New integral properties for Potential Vorticity and applications to the ocean dynamics

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Since the work of Ertel (1942), Potential Vorticity (PV) is a recognized as a key quantity to study the circulation and in particular to understand geophysical turbulence. Many processes can indeed be explained by combining PV conservation properties and the PV inversion principle. Diabatic processes transform PV but this transformation is subject to constraints that allows to use "PV thinking" even when there exists mixing.

As a lagrangian quantity, PV evolution is more naturally examined along isopycnic/isentropic surfaces (for conservation or inversion), which unfortunately complicates its calculation : diagnosing PV along isopycnic surface often requires numerical interpolations whose associated errors can be too strong to obtain a proper view of the PV evolution. Most validation of realistic models using PV thus remains qualitative. Similarly, PV is also not easily measured in situ.

We propose new diagnostics and integral constraints, based on an original expression of PV, which we believe allows easier calculation and interpretation of PV evolution. We discuss the application of these results to :

- the role of turbulence on the general circulation
- the generation of PV at the bottom boundary layer
- the link between surface density anomaly and interior PV anomalies for isolated vortices

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Oral preference

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The generation of submesoscale eddies and of turbulence by a row of mesoscale surface eddies in the Sea of Oman

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The Persian Gulf is a source of high salinity water which flows into the Oman Sea via the Strait of Hormuz. There it mixes with surrounding Indian Ocean Surface Water by cascading down the continental slope. After the strait, this salty plume stabilises as a density current along the Omani Slope (in the Sea of Oman). Then the mesoscale eddies spreads the Persian Gulf Water (PGW) from this slope current, offshore.

During the spring 2011 and 2014, the Phys-Indien 2011 [*L'Hégaret et al.*, 2016] and Phys-Indien 2014 surveys revealed the presence of submesoscale eddies at the depth of the PGW in the Oman Sea. In the same periods of time, the altimetry suggests that the surface dynamics was dominated by a row of mesoscale eddies alternatively signed.

To investigate the origin and the dynamics of such submesoscale eddies, we set up idealized simulations of a row of mesoscale surface intensified eddies alternatively signed, in a channel, by using the primitive equation ROMS model [*Shchepetkin and McWilliams*, 2005].

These experiments show that the submesoscale eddies are essentially generated by instabilities and friction in the first hundred meter depth. Once generated, they are advected offshore by the mesoscale eddies, then warped by the surrounding shear. As a result, the PGW is carried offshore by the submesoscale eddies and subsequently spread by the surrounding shear. Complementary diagnostics are run to conclude about the production rate and lifetime of such submesoscale eddies.

Also, below the mesoscale surface intensified eddies down to the bottom, a turbulent wake-like dynamics is generated over a longer period of time. We note that the generated submesoscale eddies are smaller at depth than near the surface. Kinetic and potential energy spectra, and potential enstrophy spectra are calculated to determine the respective direct and reverse cascades, and the role played by instabilities, shear or vortex merger in these cascades is studied. Complementary diagnostics are run to isolate the mechanism triggering this generation of submesoscale eddies at depth. In particular, vortex stretching and topographic generation are examined.

Poster preference

Interactions between balanced and imbalanced modes

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We report on linear stability and (nonlinear) numerical experiments conducted using the nonhydrostatic Boussinesq equations and the shallow water equations with the aim of probing interactions between balanced and imbalanced modes of the respective systems. In a previous study using the nonhydrostatic Boussinesq equations (Nadiga BT. Nonlinear evolution of a baroclinic wave and imbalanced dissipation. Journal of Fluid Mechanics. 2014 Oct 10;756:965-1006.) it was found that the the dissipation of balanced energy by imbalanced processes scales exponentially with Rossby number of the base flow. In addition to other analyses, the counterpart of such a scaling in the shallow water system is considered.

No preference

Internal gravity waves as mediator of mixing and drag in the ocean circulation

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Internal gravity waves play a major role in the energetics of oceanic circulation. Powered by energy supply from mainly tides and wind they interact with the mean circulation and eddy field, ultimately transferring energy to small-scale turbulence by wave breaking, thus mediating the energy cascade from large-scale to small-scale motions and the feed-back via density mixing. Global climate models usually resolve at most a small part of the full spectrum of gravity waves so that mixing induced by waves and wave-mean-flow interaction need special parameterizations. An energetically consistent model of the mixing and wave drag requires a closed model of the wave energetics, including generation, wave-mean-flow interaction, non-linear transfer within the wave field and dissipation. The IDEMIX (Internal wave Dissipation, Energetics and Mixing) framework meets these requirements by heavy truncation of the radiation balance equation: the energetics is formulated for the evolution of the wave field in phase space and reduced to a small number of compartments by integrals over respective parts of the spectral wavenumber space. The model is working in physical space - the global ocean - with wave propagation by spectrally averaged group velocities. The IDEMIX concept yields an energetically consistent and practical framework to describe wave effects and has been shown to be successful for ocean applications: it predicts plausible magnitudes and three-dimensional structures of internal wave energy, dissipation rates and diapycnal diffusivities in rough agreement to observational estimates. We briefly review the most important sources, sinks and interaction processes in which the gravity wave field in ocean is involved, placing emphasis on parameterizations suitable for implementation into a spectrally oriented radiative transfer approach. Wave breaking processes, critical layer effects and wave refraction in a sheared mean flow are specifically addressed in this discussion. The construction of IDEMIX models is illustrated.

Oral preference

Direct measurements of mixing efficiency from ocean mixing glider measurements

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Recent decades have seen significant advances in our capability to directly measure turbulence using microstructure probes and acoustic techniques. Yet, there remains considerable debate over the mixing efficiency (Γ) across the broad range of ocean stratification. It is intuitive that within an already well-mixed fluid, any level of additional energy will not act to increase mixing, and so has an efficiency approaching zero. Over the spectral range of stratification, and under varying contributions from a variety of candidate mixing mechanisms it is also intuitive that the mixing efficiency will be highly variable, dependent on the intensity of the turbulent event. Despite this, there is plenty of literature available that appears to confirm that, on average, the turbulent kinetic energy dissipation rate (ε) has a near constant value of Γ ~0.2, as suggested by Osborn (1982). There are however, few investigations that directly compare ε with the immediate effects of mixing over any substantial timescale to enable analysis of Γ under variable forcing.

We present 20 days of measurements from the Ocean Microstructure Glider (OMG) to examine coincident measurements of ε and thermal variance (χ) to derive Γ over a range of forcing scenarios. The OMG provides profiles of ε and χ every 15-20 minutes from the near surface to 100 m, covering the seasonal thermocline which is situated at approximately 50 m depth. We examine the apparent change Γ, relative to turbulent intensity, represented by the buoyancy Reynolds number (Re_b). Within strongly-stratified, low-intensity regions, typified by low Re_b, we confirm Γ ~0.2. With increasing intensity however, Γ reduces near linearly becoming several orders of magnitude less efficient in weakly stratified, energetic regions. We compare our results with those from observational data collected using similar methods and to proposed solutions for Γ from LES model results, such as those presented by Shih et al, 2005.

Oral preference

Shear-driven mixing at high buoyancy Reynolds numbers

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Turbulent mixing is a critical component of the ocean energy budget [*Wunsch & Ferrari*, 2004], contributes to the closure of the Meridional Overturning Circulation [Talley, 2013], and is an important driver of coastal processes [*Moum et al.*, 2013]. However, despite decades of research, we still lack a precise understanding of how mixing in a stratified environment depends on the environmental conditions that drive it [*Ivey et al.*, 2008].

The study of mixing in stratified flows has received a lot of attention over the last 40 years, several studies have been devoted to stratified turbulence generated by a grid towed or oscillated in a linearly stratified fluid. However, since the early work of *Britter* (1974), there have been only few experiments that focused on the turbulent dynamics in the presence of a vertical shear [*Odier et al.*, 2014].

We propose a new experiment that allows for performing shear-driven stratified experiments at high buoyancy Reynolds numbers while keeping the Richardson number constant and close to 1/4. For these conditions, mixing is driven by Kelvin-Helmholtz instabilities for Reynolds numbers close to 10^5, representative of the naturally occurring shear instabilities observed for instance by *Geyer et al.* (2010) or *Seim & Gregg* (1994) on field sites.

The present setup consists of a 36 m (long) x 1.2 m (high) x 0.75 m (wide) stratified recirculating tank where a shear profile is created by injecting dense salty water through a slit. The jet coming out from the slit forces a linear type velocity profile that mixes a linearly stratified density profile, triggering instabilities, turbulence and mixing.

Using combined measurements of particle image velocimetry, laser induced Fluorescence, Acoustic Doppler velocimetry, hot wire anemometry and conductivity-temperature-depth measurement, we show that mixing is essentially driven by Kelvin-Helmholtz instabilities and that secondary instabilities, located in the braids play a major role in the overall process [*Geyer et al.*, 2010].

Buoyancy and momentum fluxes are used to estimate the flux Richardson number, which define the mixing efficiency and confirm the prediction that even for high Buoyancy Reynolds numbers, the mixing efficiency for shear driven turbulence remains of the order of 0.1, consistent with the parametrization for the general circulation models of *Olbers & Eden* (2013), *Polzin* (2009) and *St Laurent et al.* (2002).

Oral preference

Influence of mixing on tracer evolution in stratified flows: theoretical aspects and numerical results.

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We study the fundamental physics of coupling between dynamics and (possibly active) tracers in stratified flows. Idealised configurations (2D and 3D), using non-hydrostatic models, are developed to investigate the effect of small scale turbulence and mixing on the distribution of tracers.

Turbulence is here associated with the development of Kelvin-Helmholtz shear instabilities.

We focus on the spatial distribution and evolution of the local concentration of tracers during the different instability and mixing phases. During the development of instabilities, tracers are stirred as a function of the local properties of the –turbulent- velocity fields. The turbulent cascade eventually leads to mixing and homogenization of tracers at small scales with a final distribution that then remains fixed along density surfaces, and which prescribes the further localisation and transport of the tracer.

The final profiles of density and tracers depend on the local volumetric ratio of tracers in small regions of the flow during the instability phase. In this perspective, any preconditioning process acting on the local distribution of tracers and density prior to the homogenization phase may have an impact on the final redistribution of tracers. As the ratio of tracers can greatly vary within the Kelvin-Helmholtz billows, a hyper-sensitivity to details of the turbulence preconditioning can be expected for the final profiles.

