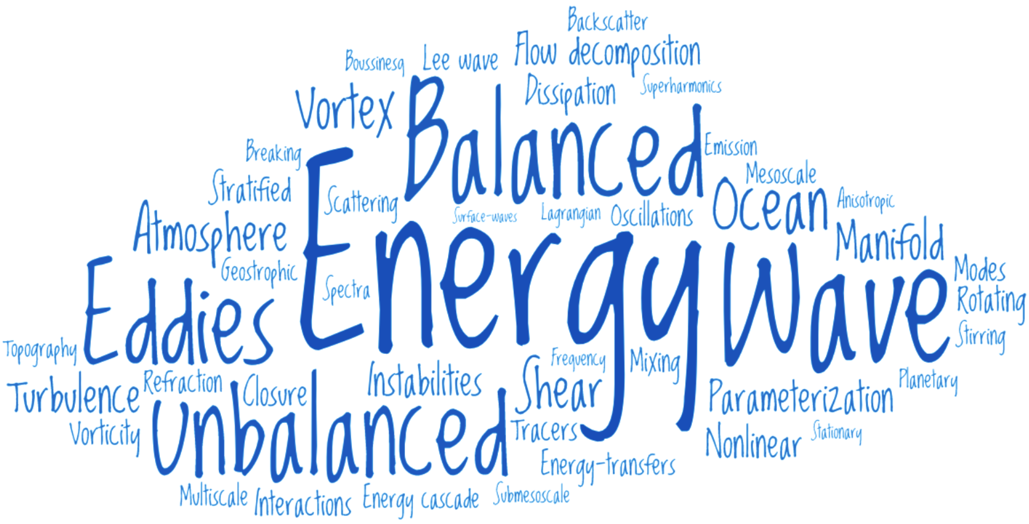
Eddies and Waves: Theory, Models, and Observations

14-16 February 2023, Hamburg



TRR181

Welcome Address

The workshop is aimed at enhancing our understanding of the interactions and energy transfers between the mesoscale (balanced) eddies and (unbalanced) internal waves, their generation and dissipation mechanisms, as well as their relevance to the global energy cycle. This workshop is a continuation of a series of international workshops within the framework of the collaborative project TRR-181 "Energy Transfers in Atmosphere and Ocean", on the topic of eddies and internal waves encompassing theoretical, modelling, and observational aspects.

Rotating, stratified geophysical flows in the atmosphere and the ocean are dominated primarily by two components: the low frequency balanced and the high frequency unbalanced motions. While the balanced state in geophysical flows describes the dynamics and energetics of the low frequency flow, the definition and diagnosis of the balanced flow remains debatable both from mathematical and physical perspectives. At the same time, the co-existing unbalanced motions significantly influence the energetics of the flow but their detection and interpretation, as well as their interactions with other motions and the resulting energy transfers continue to pose many open questions.

With this meeting, we intend to bring together the recent advancements in oceanography, meteorology, and geophysical fluid dynamics in the context of aforementioned topics, such as flow decomposition methodologies, wave and eddy parameterizations, eddy-wave interactions and energy transfers, by combining theory, models, observations, and novel developments in data science.

Best wishes!

Organizing Committee:

Manita Chouksey
Stephan Juricke

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***Online Talks**

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***Online Talks**

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***Online Talks**

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10:20-10:40	**Pauline Tedesco**	Spatio-temporal characteristics of winter mixed layer turbulence in an energetic oceanic zone
10:40-11:00	**Nils Brüggemann**	Dissipation in ageostrophic turbulence from a submesoscale resolving simulation of the North Atlantic
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11:50-12:10	**Marcel Oliver**	Quasi-convergence of optimal balance by nudging
12:10-12:30	**Manita Chouksey and Silvano Rosenau**	Seeking balance in realistic ocean flows
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***Online Talks**

February 16th, Thursday

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15:10-15:30	**Julia Draeger-Dietel**	Evidence of a dual kinetic energy cascade by surface drifter observation in the Walvis Ridge Region
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***Online Talks**

Abstracts: Talks

Internal-wave generation by tide-topography interactions in the presence of background currents

14 Feb
9:30h

Kevin Lamb

University of Waterloo

Internal wave generation by tide-topography interactions have been the subject of many studies in recent decades, most of which ignore the effects of steady background currents. Background currents can modify the wave generation process in several ways. Horizontal shear modifies the effective Coriolis frequency. Both this and horizontal variations in the stratification in geostrophic balance with the current change the criticality of the bottom slope. Variations in the effective Coriolis frequency can result in wave trapping and create blocking regions. It can also result in the creation of regions susceptible to parametric subharmonic instability if the effective Coriolis frequency is reduced to less that half the tidal frequency. Vertically shear background currents flowing across a ridge create asymmetries in internal wave propagation on either side of the ridge and are accompanied by critical layers. In this talk I will present numerical simulations illustrating these process using two-dimensional numerical simulations of internal wave generation at ridge and shelf like topography in the presence of cross-topography or along topography background currents.

Internal tides energy life cycle in the North Atlantic

14 Feb
10:00h

Adrien Bella[1,2] and Noé Lahaye[2]

[1]Laboratoire des Ecoulements Géophysiques et Industriels, Université Grenoble Alpes; [2]Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology Cottbus-Senftenberg

Internal tides in the ocean are both ubiquitous and important for the transport of tracers and the meridional overturning circulation because of the mixing in the deep ocean they cause when they break. They are generated when the astronomical tide encounters a topographic feature, resulting in an oscillation in a stratified flow that can propagate more than a thousand kilometres away. This long range propagation leaves opportunities for these wave to interact with mesoscale flows and eddies, another ubiquitous dynamical feature in the ocean of comparable length scale. Their interactions is of importance since it impacts both the wavelength and the phase of the internal tides, making them impossible to detect via altimetry once they have lost their coherency with the astronomical forcing. These interaction may also impact the energy budget of internal tides and the cascade of energy between the astronomical tide with a basin wide lengthscale to internal tides with a wavelength of the order of 10 kilometres. In this presentation. we will describe the energy life cycle of internal tides in the North Atlantic basin using diagnostics of the numerical simulation eNATL60. The simulation has an horizontal resolution of around 2 kilometres and 300 vertical levels. In order to diagnose the interaction with topography and mesoscale, we use a vertical modal decomposition based on a Sturm Liouville problem. We investigate the energy budget of the semi-diurnal internal tide and more precisely the exchanges of energy between modes triggered by the topography, the mesoscale flow and the variations of the ambient density field, as well as their time variability. We first focus on the Azores Island area of the North Atlantic, a region known for its strong internal tides generation and weak mesoscale activity. We found that topographic induced couplings are of leading order for mode 0 and 1 and induce a substantial transfer of energy from low to high modes. However, the advection of internal tides velocities by the background flow is significant in the energy cascade from mode 2 to mode 3 and higher. All the fluxes in the area are found to have a strong temporal variability, dominated by the spring-neap cycle for the topographic scattering, the others being less periodic. We will also discuss the same energy budget in the Gulf Stream area.

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14 Feb
10:20h

Internal tide beam generation by an abyssal hill of the Mid-Atlantic Ridge

Clément Vic[1] and Bruno Ferron[1]

[1]Laboratoire d'Océanographie Physique et Spatiale, Univ. Brest, CNRS, Ifremer, IRD, Plouzané, France

Internal tides are key players in the dynamics of mid-ocean ridges. The generation and propagation of internal tides over the Mid-Atlantic Ridge (MAR) have been studied through theoretical and numerical models, as well as through moored, that is, one-dimensional, observations. Yet, observations remain sparse and often restricted to the vertical direction. Here we report on the first two-dimensional in situ observation of an internal tide beam sampled by a shipboard acoustic Doppler current profiler through a vertical section over the MAR. The beam is generated by the interaction of the barotropic tidal current with a supercritical abyssal hill that sits in the rift valley of the MAR.

Despite the weak barotropic tidal current (4 cms), the generated waves feature intense currents (up to 25 cms). A vertical mode decomposition is carried out to characterize the spatio-temporal variability of the beam. Although the modal content of the velocity field is dominated by modes 1 to 3, higher modes display localized and not persistent bursts of energy. The use of an analytical theory for linear internal waves allows us to rationalize the observed velocity field and interpret it as the superposition of modal waves generated on the hill and propagating in the same direction. The observed beam is qualitatively reconstructed as the superposition of waves of modes 2 to 6. The velocity field was sampled seven times across the same section and displayed qualitatively different patterns, unveiling the complexity of the dynamics above the MAR.

Study of non-linear interactions between meso-scale turbulence and internal tides using resolvent analysis

14 Feb
10:40h

Igor Maingonnat[1], Gilles Tissot[1] and Noé Lahaye[1]
[1] INRIA, France

Understanding and characterizing the loss of coherence of internal tides propagating through turbulence has recently been a major challenge in oceanography, in particular because of its implication on data satellite interpretation. We aim at studying the non-linear interactions responsible for the loss of coherence through idealised model. We solve a one-layer Rotating Shallow Water equations on a rectangular domain where a plane wave is propagating meridionally through a zonal jet. We are particularly interested at the turbulent jet configurations that drive the most the perturbation of the wave. For this we apply Spectral Orthogonal Decomposition (SPOD) and resolvent analysis methods. These methods, strongly connected theoretically, has been mainly used in the turbulence community, and we propose to apply them to geophysical problems. SPOD can be seen as an extension of POD/EOF taking into account the temporal correlation within the data. The goal of it is to extract spatio-temporal coherent structures, expressed in spectral space at the tidal frequency. We will show that it proves its efficiency to build a basis for expressing the coherent part and incoherent part of the wave. Resolvent analysis provides an input/output model in spectral space where non-linearities are interpreted as a forcing term. A linear connection is made between forcing and response through the resolvent operator, providing the most amplified non-linearities by the linear system and the associated responses. We will finally connect both methods in order to answer our problem and get an estimation on the form of the jet perturbations that drives the coherent structure/SPOD modes. We will then briefly discuss the possible implications of this method on reduced modeling and data assimilation method.

