the PDO and Indian Ocean SST in Observations and CMIP Models *Nidheesh A Gangan Jr, CSIR -India, Physical Oceanography, Panaji, India and* ***Matthieu Lengaigne***, *LOCEAN, IRD/CNRS/UPMC/MNHN, Paris, France, Physical Oceanography, Paris, France*

PC24A-2133 Pacific decadal variability associated with trade wind forcing: Evidence from tide gauge records

ABSTRACT WITHDRAWN

PC24A-2134 Regional Sea Level Rise until the end of 23rd century over the North Western Pacific in CMIP5 models ***Mio Terada*** *and Shoshiro Minobe, Graduate School of Science, Hokkaido University, Sapporo, Japan*

PC24A-2135 Nonlinear Mechanisms of Low-Frequency Variability in Unstable Western Boundary Currents Under Variable Atmospheric Forcing ***Andrew E Kiss***[1,2] *and Leela M Frankcombe*[2,3], *(1)University of New South Wales Canberra at the Australian Defence Force Academy, Canberra, Australia, (2)ARC Centre of Excellence for Climate System Science, Australia, (3)University of New South Wales, Sydney, Australia*

PC24A-2136 The Ocean or the Atmosphere: Diagnosing Forced Versus Intrinsic Low-Frequency Variability in an Idealized North Atlantic Ocean-Atmosphere Model ***Paige Martin***[1], *Brian K Arbic*[1] *and Jeff Blundell*[2], *(1)University of Michigan Ann Arbor, Ann Arbor, MI, United States, (2)National Oceanography Centre, University of Southampton, Ocean and Earth Science, Southampton, United Kingdom*

PC24A-2137 A Conceptual Model for Extratropical Atmosphere-Ocean Interaction

ABSTRACT WITHDRAWN

PC24A-2138 The Warmer The Ocean Surface, The Shallower The Mixed Layer. How Much Of This Is True? ***Raquel Somavilla***, *Instituto Español Oceanografía, Santander, Spain, Cesar González-Pola, Spanish Institute of Oceanography, Physical Oceanography, Gijon, Spain and Julio Manuel Fernandez, University of Oviedo, Applied Physics, Oviedo, Spain*

PC24A-2139 Europe's mild winters, due to offshore wind-farms, shipping and fishery?

ABSTRACT WITHDRAWN

Tuesday, February 23, 2016

10:30 AM - 12:30 PM

Ernest N. Morial Convention Center

- Great Hall A/B

Papers

10:30 AM Welcoming Remarks ***Steven G Ackleson***, *Naval Research Laboratory, Washington, DC, United States*

10:40 AM Introductory Remarks ***Frederick Bingham***, *University of North Carolina at Wilmington, Wilmington, NC, United States*

10:45 AM A Decade after *The Day After Tomorrow*: Our Current Understanding of the Ocean's Overturning Circulation ***M Susan Lozier***, *Duke University, Earth Ocean Sciences, Durham, NC, United States*

大西洋 MOC の研究の歴史をわかりやすく解説した。1920 年代には、高緯度の表層水が中低緯度の中深層水となっていることが Sverdrup などによって発見された。1970 年代に、GEOSECS 観測によって、人為起源炭素の３０%が海に吸収され、海洋内部に入り込むことが He3 などの観測で明らかになった。1990 年代に abrupt climate change が過去に起きたことが古気候データから示され、2000 年代には、AMOC を継続観測する RAPID が始まった。その結果、AMOC は季節でファクタ５で変わることが明らかになった。Stommmel・Arons で提唱された深層西岸境界流（DWBC）の概念は、RAFOS 中層フロートが DWBC の経路に沿わず、大きく広がっていることから、改訂を迫られた。また、湾流が表層暖水を北へ運び熱放出によって深層水が形成される、という概念も、亜熱帯水は亜寒帯へ行かないという表層ドリフタの結果（Branbilla Talley）から改訂され、中層の海水が亜寒帯に移動する（Bingham et al. 2007）、ラブラドル海での滞留による深層水形成量変化と DWBC の流量変化は対応しない（Dengler et al. 2006; Fisher et al. 2010）ことが明らかにされている。現在では、NADW は、南大洋で風によって湧昇し、表面近くで軽く変質しながら北上するものは、再び北へ中層水として高緯度で湧昇し、深層水となる一方、南大洋で湧昇した一部は南極沿岸へ向かい、再冷却されて AABW になり、底層を循環する、と考えられている。最近では、SSH の変化から、AMOC 流量の変化を代表させる手法も開発されている（Frajka・Williams2015）。OSNAP（Overturning in the subpolar North Atlantic Program）が開始され、深層水形成量とオーバーフローの流量を観測で計測する計画が開始された。

In 1800 Count Rumford ascertained the ocean's meridional overturning circulation from a single profile of ocean temperature constructed with the use of a rope, a wooden bucket and a rudimentary thermometer. Over two centuries later, data from floats, gliders and moorings deployed across the North Atlantic has transformed our understanding of the temporal and spatial variability of the meridional overturning: the component of the climate system responsible for sequestering heat and anthropogenic carbon dioxide in the deep ocean. In this talk I will review our current understanding of the overturning circulation with a particular focus on what we currently do and don't understand about the mechanisms controlling its temporal change.