However, theoretical and numerical results will be presented showing that tracers cannot evolve freely with respect to density and that the redistribution of tracers within density ranges is constrained. Differential diffusion of tracers is also shown to potentially lead to stronger diapycnal mixing of tracers.

Oral preference

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Direct numerical simulation of Rayleigh-Taylor instabilities subject to double-diffusion

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Double-diffusive effects arise when the density of a fluid depends on two components with different diffusivity coefficients. The more rapid diffusion of one component (e.g., temperature) relative to the other (e.g., salinity) can cause local density anomalies resulting in instabilities. In a two tracer system, if the driving instability is due to an unstable density stratification, double-diffusion may still affect the overall flow development. This work presents the direct numerical simulation of a three-layer system comprised of upper and lower layers of denser, cool, fresh water, and an intermediate layer of lighter, hot, salty water. The unstable upper pycnocline results in the development of Rayleigh-Taylor (RT) instabilities. As these instabilities grow, and reach their finite amplitude manifestations, the rapid diffusion of the temperature field can create regions of density outside of the range of the initial conditions, resulting in a greater density difference between the sinking RT instabilities and the surrounding fluid. The resulting buoyancy drives motions that are more energetic than the mature stage of single constituent RT instability, and greater variability of the salinity and density fields compared to the temperature and density fields. Through two-dimensional spectral analysis, it is confirmed that the salinity and density fields have a stronger contribution from smaller spatial scales than temperature and kinetic energy fields.

No preference

How does internal tide generation vary in the horizontal?

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Breaking internal gravity waves are considered to be a major source of small-scale turbulence, which acts to mix density in the vertical and thus contributes to driving the global overturning circulation.

One major forcing mechanism of internal waves is the energy transfer from the barotropic tide when it interacts with rough topography. The pioneering work by Bell (1975a,b) to analytically compute this energy transfer has been extended in the past decades, but the directional dependence of the flux has so far not been considered. This piece of information, however, is crucial for a correct setup of internal gravity wave models and mixing parameterizations which are based on internal wave energetics.

We here propose an analytical method to describe the horizontal variations of the far-field energy flux. Since its main assumption of a bounded source region is not met in reality, we subdivide the ocean bottom into overlapping circular patches. The energy flux density is computed separately for each patch, neglecting the influence of the topography outside of the particular patch. We first evaluate this approach using idealized topography before calculating the angle-dependent energy conversion for the global ocean. The long-term goal is to add this information to IDEMIX, a mixing module that predicts turbulent kinetic energy dissipation rates based on internal gravity wave energy, in order to improve numerical simulations of ocean dynamics.

Oral preference

Pycnocline Mixing is Seasonally Stratified Shelf Seas

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The shelf seas, relative to their size, contribute a disproportionate fraction to total global primary production. In seasonally stratified shelf seas mixing processes at the pycnocline mediate the transfer of biological and physical fluxes that in turn control this biogeochemical cycle. Regional models generally poorly simulate mixing processes at the pycnocline, instead forming an interface between surface driven mixing and bottom boundary layer driven mixing. It is hypothesised that internal waves, missing from shelf wide regional models, are responsible for missing mixing. Internal tides are diagnosed in a 1.8km Northwest European shelf NEMO simulation and favourably compared against FASTNEt hydrographic observations. We anticipate this new class of fine resolution simulation, which can simulate non-local propagation of momentum along the pycnocline, forms the basis of improved parameterisations for shelf sea mixing. Large eddy simulation techniques are developed to explore this transition to mixing that must otherwise be parameterized in regional models.

Oral preference

Fate of internal solitary waves in Manado Bay, Indonesia

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Indonesian seas and it surrounding seas have been identified as the most active region in generating internal solitary wave (ISW). The ISW propagation in this region even can be clearly identified from MODIS satellite images [Jackson, 2007]. Strong internal tides in these regions can evolve into trains of ISW due to large number of shallow interisland sills that separate deeper basins [Nagai et. al. 2014]. Near shore breaking of these ISWs can drive strong water mass transformation. We present an analysis of shoaling ISW in Manado Bay, Sulawesi Island. This study is the first observational study of shoaling internal waves in Indonesian Seas. The observation was carried out in May 2009 in Manado Bay waters using Research Vessel Baruna Jaya VIII RCO-LIPI anchored in a fixed position around 2 km from the coast of Manado Bay. Shipboard ADCP 75 kHz RD Instrument and single beam echo sounder 120 kHz Simrad EK500 were operated during the experiment to measure the current profiles and scattering layer, respectively. Watermass properties were measured with CTD SBE Seacat Profiler. Repeated CTD profiling (*yoyo*) were conducted during sequences of high frequency waves recorded by the echosounder. Both a large wave of depression and sequence high frequency waves of elevations are observed. We use a simple Korteweg-deVries (K-dV) model to fit the large wave of depression whose amplitude reaches 40 m. The K-dV fit implies an available potential energy of 39.59 MJ/m. The sequence of high frequency waves of elevation did not show any consistent fit with the Kdv equation and could be rather interpreted as boluses running up the slope. The waves also exhibit strong turbulence, Thorpe scale analysis of the density inversions, reveals Thorpe scale up to 20 m; high eddy kinetic energy dissipation up to 10^{-4} m^2s^{-2} and diffusivity up to 10^{-3} m^2s^{-1}. To better understand their dynamics, a simulation based on a 2D non-hydrostatics model [Bourgault and Kelley, 2004] is also carried out to examine the behaviour of shoaling of ISWs propagating in a background environment representative of the conditions prevailing in the Sulawesi Sea. The shoaling ISW of depression with initial amplitude of 25 propagating from Sulawesi Sea compares well with the observations, depicting some boluses run up in the bottom layer bringing tongue of denser water masses as observed in the echosounder and measured density profiles.

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Preliminary results over the Med-CORDEX domain of a new high resolution Regional earth system model with an active biogeochemical component

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Here we illustrate some preliminary results with the RegCM-ES (Earth System Regional Climate Model) model, developed and used at ICTP [*Sitz* et al., 2017], with an active biogeochemical component (BFM, Biogeochemical Flux Model, *Vichi* et al., 2015). The new coupled model has an atmospheric component (RegCM 4.5, *Giorgi* et al., 2015) with a spatial resolution of 20 km , an ocean component (MITgcm, *Marshall* et al., 1997) with a resolution of 1/12 degree and a component to simulate river discharge (HD, *Hagemann* et al., 2001). RegCM-ES has been implemented and tested over the Med-CORDEX domain (Mediterranean region, *Giorgi* et al., 2009). Preliminary comparisons with climatological data and available reanalysis show that the new coupled model is able to reproduce the spatial pattern and the seasonal variability of phytoplankton and zooplankton as well as of nutrients as phosphate and nitrate in the domain of study and, in particular, in areas where vertical mixing is substantial, e.g. in the gulf of Lions and in the southern Adriatic.

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Poster preference

An Energetically Constrained Ocean Surface Boundary Layer Parameterization including Surface Wave Effects for Climate Applications

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Turbulent vertical mixing plays a critical role in determining the conditions of the upper-ocean and feedbacks to the air-sea fluxes. For this reason, accurate parameterization of this mixing is an important component for simulating coupled processes ranging from tropical cyclones to the Earth's climate system. Popular methods for modeling the upper ocean turbulent mixing for climate applications often suffer from either poorly constrained energetics or burdensome computational requirements. The bulk (integrated) boundary layer approach reduces the computational requirement by vertically integrating the boundary layer, but the loss of vertical information is undesirable for many applications. To overcome these obstacles, a new model has been developed which utilizes ideas from the bulk boundary layer while maintaining finite, vertical eddy mixing coefficients. The new model solves an integrated, equilibrium turbulent kinetic energy (TKE) equation including parameterized TKE sources and dissipation. Shear, buoyancy, and surface wave (Langmuir and breaking) driven mixing are parameterized based on more complete, high-resolution (but computationally demanding) simulations. These high-resolution results include several Large Eddy Simulations, which are supplemented with a comprehensive set of one-dimensional model runs (using k-epsilon two-equation turbulence closure) to cover a wide range of model forcing and initialization conditions. Results show that the new parameterization is able to produce similar profiles of turbulent mixing compared to the more demanding k-epsilon parameterization that solves additional prognostic equations. This parameterization is thus proposed as a robust, cheap method suitable for simulating the ocean surface boundary layer on scales appropriate for climate implementation. This presentation will particularly emphasize the development of the Langmuir turbulence parameterization, including its implementation in coupled climate simulations.

Oral preference

Do observations adequately resolve the natural variability of oceanic turbulence: *Revisited*.

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Following the 2007 Liege Ocean Turbulence conference we presented a paper entitled *"Do observations adequately resolve the natural variability of oceanic turbulence?"* in which we concluded that "turbulence measurements when made in a comprehensive and systematic manner … are providing significant insights into ocean dynamics" but that "the larger oceanographic problem of defining the full geographic variability of mixing remains". In this contribution we will present a number of new observations, made using a range of methods, including new moored instrumentation (eg. Lucas *et al*, 2014; Moum and Nash, 2009) which have greatly expanded our sampling capacity (to a seasonal cycle and more). Observational insights include a time series showing a 3-order of magnitude variability in open ocean dissipation (and by implication mixing) in a tidal cycle, over steep topography (eg. Mead Silvester *et al*, 2014). They also show a rapid decline in dissipation moving away from steep topography (eg. Inall *et al*, 2005). Whilst these, and other new observations, further highlight both the need for, and the problem of, defining the full geographic variability of mixing, they also provide use with insights as to how we can refine measurement campaigns, using these newly development measurement techniques, to better capture the variability in dissipation and hence mixing.

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You can send your abstract online or by e-mail to oceanphys@ulg.ac.b

Multiscale analysis of ocean color turbulent heterogeneities: comparisons of SST and Chl-a multifractal properties using 2D structure functions

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Satellite remote sensing is a powerful tool for understanding many of oceanic processes synoptically. *Renosh et al*. [2015] proposed a methodology for analyzing the multiscaling properties of satellite images using tools borrowed from the field of turbulence and multifractal analysis. The present work addresses the practical application of this study into different oceanic regions.