Evolution of a tidal beam in an eddying ocean flow

14 Feb
11:30h

Peter Dennert and Manita Chouksey
IUP and MARUM, Universität Bremen, Germany

Internal tides are an important constituent of the ocean's energy budget. The internal tidal energy is mainly focused in the first modes and in the so called tidal beams, formed at seamounts or ridges and can be identified as a spatially coherent energy flux of tidal waves with uniform directions. We focus on the evolution of a tidal beam generated at the Walvis Ridge in the South East Atlantic Ocean, where they interact with the mesoscale eddies in the form of Agulhas Rings. We employ a combination of ray tracing and a high resolution global 1/10 deg STORM-TIDE model that resolves tides. We find that on smaller timescales the tidal energy flux is not constant, as opposed to most other cases where the mean energy flux of such beams are analyzed on timescales of months to years making the beams appear stable. The changes in the tidal energy flux occur in its amplitude and direction. The spring-neap cycle of the tides impact the amplitude of the internal tides and the mesoscale eddies significantly change the direction of the fluxes. Ray tracing reveals that the interaction of internal tides with eddies change the tidal beam mostly by refraction. Therefore the tidal beams emitted at the Walvis Ridge are prone to changes in direction and strength upon interaction with eddies, resulting in convergence and divergence patterns of the tidal waves that in turn have implications for the energy dissipation and mixing patterns.

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14 Feb
11:50h

The role of mesoscale-wave interactions on energy transfers in the Sicily Channel area

Robin Rolland, Pascale Bouruet-Aubertot, Yannis Cuypers and Francesco d'Ovidio

LOCEAN

Mesoscale-wave interactions were identified as one of the routes that permit the transfer of kinetic energy from mesoscales to dissipation scales. Several idealized and realistic model studies have highlighted the role of near-inertial waves (NIWs) and internal tides (ITs) in the triggering or intensification of the forward energy cascade. However, they did not investigated the joint effect of NIWs and ITs, and were conducted in regions with no strong coastal constraints. In this work, we focus on the joint interactions of NIWs and ITs with the mesoscale and their impacts on the energy cascade in the Mediterranean Sea in an area centered over the Sicily Channel, a region of internal tide generation, with strong coastal and bathymetric constraints. To this aim, we analyse 1/60° hourly outputs of the realistic submesoscale-permitting model NEMO-eNATL60, with and without tidal forcings. We focus our analysis on two contrasted months, August 2009 (summer) and February 2010 (winter). The Sicily Channel is one of the few areas in the Mediterranean Sea that supports internal tide generations. The sharp topography and the coastal geometry also enable a strong mesoscale activity as well as an intense shear between the modified Atlantic surface water and the Levantine Intermediate Water. As a result, it is also one of the few hotpots for turbulence in the Mediterranean Sea. We first identify areas supporting NIWs and ITs (M2 and K1 components) and their generation sites. NIWs are found North of the Libyan coast in summer and are present in the Tyrrhenian and Ionian Seas in winter. However, NIWs are absent of the Sicily Channel. Indeed, the strait is too narrow and shallow to enable NIWs to propagate through it. The M2 tidal component is generated in the Sicily Channel, the Gulf of Gabès and the Messina Strait and propagates freely in the whole domain. K1 is generated near shallow water plateau in the Sicily Channel and East of Malta, and around small islands (Pantelleria, Lampedusa, etc.). As K1 frequency is subinertial, ITs generated at K1 propagate as topographically trapped waves. We are then able to identify 4 distinct regions in terms of internal wave dynamics. The Tyrrhenian Sea with NIWs in winter and M2 propagating from the Sicily Channel. The Ionian Sea with only NIWs in winter and a signal of M2 in summer. The Sicily Channel with M2 and K1 but no NIW. And the region between the Gulf of Gabès, the Lybian coast and Malta. Kinetic energy spectral fluxes are characterized in these 4 regions in the tidally-forced and the not tidally-forced NEMO-eNATL60 outputs thus highlighting the impact of ITs, NIWs. Cases studies of different kinds of eddy-wave interactions are isolated and the spectral flux characterized: NIW-anticyclonic interactions are evidenced in anticyclonic eddies with NIW trapping and accumulation of near-inertial energy at the base of the eddy, and a particular case of this effect, the trapping of the diurnal thermal breeze energy inside anticyclonic eddies with an effective inertial frequency lower than the diurnal frequency is shown.

Eddy-internal tide interactions around New Caledonia in the Southwestern Tropical Pacific: A SWOT CalVal site

14 Feb
12:10h

Bendinger, A., Cravatte S., Gourdeau, L., Tchilibou, M., Lyard, F., Brodeau, L., Albert, A.
LEGOS, Toulouse, France

The region south of New Caledonia in the Southwestern Tropical Pacific is characterized by complex bathymetry with large-scale ridges, small-scale basins, and seamounts giving rise to pronounced internal tide field with propagating beams over several hundred of km and SSH signatures of ¿5 cm. Being subject to strong barotropic/baroclinic instabilities and mesoscale eddy activity, New Caledonia is considered to be a hot spot of eddy-internal tide interactions. Here, we present for the first time in full extent the internal tide field energetics around New Caledonia using the numerical output of a dedicated high-resolution regional modeling effort while addressing SSH observability of eddy-internal tide interactions in the context of the SWOT satellite mission.

Subgrid parameterization of eddy, meanfield and topographic interactions in simulations of the Antarctic Circumpolar Current

14 Feb
12:30h

Vassili Kitsios[1,2], J.S. Frederiksen[1] and T.J.O'Kane[3]
[1] CSIRO Oceans and Atmosphere, Aspendale; [2] Monash University; [3]CSIRO Oceans and Atmosphere Hobart

The ocean is a high-dimensional multi-scale nonlinear system with inhomogenous meanfields and topography. Numerical simulations of the ocean resolve the large scales of motion on a computational grid, with the unresolved subgrid interactions parameterized. If the parameterizations are not designed appropriately, then the statistics of the simulations will become highly dependent upon the grid resolution. There are five fundamental classes of subgrid interactions: eddy-eddy; eddy-topographic; eddy-meanfield; meanfield-meanfield; and meanfield-topographic. We present here, a first calculation of scale dependent parameterizations representing each of these interaction classes for oceanic flows. Subgrid parameterizations are calculated and validated in baroclinic quasi-geostrophic simulations of the Antarctic Circumpolar Current with representative ocean floor topography. The parameterization coefficients are derived from the statistics of output generated by coarse graining high resolution reference simulations in spectral space. Stochastic and deterministic parameterizations are developed representing the eddy-eddy interactions, and deterministic forms for the remaining classes. The kinetic energy spectra resulting from large eddy simulations (LES) adopting these coefficients replicate the spectra from the higher resolution reference simulation. The eddy-eddy interactions are the dominant class, however, all classes need to be parameterized for best results. For LES where baroclinic instability is explicitly resolved the stochastic variants out-perform the deterministic ones across all scales. When baroclinic instability is not explicitly resolved, the stochastic variants out-perform the deterministic cases in the large scales, but introduce some distortions at the smallest resolved scales.

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14 Feb
14:10h

Remote versus local impacts of energy backscatter on the Northwest Atlantic SST biases in a global ocean model

Chiung-Yin (Jenny) Chang[1], Alistair Adcroft[1], Laure Zanna[2], Robert Hallberg[1,3], and Stephen Griffies[1,3]

[1]Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, USA; [2]Courant Institute of Mathematical Sciences, New York University, New York, NY, USA; [3]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA

The use of coarse resolution and strong subgrid dissipation has prevented many global ocean models from simulating the correct level of ocean kinetic energy. Recently, energy backscatter is proposed as an approach to re-energize the eddy-permitting simulations without provoking numerical instability, and it has been shown to reduce the long-lasting sea surface temperature (SST) in the Northwest Atlantic. However, these SST biases have been attributed to various deficiencies of models, so the underlying mechanism for why the backscatter reduces the SST biases remains unclear. Here, we apply the backscatter in different geographic regions to distinguish the different physical processes at play. We first verify that the SST response is approximately linear to this regional decomposition with a negligible interplay between processes at different regions. We then show that the bias reduction associated with an improved Gulf Stream path is mostly attributed to the backscatter acting north of the subtropical gyre to maintain a strong deep western boundary current. The bias reduction associated with an improved North Atlantic Current path is mostly attributed to the backscatter acting around the Newfoundland that likely improves the nearby simulation of topography-flow interactions. The results are also found to depend on the specifics of the backscatter scheme, with too strong backscatter overstabilizes the flows and the coupling with a Gent-McWilliams type parameterization changes the sign of the response. Aspects of backscatter that require further investigation are accordingly discussed.

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14 Feb
14:40h

An energy and enstrophy informed parameterization scheme for eddy potential vorticity fluxes

Rosie Eaves[1], David Marshall[1], James Maddison[2] and Stephanie Waterman[3]

[1] Oxford University; [2] University of Edinburgh; [3]University of British Columbia

In freely decaying turbulence over variable bottom topography, eddies act to drive the flow to a topography following state. Ocean mesoscale eddy parameterization schemes deployed in climate models are typically unable to produce these topography following flows. The topography following flow is a corollary of the cascades of energy and enstrophy in quasi-geostrophic turbulence. Previous studies have developed eddy parameterization schemes which are bounded by the energy, however they did not test the scheme for different topological conditions. Here we present a new parameterization scheme which is bounded both by the eddy kinetic energy and the eddy potential enstrophy. We test the performance of the scheme by determining its ability to accurately model eddy-driven topography following flows.