11:35 AM Introductory Remarks ***Steven G Ackleson***, *Naval Research Laboratory, Washington, DC, United States*

11:40 AM Panel Discussion - Interfaces: Sharing Science with Concerned Communities ***Charles A Wilson***, *Gulf of Mexico Research Initiative*, ***Nancy Knowlton***, *Sant Chair for Marine Science, Smithsonian's National Museum of Natural History, Washington, DC, United States and* ***LaDon Swann***, *Auburn University Marine Programs*

The Gulf of Mexico Research Initiative (GoMRI) was established to investigate the impact of oil, dispersed oil, and dispersant on the Gulf of Mexico ecosystem. With the leadership of a twenty-member Research Board, GOMRI will invest 500 million dollars in research on the chemical, physical, environmental and public health effects of oil spills. An important component of the GOMRI mission is communicating results of the research with the public. Consequently, GoMRI has built a robust outreach program that includes key partnerships. The challenge was how to build a bridge between the science community and the public impacted by and/or interested in the impacts of Deep Water Horizon. A portion of the GOMRI science communication goal has been achieved by establishing partnerships with Gulf State Sea Grant Programs and, at the national level, with the Smithsonian Museum of Natural History. Both partners reach different but important audiences. Sea Grant has accomplished, over the past approximately five decades of outreach, clear success in engaging local coastal communities in a two-way communication of coastal topics of concern. The Smithsonian Museum of Natural History operates an on-line Ocean Portal and the Smithsonian Magazine reaches an extensive national and international audience in communicating topical science facts. The team will describe how they communicate the scientific research accomplished in the GOMRI 10 year research program to this wide ranging public education and communication program.

Wednesday, February 24, 2016

10:30 AM - 12:30 PM

Ernest N. Morial Convention Center

- Great Hall A/B

Papers

10:30 AM Welcoming Remarks ***Karen L Casciotti***, *Stanford University, Earth System Science, Stanford, CA, United States*

10:35 AM Introductory Remarks ***Lynne D Talley***, *University of California San Diego, La Jolla, CA, United States*

10:40 AM The AGU Sverdrup Award Lecture: Glaciers on the loose: navigating the perilous waters of ice sheet-ocean interactions and interdisciplinary science ***Fiammetta Straneo***, *Woods Hole Oceanographic Institution, Woods Hole, MA, United States*

氷床モデリングの重要性についての講演。海水と接しているところで融解が生じ、氷床が崩壊する。

Collapsing ice shelves and increased iceberg calving reflect the widespread speed up of glaciers in Greenland and Antarctica that, over the last two decades, has tripled the contribution of ice sheets to sea level rise. The rapidity of these changes has come as a surprise, revealing major gaps in our understanding of how ice sheets respond to a changing climate. Recently, increased melting under floating ice shelves and at the edge of marine-terminating glaciers, associated with warming ocean waters, has emerged as the trigger for glacier speed up, making ice sheet-ocean interactions a scientific priority underlying efforts to improve predictions of climate change and sea level rise. This is a challenging task because it requires collaboration across multiple disciplines, developing new technologies, and coupling ice sheet and ocean models. This lecture focuses on advances in our understanding of these changes based on observations at the edge of massive calving glaciers in iceberg-choked fjords in Greenland using helicopters, icebreakers, fishing vessels, and autonomous vehicles. Here, melting is caused by intrusions of warm, subtropical waters into the fjords and enhanced by muddy plumes of surface melt released hundreds of meters below sea level. Progress in this emerging field of glacier/ocean interactions has only been possible thanks to a community-wide effort and exemplifies how the nature and scale of the complex problems facing earth scientists today require an inclusive, collaborative, and interdisciplinary approach that is fundamentally different from the more traditional, competition-based culture in which so many of us are accustomed to working.

11:10 AM Introductory Remarks ***Kimberly Wickland***, *USGS, National Research Program, Baltimore, MD, United States*

11:15 AM The ASLO G. Evelyn Hutchinson Award: To the Bottom of Seafloor Ecosystems ***Jack J Middelburg***, *Utrecht University, Utrecht, 3584, Netherlands*

海底生態系を理解する際には、動物の役割の理解が重要。表層では、微生物が栄養塩の再生などで動物をサポート、深層では、動物が表層から有機物を運ぶことで微生物をサポート。サンゴ生態系は、貧栄養の熱帯でのオアシス。それにはスポンジ生物が、DOC や DON を消費し、デトリタスを作ることが関与している。

Marine sediments represent the largest interface on earth governing partitioning of carbon and nitrogen cycling between the biosphere and geosphere. Moreover, it represents a habitat for a wide diversity of organisms. The link between organism identity/activity and biogeochemical processes is still poorly known. In this award talk, I present some examples how organic geochemical tools, biogeochemical process studies and whole ecosystem isotope labeling studies can be combined to elucidate the flow of carbon and nitrogen through benthic ecosystems (e.g., cold-water corals, sponges and coastal sediments).

11:45 AM Introductory Remarks ***Walter Heinrich Munk***, *University of California San Diego, La Jolla, CA, United States*

11:50 AM Office of Naval Research Presentation ***Theresa Paluszkiewicz***, *Office Naval Research, Arlington, VA, United States*

11:52 AM The TOS Munk Award Lecture: The Imperative of Global Oceanography ***Carl Wunsch***, *Massachusetts Institute of Technology, Boston, MA, United States*

海はインテグレータであり、記憶する。今問題は継続であり、高度計とアルゴは良いコンビ。コンピュータ実験ばかりになり、米国が観測をリードすることを忘れるのではないかと、不安。

Historically, physical oceanography has been an amalgam of sketchy global surveys, and intense local field programs. The result has been, and remains, considerable difficulty in quantifying changes in the ocean circulation and its properties over time-scales of decades and longer---precisely the intervals of most immediate concern in climate change. Numerous clever methods have been published intended to compensate for missing observations, but all are based upon statistical hypotheses that remain untestable owing to the same lack of data. In moving forward, so that future generations do not experience our own level of frustration, the question arises about how to quantify understanding of oceanic change. Among a number of possibilities, it is plausible that the ability to balance, within useful levels of uncertainty, global budgets of energy, freshwater, kinetic and potential energies, enthalpy, vorticity, is the zero-order measure of understanding of any system. Assuring that limited goal becomes possible requires an amalgam of basic science, infrastructure, developmental technologies, and scientific and political will.