For this purpose we have selected satellite ocean color images of Remote sensing reflectance (R_{rs}), Chlorophyll-a (Chl-a) and thermal infra-red Sea surface temperature (SST). For understanding the spatial scaling associated with turbulence, it is important to have a daily imagery of these products. As far as ocean color remote sensing is considered, it is very difficult to have cloud free images for the understanding of scaling behavior. We have identified seven contrasted regions of the global ocean, characterized by high spatial heterogeneity in Chl-a and SST. Power spectral analysis has first been used for the present study. Here we use 1D and 2D Fourier power spectra to understand the spatial scaling of Chl-a and SST. The 2D spectral slope β is derived from the 2D power spectrum using radial sum of the power spectrum.

The multi-scaling properties of these images are also studied using the 2D Structure Function (SF) method. Using a lognormal fit, we have derived the multifractal parameters (Hurst exponent H and intermittency parameter μ) of these images using SF method. The derived multifractal parameters show variability in their values depending upon the region. The scatter plot of μ versus H shows some clustering of these parameters. The SST is showing low intermittency, R_{rs} high, and Chl-a shows intermittency in between SST and R_{rs} for all the regions, indicating biological activities, which are weaker in oligotrophic regions.

This approach can be applied even for irregular images with missing data, and help to characterize the heterogeneities, and the scale dependence and intensity of physics-biology coupling at sub-mescales using ocean color satellite images.

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Turbulence and mixing in the NW Iberian shelf in response to upwelling events

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The NW Iberian shelf is influenced by upwelling events that prevail in spring-summer and strongly shape a highly productive ecosystem. Renewing of nutrients is driven by the upwelling of bottom waters, and the response of the shelf system to upwelling events is complex. In this presentation, we will study by means of a 3d model configuration of the ROMS model different upwelling events where concurrent multidisciplinary sampling of plankton with semi-automatic methods and hydrography (including dissipation rate of TKE) was carried out in order to study the response of the plankton community to the phases of upwelling winds. The impact of the variability of circulation and mixing on the plankton community will be evaluated. Special reference will be given to the sensitivity of the coupled 3d hydrodynamical-ecological model configuration to the turbulence closure.

Oral preference

A Modification to the Structure Function Method to Correct for the Impact of Wave Orbital Velocity Shear

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The structure-function methodology is an established technique for calculating the turbulent kinetic energy (TKE) dissipation rate, ε, from velocity profiles such as those obtained with an acoustic Doppler current profiler (ADCP) [*Wiles et al.*, 2006; *Lucas et al.*, 2014]. Turbulent velocity profiles are calculated by removing the background shear averaged over multiple measurement profiles during an observation period. TKE dissipation is then calculated as a function of the growth in the variance of the along-beam turbulent velocity with separation distance through relationships derived by Kolmogorov.

However, instantaneous beam coordinate velocity profiles for a vertically-oriented ADCP have the potential to be contaminated by any fluctuating velocity shear due to wave orbital motion. Since the wave period is much shorter than the averaging period normally used to determine the statistical properties of the turbulent motions, the standard procedure for calculating the structure function does not separate the turbulent velocity variation from the wave orbital velocity shear signal, potentially resulting in biased estimates of TKE dissipation rate.

The theoretical wave orbital velocity shear varies linearly with the separation distance, r, over which the shear is measured, hence it's contribution to the structure function varies as r^n, where n is the order of the structure function. By contrast, the turbulent velocity structure function varies as a function of $r^{n/3}$. Here we modify the structure function methodology on this basis to provide a simple, physically-based means of separating the true turbulent component of the structure function from the non-turbulent contribution arising due to wave orbital velocity shear.

The revised approach is then validated against observations from a long-term mooring in a tidally swept, seasonally stratified shelf sea. The mooring was equipped with three high frequency pulse-pulse coherent ADCP, making observations centred at depths of circa 24, 42 and 52m in an area with a typical water depth of 150m. Applying the modified method to observations during winter 2014/15 when the water column was unstratified produces results that show a significant improvement in agreement with standard depth scaling under a variety of wave conditions and contrasting surface forcing dominated by both (1) convective buoyancy flux and (2) significant wind stress.

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Turbulent Dissipation Rates, Mixing, and Heat Fluxes in the Canadian Arctic from Glider-based Microstructure Measurements

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Understanding mixing rates in the Arctic Ocean allows us to estimate vertical heat fluxes through the water-column which have the potential to significantly impact heat budgets as well as ocean-sea ice and ocean-atmosphere interactions. We present new observations consisting of 340 quasi-vertical microstructure profiles of shear and temperature variance alongside profiles of finescale temperature and salinity in the Amundsen Gulf region of the Canadian Arctic. We use these to characterize the variability of turbulent mixing rates in both space and time, and to begin identifying the dominant physical processes responsible for mixing in this region. The measurements were collected over two weeks by an autonomous glider in August 2015, and they represent one of the most dense microstructure sampling schemes in the Arctic to date. Profiles encompass the most prominent features of the Arctic water column, including the warm Atlantic water layer at depths below 250 m, the halocline between the Pacific and Atlantic water layers, and the surface mixed layer which exhibits a strongly stratified base. From the microstructure measurements, we calculate ε and χ, the dissipation rates of turbulent kinetic energy and thermal variance. Dissipation rates very across four orders of magnitude but are generally very low; consequently, mixing tends to be inhibited everywhere by the strong stratification.

Oral preference

Comparisons between transect and fixed point measurements in an oceanic turbulent flow: comparisons between intermittency parameters

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Oceanic processes possess important fluctuations over large ranges of spatial and temporal scales. These fluctuations are related with the turbulence of the ocean. Usually, in turbulence, one considers fixed point Eulerian measurements, or Lagrangian measurements following an elements of fluid. On the other hand, in oceanography, measurements are often done from a boat operating over a transect, where the boat is moving in the medium at a fixed speed (relative to the flow). This was the case of the first clear evidence of Kolmogorov spectrum from a field experiment, performed in a tidal stream near Vancouver [*Grant et al.*, 1962].

Here the aim of our study is to consider if such moving reference frame is modifying the statistics of the measurements. For this we compare two type of measurements at high frequency: fixed point measurements, and transect measurements, where the boat is moving at a fixed speed relative to the flow. 1 Hz fluorometer measurements are considered in both cases. Measurements have been done the same day, under similar conditions.

Power spectra of time series are considered, as well as local mean and variance measurements along each transect. It is found that the spectral scaling slope of the measurement is not modified, but the variance is very different, being much larger for the moving frame. The intermittency is also considered, using cumulant scaling analysis in order to compare the statistics between fixed point and moving frame.

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No preference

Shallow stratified shelf sea turbulence and mixing rates measured by autonomous underwater gliders

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The quantification of turbulence and mixing rates in the field is a challenging task, in that data should be ideally collected in such reliable manner that surrounding uncertainties, such as instrument vibrations, ship wakes and other factors that could potentially disturb the measurements, can be disregarded. In this study, two data sets spanning 33 days collected by autonomous underwater gliders are presented. The gliders were equipped with a microstructure package to measure turbulence dissipation rates in the German Bight of the North Sea under strongly and weakly stratified, and well-mixed conditions. Strong tidally-driven bottom boundary layer turbulence was observed, which reached up until the thermocline and was subsequently damped by sharp and relatively weak stratification. Squared buoyancy frequencies as low as 10^{-5} s^{-2} were found to reduce the buoyancy Reynolds number from a fully turbulent state ($Re_b > 100$) to an intermediate turbulence level ($7 < Re_b < 100$) [*Shih et al.*, 2005]. Within the thermocline, the dissipation rate of turbulent kinetic energy was intermittent, however the flow was mainly marked by laminar to low turbulent conditions ($Re_b < 7$). Vertical mixing took place at a relatively constant background rate with discernible peaks of stronger diapycnal fluxes, which appear to account for much of the change in temperature in the bottom mixed layer. Moreover, the thermocline acts as a natural barrier between surface and bottom mixed layers, controlling vertical fluxes and turbulence. A distinct sub-surface chlorophyll maximum was observed in the bottom of the thermocline, which might have been formed due to favourable light, gases and nutrient conditions, together with the relatively quiescent environment encountered [*Ross and Sharples*, 2007].

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No preference

Slope-induced tidal straining: Analysis of rotational effects

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Estuaries and many regions of the coastal ocean are characterized by a persistent horizontal density gradient, typically generated by river-runoff, differential heating, or horizontal variations in turbulent mixing. The interaction of this externally imposed gradient with a tidal current leads to a periodic stabilization and destabilization of near-bottom stratification – with important implications for near-bottom turbulence. The resulting tidal asymmetries in turbulent mixing feed back on the momentum budget, creating residual currents and transports of suspended sediment. In a recent model study (Schulz and Umlauf, 2016), a similar process called "slope-induced" tidal straining has been investigated, which is generated by the projection of the vertical density stratification onto a sloping bottom, and does not require an externally imposed density gradient. When the tidal current is directed up the slope, dense water is advected on top of lighter water by friction-induced shear, creating a gravitationally unstable and thus strongly turbulent near-bottom layer. Vice-versa, when the current reverses, stable stratification is established and turbulence is suppressed. Again, this induces a residual current and suspended matter transport, which is in most cases directed up slope with transport rates of several kilometers per tidal cycle.

A recent data from the East China Sea (Endoh et. al. 2016) provides first observational evidence for slope-induced tidal straining on a continental shelf. To reproduce these observations, the model above has been extended to include Earth rotation effects, which had previously been neglected. In the present study, it is shown that this simple, one-dimensional model can reproduce the key features of the observations. The effect of changes in rotation rates and other key parameters on the effective transport of suspended material are discussed.