Simulating ocean eddies: Development and evaluation of viscous and backscatter parametrizations

14 Feb
15:00h

Stephan Juricke[1,2], Sergey Danilov[1,2], Ekaterina Bagaeva[1,2], Anton Kutsenko[3], and Marcel Oliver[3]

[1] Constructor University Bremen; [2] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven; [3] Katholische Universität Eichstätt - Ingolstadt

An accurate representation of mesoscale eddy dynamics is crucial for simulating large-scale ocean currents as well as ocean and climate variability. The interaction of eddies and the mean flow affects the strength, position and variations of ocean currents. Furthermore, eddies have a substantial impact on the coupling between the atmosphere and ocean and on oceanic heat transport. However, at so-called eddy-permitting model resolutions around $\frac{1}{4}^{\circ}$, eddy kinetic energy and variability is generally underestimated and we can observe an excessive dissipation of kinetic energy. To counter such substantial biases in ocean simulations, new eddy parametrizations need to be developed and implemented.
In this study, a set of oceanic eddy parameterizations is introduced and evaluated, including novel viscous and kinetic energy backscatter closures with different complexity. Various diagnostics that are suitable for applications on unstructured meshes are used to analyze their effect and guide further improvements.
The schemes are implemented in the unstructured grid, finite volume ocean model FESOM2 and tested in both global ocean and idealized channel simulations. Adjusted viscosity and kinetic energy backscatter parameterizations can substantially reduce some of the eddy related biases such as incorrect mean currents and water mass properties and underestimated sea surface height variability. The novel eddy parametrizations outperform previously used viscous closures. A comparison to higher resolution simulations shows that they are also computationally less expensive while achieving similar results.

MS-GWaM – A three dimensional transient parameterization for internal gravity waves in atmospheric models

14 Feb
15:20h

Georg S. Voelker[1], Young-Ha Kim[1], Gergely Bölöni[2], Günther Zängl[2] and Ulrich Achatz[1]

[1]Goethe Universität Frankfurt, Frankfurt am Main, Germany; [2]Deutscher Wetterdienst, Offenbach, Germany

Internal gravity waves (IGWs) are important distributors of energy and momentum in a stratified atmosphere. While most IGWs are presumably excited at lower altitudes their effects are most important between the upper troposphere and the mesopause (85km). During propagating–both in the vertical and the horizontal–nonlinear IGWs can exert a wave drag on the large-scale winds, interact with the large-scale potential temperature, and influence transport and mixing of atmospheric constituents such as aerosols or greenhouse gases. In state-of-the art weather and climate prediction models subgrid-scale IGWs are typically parameterized neglecting both the horizontal wave propagation (single-column assumption), the transient wave behavior including its effect on wave-mean-flow interactions (steady-state assumption) as well as time dependent wave generation. That is, a large part of the time dependent interaction between gravity waves and the mean flow, such as wave refraction, are excluded. The potential importance of the horizontal wave propagation and wave transience has, however, been shown in various theoretical, numerical and experimental studies. The transient Multi Scale Gravity Wave Model (MS-GWaM)–implemented in the high-top model UA-ICON–aims to improve these shortcomings by allowing for transient and three dimensional wave propagation. Being

based on a multi scale WKBJ analysis of the compressible atmosphere, MS-GWaM includes various non-orographic wave sources, wave breaking as well as non-dissipative wave-mean-flow interactions. What is more, an efficient parallelization of the ray-tracing scheme allows for simulations in reasonable computation times. While satisfactorily reproducing the observed zonal-mean wind and potential temperature climatology the model results reveal new insight into the detail of the role of IGWs in the atmosphere. The effects of transience, that is the time dependent interaction between the waves and the mean-flow, have a range of implications. For instance, the probability density of wave momentum fluxes exhibit the typical observed long tails (i.e. wave intermittency). Moreover, the three dimensional distribution of wave momentum and wave action fluxes differ greatly when relaxing the single-column assumption. As an example the well known and often observed three dimensional scattering of IGWs into polar jets can be shown.

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14 Feb
16:10h

A parameterization of local and remote tidal mixing

Casimir de Lavergne[1]

[1]LOCEAN Laboratory, Sorbonne University

Internal tides power much of the observed small-scale turbulence in the ocean interior. To represent mixing induced by this turbulence in climate-scale ocean models, energy routes from the generation to the dissipation of internal tides must be understood and mapped. Here we present a mixing scheme which accounts for the local breaking of high-mode internal tides and the distant dissipation of low-mode internal tides. The scheme relies on four static 2D maps of internal tide dissipation, constructed using mode-by-mode Lagrangian tracking of energy beams from sources to sinks. Each map is associated with a distinct dissipative process and a corresponding vertical structure. Applied to an observational climatology of stratification, the scheme produces a global 3D map of dissipation and mixing which compares well with available microstructure observations and with upper-ocean finestructure mixing estimates. Implemented in the NEMO global ocean model, the scheme improves the representation of deep-ocean ventilation and obviates the need for a constant background diffusivity.

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14 Feb
16:30h

The horizontal direction of the barotropic-to-baroclinic tidal energy transfer: global computations for the M2 tide's first mode and implications for mixing parameterizations

Friederike Pollmann[1], Jonas Nycander[2], Carsten Eden[1] and Dirk Olbers[3]

[1]Institut für Meereskunde, Universität Hamburg, Germany; [2]MISU, Stockholms Universitet, Sweden; [3]Alfred Wegener Institute for Polar and Marine Research, and MARUM – Center for Marine Environmental Sciences, Universität Bremen, Germany

The interaction between barotropic tidal currents and bottom topography is one of the main generation mechanisms of internal gravity waves. Energetically consistent parameterizations of turbulent mixing induced by wave breaking hence rely on a realistic representation of this generation mechanism. While a number of global generation estimates are available, until recently all of them assumed the barotropic-to-baroclinic energy transfer to be isotropic. We here present the global application of a new method based on linear theory that for the first time also resolves the horizontal direction of the modal internal tide generation. The results can vary substantially with direction depending on the shape and orientation of topographic obstacles and the direction of the local tidal currents. The impact of this anisotropy on tidally driven mixing is assessed for the internal gravity wave model IDEMIX, a backbone of energetically consistent parameterizations of wave-induced mixing.

The impact of representations of realistic topography on parameterised oceanic lee wave energy flux

14 Feb 16:50h

Lois Baker [1] and Ali Mashayek[1,2]

[1]Imperial College London; [2]University of Cambridge

Oceanic lee waves are generated when quasi-steady flows interact with rough topography at the bottom of the ocean, providing an important sink of energy and momentum from the mean flow and a source of turbulent kinetic energy. Linear theory with a spectral representation of topography is typically used to inform parameterisations of lee wave generation. Here, we use a realistic wave resolving simulation of the Drake Passage, a hot-spot of lee wave generation, to investigate the utility of such parameterisations for areas of complex large scale topography. The flow is often blocked and split by large amplitude topographic features, creating an "effective topography," and calling into question the spectral representation of small scale topography for lee wave generation. By comparing the resolved modeled wavefield to parameterisations employing various representations of topography, we show that spectral methods may not be appropriate in areas of rough topography. We develop a simple topographic representation consisting of an ensemble of topographic peaks, which allows physical treatment of flow blocking at finite amplitude topography. This method effectively predicts bottom vertical velocities and lee wave energy flux, whereas spectral methods overestimate the energy flux by approximately 4 times. Our results also imply that the nature of lee waves in such regions can be misrepresented by a spectral approach to topographic representation. This leads to both an overestimate of wave energy flux and an underestimate of wave nonlinearity, with implications for the mechanisms by which lee waves break and mix in the abyssal ocean.

The imprint of ocean currents on surface gravity waves

15 Feb 9:30h

Jacques Vanneste [1], A B Villas Boas [1], H Wang [1] and W R Young [2]

[1]University of Edinburgh; [2]Scripps Institute of Oceanography

The refraction of surface gravity waves by currents leads to the spatial modulation of the wave field and, in particular, to spatial inhomogeneities in the significant wave height. This can be captured by an asymptotic theory based on the smallness of the ratio between the typical current velocity and the wave group speed. For swell-like, highly directional wave spectra, the angular spread of the spectrum is another small parameter. I will explain how the relative size of the two parameters controls the structure of the modulations in significant wave height, and I will illustrate the results for simple localised flow structures such as vortices and dipoles. A broad conclusion is that the formation of caustics, which have attracted a great deal of attention, is unlikely for realistic wave spectra. The theoretical predictions are tested against numerical simulation using WAVEWATCH.

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15 Feb
10:00h

Turbulent transition of a flow from small to O(1) Rossby numbers

Jim Thomas[1,2]

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Oceanic flows are energetically dominated by low vertical modes. However, disturbances in the form of atmospheric storms, eddy interactions with various forms of boundaries, or spontaneous emission by coherent structures can generate weak high-baroclinic modes. The feedback of the low-energy high-baroclinic modes on large-scale energetically dominant low modes may be weak or strong depending on the flow Rossby number. In this paper we study this interaction using an idealized setup by constraining the flow dynamics to a high-energy barotropic mode and a single low-energy high-baroclinic mode. Our investigation points out that at low Rossby numbers the barotropic flow organizes into large-scale coherent vortices via an inverse energy flux while the baroclinic flow accumulates predominantly in anticyclonic barotropic vortices. In contrast, with increasing Rossby number, the baroclinic flow catalyzes a forward flux of barotropic energy. The barotropic coherent vortices decrease in size and number, with a strong preference for cyclonic coherent vortices at higher Rossby numbers. On partitioning the flow domain into strain-dominant and vorticity-dominant regions based on the barotropic flow, we find that at higher Rossby numbers baroclinic flow accumulates in strain-dominant regions, away from vortex cores. Additionally, a major fraction of the forward energy flux of the flow takes place in strain-dominant regions. Overall, one of the key outcomes of this study is the finding that even a low-energy high-baroclinic flow can deplete and dissipate large-scale coherent structures at O(1) Rossby numbers.