12:20 PM Introductory Remarks ***Peter B Rhines***, *University of Washington, Seattle, WA, United States*

12:22 PM Albatross Award of the American Miscellaneous Society

Lynne　Talley が受賞。鳥のはく製を受け取った。

Princeton University
Princeton, NJ
United States
NOAA
Princeton, NJ
United States
yohan.ruprich-robert@noaa.gov

Associated Entries

PC23A-02 Extreme Conditions Over Europe and North America: Role of the Atlantic Multidecadal Variability

Tuesday, February 23, 2016

02:15 PM - 02:30 PM

Ernest N. Morial Convention Center

- *211-213*

The Atlantic Multidecadal Variability (AMV) is associated with, and possibly the source of, marked modulations of the climate over many areas of the globe. For instance, the relatively warm and dry climate of North America throughout the 30-yr interval of 1931-60, during which the Dust Bowl and the 1950's drought occurred, has been linked to the concomitant warm phase of the AMV. During this period relative warm and wet conditions prevailed over Europe. After 1960, the Atlantic began to cool, and for almost three decades the North American climate turned wetter and cooler whereas Europe experienced cooler and dryer conditions. However, the shortness of the historical observations compared to the AMV period (~60-80yr) does not allow to firmly conclude on the causal effect of the AMV. We use a model approach to isolate the causal role of the AMV on the occurrence of extreme events over Europe and North America. We present experiments based on two GFDL global climate models, a low resolution version, CM2.1 and a higher resolution model for the atmospheric component, FLOR. In both model experiments sea surface temperatures in the North Atlantic sector are restored to the observed AMV pattern, while the other basins are left fully coupled. In order to explore and robustly isolate the AMV impacts on extreme events, we use large ensemble simulations (100 members for CM2.1 and 50 for FLOR) that we run for 20 years. We find that a positive phase of the AMV increases the frequency of occurrence of drought over North America and of extremely cold/warm conditions over Europe during winter/summer. Interestingly, we find that the AMV impacts on these extreme conditions are modulated by the Pacific response to the AMV itself. Members that develop a weak Pacific response show more extreme events over Europe whereas those that develop a strong Pacific response show more extreme events over North America. By comparing the two model results, we highlight the importance of well representing weather regimes in order to capture AMV impacts over Europe and North America.

PO54A-3228 Atlantic Multidecadal Variability climate impacts: Idealized Experiments with NCAR and GFDL coupled climate models

Friday, February 26, 2016

04:00 PM - 06:00 PM

Ernest N. Morial Convention Center

- Poster Hall

We will present results from an ensemble set of the NCAR Community Earth System Model (CESM1) and GFDL Climate Model (CM2.1) fully-coupled simulations in which the sea surface temperatures (SSTs) in the North Atlantic are restored towards the SST anomalies associated with the observed Atlantic Multidecadal Variability (AMV), a fingerprint of multidecadal Atlantic Meridional Overturning Circulation (AMOC) variability. The SST anomalies exclude the anthropogenic effects. We consider climatological anomalies associated with both the negative and positive phases of the AMV. In addition to the experiments where the SST anomalies are imposed over the entire North Atlantic, we perform experiments in which the anomalies are separately imposed only in the northern North Atlantic and only in the tropical Atlantic. Each ensemble set of simulations has been integrated for 10 years, using 30 ensemble members for CESM1 and 100 ensemble members for CM2.1. Our results show that a positive (negative) AMV phase is associated with a negative (positive) phase of the Pacific Decadal Variability (PDV). We also find that AMV has far-reaching global impacts via mechanisms involving atmospheric teleconnections primarily associated with tropical Atlantic SST anomalies.

HE51B North Meets South: An Integrated Perspective of High-Latitude Ocean Dynamics I

Ernest N. Morial Convention Center

215-216

Papers

08:00 AM HE51B-01 What's happening over the poles? ***John Marshall***, *Massachusetts Institute of Technology, Cambridge, MA, United States*

In recent decades, the Arctic has been warming and sea ice disappearing. By contrast, the Southern Ocean around Antarctica has been (mainly) cooling and sea-ice extent growing. We argue here that inter-hemispheric asymmetries in the mean ocean circulation, with sinking in the northern North Atlantic and upwelling around Antarctica, strongly influence the sea-surface temperature (SST) response to anthropogenic greenhouse gas (GHG) forcing, accelerating warming in the Arctic while delaying it in the Antarctic. Furthermore, while the amplitude of GHG forcing has been similar at the poles, significant ozone depletion only occurs over Antarctica contributing to enhanced surface westerly wind trends around Antarctica. Through analysis of a hierarchy of models and observations, we suggest that the initial response of SST around Antarctica to westerly wind trends is one of cooling and sea-ice expansion. However, this could be followed on decadal timescales by upwelling of relatively warm water from depth, under the seasonal sea-ice zone, leading to sea-ice loss.