Oral preference

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Energy and mixing in stratified turbulent flows

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Energy-based arguments provide a fundamental diagnostic tool in turbulent flows. In incompressible flows where the density ρ is constant, the energy is the familiar kinetic energy $E_{\mathrm{k}} = \rho \boldsymbol{u}^2/2$, which enjoys the property of being a convex function on the phase space. It can thus be readily split into a mean and turbulent (or eddy) component once an appropriate notion of average is introduced. The insight comes by an analysis of the sink and source terms in the appropriate transport equations for the mean and turbulent components. In stratified (but still incompressible, i.e. Bussinesq) flows there is a second reservoir of energy, the potential energy of the flows. However, the standard expression $E_{\mathrm{p}} = \rho g Z$ for the latter is not convex, and thus, within an energetic framework based on this definition, turbulent fluctuations have zero potential energy, a rather unsatisfactorily state of affairs. Further, there is no term in the equations that represents a truly irreversible sink of potential energy. The solution is to modify the definition of potential energy to include only the portion that is effectively available. This introduces the concept of Available Potential Energy (APE), initially formulated by Margules [1903] for isolated storms and later extended by Lorenz [1955] to the entire atmosphere. Lorenz APE assumes small deviations from equilibrium (hence, the APE is quadratic in density fluctuations). Subsequent developments removed the small-amplitude requirement [Andrews, 1981, Holliday and McIntyre, 1981], extended the APE framework to diagnose overall mixing in a closed system via a global APE [Winters et al., 1995], and localized mixing with a local APE [Scotti and White, 2014]. Along the way, Shepherd [1993] showed the connection between APE and the Casimirs of the Hamiltonian that describes the adiabatic dynamics. A common feature of all APEs proposed so far is that the APE depends only on the buoyancy distribution, and not on the combined buoyancy and momentum distribution. In this talk, we approach the problem of APE using a general framework based on a variational approach that uses the Casimir functionals of the Hamiltonian as Lagrange multipliers [Scotti and Passaggia, 2017]. It recovers the standard buoyancy-only dependent formulation in non-rotating systems. Unlike the standard formulation, rotation (and other) effects can be included in a natural way, in which case the Available Energy depends both on the buoyancy and potential vorticity distribution. We discuss some applications to a simple Eady problem Eady [1949]. We show that mixing is intimately connected to the evolution of the Casimir functionals under diabatic conditions.

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On the Relationship Between Turbulent Cascades and Eddy Tilts

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Owing to its similarity with the 2D vorticity equation, the quasi-geostrophic equation permits the existence of a dual cascade of energy and enstrophy. This is characterised by the formation of large-scale structures, a consequence of energy being transported to successively larger scales through local interactions between eddies of similar wavenumber. The spontaneous formation of zonal jets in the oceans could be explained as intermediate or final states in the evolution of an inverse energy cascade. Jets are also known to be supported by an effective negative viscosity, where the divergence of the Reynolds' stress pattern reveals eddies tilting in such a manner to flux momentum into the mean flow. What is unclear is how these eddy-mean-flow interactions fit in to the picture of geostrophic turbulence. Using a channel model forced at small scales and dissipated through Rayleigh friction, the relationship between eddy-tilts and the formation of turbulent zonal jets is investigated.

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Poster preference

Regional dynamics influence on small-scale mixing in the boundary current regions of the North Western Mediterranean and the northwestern Japan Sea

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Here we study relationship between mesoscale and submesoscale dynamics and temporal variability of small-scale mixing parameters in the ocean northern boundary current region. The data were obtained during two deployments of the Aqualog moored profiler: in Besos Canyon (the north-western Mediterranean Sea) in March 2012 and in the northern part of the Sea of Japan in April-October 2015. The thermohaline and hydrodynamic conditions in two regions have much in common featuring the overall cyclonic circulation, meanders of the strong longshore currents, numerous eddies of various spatial scales and near-coast trapped waves. The profiler was equipped with the Nortek Aquadopp Doppler current meter and the SBE CTD 52MP probe providing us with high-resolution (about 1 meter) vertical profiles of current velocities, salinity and temperature several times a day. The data were used to estimate the diapycnal turbulent eddy diffusivity of mass based on finescale parameterization approach [*Polzin,* 1995]. For the data processing we applied the Mixing Oceanographic Toolbox code [*Meyer et al.,* 2014] modified to process the Aqualog data. The vertical distributions of diffusivities varied in time during the observational surveys. We analyze relation between the depth-time variability of diffusivities and the thermohaline stratification in the anticyclonic and cyclonic eddies as well as the peculiarities of the ocean current dynamics. The comparative analysis of the estimates obtained for two ocean regions appeared to be particularly useful for better understanding of mixing sources and the role of regional dynamics in the mixing distribution. The seasonal variability of the mixing parameters is also described for the Japan Sea conditions.

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Poster preference

Marginal instability and deep cycle turbulence in the equatorial Pacific cold tongue

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The upper equatorial oceans provide a natural laboratory for the study of turbulence in stratified, parallel shear flows. The combination of steady trade winds and vanishing Coriolis acceleration leads to persistent, sheared currents, and thereby supports a turbulence regime that is roughly in equilibrium with the forcing - the so-called "deep cycle" of equatorial turbulence. The downward heat flux carried by this turbulence is a critical element of the equatorial climate system and is notoriously difficult to represent in climate models. In this talk I'll describe the discovery of the deep cycle in the 1980s and efforts to explain its physics, including our current understanding and its implications for stratified shear flows in general (e.g. estuarine flows, gravity currents).

Oral preference (keynote)

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Langmuir cells and ramp-like structures in the upper ocean turbulent boundary layer

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Langmuir circulation has been recognized as an important part of the upper ocean turbulent boundary layer [*McWilliams et al. 1997*]. The traditional models of Langmuir circulation, however, do not account for ramp-like structures [*Soloviev and Lukas 2014*]. The ramp-like structures are widespread features in the upper ocean turbulent boundary layer, with rotational axes perpendicular to the axes of Langmuir circulation [*Thorpe* 1985: *Soloviev* 1990; *Wijesekera et al.* 1999]. Vortices associated with ramp-like structures have transverse axes, while Langmuir circulations have a longitudinal axis, relative to the wind. How can ramp-like structures coexist with Langmuir cells? We are reporting a new concept, which links ramp-like structures and wave-breaking turbulence to Langmuir circulation and the Craik and Leibovich [1976] model. Using computational fluid dynamics tools, we have been able to reproduce both Langmuir cells and ramp-like structures coexisting in space though intermittent in time. The mechanism resembles convective initiation of longitudinal rolls in the atmospheric boundary layer [*Brown* 1991]. However, in the upper ocean turbulent boundary layer, the vorticity transport in the vertical direction is caused by breaking waves stirring the near-surface layer of the ocean; while, in the atmospheric boundary layer, by penetrative convection. The proposed mechanism for Langmuir circulation is expected to be most efficient under developing seas, including high wind speed conditions when the Stokes vortex force term can be partially suppressed due to strong near-surface turbulence [*Terray et al.* 1999]. We also discuss the available observational data that can help with the verification of models of spatially-coherent organized structures in the upper ocean turbulent boundary layer.

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Oral preference

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Horizontal dispersion in shelf seas: high resolution modelling as an aid to sparse sampling

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The ability of a hydrodynamic model to reproduce the results of a dye release experiment conducted in a wide shelf sea environment was investigated with the help of the Massachusetts Institute of Technology general circulation model (MITgcm).

In the field experiment a fluorescent tracer, Rhodamine WT, was injected into the seasonal pycnocline, and its evolution was tracked for two days using a towed undulating vehicle equipped with a fluorometer and a CTD.

With a 50 m horizontal resolution grid, and with three different forcings initialised in the model (viz: tides, stationary current, and wind stress on the free surface), it was possible to replicate the dye patch evolution quite accurately. The mechanisms responsible for the enhancement of horizontal dispersion were investigated on the basis of the model results.

It was found that enhancement of the dye dispersion was controlled by vertically sheared currents that, in combination with vertical diapycnal mixing, led to a substantial increase in the "effective" horizontal mixing.

The values of "effective" horizontal mixing found from the model runs were in good agreement with those obtained from in-situ data, and the probable degree to which the observational techniques under-sampled the dye patch was revealed.

Oral preference

Mathematical versus physical constraints on ocean mixing parameterisations.

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The development of turbulent mixing parameterisations in numerical ocean models relies on two distinct approaches: the first one is theoretical in nature and is primarily concerned with rooting the parameterisations in sound physical principles; the second one is empirical in nature, and seeks to exploit available observations to optimally constrain the various adjustable parameters and constants that inevitably enter most mixing parameterisations. In the first part of this work, we investigate which components of rotated diffusion tensors can be inferred --- at least in principle --- from the knowledge of the full turbulent heat and salt fluxes, assuming that the latter can be constrained from observations. The main result is that the answer depends on whether equal or different diapycnal diffusivities are assumed for heat and salt. If identical diffusivities are assumed, as is most commonly done, then the knowledge of the turbulent heat and salt fluxes (referred to as 'observations' in the following) is found to constrain both the anti-symmetric and symmetric parts of rotated diffusion tensors. Regarding the former, which is related to the meso-scale eddy-induced advection, observations are able to constrain both the direction of the velocity potential vector and its amplitude. Regarding the latter, observations constrain not only the isopycnal and diapycnal mixing coefficients, but also the unit vector controlling the isopycnal and diapycnal mixing directions. If different diffusivities are assumed, which corresponds to so-called differential diffusion, then observations are able to constrain the isopycnal as well as the two diapycnal diffusivities; in that case, the values obtained depends on the choice of mixing directions, which can be chosen arbitrarily either to align with isopycnal and diapycnal directions, or with the horizontal/vertical directions. In the second part of this work, we will investigate the feasibility of using observations for constraining the full turbulent heat and salt fluxes. Two important implications of this work will be discussed. The first discusses some of the potential missing ingredients of current meso-scale eddy parameterisations, and in particular of the widely used Gent-McWilliams parameterisations. The second discusses the validity of the widely held belief that the mixing directions in rotated diffusion tensors should be parallel and perpendicular to the local neutral vector.

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Turbulence controls size distribution of aggregates: in-situ observations by a microstructure profiler and a cabled observatory

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Marine aggregates are ubiquitous particles formed from the accretion of smaller biogenic and non-biogenic components. Visible aggregates, known as marine snow, are typically in the 0.5 to few mm size range. Aggregates formation is an important pathway for transferring materials from surface to the deep ocean [*Buesseler& Boyd, 2009*]. Aggregates are well recognised as hotspot of microbial and planktonic activities [*Azam & Long, 2001*]. Turbulence is an important physical mechanism in the aggregates formation and destruction. However, the relative roles of turbulence in aggregates formation and destruction have not been clarified due to few observational studies. In this study, we analysed simultaneous in-situ observations of turbulence and aggregate in the ocean and in a lake. A microstructure profiler, TurboMAP-L, was used to collect shear data and a digital still logger camera was used to collect images of aggregates. Digital images were subsequently used to determine particle abundances and size distributions. Direct comparison of turbulence intensity and aggregate size distributions show that turbulence below $\varepsilon=10^{-6}$[W/kg] enhances aggregation, increasing average particle size; greater turbulence causes particle breakup, limiting the average maximum aggregate size and decreasing the slopes of size distributions. This indicates the role of turbulence controlling aggregate size distributions. We also present observations from a cabled observatory further substantiate these conclusions.