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15 Feb
10:20h

The parametric IDEMIX model

Dirk Olbers[1], Friederike Pollmann [2], Ankitkumar Patel[2], and Carsten Eden[2]

[1]Alfred-Wegener-Institut, Germany; [2]Universität Hamburg, Germany

The spectral description of the energy of oceanic internal gravity waves is generally represented by the Garrett-Munk (GM) model, a function with a power-law decrease of spectral energy in wavenumber-frequency space. Besides the slopes of these power-laws the spectrum is expressed as function of energy and a bandwidth parameter which fixes the range of vertical modes excited in the respective state. Whereas concepts have been developed and agreed upon of what processes feed the wave spectrum and what dissipates energy, there is no explanation what shapes the spectral distribution, i.e. how the power-laws come about and what sets the bandwidth. The present study develops a parametric spectral model of energy and bandwidth from the basic underlying energy balance in terms of forcing, propagation, refraction, spectral transfer, and dissipation. The model is an extension of the IDEMIX (Internal Wave Dissipation, Energy and Mixing) models where bandwidth was so far taken as a constant parameter. The current version of the model is restricted to single-column mode and the slopes of the spectral power-laws are fixed. A coupled system of predictive equations for energy and bandwidth (for up- and downward propagating waves) results. The equations imply that bandwidth relates to energy by a power-law with an exponent given by the dynamical parameters. It agrees favorably with energy, bandwidth, and slope data from previous published fits of the GM model to Argo float observations. Numerical solutions of the coupled energy-bandwidth model in stand-alone modus are presented.

Breaking of internal waves parametrically excited by ageostrophic anticyclonic instability

15 Feb 10:40h

Yohei Onuki[1], Sylvain Joubaud [2], and Thierry Dauxois[2]
[1]Kyushu University; [2]Laboratoire de Physique, ENS de Lyon

A gradient-wind balanced flow with an elliptic streamline parametrically excites internal inertia-gravity waves through ageostrophic anticyclonic instability (AAI). This study numerically investigates the breaking of internal waves and the following turbulence generation resulting from the AAI. In our simulation, we periodically distort the calculation domain following the streamlines of an elliptic vortex and integrate the equations of motion using a Fourier spectral method. This technique enables us to exclude the overall structure of the large-scale vortex from the computation and concentrate on resolving the small-scale waves and turbulence. From a series of experiments, we identify two different scenarios of wave breaking conditioned on the magnitude of the instability growth rate scaled by the buoyancy frequency, λ/N. First, when $\lambda/N \geq 0.008$, the primary wave amplitude excited by AAI quickly goes far beyond the overturning threshold and directly breaks. The resulting state is thus strongly nonlinear turbulence. Second, if $\lambda/N \leq 0.008$, weak wave-wave interactions begin to redistribute energy across frequency space before the primary wave reaches a breaking limit. Then, after a sufficiently long time, the system approaches a Garrett-Munk-like stationary spectrum, in which wave breaking occurs at finer vertical scales. Throughout the experimental conditions, the growth and decay time scales of the primary wave energy are well correlated. However, since the primary wave amplitude reaches a prescribed limit in one scenario but not in the other, the energy dissipation rates exhibit two types of scaling properties. This scaling classification has similarities and differences with D'Asaro and Lien's (2000) wave-turbulence transition model.

Exploring eddy ellipse geometry as metrics of eddy-mean flow interactions in a mixed instability jet

15 Feb 11:30h

Connor Henderson[1], Stephanie Waterman[2] and Scott D. Bachman[3]
[1] University of New South Wales; [2] University of British Columbia; [3]National Center for Atmospheric Research Boulder

Eddies have important feedbacks on the larger-scale flow and cannot be neglected in the description of the large-scale dynamics. GEOMETRIC is a promising framework for eddy parameterization that describes the eddy forcing in terms of the geometry of ellipses describing the eddy stress tensor. A systematic understanding of how the various geometric parameters describe and differentiate systems that include eddy forcing from barotropic versus baroclinic instability is needed to better understand how the geometric parameters should be prescribed. In this study, we use an idealized model of a western boundary current jet extension subject to both barotropic and baroclinic instabilities to understand how the various geometric parameters of the framework vary and relate to eddy-mean flow interaction dynamics. Specifically, we systematically vary the jet parameters to transition between a system dominated by barotropic instability to a system dominated by baroclinic instability to understand how this transition is recorded in the geometric terms. The geometric parameters show systematic differences between the barotropically-dominant and baroclinically-dominant case study runs, as well as systematic variations across the full suite of runs. The geometric parameters also show systematic relationships to eddy-mean flow interaction metrics. This work demonstrates that the geometric parameters can be useful for informing on eddy-mean flow interaction dynamics and vice versa; the latter suggesting that there is potential to prescribe some aspects of the geometric parameter variability from knowledge of eddy-mean flow interaction dynamics.

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15 Feb
11:50h

The physical basis for the specification of the lateral stirring directions in rotated diffusion tensors

Remi Tailleux
Department of Meteorology, University of Reading

Although the large-scale horizontal gradients of the active tracers potential temperature and salinity are much smaller than their vertical gradients, the fact that lateral stirring by meso-scale ocean eddies is about 7 to 8 orders of magnitude larger than vertical stirring means that in practice, lateral and vertical stirring contribute equally to the forward cascade ultimately leading to the irreversible dissipation of the tracers' variance by molecular diffusive processes of heat and salt. To accurately represent the effects of lateral and vertical stirring in coarse resolution numerical ocean models, the accepted practice has been to use rotated diffusion tensors mixing separately along the lateral and vertical stirring directions. In the absence of obvious rigorous theoretical arguments for how to specify such directions, it has been generally assumed based on heuristic arguments that such directions should align with the iso-neutral and dia-neutral directions. Physically, this is because lateral stirring along the iso-neutral directions is generally thought be facilitated due to their low energy cost. Nevertheless, whether this choice is optimal has remained unclear. The issue is important, because it is widely accepted that any error in the choice of mixing directions would result in spurious diapycnal mixing associated with the so-called Veronis effect. How to diagnose spurious mixing, be it of numerical or physical origin, is a longstanding challenge in numerical ocean modelling that has yet to receive a satisfactory solution, however. In this work, I suggest that the physical basis for specifying the mixing directions in rotated diffusion tensors requires a theoretical understanding of the kinetic (KE) and available potential energy (APE) cascades. Specifically, the question to be understood is how the removal of resolved KE and APE by subgrid-scale parameterisations relate to the irreversible dissipation of KE and APE by molecular viscous and diffusive processes at the end of the cascades. Using plausible hypotheses on the nature of such energy cascades, I present calculations suggesting that the use of neutral rotated diffusion tensors is likely to significantly overestimate diapycnal mixing in the Southern Ocean, a region known to be critical for the uptake of heat and carbon, and where most numerical ocean models still exhibit many important systematic biases.

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15 Feb
12:10h

Inertia-gravity-wave diffusion by geostrophic turbulence: the role of flow time dependence and stratification change

Michael R. Cox [1], Hossein A. Kafiabad [2] and Jacques Vanneste [1]
[1]University of Edinburgh; [2]Durham University

The scattering of inertia-gravity waves by balanced flow leads to the redistribution of action in wavevector space through what is approximately a diffusion process. Previous work finds that in a three-dimensional system, action diffuses along constant-frequency cones, assuming (1) the flow is time-independent; and (2) the flow only affects the IGWs through Doppler shift. We relax these assumptions and account for (1) a slow time-dependent flow; and (2) the change in stratification the flow introduces. In the case of time-dependent flow, we find an explicit formula for the stationary wave-energy spectrum which is localised within a thin boundary layer around the constant-frequency cone. The spectrum performs well when compared to a high-resolution Boussinesq simulation. For the impact of stratification changes, we compare the case of a Boussinesq fluid with the shallow water system.

Two-dimensional Ekman-Inertial instability

15 Feb
12:30h

Fabiola Trujano-Jimenez[1], Varvara E. Zemskova[2] and Nicolas Grisouard[1]

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Submesoscale ocean flows are energetically relevant because they could provide a path for dissipation from large to small scales. In addition, they induce large vertical velocities that enhance the transport of mass, heat, gases, and nutrients. Therefore, submesoscale flows can impact the ocean circulation and the climate system in ways that remain largely unknown. Dynamically speaking, submesoscale flows are especially prone to undergo instabilities. In particular, Ekman-Inertial Instability (EII) has recently been theoretically predicted to develop in submesoscale flows forced by a sudden change in surface wind stress. EII, which occurs under Ro¡-1 can be seen as the unstable counterpart of the Ekman layer, which occurs for Ro¿-1. However, it is characterised by non-normal growth rates and its time evolution initially follows that of the atmospheric conditions that trigger it. Consequently, EII may grow at a much faster rate than other common interior submesoscale instabilities, such as the symmetric or inertial instabilities. The current analytical description of EII is one-dimensional in the vertical direction. We aim to investigate its development in a 2D submesoscale current. In order to do so, we conduct numerical simulations of three cases: a stable case, which corresponds to the development of an Ekman layer; and two unstable cases, namely, the (normal-mode) Inertial Instability, and EII. Our results show that EII induces a horizontal flow stronger than the one induced by the Ekman layer, and it develops much faster than Inertial Instability, inducing intense vertical pumping at earlier stages of the instability. Moreover, Inertial Instability and EII both grow fast enough to emit internal waves. However, their very different growth rates result in very different frequency spectra for the internal wave field. Inertial instability emits near-inertial waves that primarily radiate in the far-field. On the other hand, a significant fraction of the internal waves emitted during EII are characterized by a larger frequency and remain trapped within the current. We further investigate how these fundamental differences shape the energy exchanges between the internal waves and the mean flow in each case.

Leveraging theory and machine learning for mesoscale eddy parameterizations

15 Feb
14:10h

Laure Zanna

New York University

TBA

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15 Feb
14:40h

Dynamical insights from frequency-filtered Lagrangian structure functions

Han Wang[1], Dhruv Balwada[2], and Jin-han Xie[3]

[1] University of Edinburgh; [2]Columbia University; [3]Peking University

Surface drifters record oceanic surface currents in an Lagrangian manner. They can resolve spatial scales from 1 km to a few hundred kilometers, providing crucial insights into the scale-dependent dynamics of the ocean. One common set of statistical metrics studied from surface drifter observations are the structure functions. Based on recent theoretical advances, second-order structure functions can be used to determine the dominance of rotational or divergent motions at different spatial scales, while third-order structure functions can be used to infer directions of kinetic energy transfers. In this work, we aim to gain more insights of the second and third order structure functions by combing them with temporal filtering. Preliminary results show, for example, that near-inertial waves can be observed more distinctly in the second order structure functions after such operations.