08:15 AM HE51B-02 The Buoyancy-Driven Ocean Circulation with Realistic Bathymetry ***Ada Gjermundsen*** *and Joseph Henry LaCasce, University of Oslo, Department of Geosciences, Oslo, Norway*

The large scale ocean circulation is forced by buoyancy fluxes, winds and fresh water. The mechanisms controlling the circulation and its stability are critical issues in understanding the present state and future changes of the climate. Although the buoyancy fluxes at the surface, and most importantly the differential heating, are a crucial part of the mechanisms driving the large scale circulation, we lack a simple dynamical framework for rationalizing the buoyancy-driven circulation. Most of our intuition is based on numerical solutions, primarily in idealized basins.

Here we examine numerical solutions of the global circulation with realistic bathymetry, driven solely by surface buoyancy forcing. Explicit wind forcing is excluded, although vertical mixing is retained. The character of the resulting flow is consistent in many ways with the observed ocean circulation. There is inflow to and sinking in the Nordic Seas, baroclinic western boundary currents and an overturning streamfunction which closely resembles those obtained in full GCMs and in observations. We also examine the complex interplay between the basins, as well as the important sites for up and downwelling. Furthermore, the solutions share many features with solutions obtained with a linear analytical model , suggesting the latter may be conceptually useful, despite lacking bathymetry. We discuss these points, as well as implications for the climate system in general.

08:30 AM HE51B-03 Size matters: another reason why the Atlantic is saltier than the Pacific ***Paola Cessi*** *and Catherine Spencer Jones, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States*

Idealized numerical experiments are performed with an ocean-only circulation forced by wind-stress, surface temperature and freshwater flux, all independent of longitude, in a domain consisting of two basins, differing only in their widths, which are connected by a circumpolar channel at the south and. These experiments show that a spontaneous asymmetry in the latitudinal distribution of surface salinity develops, which favors salinification of the narrow basin over the wide basin. This salinification induces a stable pole-to-pole overturning in the narrow basin, maintained by the salt-advection feedback. Pole-to-pole overturning in the wide basin does not occur for zonally-symmetric forcing, but can be induced by reducing the precipitation over the northern end of the wide basin. The preference

for sinking at the northern end of the narrow basin over sinking in the wide basin is due to two compounding processes: a larger overturning velocity associated with narrow-basin sinking, and a smaller gyral velocity, which is always found in the narrow basin compared to the wide basin. Together, these differences in salt

advection favor sinking in the narrow basin.

08:45 AM HE51B-04 The Two Branches of the Recirculation of Atlantic Water in Fram Strait ***Wilken-Jon von Appen***[1], *Ursula Schauer*[1], *Tore Hattermann*[1] *and Jon Albretsen*[2], *(1)Alfred Wegener Institute Helmholtz-Center for Polar and Marine Research Bremerhaven, Bremerhaven, Germany, (2)Institute for Marine Research*

The Fram Strait between Greenland and Svalbard is one of the two gateways by which warm Atlantic Water enters the Arctic Ocean providing oceanic heat. The West Spitsbergen Current advects the warm water northward in the eastern Fram Strait. However, only some of this water stays in the boundary current and enters the Arctic Ocean. Another part leaves the boundary current and flows westward across Fram Strait before turning southward in the East Greenland Current. This recirculation of Atlantic Water corresponds with the ice edge in Fram Strait and the two likely depend on each other. Here we present results from a high resolution regional numerical model that shows the recirculation to consist of two branches. The northern branch depends on eddy fluxes while the southern branch exhibits less high frequency variability. We also present a compilation of different observational data in the center of Fram Strait around 0°EW that give insight into the structure of the southern recirculation branch near the ice edge. A glider section resolves the small horizontal scale over which the geostrophic flow occurs. Several meridional CTD sections capture the differences and similarities between different summers. Moorings and Argo floats provide information in winter as well. These observations are compared to the representation of the recirculation in the numerical model. We show that the southern recirculation occurs over a small horizontal distance of about 20km in the vicinity of 79°N and is significantly stronger in winter than in summer. While there is cold freshwater at the surface north of the front, the temperature down to 500m is much higher in the recirculation than further south.

09:00 AM HE51B-05 Stationary Sea Surface Height Anomalies in Cyclonic Boundary Currents; the Role of PV-Conservation Along a Topographic Slope ***Sara Broomé***[1], *Johan Nilsson*[2] *and Jonas Nycander*[1], *(1)Stockholm University, Department of Meteorology, Stockholm, Sweden, (2)Stockholm University, Department of meteorology, Stockholm, Sweden*

In northern high-latitude sub-polar seas, such as the Nordic Seas and the Labrador Sea, time-mean geostrophic currents mediate the meridional oceanic heat transport. These currents are often found on the continental slopes as intense cyclonic boundary currents, which, due to the relatively weak stratification, are strongly steered by the bottom topography. However, analysis of hydrographic and satellite altimetric data along depth contours exhibit some remarkable stationary along-stream variations in the depth-integrated buoyancy. A closer examination reveals that the variations seem to be linked to changes in steepness and curvature of the topography beneath.

In order to examine the underlying dynamics, a steady-state model of a cyclonic stratified boundary current over a topographic slope is developed in the limit of small Rossby numbers. To the lowest order, the bottom velocities are aligned with the bottom topography. Based on the conservation of potential vorticity, equations for variations of the first-order pressure and buoyancy fields along the depth contours are derived. These show that the pressure and the depth-integrated buoyancy tend to increase (decrease) where the lowest order flow increases (decreases) its relative vorticity. Along-isobath variations in relative vorticity, in turn, tend to be most pronounced for cyclonic anomalies and occur where the topography is steep and/or curves. The thus predicted variations in pressure and buoyancy are comparable in magnitude to the ones found in the data.