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Flow-limited diurnal vertical migration

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While zooplankton Diurnal Vertical Migration (DVM) is cued by light, zooplankton behavioral responses to physical processes, such as flow pattern and turbulence, have been discussed with limited observed data. How do the physical processes modify zooplankton DVM? We present light-cued but flow-limited zooplankton DVM observed by a cabled observatory deployed on the ocean bottom at 20 m depth near an isolated island in Japan, which simultaneously measured biological and physical parameters. Zooplankton images taken by an *in situ* microscope camera, Continuous Plankton Imaging and Classification System (CPICS), were used for classification and to estimate population density. Mysids and ostracods appeared during only nighttime with maximum density of 3,000 mysids (or ostracods) m^{-3}, respectively. Optical backscatter signal from turbidity sensor was intermittent and dramatically higher during nighttime than daytime. This suggests that the zooplankton was the source of the high turbidity data. In fact, the increase in zooplankton abundance at night was observed frequently over the observation period. However, this increase was significantly reduced when wave height was over 1 meter (e.g. when typhoons or tropical cyclones passed over) which roughly corresponds to a maximum wave orbital velocity of 0.3 m s^{-1} at the observatory depth. In addition, even when background flow velocity with period longer than 60 s was over 0.1 m s^{-1}, the increase in zooplankton at night was significantly suppressed. We present that the observed feature of zooplankton DVM associated with the fluid motion caused by waves and currents.

Oral preference

Large-eddy simulations of the interaction between sub-mesoscale eddies and three-dimensional turbulence

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Sub-mesoscale eddies, with typical sizes ranging from 1-10 km, are ubiquitous and important features in the upper ocean. Sub-mesoscales develop through a variety of fluid instabilities and grow at the expense of the kinetic and potential energy associated with larger scale currents. At the same time, sub-mesoscales exist in a very energetic environment where much smaller three-dimensional turbulence is generated, in part, by surface winds, breaking waves and convection. Here, I will describe recent work using large-eddy simulations to examine the interaction between sub-mesoscale eddies and three-dimensional turbulence in the ocean mixed layer.

The simulations show that sub-mesoscales and three-dimensional turbulence interact in two competing ways. First, sub-mesoscale currents drive the formation of very sharp fronts through sub-mesoscale frontogenesis. These fronts develop very strong horizontal and vertical shear, which eventually becomes unstable to shear instabilities and leads to intense subduction and three-dimensional turbulence.

Sub-mesoscales can also act to suppress three-dimensional turbulence. As they extract energy from the large-scale flow, sub-mesoscales can lead to a stable vertical density profile. This stable stratification acts to suppress three-dimensional turbulence that would otherwise be generated by surface wind and buoyancy forcing. The large-eddy simulations show that the re-stratifiation process is very inhomogeneous, leading to patches of intense turbulence surrounded by relatively quiescent waters.

The interaction between sub-mesoscales and three-dimensional turbulence has a strong impact on biogeochemistry and the distribution of buoyant material. Recent work has indicated that the competition between re-stratification and surface cooling can either trigger or delay phytoplankton blooms [Taylor and Ferrari, 2011, Mahadevan et al., 2012, Taylor, 2016]. New simulations reveal that buoyant tracers accumulate in regions of strong surface convergence and subduction. These tracers preferentially sample regions with very intense three-dimensional turbulence, and their resulting mixing rate is modified relative to neutral tracers. This has important implications for the mixing and distribution of buoyant material such including micro-plastics, oil droplets, and bubbles.

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Oral preference

Wave-vortex interactions in rotating shallow water

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In this talk I will present recent theoretical work examining various possible interactions between fast inertia-gravity waves and slow balanced quasi-geostrophic motions in a rotating shallow water. Using multi-scale asymptotic analysis, a set of evolution equations will be presented for the potential vorticity. These equations capture the slow dynamics of the rotating shallow water to a higher degree of accuracy than the lowest order approximate model - the quasi-geostrophic equation. These new asymptotic reduced models, whose validity is confirmed by numerical experiments, point out that fast waves can energetically interact with slow balanced motions. The results from asymptotic models will be complemented by a series of high resolution numerical simulations of the rotating shallow water equations in regimes not directly accessible by asymptotic analysis, such as characterizing turbulent wave-vortex interactions. The main findings of these simulations is that the presence of strong waves can significantly impact the balanced motion. For instance, it is observed that wave activity can prevent vortex mergers and inverse cascades, these being well known features of balanced models such as the quasi-geostrophic equation.

Oral preference

AUV based study on physical and ecological processes at fronts

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Alfred Wegener Institute

Small-scale processes and their effects get more and more attention when it comes to understanding processes and changes in the (Arctic) ocean. Here we present a study on physical processes and ecological responses at submesoscale frontal systems in the Fram Strait investigated using an autonomous underwater vehicle (AUV). The AUV is equipped with physical and biogeochemical sensors such as an acoustic Doppler current profiler, a turbulence probe, a conductivity-temperature-depth probe, and sensors for Oxygen, Nitrate, Chlorophyll *a*, and photosynthetically active radiation (PAR).

The study is designed such that the AUV covers tracks of several kilometers length in cross-frontal direction with the front roughly located in the middle of the track. On its way, the AUV records high-resolution vertical or zigzag profiles of the physical and biogeochemical properties in the upper 50 m which includes the euphotic zone. In both, physical and biogeochemical terms, the measurements revealed a complex structure of the water column. At the fronts the distribution of phytoplankton and nutrients was highly inhomogeneous, possibly due to wind-driven frontogenesis or the growth of mixed layer eddies. To set the observations into a larger context we also examine ship-based and satellite data. We investigate how the observed patterns of the potential vorticity and the biogeochemical properties may be formed and which processes could lead to a smoothing of the observed gradients.

No preference

The role of barotropic to baroclinic tidal energy conversion: a view towards improved turbulent mixing parameterisation in shelf Seas

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The seasonal pycnocline in temperate shelf seas represents a critical pathway for the transport of heat, nutrient and carbon. Accurate parameterisation of pycnocline exchange processes is therefore key to the accurate determination of biogeogeochemical fluxes in these systems. However, it is well established that the turbulence closure schemes currently utilized in regional scale models fail to reproduce, by orders of magnitude, the observed levels of turbulent dissipation within the seasonal pycnocline of shelf seas.

We hypothesise that this deficiency in turbulent mixing may be addressed via the inclusion of an additional function, representing the energy input via tidal energy conversion. We propose that this parameterisation can be derived via a spatial relationship, between the forcing imparted on the baroclinic flow from the barotropic tide, and statistical distributions of observed TKE dissipation rates (ε).

Preliminary results obtained from the comparison of output from the AMM6O NEMO model, and turbulence observations from vertical free falling probes deployed in the Malin Shelf region, suggest the existence of such a relationship.

Our hope is that the development of this relationship into a practicable parameterisation for turbulent mixing within regional scale models, will result in an improvement in the ability to predict pycnocline behaviour in shelf seas.

Poster preference

Marine turbulence in nearshore and surfzone areas

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KU Leuven

Climate change and sea level rise create a lot of concerns with regard to the vulnerability of coasts all around the world. However, few of the flood risk studies take into account the morphodynamic evolution of the coast over the long-term period of the prediction. Indeed, the numerical simulation of beach morphodynamics is a very challenging problem. It requires the calculation of forces by waves and currents on the shore. A neglected aspect is the interaction between sediments and turbulence above the bottom. Even though it is has been acknowledged for a long time that sediments in the water column cause drag modulation, it is not properly accounted for in numerical models. At best, the energy loss to sediment transport is implicitly accounted for by tuning the bottom friction parameter.

Based on a long time investigation of this problem, based primarily on laboratory flume test data and the failure to simulate these experiments with any numerical model, including experience with the author's (finite elements) research code FENST-2D, the main bottleneck has been identified in the turbulence model, which cannot properly take into account particle-turbulence interactions. Even in advanced models based on two-phase flow theory where the k-epsilon model is adapted semi-empirically with extra dissipation terms, the models fail because they neglect the fact that turbulence is no longer fully-developed in the bedload transport layer and that the near-bottom boundary conditions for turbulent kinetic energy and its dissipation rate should be adapted accordingly.

A new modelling strategy has been designed, applicable to large scale 3D coastal engineering studies, consisting of a two-layer turbulence model (a new low-Reynolds mixing length model in the bottom layer and a compatible new low-Reynolds k-epsilon model for the outer layer), including semi-empirical corrections for particle-turbulence interactions. The new mixing-length model also lies at the basis of a new dynamic bottom friction model, accounting for energy dissipation by the sediments above the bottom. The latter has already successfully been implemented in a 2DH model for the Belgian coast and Scheldt estuary [*Bi & Toorman*, 2015].

Within the framework of the CREST - Climate Resilient Coast project (www.crestproject.be) attention is given to the incorporation of wave energy dissipation by different mechanisms. One of the aims is to implement the new bottom friction closure in a 3D wave-resolved modelling of beach morphodynamics. For this purpose, the modelling strategy will be implemented in OpenFOAM. Eventually the model will be used to study how beach erosion extracts energy from the waves and modifies their properties and their subsequent impact on the coast during storm conditions.

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Oral preference

Benthic turbulence in the deep waters of a large lake

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We report very near-bed mean flow and turbulence measurements from a deep water (55m depth) site in Lake Michigan (USA), a 450km long by 135km wide lake. The measurements span a full year, and the focus of this paper is on turbulence and mean flow properties within the bottom 1m of the water column. These measurements were obtained from a burst-sampled 2MHz Nortek Aquadopp HR profiler. For mean currents, observations show consistent logarithmic structure within the bottom 1m, with modifications at low speeds for stratification and unsteadiness. A log-linear formulation for mean current distributions is seen to improve roughness and drag coefficient inferences, even when fitting distributions within the bottom 1m. The log-linear formulation is also shown to explain diminished drag coefficients inferred from an outer, weakly-stratified layer. We employ a four quadrant analysis involving acceleration and stratification length scales to quantify the relative importance of flow acceleration/deceleration and stable/unstable stratification. This analysis identifies stratification to be relatively unimportant for the well-mixed winter and spring periods, but unsteadiness to be important for much of the deployment.