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15 Feb
15:00h

Computing Lagrangian means without particle tracking

Hossein A. Kafiabad[1] and Jacques Vanneste[2]

[1]Durham University; [2]University of Edinburgh

Lagrangian averaging plays an important role in the analysis of wave–mean-flow interactions and other multi-scale fluid phenomena. The numerical computation of Lagrangian means, e.g. from simulation data, is however challenging. Typical implementations require tracking a large number of particles to construct Lagrangian time series, which are then averaged using a low-pass filter. This has drawbacks that include large memory demands, particle clustering and complications of parallelisation. We develop a novel approach in which the Lagrangian means of various fields (including particle positions) are computed by solving partial differential equations (PDEs) that are integrated over successive averaging time intervals. We propose two strategies, distinguished by their spatial independent variables. The first, uses end-of-interval particle positions; the second directly uses the Lagrangian mean positions. The PDEs can be discretised in a variety of ways, e.g. using the same discretisation as that employed for the governing dynamical equations, and solved on-the-fly to minimise the memory footprint. We illustrate the new approach with a pseudo-spectral implementation for the rotating shallow-water model.

Exact expressions for available potential energy and available potential vorticity

15 Feb
15:20h

Jeffrey J. Early[1], Leslie M. Smith[2], Gerardo Hernández-Dueñas[3] and M.-Pascale Lelong[1]

[1]NorthWest Research Associates; [2]University of Wisconsin–Madison; [3]Universidad Nacional Autonoma de Mexico

The traditional full expressions for energy and potential vorticity of a rotating stratified fluid contain large nonzero values in the state of no-motion, which obscure the amount of energy and potential vorticity available to the dynamics. This has led to the concept of available potential energy (APE) and vorticity (APV). Expressions for APE and APV have been previously found using perturbation expansions in Holliday and Mcintyre (1981) and Wagner and Young (2015), respectively. Here we show how both APE and APV can be derived from first principles, leading to exact analytical expressions that are easily implemented in numerical computations of Boussinesq dynamics with non-constant stratification. Not only do these expressions vanish in the state of no-motion and satisfy the appropriate conservation laws, but their perturbation expansions are consistent with the equivalent expressions derived from the linearized equations of motion, an important feature that is lacking in the more traditional full expressions for potential energy and potential vorticity.

Can inertia-gravity waves impact the evolution of geostrophic flows?

15 Feb
16:10h

Gerardo Hernandez Dueñas, M.-Pascale Lelong and Leslie M. Smith

NorthWest Research Associates

Whereas the catalytic impact of geostrophic (vortical) flows on inertia-gravity wave energy cascades is well documented, much less attention has been devoted to understanding interactions that can lead to energy exchanges between the two motions. In this study, we investigate the role of different nonlinear interactions (resonant and off-resonant) between these two motions with a set of intermediate models. Using a projection method, the models are formulated in terms of wave-mode and vortical-mode nonlinear interactions. The models range in complexity from full Boussinesq to waves-only and vortical-mode-only models. We find that off-resonant interactions are responsible for significant energy exchanges between IGWs and vortical flow. In particular, we show that waves are instrumental in filling out the spectra of vortical-mode energy at small scales through vortical-wave-wave off-resonant interactions. This is in contrast to the impact of resonant vortical-wave-wave interactions which can only redistribute energy in the wave field.

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15 Feb
16:30h

Long lived deep coherent vortices in the Atlantic Ocean

Ashwita Chouksey, Jonathan Gula and Xavier Carton

Univesity of Brest, CNRS, Laboratoire d'Océanographie Physique et Spatiale, IUEM, France

The ocean is densely populated with energetic coherent vortices (CVs) of different sizes which contribute in stirring of the ocean, transporting and redistributing water masses and tracers (active and passive), affecting ventilation pathways and thus impacting large-scale circulation. CVs with radii between 1-30 km have been detected via satellite and in-situ measurements at surface or at depth (usually not more than about 2000 m depth). They are found to be of different shapes and sizes depending upon latitude and place of origin. Previous studies have mostly described the surface vortices than the deep CVs (DCVs > 1000 m). This study focuses on DCVs below the mixed layer depth along three different isopycnal surfaces: 27.60, 27.80, and 27.86; which lies at the depth range of 200-2000 m, 1200-3000 m, and 1800-4500 m respectively. We aim to quantify their physical characteristics (radius, thickness, bias in polarity: cyclones Vs anticyclones) in different parts of the Atlantic ocean, and analyze the dynamics involved in the generation and destruction of the DCVs throughout their life-cycle. We use the Coastal and Regional Ocean COmmunity model ocean model in a high resolution setup (3 km) of the Atlantic Ocean. The detection of DCVs are done every 12 hr using the Okubo-Weiss parameter along the isopycnal surfaces using py-eddy-tracker as the eddy-tracking algorithm. We consider DCVs living for more than 21 days and focus on ones living > 365 days. Cyclones are on average smaller and shorter lived, such that there is a dominance of anticyclones while considering long-lived and larger distance travelling DCVs. We concentrate on the strongest and longest lived DCVs among which meddies that we compare to previous in-situ observations. This study is the first step in the understanding of the formation, occurrences and structure of DCVs in the Atlantic Ocean.

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15 Feb
16:50h

On the impact on wind and surface waves on balanced fronts in the oceanic surface mixed layer

Lars Czeschel

Universität Hamburg

Large eddy simulations are used to study fronts in in the oceanic mixed layer including the impact of surface gravity waves. We focus on two scenarios: the impact of short local storm events and the arrival of swell from distant storms. Several mechanisms can be identified which lead to cross frontal circulation and associated symmetric and Kelvin-Helmholtz instabilities. These mechanisms include turbulence driven frontogenesis, inertial oscillations, Ekman buoyancy fluxes and vorticity injected by the depth dependence of the Stokes drift and the associated anti-Stokes flow. All the suggested mechanisms provide a direct route to dissipation, i.e. they are part of the forward energy cascade.

Diurnal variability of frontal dynamics, instability, and energy dissipation

16 Feb
9:30h

Jen-Ping Peng[1], Lars Umlauf [2] and Nicole Jones [1]

[1]University of Western Australia; [2]Leibniz Institute for Baltic Sea Research Warnemünde

Interactions between mesoscale, submesoscale, and small-scale processes are frequently observed dynamics in frontal regions of the ocean, with submesoscale motions being especially critical due to their important role for surface-layer restratification, lateral dispersion, and the turbulent energy cascade. Submesoscale motions have been extensively studied over the past decade, however, mostly focusing on night-time conditions (i.e., surface cooling). Here we present high-resolution observational data sets obtained from a submesoscale filament in the Benguela upwelling system (South-East Atlantic Ocean) and a submesoscale front on the Australian Northwest Shelf (South-East Indian Ocean) under strong diurnal solar radiation. Two scenarios for the diurnal variability of submesoscale frontal processes are identified. First, for stronger winds, wind-driven turbulence redistributes heat (due to the penetration of solar radiation near the ocean surface) downward to depths of the SBL via mixing, resulting in a tendency for frontal restratification that competes with frontal turbulence; a complete frontal collapse is expected when solar radiation is near its maximum. Second, under conditions with weaker winds, diurnal warm layers form due to solar heating, resulting in a thin but strong near-surface stratification in the upper few meters, resulting in a decoupling of frontal turbulent processes in the lower parts of the SBL from the surface forcing. In both cases, frontal turbulence is generated by symmetric instability and marginal shear instability. These are the first direct field observations supporting the relevance of frontal instabilities and turbulence as well as their importance for SBL turbulence and upper-ocean energy cycles under strong stabilizing surface forcing, which so far has rarely been discussed in theoretical and numerical investigations.

Estimating the submesoscale oceanic inverse cascade from satellite along-track altimetry

16 Feb
10:00h

René Schubert and Jonathan Gula

Ifremer, Laboratoire d'Océanographie Physique et Spatiale (LOPS), IUEM

With two submesoscale-permitting simulations it is shown that the geostrophic inverse scale kinetic energy flux averaged over 5°x5° boxes is linearly related to quantities that are computable from along-track altimetry when averaged over the same region. This linear relationship is used to estimate for the first time the submesoscale inverse kinetic energy cascade, as well as its regional distribution and seasonal cycle for large parts of the global ocean. The results are consistent with previous findings based on regional observations, simulations, and indirect comparisons of spectral properties of satellite data. Work in progress focuses on a theoretical explanation why the estimation works.

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16 Feb
10:20h

Spatio-temporal characteristics of winter mixed layer turbulence in an energetic oceanic zone

Pauline Tedesco [1], Lois Baker[1], Ali Mashayek[1], Alberto Naveira-Garabato[2], Colm-cille Caulfield[3], Matthew Mazloff[4], Sarah Gilles[4] and Bruce Cornuelle[4]

[1]Imperial College London; [2]University of Southampton;[3]University of Cambridge; [4]Scripps Institution of Oceanography

Mixed layer (ML) turbulence in the submesoscale range plays a pivotal role in the ocean energy budget by transferring kinetic energy (KE) either up- or down-scale. Understanding ML turbulence relies, in part, on the knowledge of its characteristic spatio-temporal scales. Here, we physically inform the need for high spatio-temporal resolution to infer ML turbulence. Based on a numerical simulation of the Drake Passage in winter, we combine a Lagrangian filtering and Helmholtz decomposition to distinguish classes of ML motions (low vs. high frequency) and their governing dynamics (rotational vs. divergent). The KE reservoir in the ML is typical of a winter regime, with rotational low frequency motions dominating at all scales (O(Rd — 1 km); O(days — 1hour)). Divergent low-frequency (O(Rd — 10 km) km; O(1day — 6hour)) and high-frequency motions (O(10km — 1km); O(6hour—2hour)) — of significant rotational and divergent part —contribute to KE over smaller range of scales. ML turbulence results in an intense up-scale turbulent cascade, occurring over most of spatial scales, and in a weak down-scale cascade at small scales (L ¡ 6 km). The rotational and divergent component cleanly separates the upscale cascade from the downscale one, but not the low and high frequency motions, which both have significant rotational and divergent parts. Purely rotational low frequency motions realise most of the upscale cascade and interactions between rotational and divergent parts of low and high frequency motions realise the downscale cascade. Our results show that all classes of motions should be represented to comprehensively infer winter ML turbulence. This has implications for study strategies and advocates for the parameterization of ML turbulence in models, because all classes of motions are sensitive to high spatio-temporal resolution (L ¿ 1km; T ¿ 1h).