09:15 AM HE51B-06 On the Freshwater Sensitivity of the Arctic-Atlantic Thermohaline Circulation ***Erwin Lambert****, Tor Eldevik and Peter Haugan, Geophysical Institute, University of Bergen, and Bjerknes Centre for Climate Research, Bergen, Norway.*

The North Atlantic thermohaline circulation (THC) carries heat and salt toward the Arctic. This circulation is generally believed to be inhibited by northern freshwater input as indicated by the `box-model' of Stommel (1961). The inferred freshwater-sensitivity of the THC, however, varies considerably between studies, both quantitatively and qualitatively. The northernmost branch of the Atlantic THC, which forms a double estuarine circulation in the Arctic Mediterranean, is one example where both strengthening and weakening of the circulation may occur due to increased freshwater input. We have accordingly built on Stommel's original concept to accomodate a THC similar to that in the Arctic Mediterranean. This model consists of three idealized basins, or boxes, connected by two coupled branches of circulation - the double estuary. The net transport of these two branches represents the extension of the Gulf Stream toward the Arctic. Its sensitivity to a change in freshwater forcing depends largely on the distribution of freshwater over the two northern basins. Varying this distribution opens a spectrum of qualitative behaviours ranging from Stommel's original freshwater-inhibited overturning circulation to a freshwater-facilitated estuarine circulation. Between these limiting cases, a Hopf and a cusp bifurcation divide the spectrum into three qualitative regions. In the first region, the circulation behaves similarly to Stommel's circulation, and sufficient freshwater input can induce an abrupt transition into a reversed flow; in the second, a similar transition can be found, although it does not reverse the circulation; in the third, no transition can occur and the circulation is generally facilitated by the northern freshwater input. Overall, the northern THC appears more stable than what would be inferred based on Stommel's model; it requires a larger amount and more localized freshwater input to `collapse' it, and a double estuary circulation is less prone to flow reversal.

09:30 AM HE51B-07 On the Long-term Stability of the Lofoten Basin Eddy ***H. Thomas Thomas Rossby****, Univ Rhode Island, Narragansett, RI, United States, Henrik Søiland, Institute of Marine Research, Ocean Physics, Bergen, Norway and Léon Chafik, NOAA Washington DC, Washington, DC, United States*

In recent years several studies have identified an area of intense anticyclonic activity about 500 km straight west of the Lofoten Islands at 70°N in the northern Norwegian Sea; it is now recognized as the coherent Lofoten Basin

Eddy (LBE). While we normally think of coherent eddies as short-lived (months to a few years), we infer here that the eddy may have been in existence for hundreds of years if not longer. First, we show from five acoustic Doppler current profiler surveys that it is quite stable with a rotating solid body core ~1000 m deep and ~8 km radius with relative vorticity close to its theoretical limit –f. The surveys also show the LBE typically has a >60 km radius with maximum swirl velocities at about 17-20 km radius. From the velocity field we estimate the dynamic height amplitude at the surface to be about ~0.21±0.03 dyn. Second, and as others have noted from both hydrography and altimetry, the LBE is maintained by a supply of anticyclonic eddies that break away from the Norwegian Atlantic Current where it appears to go unstable over the steep Lofoten Escarpment. Third, altimetry from the last 20 years shows the extremum in sea surface height relative to the surrounding waters to be about the same over time, 0.2 dyn. m. Altimetric analysis also shows the LBE to undergo a cyclonic wandering over the deepest (>3000 m) part of the Lofoten Basin. Lastly, three hydrographic sections from the 1960s show the dynamic height signal to be virtually the same then as it is now. From these observations we conclude that the LBE is a permanent feature of the Nordic Seas and plays a central role in maintaining the pool of warm water in the western Lofoten Basin. The fact that it is fed and maintained by a continual and plentiful supply of pinched-off eddies from the warm Norwegian Atlantic Current at the Lofoten Escarpment leads us to suggest that the LBE has been in existence for hundreds of years if not longer.

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- 09:45 AM HE51B-08 High latitude internal tides ***Ruth C Musgrave***[1], *Robert Pinkel*[2], *Jennifer A MacKinnon*[2], *Matthew R Mazloff*[3] *and William R Young*[4], *(1)Scripps Institution of Oceanography, La Jolla, CA, United States, (2)University of California San Diego, La Jolla, CA, United States, (3)UC San Diego, La Jolla, CA, United States, (4)University of California, La Jolla, CA, United States*

- The interaction of the barotropic tide with a tall, two-dimensional ridge is examined analytically and numerically at latitudes where the tide is subinertial (generating evanescent internal tides), and contrasted to when the tide is superinertial (generating radiating internal tides). Unlike superinertial internal tides, the energy density of subinertial tides close to topography grows with latitude due to increasing oscillatory along-ridge flows and isopycnal displacements. Nonlinear processes lead to the formation of rectified along-ridge jets, which become faster at high latitudes. When the tide is subinertial, dissipation and mixing is larger, and these peak later in the tidal cycle compared to when the tide is superinertial. Mixing occurs mainly on the flanks of the topography in both cases, though a superinertial tide may additionally generate mixing above topography arising from convective breaking of radiating waves. Subinertial internal tides may provide a relatively important pathway leading to mixing along continental shelves at high latitudes.
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- **B53A** From WOCE through CLIVAR to GO-SHIP: Results from Global Repeat Hydrographic Surveys I