Estimates of turbulent kinetic energy, turbulent kinetic energy dissipation, and autocorrelation length scales show that standard law-of-the-wall (LOW) distributions for these quantities are approached for high current speeds (1 mab speeds of 10 cm s^{-1} at this site). Turbulent kinetic energy dissipation estimates from -5/3 spectral fitting and structure function fitting are in good agreement with one another but show departures from LOW estimates for low speeds.

As an application of the measurements, we perform simple 1-D mussel clearance modeling to simulate the influence of invasive quagga mussels on passive water column constituents under the turbulent conditions observed at the site. These simulations show that mussel filtration effects in these deep, sluggish waters should be restricted to a compact near-bed layer corresponding to the zone of active turbulence above the lake bed.

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Boundary mixing in nontidal basins: Observations from the Baltic Sea

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Diapycnal mixing in large nontidal basins is often assumed to be related to the effect of near-inertial waves. While the role of near-inertial shear for the generation of shear instabilities in the stratified interior is relatively well understood, much less is known about the impact of near-inertial motions on boundary mixing processes in nontidal systems, mainly owing to the lack of appropriate observations. Here, an extensive data set is discussed, describing the variability of boundary mixing induced by near-inertial motions near the sloping topography of one of the main basins of the Baltic Sea. These data reveal the existence of a vigorously turbulent bottom boundary layer of a few meters thickness covering the entire slope region above and below the permanent halocline that constitutes the main obstacle for vertical transport in the Baltic Sea. Near-bottom turbulence was driven by the near-inertial shear in the frictional boundary layer rather than by breaking of near-inertial waves near critical slopes. Large regions of the bottom boundary layer remained strongly stratified, and therefore, different from the traditional view of inefficient boundary mixing, mixing efficiencies reached values typical for the ocean's interior.

Oral preference

Stimulated loss of balance and other mechanisms of wave–turbulence interactions

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Internal waves, near-inertial waves in particular, are strongly affected by the turbulent mesoscale flow in which they propagate. When advected and refracted, they in turn exert a feedback on the flow, resulting in significant energy transfers between waves and flow. It has recently been proposed that these energy transfers provide a sizeable sink for mesoscale kinetic energy and thus make a significant contribution to the ocean energy budget comparable, for instance, to that of bottom drag. A key to this is that the waves are excited externally, by winds and tides, and reach substantial amplitudes. This is contrast with mechanisms of spontaneous loss of balance, in which waves are generated by the slow evolution of the flow in the absence of any high-frequency forcing. While spontaneous generation has been shown to be very weak and most likely negligible except in strongly ageostrophic flows, the new mechanisms in which the loss of balance is stimulated by a pre-existing wave field are active in weak, nearly geostrophic flows.

In this talk I will discuss a simplified model of stimulated loss of balance that couples the Young–Ben Jelloul model of near-inertial waves with a quasi-geostrophic model for the flow (joint work with Xie). The model captures both the advection and refraction of the waves by the flow, and the wave feedback which is described by a modification of the familiar relation between potential vorticity and velocity of quasi-geostrophic theory. This form of wave feedback is consistent with the predictions of generalised-lagrangian-mean (GLM) theory which provides a convenient route for the computation of the wave feedback. I will also discuss an extension due to Wagner & Young that incorporates the nonlinear generation of harmonic waves with frequency 2*f*.

When propagating in a turbulent flow, waves are scattered by advection and refraction, leading to a statistically isotropic wave field with well defined characteristics. Understanding this process is important for the quantification of wave-flow energy transfers as well as for the separation between flow and waves that is often requiring to analyse observations of ocean fields, e.g., from satellite altimetry. Time permitting I will explain how this scattering can be described by a relatively simple kinetic equation obtained by modelling the turbulent flow as a homogeneous random process (joint work with Danioux and Savva).

Oral preference

Kinematics of non-spherical particles in turbulence: effect of size and shape

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Natural particles suspended in water are often non-spherical. We explore the ways in which particle size and shape affects particle motion, focusing on particle parameters relevant for plankton, sediment aggregates, or autonomous vehicles. We find that shape has only a very weak effect on particle angular velocity, which is a quantity calculated with respect the global reference frame (i.e. east/north/up). If we analyze rotation in a particle's local frame (i.e. the particle's principle axes of rotation), then particle shape has a strong effect on rotation. In the local frame, rotation is described by two components: tumbling and spinning. We find that rod-shaped particles spin more than they tumble, and we find that disc-shaped particles tumble more than they spin. These preferential rotations, as well as total angular velocity, decrease with increasing particle size. Such behavior is indicative of how particles respond to the directional influence of vortex tubes in turbulence, and such response has implications for particle motion other than rotation. Understanding particle alignment is relevant for predicting particle-particle collision rates, particle-wall collision rates, and the shear-driven breakup of aggregates. We discuss these briefly in the context of what can be concluded from the rotation data discussed above.

Presentation: Oral

Prediction of turbulent diapycnal mixing in density stratified flows

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Quantitative prediction of diapycnal mixing of density and momentum in density stratified flows remains an ongoing challenge in marine turbulence. From a practical standpoint, a major goal is the inference of turbulent heat and momentum fluxes using indirect measurements in field studies of oceanic flows. To this end, two key quantities need to either be measured or inferred. These are: (i) the rate of dissipation of turbulent kinetic energy ε, and (ii) the flux Richardson number R_f (also commonly referred to as the mixing efficiency), which is a measure of the amount of turbulent kinetic energy that is irreversibly converted into background potential energy. A common (indirect) approach to estimates ε in oceanic flows is to assume a linear relationship between the Thorpe (vertical overturn) length scale L_T and the Ozmidov scale L_O. This approach is popular since the vertical scales of overturns are easily calculable using a sorting algorithm from inversions in standard density profiles obtained from Conductivity-Temperature-Depth (CTD) measurements in the ocean. Hence the Thorpe scale is essentially a kinematic scale that provides a description of the turbulence at a given sampling location and instant in time. On the other hand, The Ozmidov scale is obtained from dimensional reasoning based on the assumption that there is a balance between inertial and buoyancy forces. In other words, the Ozmidov scale is a representative dynamic length scale of the largest eddy that is unaffected by buoyancy. A review of a number of recent studies that were conducted in our research group will be presented in this talk to highlight the lack of a linear relationship between the Thorpe length scale and the Ozmidov scale. These studies indicate that inferred estimates of the dissipation rate of turbulent kinetic energy may be biased high by up to an order of magnitude or more especially for large overturns in the ocean. An alternative framework using a two-dimensional parameter space based on a buoyancy strength parameter (i.e. an inverse Froude number) and a shear strength parameter will be presented to characterize the scaling correspondence of the overturning scale with pertinent turbulent length scales. The second key quantity that is a necessary ingredient for the inference of diapycnal mixing from oceanic measurements is the flux Richardson number R_f. To date, however, no unifying parameterization of R_f exists due to both the variability inherent in geophysical flows as well as certain ambiguities that are introduced in descriptions based on ill-conditioned single parameters. A discussion on the mixing efficiency and implications for estimates of diapycnal mixing in marine turbulence will be presented.

Oral preference

What is the role of mixing in controlling microphytoplankton community composition?

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Turbulence and mixing largely determine the availability of light and nutrients in the water column, which in turn control the composition of the phytoplankton community. Due to the difficulty of quantifying turbulence in the field, previous attempts to investigate the relationship between mixing, nutrient and light availability, and phytoplankton community composition have often relied on indirect proxies for characterizing mixing conditions of the water column. Here we combine, for the first time, a large dataset of dissipation rates of turbulent kinetic energy, measured by a microstructure turbulence profiler, with data of inorganic nutrient concentration, and microscopy-based phytoplankton taxonomy, in order to investigate the role of mixing in controlling microphytoplankton community composition. Our dataset includes 76 stations visited in three contrasting environments which covered a wide gradient of nitrate availability conditions: the Galician upwelling region (NW Iberian Peninsula), the NW Mediterranean, and the tropical and subtropical Atlantic, Pacific and Indian oceans. Vertical mixing, derived from microstructure turbulence, was used to compute light and nutrient availability for phytoplankton cells in the upper layer. Our results indicate that nutrient supply was more important than light availability in controlling the composition of microphytoplankton. In agreement with the famous model proposed by Margalef in 1978, the contribution of diatoms to biomass becomes larger with increasing nutrient supply. Moreover, mixing regimes for diatoms and dinoflagellates coincide with the values suggested in the conceptual model proposed by Margalef mandala. These results demonstrate that accurate estimates of nutrient supply, which, particularly in oligotrophic surface waters, are better predictors of nutrient availability than nutrient concentrations, are crucial to discern the role that environmental factors play in the composition of phytoplankton.

Oral preference

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Characterisation of mixing efficiency from microstructure measurements in the Sicily Channel

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Microstructure measurements taken with a Vertical Microstructure Profiler (VMP) at two deep passages show that the Sicily Channel is a hotspot for turbulent mixing. Average dissipation rates of turbulent kinetic energy are high due to shear instabilities, internal tides, baroclinic near-inertial waves breaking and interactions with the rough topography. A contrast for the deeper layers was found between the eastern passage, where there is strong mechanically driven turbulence with high turbulence intensities, and the western passage, in regions of lower turbulent kinetic energy dissipation rates and smaller turbulence intensities, where double diffusive processes are active.

This study aims to characterise mixing efficiency based on microstructure measurements, in the context of these dynamical regimes. The variations in mixing efficiency are investigated in order to characterise different mixing regimes (turbulence, double diffusive salt fingers, double diffusive convection).

The dissipation rate of turbulent kinetic energy and the dissipation rate of thermal variance were inferred from the microstructure shear and temperature sensors, respectively, and finescale temperature and density gradients were obtained from the Seabird temperature and conductivity sensors.