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16 Feb
10:40h

Dissipation in ageostrophic turbulence from a submesoscale resolving simulation of the North Atlantic

Nils Brğgemann, Leonidas Linardakis and Peter Korn

Max-Planck Institut für Meteorologie

We diagnose dissipation associated with a downscale energy flux of ageostrophic turbulence in a submesoscale resolving simulation of the North Atlantic. Ageostrophic turbulence was shown to transfer energy towards smaller scales in idealized simulations. To which extent this effect is relevant in more realistic simulations is unclear. Therefore, we use a novel configuration of the ICON-O ocean model where the grid resolution is refined to smaller than 600m over a large area of the North Atlantic. In this simulation, we identify ageostrophic submesoscale eddies by their high Rossby number and diagnose the dissipation associated with these eddies. We find that dissipation is strongly enhanced within the upper ocean, within and south of the Gulf Stream front. Attempts are made to develop parameterizations for the ageostrophic downscale energy flux to couple this energy dissipation with other ocean energy reservoirs. Therewith, we aim to obtain a more realistic view of how much energy becaomes available for diapycnal mixing.

On constraining the mesoscale eddy energy dissipation time-scale

16 Feb
11:30h

Julian Mak[1,2], A. Avdis[3,4], T. David[5], H. S. Lee[1], Y. Na[1], Y. Wang[1,2], and F. E. Yan[1]

[1]Department of Ocean Science, Hong Kong University of Science and Technology; [2]Center for Ocean Research in Hong Kong and Macau, Hong Kong University of Science and Technology; [3]Department of Earth Science and Engineering, Imperial College London; [4]HPC department, Boston Limited; [5]Laboratoire de Physique, École Normale Supérieure de Lyon

Energy plays an important role in quantifying the magnitude of motions at different time and spatial scales. Many different dynamical processes contribute to energy transfers within the ocean, and constraining the rate of transfer remains a formidable challenge. This work provides a bulk constraint on the overall magnitude and spatial variation of an eddy energy dissipation time-scale, which relates to the rate of energy transfer out of the motions at 10 to 100 km in the ocean where rotation and density stratification play a leading order role in the dynamics. A time-scale is "backed out" from a model via an inverse approach: given a model for the eddy energy evolution and what we should end up with (the eddy energy signature), what should we have started off with in the first place (the dissipation time-scale)? Although our solution should be interpreted as a lower estimate given the assumptions going into the calculation, it serves as an important physically consistent base line reference for further investigations into ocean energetics, as well as for an intended inverse calculation that is more complete but also much more complex.

Quasi-convergence of optimal balance by nudging

16 Feb
11:50h

Marcel Oliver [1], G. Tuba Masur[2], and H. Mohamad [1]

[1]KU Eichstätt-Ingolstadt; [2]Goethe-Universität Frankfurt

Optimal balance is a non-asymptotic numerical method for computing a point on an elliptic slow manifold for two-scale dynamical systems with strong gyroscopic forces. It works by solving a modified differential equation as a boundary value problem in time, where the nonlinear terms are adiabatically ramped up from zero to the fully nonlinear dynamics. A dedicated boundary value solver, however, is often not directly available. The most natural alternative is a nudging solver, where the problem is repeatedly solved forward and backward in time and the respective boundary conditions are restored whenever one of the temporal end points is visited. In this paper, we show quasi-convergence of this scheme in the sense that the termination residual of the nudging iteration is as small as the asymptotic error of the method itself, i.e., under appropriate assumptions exponentially small. This confirms that optimal balance in its nudging formulation is an effective algorithm. Further, it shows that the boundary value problem formulation of optimal balance is well posed up at most a residual error as small as the asymptotic error of the method itself. The key step in our proof is a careful two-component Gronwall inequality.

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16 Feb
12:10h

Seeking balance in realistic ocean flows

Silvano Gordian Rosenau[1], Manita Chouksey[2], and Carsten Eden[1]
[1]Universität Hamburg, Germany;[2]Universität Bremen, Germany

The decomposition of the oceanic flow field into its slow balanced and fast unbalanced components is fundamental to understand the energy transfers between them via mechanisms such as spontaneous wave emission and mesoscale eddy dissipation, that are potentially important eddy energy sinks and wave energy sources, and thus necessary to improve parameterizations in models. The first order approach is to decompose the flow into geostrophic and non-geostrophic components. However, since a part of the non-geostrophic component evolves slowly due to nonlinear interactions between both components, this approach is not precise enough to quantify energy transfers. High precision methods, such as optimal balance or nonlinear normal mode decomposition at higher orders, can decompose the flow field with higher accuracy, but their application is limited to idealized model settings that neither include topography nor a varying Coriolis parameter. Here, we propose a novel flow decomposition method with a time-averaging procedure, a modified version of the optimal balance method, such that it is applicable to more realistic ocean models. A comparison of the new time-averaging method with the aforementioned methods, in a shallow water model and in a non-hydrostatic model, is promising and shows that the new method can decompose the flow field with similar accuracy. We find that for longer time averaging periods, the modified optimal balance method converges against the original method, thus expanding the applicability to a wide range of ocean scenarios.

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16 Feb
11:50h

Observations of near-inertial wave interaction with coherent anticyclonic eddies

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[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany; [2]Scottish Association for Marine Science, Oban, Scotland

More than thirty years ago, the interaction between the propagation of near-inertial waves and geostrophic flow was already studied by Kunze et al. (1985). It was shown that anticyclonic eddies can trap and enhance the downward propagation of near-inertial wave energy. Below these eddies, a critical layer can form in which the associated vorticity anomaly disappears. Several recent modeling studies now point to the importance of this interaction between eddies and near-inertial waves for the downward transport of near-inertial energy to the deep ocean. There, it could provide a source of energy for small-scale dissipation. However, observations of critical layer trapping are rare. Here we present the results of several cross-platform observational studies based on gliders, moorings, and shipboard measurements in the Pacific and Atlantic oceans. The study of several coherent anticyclonic eddies provides a detailed view on their impacts on the near-inertial energy distribution. Velocity measurements in coherent anticyclonic eddies show pronounced alternating current bands with amplitudes up to 15 cm/s. They are associated with near-inertial waves. The strongest amplitudes are found near the mixed layer depth and at the eddy base. In addition, microstructure measurements show increased dissipation rates associated with the high amplitudes of the near-inertial waves. This suggests that a critical layer is forming where near-inertial energy accumulates. In summary, our observations provide evidence for an interaction of mesoscale eddies with the near-inertial wave field (downward energy transport) and probably also with the small-scale turbulence regime (turbulence at the eddy base).

How white is the sky?

16 Feb
14:10h

Nedjeljka Žagar and Valetnino Neduhal
Meteorologisches Institut, Universität Hamburg

This talk discusses the slopes of the kinetic energy spectra of vertical motions associated with the Rossby wave and inertia-gravity wave dynamics in the hydrostatic atmosphere. Traditionally, vertical velocities associated with the Rossby and gravity waves have been treated separately using the quasi-geostrophic omega equations and polarization relations for the stratified Boussinesq fluid in the vertically-aligned plane, respectively. In the tropics, the Rossby and gravity wave regimes become inseparable and their frequency gap, present in the extra-tropics, is filled with the Kelvin and mixed Rossby-gravity waves. We present a unified framework for the computation of vertical velocities associated with the Rossby and inertia-gravity waves using the normal-mode framework in the hydrostatic atmosphere. It provides the vertical kinetic energy spectra per latitude and altitude bands. The application of the new framework to the high-resolution reanalysis data confirm the redness of the Rossby part and whiteness of the inertia-gravity part with significant deviations among the latitudes and levels.

Energy of the semidiurnal internal tide from Argo data compared with theory

16 Feb
14:30h

Gaspard Geoffroy[1], Jonas Nycander[1] and Casimir de Lavergne[2]
[1]Department of Meteorology, Stockholm University, Stockholm, Sweden; [2]LOCEAN Laboratory, Sorbonne Université-CNRS-IRD-MNHN, Paris, France

A global map of the amplitude of the semidiurnal internal tide at the 1000 dbar level, obtained from Argo park-phase data, is converted to depth-integrated energy density. As opposed to current satellite altimeter data, the high sampling rate of the floats enables the direct observation of the total wave field, including waves with a time varying phase difference to the astronomical forcing. Thus, the Argo-derived energy content is only affected by mixing, scattering, and nonlinear processes. The Argo data alone do not allow for retrieving the distribution of the energy over the different vertical modes. Nevertheless, the modal partitioning of the Argo-derived energy content is inferred from other datasets. The results are compared with a geographical distribution of the internal tide energy content estimated with a Lagrangian ray tracing model. The outcome is in turn used to tune the modelled attenuation of low-mode internal tides.