  - *Ernest N. Morial Convention Center*
  - *225-227*

Papers

- 02:00 PM B53A-01 Toward a global synthesis of the oceanic carbon sink since the mid 1990s ***Nicolas Gruber***[1], *Dominic Clement*[1], *Peter Landschutzer*[1], *Toste S Tanhua*[2], *Masao Ishii*[3], *Jeremy T Mathis*[4], *Dorothee C E Bakker*[5], *Richard H Wanninkhof*[6], *Are Olsen*[7], *Robert M Key*[8] *and Steven van Heuven*[9], *(1)ETH Swiss Federal Institute of Technology Zurich, Zurich, Switzerland, (2)GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany, (3)Meteorological Research Institute, Ibaraki, Japan, (4)NOAA Seattle, Seattle, WA, United States, (5)University of East Anglia, Norwich, United Kingdom, (6)NOAA AOML, Miami, FL, United States, (7)Bjerknes Centre for Climate Research, Bergen, Norway, (8)Princeton University, Princeton, NJ, United States, (9)Royal Netherlands Institute for Sea Research, Texel, The Netherlands, Netherlands*
- Substantial efforts have been undertaken in the past 5 years by the international community with guidance by the IMBER/SOLAS carbon working groups and the IOCCP to assemble, harmonize, and interpret global ocean surface and interior carbon data sets, such as SOCAT (www.socat.info) and GLODAPv2. While the interpretation of these data sets is on-going, among the first emerging results are: (i) an estimate of the oceanic accumulation of anthropogenic CO2 between the 1990s and the mid-2000s (Gruber et al., in prep.) based on the ocean interior carbon data, and (ii) monthly resolved global air-sea CO2 fluxes for this entire period and extending back as far as 1982 developed on the basis of the surface ocean data (e.g., Landschützer et al., 2015). Here, we aim to synthesize and compare these two estimates in order to assess the consistency in time and space between the time-integrated air-sea CO2 fluxes and the changes in ocean interior storage. The results suggest a global increase in the inventory of anthropogenic CO2 of 32±6 Pg C between 1994 and 2007, while the cumulative air-sea CO2 flux over this period amounts to about 17±3 Pg C. Assuming a cumulative outgassing flux of ~6 Pg of “natural” carbon stemming from the carbon input by rivers, the surface ocean perspective suggests an anthropogenic CO2 uptake of about 23±4 Pg C over the 13 years, i.e., considerably smaller than the ocean interior estimate, although not statistically different. Thus the two perspectives suggest an ocean sink rate for anthropogenic CO2 between 1.8±0.3 Pg C yr-1 (surface ocean) and 2.5±0.5 Pg C yr-1 (interior ocean), which is consistent with the expected uptake based on the increase in atmospheric CO2, although at the lower end. Substantial variability emerges in both uptake flux and ocean interior storage in response to recent climate variations, suggesting an ocean carbon cycle that responds quite sensitively to changes in climate forcing.
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- 02:15 PM B53A-02 Variability in ocean ventilation from three decades of transient tracer measurements. ***Darryn Waugh***, *Johns Hopkins University, Baltimore, MD, United States*

- Measurements of chlorofluorocarbons (CFCs) and other transient tracers provide information on the rates and pathways of ocean transport. Here we use measurements of CFCs, SF6, tritium and helium made over the last three decades, as part of WOCE, Repeat Hydrography, GO-SHIP and other programs, to constrain the time scales of ocean ventilation. Simultaneous measurements of transient tracers with different time dependencies are used to constrain the mean time since water was last at the surface (mean age) as well as other ventilation time scales, while repeat sampling of CFCs between the late 1980s and recent years late 2000s are used to infer changes in the ventilation. Measurements along multiple transects in the southern oceans (including the most recent sampling in the Pacific) show large-scale coherent changes in ventilation of southern oceans over the last three decades, with a decrease in the age of subtropical SubAntarctic Mode Waters and an increase in the age of Circumpolar Deep Waters. This is contrasted with variability of ventilation times in the North Atlantic and Pacific oceans.
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- 02:30 PM B53A-03 Understanding the Changing Global Distribution of Radiocarbon: What are we learning from the WOCE and CLIVAR Repeat Hydrography Results ***Ann P McNichol***[1], *Robert M Key*[2], *Kathryn L Elder*[1], *Karl F Von Reden*[1], *Alan R Gagnon*[1] *and Joshua R Burton*[1], *(1)Woods Hole Oceanographic Institution, Geology and Geophysics, Woods Hole, MA, United States, (2)Princeton University, Princeton, NJ, United States*

- Radiocarbon (DI^{14}C) is an important tracer for studies of ocean processes. It has been used to study mixing, ventilation rates, production rates, and residence times in the deep ocean, deep ocean biogeochemistry and oxygen utilization rates, air-sea gas exchange, thermocline ventilation rates, as a proxy for anthropogenic CO_2 in the ocean, to estimate deep water mass ages for anthropogenic CO_2 uptake and carbon studies, and to evaluate ocean general circulation model (OGCM) performance. DI^{14}C has been used to study the aging of the water masses and calculate pre-bomb surface water values. DI^{14}C has also been used with CFCs and anthropogenic CO_2 to investigate the influence of eddies on mixing/ventilation in moderately high resolution ocean. More recently, it has been used to demonstrate the evolving applications of radiocarbon as the shock of the initial bomb-produced radiocarbon spike has passed through the surface ocean and upper thermocline. The radiocarbon distribution is now illuminating mechanisms, pathways and rates of ^{14}C transfer into the lower thermocline and deeper levels.