The resulting mixing efficiency compares qualitatively well with the Bouffard and Boegman (2013) parameterisation. However, the mixing efficiency computation is sensitive to the choice of parameters, and the lack of a detailed method makes such a comparison problematic; an optimal comparison should be conducted with the same choice of computation intervals and parameters. At the eastern location, where mechanically driven mixing dominates, mixing efficiency decreases with increasing turbulence intensity, and ranges from 1 to 0.005. When double diffusion occurs (most often at the western location), values are up to 2 orders of magnitude higher than the conventional value of 0.2. At high turbulence intensity ($>10^3$-10^4), the mixing efficiency is up to 1-2 orders of magnitude higher than the values obtained using the parameterisation.

Turbulence and double diffusion may occur simultaneously, and their relative contribution to mixing is estimated, by comparing vertical turbulent diffusive fluxes to double diffusive fluxes. Diapycnal diffusivity was inferred from the observations. The density variation per unit time resulting from diffusive vertical mixing confirms the occurrence of significant water mass transformations, notably a lightening of intermediate waters, which are diffusively diluted.

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Poster preference

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North Atlantic water overflow through the Wyville Thomson Ridge: Observational evidence and numerical modelling

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An overflow of dense cold water from the Faroe Bank Channel (FBC) through the Wyville Thomson Ridge (WTR) into Rockall Trough was recorded during 136-th cruise of the RRS "James Cook" in June 2016. Overflow event happened in the eastern most section of the ridge where overflows were never recorded before. The Remotely Operated Vehicle ISIS deployed for collection of bottom samples at 500m depth recorded abrupt drop of temperature. Before the event at 02:08am on 5-th of June bottom water was nearly homogeneous below 400m depth with its temperature of about 8.73^{O}C and salinity 35.26 in the bottom 200m layer. Over 20 min water temperature dropped to 6.74^{O}C and salinity to 35.16, with fastest change of 1.10^{O}C just over 1 minute 50 seconds. The possibility of such a radical change of bottom sea water characteristics due a spillage of North Atlantic bottom waters intruded into the FBC through the WTR is discussed based on the observational data and the results of numerical modelling conducted using the Massachusetts Institute of Technology general circulation model. The conditions of the recently recorded overflow event are compared against the results published in [*Stashchuk et al.*, 2010; 2011] where the analysis of mixing processes in a downslope propagating gravity current, specifically, explosive detrainment regime, is investigated using a passive tracer transport equation.

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Oral preference

Abyssal Turbulent Mixing in the Samoan Passage

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The Samoan Passage is a major choke point for the Global Overturning Circulation. About 6 Sv (1 Sv ≡ 1 × 10^6 m^3 s^{-1}), more than half of the abyssal northward limb of the Pacific Meridional Overturning Circulation, flows through the Samoan Passage [*Rudnick*, 1997]. As the bottom current is forced through the narrow channels and across the sills of the Samoan Passage it is strongly modified by turbulent mixing. In our recent NSF-funded Samoan Passage Abyssal Mixing Experiment we found turbulent mixing in the Samoan Passage 1,000 to 10,000 times elevated above oceanic background levels [*Alford et al.*, 2013]. High levels of mixing were strongly tied to hydraulic jumps and breaking internal waves behind the major sills [*Voet et al.*, 2015].

A rich observational dataset, comprised of highly resolved moored and shipboard hydrographic and velocity measurements, as well as more than 100 full ocean-depth microstructure profiles, allows us to discern the role of these physical processes in the mixing of the abyssal current with its surrounding water masses. Hydraulic jumps lead to strong local turbulence whereas part of the energy removed from the mean flow and transferred to lee waves can radiate upwards. Lee waves also re-distribute momentum in the vertical. The detailed observations allow for an examination of the three-dimensional nature of flow and turbulent mixing over rough topography.

Hydraulic aspects of the flow through Samoan Passage, including the complex bathymetry with complicated sill configurations, multiple connecting passages and time dependence are now the topic of a newly NSF-funded project. We will conclude the presentation with a brief outlook on the upcoming work.

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Contribution of high and low frequency internal waves to boundary turbulence in a lake

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Stratification in lakes restricts vertical mixing and often controls the spatial variability of nutrients and other substances, affecting the distribution of dissolved oxygen in the water column, the availability of nutrients to phytoplankton, and transport of pollutants between the hypolimnion and epilimnion. The interior of lakes is often quiescent and most of the mixing in a lake occurs at the sloping boundaries, where wind-induced internal waves create turbulence (which leads to mixing) through interactions with the lakebed. To predict the occurrence and strength of turbulence in terms of meteorological forcing and stratification, we investigated the dependence of internal wave type, and their contribution to turbulence on the slope, on the Lake number, which compares the stabilizing tendency of stratification to the destabilizing tendency of the wind.

Three thermistor chains and a meteorological station were deployed in West Okoboji Lake (length ~ 9 km, max. depth ~ 40 m) for two weeks. A wavelet analysis was conducted to determine time periods when different wave frequencies were excited, with particular focus on the first vertical mode seiche, the critical frequency with respect to the stratification and slope, and high frequency waves in the band of 1-10 times the buoyancy frequency. We measured the velocities in the bottom boundary layer (BBL) with a high resolution acoustic current profiler (2 MHz Nortek HR Aquadopp) and then computed the turbulent dissipation rate using the structure function method, which uses the spatial correlations of velocity along a beam to estimate the dissipation. This generated a two week time series of turbulent dissipation rate in the BBL which was then compared to the wavelet amplitudes.

During the deployment, a strong daily wind forced near constant internal wave activity. The theoretical period of the first vertical mode seiche was ~17 hours, but the diurnal wind forcing interfered with free oscillation of this mode. Although not an obvious natural frequency of the lake, waves of the critical frequency (which had a period of ~11 hours) were activated throughout the measurement period. High-frequency waves were observed in the thermistor chain near the slope at the lowest Lake number wind events. The turbulence observed on the boundary was highest during these events, implying that the low frequency seiching was less important than higher frequency motions in driving turbulence on the slope.

Oral preference

How climate changed driven turbulent mixing impact the water quality dynamics: A case study in Chesapeake Bay, USA

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In the partially-mixed estuary of Chesapeake Bay, the mechanisms of turbulent mixing in regulating the biogeochemical cycles were given examination by using a newly developed three-dimensional unstructured-grid hydrodynamic-eutrophication model (FVOCM-ICM, Xia and Jiang, 2016). Turbulent mixing was examined at the along-channel and across-channel directions from a 10-year (2003-2012) simulation, and was found to be very sensitive to the physical forcing and climatic variability. Thus, the physical forcing projected by the CMIP5 (Coupled Model Inter-comparison Project Phase 5) in the coming decades, including wind pattern shifts, river discharge fluctuations, sea level rise, sea temperature increase, and salinity change in the ambient shelf waters, were utilized to drive the coupled hydrodynamic-biogeochemical model. The difference between past 10-year and forthcoming-decade turbulent mixing in the estuary was compared to quantify the magnitude and direction of potential future changes. Impacts of these variations in turbulent mixing on oxygen ventilation and regenerative nutrient (nitrogen, phosphorus, and silicon) transport were further discussed. The statistical relationship between mixing intensity and nutrient and oxygen budgets were established, which provides reference to the stakeholders and policy makers on future water quality management activities.

Presentation : No Preference

Oceanic turbulence and highly intermittent phytoplankton dynamics

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Phytoplankton requires both light and nutrient, thus requires to stay in the upper ocean where turbulence stirs water column. Turbulence mixes oceanic properties, such as salinity and temperature. How does it mix phytoplankton? How do they distribute in space? How small scale do we need to resolve the microscale distribution? We have developed two types of fluorescence probe, LED (2 cm resolution) and laser (2 mm resolution). We have found that the LED data are significantly different from the laser data that exhibit highly intermittent features. The local signals are considerably stronger than the spatially average signal. We also mounted an optic system on the microstructure profiler TurboMAP-L to identify the source of intermittent fluorescence signals and found the strong signals came from marine aggregates. From ten different field campaigns we compiled the average size of aggregate and the average rate of kinetic energy dissipation rate and found they are positively correlated. The implications of the field data will be presented in this talk. Also I will introduce new plankton ecosystem models that take microscale spatial heterogeneity into account.

Oral preference

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Surface horizontal diffusivity estimated from submesoscale observations of surface currents and passive tracers

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The optimal solutions)of surface horizontal diffusivity are quantified using submesoscale [*O*(1) km spatial scale and *O*(1) hour time scale] observations of high-frequency derived surface current fields and geostationary ocean color imagery-derived surface chlorophyll concentrations in a coastal region, which correspond to the advection and concentration terms, respectively, in the one- and two-dimensional advection-diffusion equations. We practice the ways to estimate the diffusion coefficients using an idealized flow model and the model-derived concentrations. The model currents are simulated uni-directional steady currents under specific temporal and spatial decorrelation scales with a Gaussian noise, and the concentrations are derived using random walk and flight schemes, which have been used for tracking of the concentration of phytoplankton, zooplankton, and individuals of fishes as a statistical approach. Then, the diffusion equations are solved in terms of random parameters and diffusion coefficients. This work will be applicable to the ecosystem process studies at submesoscale and improve the limitation of the present-day statistical modeling.

Poster preference

Instabilities of vortices in thermal rotating shallow water model, and their nonlinear saturation

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We find a class of instabilities of convective character in the so-called thermal rotating shallow water model, which is used in literature for modelling well-mixed boundary layers in the ocean and in the atmosphere. These instabilities co-exist with standard barotropic instability, having higher than this latter growth rates in a wide range of parameters. A whole variety of unstable modes is found with the help of pseudo-spectral collocation method. The azimuthal structure of these modes strongly resembles that of the centrifugal instability. Nonlinear evolution of the new instability was studied with th the help of numerical simulations with the finite-difference scheme for rotating shallow water, which was appropriately modified. We show that at nonlinear stage the instability produces characteristic pattern of convective instabilities, which leads to rapid and efficient mixing inside the vortex. Dependence of the growth rates of these unstable modes on the parameters: Rossby and Burger numbers, as well as on relative strength of pressure and buoyancy gradients and their mutual orientation in the vortex is investigated.