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16 Feb
14:50h

Spatial and temporal variability of mode-1 and mode-2 internal solitary waves from MODIS/TERRA sunglint off the Amazon shelf

Carina Regina de Macedo[1,2], Ariane Koch-Larrouy[2], José Carlos Bastos da Silva[3], Carlos Alessandre Domingos Lentini[4], Jorge Manuel Magalhães[3], Trung Kien Tran[1], Marcelo Caetano Barreto Rosa[4] and Vincent Vantrepotte[1]

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The Amazon shelf is a key region for intense internal tides (ITs) and nonlinear internal solitary waves (ISWs) generation associated with them. The region shows well-marked seasonal variability (boreal Summerfall ASOND vs spring MAMJJ) of the circulation and stratification, which can both induce changes in the ISWs physical characteristics. Satellite remote sensing is a key tool for providing information about ISW propagation, and eventually dissipation mechanisms. The description of the seasonal and neap-spring tidal variability of the ISWs off the Amazon shelf is performed for the first time using a meaningful data set composed of more than a hundred MODISTERRA imagery from 2005 to 2021, where more than 500 ISW signatures were identified in the sun glint region. Previous studies have documented the existence of mode-1 ISW, but the region appears as a newly described hotspot for mode-2 ISWs. ISWs packets separated by typical mode-1 (95 - 170 km; 2.1 - 3.8 m.s-1) and mode-2 (46 - 85 km; 1.0 - 1.9 m.s-1) ITs wavelengths have been identified and mapped coming from sites A, B, and F. Site A likely shows a higher ISW activity because waves emanating from site D are focussing on the same propagation path. In region A, patches of higher occurrence of ISWs appear separated by typical mode-1 wavelength likely corresponding to the reflection beams at the surface. A third patch structured as a tail with finer scales might indicate some region of instability, a transfer to higher modes or dissipation. The range and values of mode-1 and mode-2 propagation velocitieswavelengths do not show significant differences according to areas A and B. Mode-2mode-1 ratio is larger for site B likely linked to shallower pycnocline with higher maximum values when compared to area A. The wave activity is higher during spring tides than neap tides (for both A and B sites). During ASOND, mode-1 ISWs from A exhibit higher wave propagation velocitieswavelengths than MAMJJ. In contrast, no seasonal variation of mode-2 propagation velocitieswavelengths was found. During ASOND in area A, the reinforcement of the North Equatorial Countercurrent appears to play a role in deviating the waves towards the northeast, increasing their phase velocities and their eastern traveling direction component which gives them an extra offshore acceleration. The impact of the circulation on the propagation velocitieswavelength is even more evident for the shorter-scale waves. During ASOND, when the circulation has higher small-scale variability the ISWs propagate in a wider pathway and have a higher diversity of propagation velocities. Calculations of the IT velocities using the Taylor-Goldstein equation supported our results of the presence of mode-2 ISWs associated with mode-2 IT wavelengths in the study area and additionally into the ISWIT seasonal variability in terms of waves with higher diversity and higher mean values of wavelength during ASOND.

Evidence of a dual kinetic energy cascade by surface drifter observation in the Walvis Ridge Region

16 Feb
15:10h

Julia Draeger-Dietel[1], Alexa Griesel[1] and Jochen Horstmann[2]

[1]Universität Hamburg, Faculty of Mathematics, Informatics and Natural Sciences, Theoretical Oceanography, Germany; [2]Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany

The characteristics of turbulence and processes driving it in the regime connecting mesoscales (mainly upscale energy transfer rates) and classical microscales turbulence (downscale energy transfer) are not fully well-established. Here we analyse two-point velocity data from 2 entangled near-simultaneous relases of two different kinds of surface drifters floating in different depth (50 cm and 15 m) of the ocean mixed layer in the Walvis Ridge Region. For the 'deep drifters' the compensated third order longitudinal velocity structure function shows a positive plateau for inertial scales roughly between 15 km and 150 km, revealing evidenve of an inverse cascade similar to former findings in the Benguela region. In contrast the 'shallow drifter' do not show a positive platau at these scales, but show evidence of a forward cascade (negative plateau) and Kolmogorov self-similarity on spatial scale around 500 m.

Decadal variability of eddy temperature fluxes in the Labrador Sea

16 Feb
15:30h

Christopher Danek[1], Patrick Scholz[1] and Gerrit Lohmann[1]

[1]Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany

Small-scale eddies play an important role in preconditioning and restratifying the water column before and after mixing events, thereby affecting deep water formation variability. Results from a realistic eddy-resolving (5 km local horizontal resolution) ocean model suggest that small-scale temperature fluxes due to turbulent potential to kinetic energy conversion are the main driver of mixed layer restratification during deep convection in the Labrador Sea interior and the West Greenland Current. This resupply of heat due to turbulent upward buoyancy fluxes exhibits a large interannual variability imposed by the atmospheric forcing. Eddy fluxes only become active in periods of strong buoyancy loss, while being quiescent otherwise. In a low-resolution (20 km) control simulation the modeled turbulence is strongly reduced and the associated modeled and parameterized heat fluxes are too weak to increase stratification.

Abstracts: Posters

Bottom generated internal waves from surface wind forcing

14 Feb
17:30

Ashley J. Barnes[1], Andrew M. Hogg, Navid C. Constantinou, and Callum J. Shakespeare
[1]Australian National University

Changes to wind forcing can readily generate near inertial waves (NIWs) that propagate downwards from the ocean surface. In this study, we investigate secondary, topographically generated inertial waves that that are excited by the oscillatory bottom pressure signature of the wind response. Such waves would contribute to the internal wave spectrum in the ocean, and we aim to understand how significant this contribution might be under different dynamical regimes. We hypothesise that such waves would arise due to a rapid, hydrostatic communication of isopycnal surface perturbations to the seafloor, resulting in oscillatory flow over bathymetric features. Under the right circumstances, this flow would generate internal waves in a similar way to internal tides. Preliminary results from an idealised numerical model have demonstrated a near instantaneous internal signal with a significant energy flux when compared to the purely wind generated NIWs, and shown that these waves are dependent on the forcing spectrum at the surface, stratification profile as well as the topography. An analytical framework based on the shallow water equations is currently being used to investigate the mechanism, and how it should change with varied model parameters.

Internal tide extraction using deep learning with spectral loss

14 Feb
18:00

Jeffrey Uncu[1], Nicolas Grisouard[1], and Han Wang[2]
[1]University of Toronto; [2]University of Edinburgh

The Surface Water and Ocean Topography (SWOT) mission will measure the sea surface height (SSH) at resolutions 10x that of previous altimetry missions. The disentanglement of internal tide and balanced flow signals in the SSH snapshots will be required to infer other dynamical fields. However, the newly resolvable length scales combined with the low temporal sampling of a given region by SWOT will not allow for frequency filtering to separate these signals, as done in previous altimetry missions. We improve upon a conditional Generative Adversarial Network named the Toronto Internal Tide Emulator which treats the internal tide extraction as an image translation problem. The input to the network is the 2D snapshot of the SSH and the output is the internal tide component. We improve on this algorithm by introducing a spectral loss function to the network which enforces that generated internal tide spectra are more representative of real internal tide spectra. We find up to 34% better agreement in the generated wave spectra with this method, as well as improved extraction performance overall. The dependence of the model accuracy on the strength of the turbulent balanced flows will also be analyzed. We plan to apply other physical constraints to make the machine learning algorithm produce more physically realizable results.

14/15 Feb
17:30

Parametrisation of mesoscale eddies via kinetic energy backscatter and interaction with GM parametrisation

Ekaterina Bagaeva[1,2] and Stephan Juricke[1,2]

[1]Constructor University Bremen; [2]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven

In this study, we address two setups for numerical simulation, which represent intermediate complexity step between idealized theoretical systems and full global configuration. Our intention is to examine subgrid kinetic energy equation modifications for the performance of energy backscatter. Modifications assumes addition of an advection tern and a stochastic component. Connection of energy backscatter with the Gent-McWilliams (GM) parameterization is another direction of our reserach.

14/15 Feb
17:30

Interactions between symmetric and baroclinic instabilities in the Irminger Sea

Fraser Goldsworth[1], Isabela Le Bras[2], David Marshall[3], and Helen Johnson[3]

[1]Max Planck Institut für Meteorologie; [2]Woods Hole Oceanographic Institution; [3]University of Oxford

Mooring observations from the OSNAP-East array have demonstrated the excitement of symmetric instability in the Irminger Sea off the coast of Greenland during winter-time down front wind events. Here we will use both models and observations to quantify the water mass transformation rates associated with these events. We will also explore the interactions between symmetric and baroclinic instabilities. In particular we will examine whether symmetric instability (the short time-scale response to these wind events) leads to an enhancement of mesoscale eddy activity.

14/15 Feb
17:30

The effect of tide-induced motions on the surface dispersion of floating material

Laura Gómez Navarro[1], Erik van Sebille[1], Verónica Morales Marquez[2], Ismael Hernandez Carrasco[3], Aurelie Aubert[4], Clement Ubelmann[5], Jean-Marc Molines[4], Julien Le Sommer[4], and Laurent Brodeau[4]

[1]Utrecht University (The Netherlands); [2]Université de Toulon - Institut Méditerranéen d'Océanologie (France); [3]IMEDEA (Spain);[4]UGA - CNRS, IGE (France); [5]DATLAS (France)

Understanding the pathways of floating material at the surface ocean is important to improve our knowledge on surface circulation and for its ecological and environmental impacts. Virtual particle simulations are a common method to simulate the dispersion of floating material. To advect the particles, ocean models' velocities are usually used, but only recent ones include tidal forcing. Our research question is: What is the effect of tidal forcing on virtual particle dispersion and accumulation at the ocean surface? As inputs we use velocity outputs from eNATL60, a twin simulation with and without tidal forcing. We focus on the Açores Islands region, and we find: 1) surface particles travel a longer cumulative distance and a lower total distance with than without tidal forcing; 2) differences are found in the surface particle accumulation patterns without and with tidal forcing, reaching differences up to 40%; and 3) a greater temporal variability in surface accumulation patterns is present with tidal forcing. We conclude that tides play an important role in horizontal Lagrangian dynamics.

Changes in global ocean circulation due to isopycnal diffusion

14/15 Feb
17:30

Ashwita Chouksey[1,2], Alexa Griesel[1], Manita Chouksey[1,3], and Carsten Eden[1]

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We investigate changes in the ocean circulation due to the variation of isopycnal diffusivity (κ_{iso}) in a global non-eddy-resolving model. Although isopycnal diffusion is thought to have minor effects on interior density gradients, the model circulation shows a surprisingly large sensitivity to the changes: with increasing κ_{iso}, the strength of the Atlantic residual overturning circulation (AMOC) and the Antarctic Circumpolar Current (ACC) transport weaken. At high latitudes, the isopycnal diffusion diffuses temperature and salinity upward and poleward, and at low latitudes downward close to the surface. Increasing isopycnal diffusivity increases the meridional isopycnal fluxes whose meridional gradient is equatorward, hence leading to a negative contribution to the flux divergence in the tracer equations and predominant cooling and freshening equatorward of 40º. The effect on temperature overcompensates the countering effect of salinity diffusion, such that the meridional density differences decrease, along with which ACC and AMOC decrease. We diagnose the adjustment process to the new equilibrium with increased isopycnal diffusion to assess how the other terms in the tracer equations react to the increased κ_{iso}. It reveals that around ±40º latitude, the cooling induced by the increased isopycnal flux is only partly compensated by warming by advection, explaining the net cooling. Overall, the results emphasize the importance of isopycnal diffusion on ocean circulation and dynamics, and hence the necessity of its careful representation in models.