- ^{14}C results from over 28,000 samples taken as part of the WOCE and CLIVAR programs have been reported. Significant changes, well above the analytical uncertainty, are seen in all three major ocean basins. Simply mapping the distribution measured during the WOCE program provided new insights. In the Southern Ocean near the Antarctic coast, DI^{14}C values in the western-most Pacific transect are much lower than those observed in the eastern transects. If this is a real feature (rather than a gridding artifact), it has important implications for understanding the role of the Southern Ocean in global climate change. Another extremely interesting feature is a break observed in the southward pointing tongue (NPDW) along the P16 line just west of the islands near 20-25S. It seems quite likely that this unexpected distribution is related to or controlled by proximity to the extreme topography in that area of the Pacific just east of the section. More examples of the changes that repeated sampling has revealed will be presented as well as a discussion of the implications of some of the most interesting observations.

- 02:45 PM B53A-04 Rapid Anthropogenic Changes in CO_2 and pH in the Atlantic Ocean: 2003-2014 ***Ryan Jay Woosley****, RSMAS, Miami, FL, United States, Frank J Millero Jr, University of Miami, RSMAS, Miami, FL, United States and Richard H Wanninkhof, NOAA AOML, Ocean Chemistry and Escosystem Division, Miami, FL, United States*

- The extended multi-linear regression (eMLR) method is used to determine the uptake of anthropogenic carbon in the Atlantic Ocean based on repeat occupations of 4 cruises from 1989– 2014 (A16, A20, A22, and A10), with an emphasis on the 2003–2014 period. The results show a significant increase in basin wide anthropogenic carbon storage in the North Atlantic, which absorbed 4.4± 1.2 Pg C/decade from 2003–2014 compared to 1.9 ± 1 Pg C/decade for the 1989–2003 period. This decadal variability is attributed to changing ventilation patterns associated with the North Atlantic Oscillation (NAO) and increasing release of anthropogenic carbon into the atmosphere. There are small changes in the uptake rate of CO_2 in the South Atlantic for these time periods, but within the uncertainty. Several eddies are identified that transport 20% more anthropogenic carbon than the surrounding waters in the South Atlantic showing the importance of eddies in transporting anthropogenic carbon. The uptake of carbon results in a decrease in pH of ~0.0021 ± 0.0007 yr^{-1} for surface waters during the last 10 years, in line with the atmospheric increase in CO_2.
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- 03:00 PM B53A-05 OVIDE-A25, a Biennial Hydrographic Transect across the North Atlantic Subpolar Gyre since 2002: Overview of the Main Scientific Findings about the Variability of the Meridional Overturning Circulation and its Impact on the CO_2 Physical Pump ***Pascale Lherminier***[1]*, Herle Mercier*[1]*, F.F. F Pérez*[2]*, Aida F. Rios*[2]*, Patricia Zunino*[1]*, Ma Isabel Garcia-Ibanez*[2]*, Virginie Racapé*[3]*, Marion Gehlen*[4]*, Laurent Bopp*[5] *and the OVIDE team, (1)IFREMER, Plouzané, France, (2)IIM, CSIC, Vigo, Spain, (3)UVSQ, LSCE, Gif-Sur-Yvette, France, (4)CEA, LSCE, Gif-Sur-Yvette, France, (5)LSCE Laboratoire des Sciences du Climat et de l'Environnement, Gif-Sur-Yvette Cedex, France*
- The meridional overturning circulation (MOC) transports heat from the subtropics to high latitudes and hence plays an important role in the Earth’s climate. A region crucial for the MOC is the northern North Atlantic, where waters transported northwards in the MOC upper limb gain density and eventually sink into the southward flowing lower limb. The variability of the subpolar gyre circulation, the MOC and heat transport was quantified from a joint analysis of hydrographic and velocity data from eight repeats of the

Greenland to Portugal OVIDE section. The obtained circulation patterns revealed remarkable transport changes in the whole water column and evidenced large variations in the magnitude of the MOC computed in density coordinates (MOC_{σ}). The extent and timescales of the MOC_{σ} variability in 1993–2014 were then evaluated using a monthly MOC_{σ} index built upon altimetry and ARGO data at the OVIDE section location. The MOC_{σ} index, validated by the good agreement with the in situ estimates, shows a large variability on monthly to decadal time scales. The heat transport estimated from the repeated hydrographic OVIDE sections is linearly related to the MOC_{σ} intensity. The uptake of atmospheric carbon dioxide in the subpolar North Atlantic Ocean is also strongly impacted by the variability of the MOC_{σ}. We found that the uptake of anthropogenic carbon dioxide occurred almost exclusively in the subtropical gyre. In contrast, natural carbon dioxide uptake dominated in the subpolar gyre. We attributed the weakening of total carbon dioxide uptake observed between 1997 and 2006 in the subpolar North Atlantic to a reduction in the natural component. We also showed that the transitory slowdown of the MOC_{σ} was largely responsible for this phenomenon, through a reduction of oceanic heat loss to the atmosphere, and for the concomitant decline in anthropogenic carbon dioxide storage in subpolar waters.