Oral preference

Symmetric Instability (SI)-Turbulence: A Unique Form of Boundary Layer Turbulence

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Turbulence in the surface boundary layer is typically assumed to derive its kinetic energy (KE) from the winds, buoyancy fluxes, and/or waves at the air-sea interface. This assumption can break down at ocean fronts, where strong geostrophic shear associated with lateral density gradients can supply KE to boundary layer turbulence via symmetric instability (SI). This *SI-turbulence* is thus distinct from other forms of boundary layer turbulence in that it represents a sink of KE for the balanced circulation. In this presentation, I will describe the instability criteria, energetics, coherent structures, and turbulent fluxes associated with SI-turbulence and outline a model for its parameterization. Observational examples of symmetrically unstable currents will be highlighted and the implications for the dissipation of the KE of the circulation will be discussed. I will conclude by speculating on the potential for SI-turbulence in the bottom boundary layer, where the intersection of isopycnals with sloping bathymetry and friction can lead to favorable conditions for SI.

Keynote

A preliminary study of small scale turbulence and its association with (sub-) mesoscale processes in the Denmark Strait overflow plume.

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The Denmark Strait overflow plume is a key component of the climate system in the North Atlantic. During its descend into the subpolar North Atlantic, the plume almost doubles its volume due to the entrainment of ambient waters. To study small-scale processes associated with entrainment a multi-platform experiment was carried out 180 km downstream of Denmark Strait in the pathway of the overflow plume. Moored observations revealed pronounced eddy-activity with periods near 1.6 days (Schaffer et al, 2016). Using velocity measurements from a high-frequency (1200KHz) ADCP we link the passage of (sub-) mesoscale features within the plume with: a) the evolution of the internal wave field and b) enhanced small scale turbulence events.

Fission of internal solitary waves over shoaling topography cascades tidal energy to turbulence

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The tides are a major energy source of small-scale turbulence, and therefore diapycnal mixing, in the world's oceans. An understanding of the processes responsible for the cascade of energy from tides to turbulence is important in identifying when and where this mixing will take place. Internal solitary waves (ISWs) generated by tide-topography interactions are ubiquitous in the world's oceans and are thought to be important sources of mixing. Whilst the understanding of the dynamics and energetics of ISWs have been greatly advanced in the past a few decades, identification of the processes and mechanisms responsible for their dissipation is limited. Here we present velocity and turbulence measurements from the South China Sea, together with process-orientated numerical simulations, to demonstrate the key role of ISW fission, into groups of high-frequency internal waves over rough topography, in the dissipation of tidal energy. The results show that, as a result of the fission, wave-induced velocity shear is elevated over significant time periods coincident with a period of enhanced turbulent dissipation. We suggest that the enhanced dissipation is a result of instability and breaking of the high-frequency internal waves. The finding reveals an important pathway of tides-to-turbulence cascade and generation of turbulence and mixing in the ocean interior, having important implications for understanding ocean dynamics as well as its ecological and climatic impacts.

Regimes of oceanic turbulence in the Western Mediterranean represented by satellite data

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Satellite observations provide encouraging opportunities for observing oceanic turbulence at a wide range of spatio-temporal scales and through using different techniques and sensors. However, most studies in this field are typically devoted to investigating multiscaling [e.g. *Renosh et al.*, 2015] or multifractal [e.g. *Pont et al.*, 2013] properties of satellite, mostly thermal infrared, images. In the present work, we apply satellite data both for observing turbulent features of surface currents and for an analysis of the mechanisms inducing such features.

The main test site of the present study is the Western Mediterranean (WMed) Basin, which is known for its well-developed turbulence giving rise to a cascade of coherent vortical structures. Turbulence in surface waters of this area exhibits significant temporal variability, which provides additional stimulus to studying the triggering mechanisms of the changes of the turbulent regime in the area under investigation. Observation of turbulent features in the work being presented was performed via a registration of coherent vortical structures manifested in two types of satellite imagery: (i) thermal infrared (namely, the L3S product of sea surface temperature) and (ii) synthetic aperture radar (SAR) images, namely the Envisat Advanced SAR (ASAR) imagery. Using such a dataset allows for observing coherent structures in the range O(1-100 km). The cumulative temporal coverage of the region of interest by the imagery analysed is from 2008 to 2015. An inspection of the images mentioned revealed in WMed an asymmetry of turbulent stirring typical for inner and marginal seas [*Karimova et al.*, 2017]. Thus, vortical structures with diameters less than approx. 70 km in diameter mostly had a cyclonic sign of rotation, while those bigger than 70 km were mostly anticyclonic.

Studying the factors that trigger establishing different turbulent regimes in the region of interest was performed via an analysis of concurrent information on spatial distribution of some dynamical and geophysical parameters obtained from satellite observations and from the reanalysis. Additional satellite data scrutinized at this stage among others include geostrophic and Ekman surface currents provided by different altimetry-derived products. One of the most important parameters provided by the numerical simulations and analysed in the present work is the mixed layer depth. Thus, it was discovered that most submesoscale eddies in the region of interest were observed in quite shallow upper mixed layer, which can question mixed layer instabilities being a possible mechanism of generation of such eddies.

This research is supported by the University of Liege and the EU in the context of the FP7-PEOPLE-COFUND-BeIPD project. SAR imagery was provided by the European Space Agency. The study has been conducted using E.U. Copernicus Marine Service Information.

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Poster preference

Oceanic Turbulence from a Planktonic Perspective

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Turbulence is often invoked as an essential dynamic controlling the interactions among the plankton. Predator-prey and mating encounters are thought to be strongly influenced by the relative motions driven by turbulence. However, analyses of a synthesis of more than 1.6 million turbulence dissipation measurements from all over the world's ocean show that in most of the ocean, most of the time, the turbulence is extremely weak, with eddy viscosities close to molecular viscosity values. From the point of view of the plankton, the ocean is a relatively tranquil environment – a view seemingly antithetical to most plankton ecologist's intuition. The strongly skewed statistics of dissipation rates suggest that only a small portion of a population experiences the high velocities, shears, strains and vorticities associated with mean dissipation rates. Furthermore, plankton drift with the flow, experiencing turbulence from a Lagrangian point of view. However, most of the theory exploring the effects of turbulence on plankton has been developed from an Eulerian perspective, based on the relative velocities at two points fixed in space. I will show analyses of a recent compilation of turbulence measurements and attempt to introduce contemporary understanding of the statistics of turbulence and the Lagrangian properties of turbulence from a planktonic viewpoint. My goal is to help plankton ecologists understand the structure of turbulence and how it affects planktonic dynamics at different spatial scales. In particular I would like to help biologists to move beyond the simple Kolmogorov scalings that are typically used, to obtain a more nuanced understanding of the microscale structure of turbulence intensity. A better understanding of how plankton experience the Lagrangian properties of turbulence will allow plankton ecologists to gain insights into the evolution of planktonic behaviors and morphologies.

Keynote

The Annual Cycle of Upper-Ocean Potential Vorticity and its Relationship with Submesoscale Instabilities: Insights from Mooring Observations

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Potential vorticity (PV) is a key ingredient to understand the competing processes in deepening and shoaling the ocean surface boundary layer (OSBL). Previous PV studies were mainly based on numerical simulations. Here we use a year-long, meso- and submesoscale resolving time series of buoyancy and horizontal velocity, obtained from mooring observations in the Northeast Atlantic under the auspices of the U.K. OSMOSIS programme, to investigate the upper-ocean PV budget and its relationship with submesoscale frontal instabilities. Results show that non-advective PV changes in the OSBL are balanced by the frictional and diabatic components of J vector in an integral sense. Deep mixed layers (up to about 350 m) during wintertime are attributed to persistent atmospheric cooling, predominantly through gravitational instability. However, on shorter time scales, conditions favourable to symmetric instability are often observed when winds are aligned with the frontal flow. The ensuing overturning instabilities rapidly re-stratify the mixed layer and limit the reduction of PV, as indicated by the approximate balance between the temporal change of PV and the advection of PV below the convective layer. These results emphasize the key role of submesoscale instabilities in determining the evolution of the OSBL.

Oral preference

Turbulent dissipation at the western boundary of the Atlantic in an eddy

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Oceanic mesoscale eddies disappear from altimetry data at the western boundary of ocean basins. While disappearance could mean a transfer of energy to other wave modes or mean flow in the region, we investigate whether local dissipation is a leading order term in the mesoscale eddy dissipation. From a short survey east of the Bahamas using a microstructure profiler, we identified regions of elevated dissipation (10^-8, and occasionally exceeding 10^-7 W/kg) in the lee of topography. These observations are consistent with estimates of dissipation derived using a fine scale parameterisation from a moored 75 kHz ADCP in the RAPID 26N mooring array (Clement et al., 2016). The 18 month record further showed that levels of estimated dissipation are higher in anticyclones than cyclones. In addition to upward propagating internal waves, the survey also identified 100 m-thick layers of high dissipation in a region of strong shear about 100 m off the bottom. From the mooring and in situ observations, it is unclear whether a single candidate mechanism dominates the local dissipation in an anticyclonic eddy. The level of mixing observed is, however, O(100) times above background mixing levels in the ocean, and may represent an important term in the mesoscale eddy energy budget.

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[2] Second adress using the « Adresses » style.

3D hydrodynamical modelling of the Southern Bight of the North Sea: first achievements and perspectives.

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The impact of offshore wind farm installation and dredging activities on the spatial distribution and dynamics of sediment grain size, biogeochemistry and biodiversity will be estimated in the Southern Bight of the North Sea (SBNS) with a focus on the Belgian Coastal Zone (BCZ) in the frame of the FaCE-It research project (Functional biodiversity in a Changing sedimentary Environment: Implications for biogeochemistry and food webs in a managerial setting).

The three-dimensional hydrodynamical model ROMS-COAWST was implemented for simulation of the complex hydrodynamics of SBNS and sediment transport. The first level of nesting with the resolution of 1 km was used in the area of Belgian Economical Zone. Six-hourly ECMWF ERA-interim meteorological data was used to force the model at the sea-air boundary and the coarse resolution model results available from Copernicus Marine Environment Monitoring Service were used to force the model at the open boundaries. Tides and rivers were also considered.

Next types of long-run simulations have been conducted: a 10-years climatological simulation and an interannual simulation over 2004-2013 in order to investigate the interannual dynamics. The model accuracy was evaluated through validation of its outputs against observed salinity, temperature and currents data (remote sensing and in-situ).

Results validation of currents and temperature and salinity horizontal fields and vertical profiles against available satellite fields and in-situ data, i.e. from the project field campaign, is conducted and discussed. Application of the nested grid and its benefits for results accuracy is also presented.