Overturning of mixed layer eddies in a submesoscale resolving simulation of the North Atlantic

14/15 Feb
17:30

Moritz Epke[1,2] and Nils Brüggemann[1,2]

[1]Institut für Meereskunde, Universität of Hamburg and [2]Max Planck Institute for Meteorology

Submesoscale Instabilities in the mixed layer can lead to ocean restratification and Submesoscale Instabilities in the mixed layer can lead to ocean restratification and thus affect ocean-atmosphere feedbacks. In this study, a novel configuration of the ICON ocean model is applied which makes use of telescoping grid refinement such that a horizontal resolution finer than 600m is achieved over wide areas of the North Atlantic. The ability of the model to simulate mesoscale to submesoscale turbulence is validated by comparing spatial power spectra of sea surface temperature and sea surface hight with those of satellite products and a ICON simulation of 10km horizontal resolution (often referred to as "mesoscale eddy resolving").

We find more realistic variability in the simulation with the refined grid compared with coarser simulation over a wide range of scales that even includes the mesoscale eddy regime. Moreover, the high-resolution permits submesoscale baroclinic and symmetric instabilities. At single fronts, we observe strong overturning re-stratifying the fronts. Overturning rates are diagnosed regarding mean characteristics of the fronts like mean horizontal and vertical density gradients and mixed layer depth. Finally, the diagnosed overturning rates are compared to recent parameterizations introduced by Stone (1971) and Fox-Kemper (2008). It turns out that both parameterizations are roughly able to capture the bulk overturning along strong fronts but have problems in non-frontal regions.

14/15 Feb 17:30

Interaction between internal gravity waves and meso-scale eddies

Pablo Sebastia Saez[1], Carsten Eden[1], and Manita Chouksey[2]
[1]Universität Hamburg; [2]Universität Bremen, Marum

We investigate the interaction of internal gravity waves (IGW) with mesoscale eddies using the novel numerical Internal Wave Energy Model (IWEM). With IWEM, we evaluate the evolution, propagation and refraction of a typical internal wave spectrum along a water column and over an eddy cross-section by the radiative transfer equation to investigate the energy exchange between internal waves and geostrophic (eddying) flows. We compare the simulations against observations of coherent mesoscale eddy features in the Canary Current System. Results show that the changes in wave energy are dominated by wave-eddy interaction and wave breaking at critical layers, while wave capture effects are two orders of magnitude smaller. Energy gain by wave-eddy interaction is dominated by low-frequency waves in the eddy center, while high-frequency waves are trapped in a cyclo-stationary up-/downward propagation cancelling out their gain or loss of energy. Energy loss by wave-eddy interaction or wave breaking is largest at the eddy rim, where waves undergo a downscale energy transfer to small vertical scales and to the inertial frequency. A shallow water maximum in stratification enhances the wave-eddy interaction and wave breaking. Following the Osborn-Cox relation, wave-breaking induced vertical diffusivities are found to be maximal at the eddy rim, partly in range with the observed values in the ocean. Internal wave-eddy interaction is therefore a plausible mechanism for explaining enhanced mixing at the near-surface.

14/15 Feb 17:30

Using neural networks and high-resolution simulations to improve mesoscale eddy representation in ocean models

Rajka Juhrbandt[1,2], Stephan Juricke[1,2], Thomas Jung[2,3], and Peter Zaspel[1]
[1]Jacobs University Bremen; [2]Alfred Wegener Institute Bremerhaven; [3]University of Bremen

Climate models are one of the most useful tools for predicting future climate states, which has become more important than ever in the ongoing climate crisis. However, due to their spatial and temporal resolutions, which are constrained by computing power and resources, climate models are not able to represent all processes in the ocean and atmosphere. Therefore, modelers need to estimate the effects unresolved processes have on the resolved processes. One such structure is turbulent mesoscale eddies in the ocean. It is known from observations that eddies carry a large amount of kinetic energy and play a significant role in transport of tracers such as temperature and salinity as well as in heat uptake from the atmosphere. Therefore, it is crucial that eddies and their effects on the processes mentioned above are represented accurately in climate models. To better estimate these effects in low-resolution simulations, high-resolution simulations can be used to constrain the parameters necessary for the estimates. However, tuning these parameters can be subjective and time-consuming. In this project, Machine Learning (ML) methods will be used to facilitate and speed up this process. In my PhD project, high-resolution data from the FESOM2 ocean model will be used. At low resolution, which is insufficient to represent eddies, FESOM2 estimates the effects of the missing eddies using the Gent-McWilliams (GM) parameterization containing a GM coefficient. With the help of Bayesian Neural Networks, a framework will be developed to calculate a predictor for this parameterization as well as its variability. Using this framework, maps of the GM coefficient for multiple setups with increasing complexity and data volume will be created.

Interactions of low-mode internal tides with mesoscale eddies in a high-resolution ocean model (ICON-O)

14/15 Feb
17:30

Zoi Kourkouraidou[1] and Jin-Song von Storch[1]

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Low-mode internal (baroclinic) tides in the open ocean are generated when barotropic tides flow over seafloor topography. These low modes carry a large part of the internal tide energy and can propagate far away from the generation sites. The fate of these internal waves and especially their contribution to internal mixing in the ocean is not yet well known. One possibility low-mode internal tides have to contribute to ocean mixing is by interacting with mesoscale eddies. These interactions are assumed to alter the vertical mode structure and wavenumbers of low-mode internal tides due to energy transfer from smaller to higher wavenumbers and modes. Waves with higher vertical mode numbers are related to high velocity shear and are prone to break. The scattering and refraction of low-mode internal tides caused by such interactions can provide a direct energetic link between mesoscale processes and the internal wavefield. Despite their importance for the geographical distribution of internal tides and the intensity of mixing in the ocean, these processes have so far not been well studied nor understood. Using the uncoupled model ICON-O with a high resolution of 5km, we aim to understand the working principles of wave-eddy interactions and their effect on breaking and mixing. We focus the research on the Walvis Ridge region in the southeast Atlantic, since this is where energetic low-mode internal tides at the frequency of the principal lunar semidiurnal constituent (M2) are generated and propagate away from the ridge crossing the paths of eddies, which take the form of both Agulhas rings and other mesoscale features. Focusing on the stationary changes in the wave properties, we identify the eddies in the area of interest in order to specify the possible locations of interaction. We then investigate the vertical structure of the internal tidal velocities and energy in the vicinity of an eddy as well as far away from it. Repeating the procedure in a bigger number of areas and taking the average over all of them, gives us an idea about the overall behaviour. Preliminary results indicating such wave-eddy interactions are shown and discussed on the poster.

Incoherence of the internal tide in the North Atlantic Ocean

14/15 Feb
17:30

Noé Lahaye[1], Aurélien Ponte[2], and Julien Le Sommer[3]

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Although the internal tidal wave field generation is thought to be highly regular – essentially because it comes from the interaction of the astronomical tide, which is highly regular, with the corrugated ocean topography –, their subsequent long range propagation in the unsteady and inhomogeneous ocean alters this property. The resulting internal tide field incoherency (a.k.a non-stationarity or non phase-locked nature) raises major difficulties when it comes to estimating the ocean dynamics (both the eddy and wave component) using in-situ or remote observations. Although the loss-of-coherency has been identified for decades, the properties of the incoherent internal tide fields remain poorly quantified. With the emergence of novel-generation remote sensing of the ocean (sea level anomaly – e.g. SWOT – and sea surface currents), this limitation has become of growing importance. In this paper, we will discuss the properties of the incoherent surface signature of the internal tides in the North Atlantic as follows from a state-of-the-art realistic high-resolution simulation. We quantify the typical fraction of incoherent internal tide energy and the associated incoherent timescale. A major

novelty in our analysis is that the different spatial scales (based on the associated vertical modes) are separated from each others, allowing to render a clear picture in connection with the mesoscale dynamics throughout the basin. In particular, we show that the average incoherent energy fraction for the first baroclinic mode is of order 50%, as suggested by recent model-based and altimeter-based studies, and that the typical incoherent timescale is globally smaller than 20 days. Both quantities have a strong horizontal variability, with a significant portion of the domain that exhibit very short incoherent timescale of the order of a day. Higher modes have a larger incoherent energy fraction and a shorter incoherent timescale.

14/15 Feb
17:30

Spectral resolution of the ocean's Lorenz energy cycle

Jan Niklas Dettmer[1] and Carsten Eden[1]
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Eddy kinetic energy (EKE) and the conversion terms of the Lorenz energy cycle are estimated from an eddy-resolving global ocean model and resolved spectrally per horizontal wavenumber. The baroclinic conversion term (BC) exhibits a dipolar structure, where it is a source for EKE at scales close to the first baroclinic Rossby radius and a sink for EKE at larger scales close to the Rhines scale. The geographical and vertical distributions of the BC term are explored. It is found that in the ocean interior negative BC is limited to regions poleward of approximately 30° north and south. It is suggested that the cause for this distribution is the transfer of eddy energy to Rossby waves and zonal jets equatorward of 30°. It removes eddy energy before it cascades up to the scale where negative BC takes place. Equatorward of 30° the existence of a closed energy loop is suggested. Positive BC produces EKE which cascades upscale where it is converted to available eddy potential energy (EAPE) by negative BC, which cascades downscale again. The sink of EKE partly balances the EKE produced by baroclinic instability. The energy loop traps a certain amount of energy. Finally, the baroclinic conversion term is explored further in idealized model setups. The goal of the idealized setups is to test the robustness of the diagnostic methods and gain physical understanding of the negative baroclinic conversion.

Participants

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