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- 03:15 PM B53A-06 Decadal Anthropogenic Carbon Storage Along P16 and P02 ***Brendan R Carter**, University of Washington, JISAO, Seattle, WA, United States, Richard A Feely, NOAA Pacific Marine Environmental Laboratory, Seattle, WA, United States, Lynne D Talley, University of California San Diego, La Jolla, CA, United States, Jessica N Cross, University of Alaska Fairbanks, Fairbanks, AK, United States, Alison M Macdonald, Woods Hole Oceanographic Institution, Woods Hole, MA, United States, Sabine Mecking, University of Washington Seattle Campus, Seattle, WA, United States and Samantha A Siedlecki, Univ of Washington-JISAO, Seattle, WA, United States*
- The Pacific Ocean has the largest ocean basin anthropogenic carbon (Canth) inventory due to the large size of the basin. We estimate anthropogenic carbon (Canth) concentrations and decadal storages along the meridional P16 and zonal P02 lines since the mid 90s using a modified version of the extended multiple linear regression (EMLR) technique with data from the WOCE, CLIVAR, and GO-SHIP occupations of these lines. We present our estimates and map the aragonite saturation state (ΩA) decreases and saturation horizon shoaling resulting from continued Canth storage. The average storage rate was larger along both sections during the most recent decade (2000’s to 2010’s) than during the previous decade (1990’s to 2000’s), especially along P02. Significant decadal concentration increases were found in the mixed layers, shallow thermoclines, mode waters, and portions of the intermediate water masses.
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- 03:30 PM B53A-07 30 Years of Repeat Hydrography in the Mediterranean ***Toste S Tanhua**[1], Katrin Schroeder[2], Dagmar Hainbucher[3], Marta Alvarez[4], Vanessa R. Cardin[5], Giuseppe Civitarese[5], Harry L Bryden[6] and Jacopo Chiggiato[2], (1)GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany, (2)CNR – ISMAR, Institute for Marine Science, Veneziia, Italy, (3)Universität Hamburg, Institut für Meereskunde, CEN, Hamburg, Germany, (4)Instituto Español de Oceanogr, A Coruña, Spain, (5)OGS,*

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Oceanography, Trieste, Italy, (6)National Oceanography Center, Soton, Southampton, United Kingdom

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- The Mediterranean Sea is a semi-enclosed Sea characterized by high salinities, temperatures and densities. The net evaporation exceeds the precipitation that, coupled to net heat-loss, drives an anti-estuarine, shallow overturning circulation through the Strait of Gibraltar that communicates directly with the Atlantic Ocean. The Mediterranean Sea also has an active deep water overturning circulation with one cell in each main basin. It is surrounded by populated areas and is thus sensitive to anthropogenic forcing. In a biogeochemical sense the Mediterranean Sea is characterized by very low nutrient and high oxygen concentrations. The high temperature and alkalinity coupled with the well ventilated waters make the Mediterranean Sea an area with very high average anthropogenic CO_2 (C_{ant}) concentration, so that the basin acts as a globally significant C_{ant} sink despite its low volume. Several dramatic changes in the oceanographic and biogeochemical conditions have been observed during the past several decades, emphasising the need to better monitor and understand the changing conditions and their drivers.

- Although no Mediterranean section was conducted within the WOCE program, several full depth hydrogeochemical cruises has been performed in the Mediterranean Sea during the past several decades, although mostly not covering the whole Mediterranean. During 2011 three oceanographic cruises were conducted in a coordinated fashion in order to produce base-line data of important physical and biogeochemical parameters that can be compared to historic data and be used as reference for future observational campaigns. Since then a zonal section through the Med has been adopted by the international GO-SHIP program to be regularly sampled on a sub-decadal basis. This contribution shows results on major changes in Mediterranean oceanographic conditions during the past 3 decades.
- 03:45 PM B53A-08 A declining ventilation rate of Antarctic Bottom Water within the Ross Gyre ***Sarah Purkey**, Columbia University, Lamont-Doherty Earth Observatory, New York, NY, United States, William M Smethie Jr, Lamont -Doherty Earth Observatory, Palisades, NY, United States and Stan Jacobs, Columbia Univ, Palisades, NY, United States*
- The global abyssal ocean has warmed significantly over the past two decades, possibly linked to a decrease in the production rate of Antarctic Bottom Water (AABW), the cold dense water mass formed around Antarctica that feeds most of the global abyssal ocean. Here we use chlorofluorocarbons (CFCs), sulfur hexafluoride (SF6) and conservative tracers from repeat S4P sections along 67 S to quantify a decrease in the ventilation rate of Antarctic Bottom Water (AABW) in the Pacific sector of the Southern Ocean, and show the relative mass fractions of its end members has remained the same. Regionally generated AABW is a combination of cold dense Shelf Water (SW) formed over the continental shelf during sea ice production and partially modified by melting and freezing under the Ross Ice Shelf, with warmer Circumpolar Deep Water (CDW) entrained during flow down and along the continental slope. An optimum multi-parameter analysis shows no significant change in the relative fraction of these two end members

between 1992 and 2011, suggesting their mixing processes have not changed over the past 20 years. However, an apparent shift in the relative contributions of higher salinity SW from the western Ross Sea and lower salinity SWs from the central and eastern Ross Sea is seen in the newest formed AABW found in the westward flowing boundary current at Cape Adare and within the interior of the Ross Gyre. CFC and SF6 concentration histories in the SW show its component within the Ross Gyre was 5-10 years older in 2011 than in 1992. The OMP and CFC analyses thus provide strong evidence that the rate of ventilation and circulation within the abyssal Pacific sector of the Southern Ocean have significantly decreased over the past 20 years.