First turbulence observations in the southern Brazilian shelf

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Introduction

The Southern Brazilian Shelf (SBS) is the shelf area located between the latitudes of 28°S and 34°S, in the southwestern boundary of the South Atlantic Ocean [*Soares and Möller*, 2001]. The local hydrography and circulation are highly variable, modulated by seasonal wind variations, which are NE during spring and summer and SW during autumn and winter [Lima et al., 1996]. In addition, the La Plata River plume has a strong impact on the local dynamics, as it creates strong horizontal and vertical density gradients [*Guerrero et al.*, 1997, *Marcelo Acha et al.*, 2008, *Piola et al.*, 2005]. The SBS is a wide and shallow shelf region highly influenced by wind shear, which in theory would yield intense vertical mixing, aided by shear instabilities induced by a western boundary current, namely the Brazil Current, near the shelf break [*Cerda and Castro*, 2014]. However, the presence of a massive low density plume induces strong stratification and inhibits vertical mixing and turbulence. In this context, the main goal of this study is to describe the turbulence patterns, expressed in terms of the dissipation rate of turbulent kinetic energy (TKE), ε, in a continental shelf highly influenced by a large buoyancy plume.

Material and methods

The microstructure data was obtained with a Rockland Scientific VMP-250, equipped with a SBE7 micro-conductivity and a FP07 thermistor. Both measured conductivity and temperature with a 512 Hz sample rate. The instrument collected data during its descend (down mode). In total, data was obtained in 16 stations along three cross-shelf transects (figure 1): near *Albardão* (AL, 8 stations), *Sta. Marta Cape* (SM, 5 stations) and in *Mostardas* (MO, 3 stations). The dissipation rate of TKE was obtained by fitting the theoretical Batchelor spectral form to the measured microstructure temperature gradient spectrum. The Batchelor spectrum describes the behavior of diffusive scalars wavenumber spectra, such as conductivity and temperature, being passively convected in a highly turbulent environment [*Batchelor et al.*, 1959]. The dissipation of TKE is obtained in $\varepsilon = k_B^2 \nu D_T^4$, where ν is the kinematic viscosity and D_T is the diusivity of heat, by finding the best fit Batchelor wavenumber, k_B. To fit the theoretical to the observed spectra was used the maximum likelihood estimate (MLE) for spectral fitting [*Ruddick et al.*, 2000]. By constraining the value of the thermal variance, χ_T, obtained from the measured spectrum, the fitting technique uses a range of k_B to find the best fit.

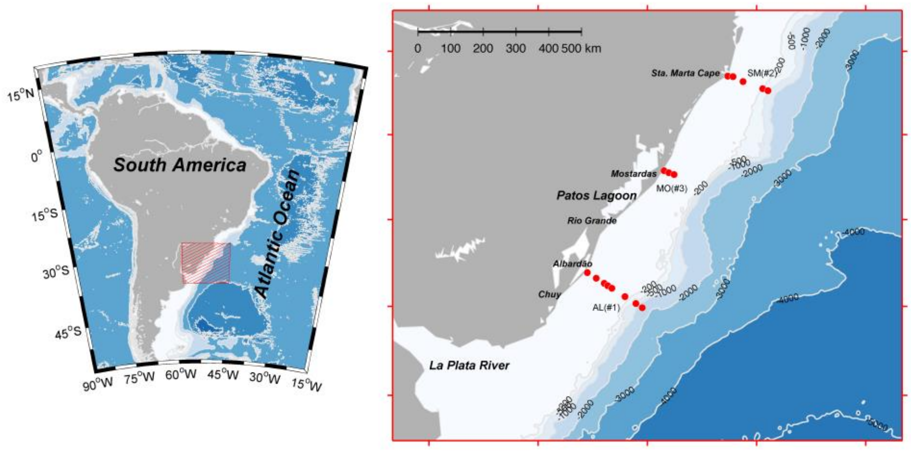

Figure 1. The SBS location (left panel) and details of the area (right panel); the red dots are the stations locations.

Results and discussion

Results (figures 2, 3 and 4) show that the turbulence pattern for the SBS presented higher values for the shelf break areas beneath the surface mixing layer depth (MLD), while the presence of a large buoyancy plume inhibit the vertical mixing on continental shelf. The surface MLD was restricted to close to the surface on the shelf, with depths between 5 and 10 m, due to the plume density gradient. The vertical position of the surface MLD is highly correlated with the magnitude of the dissipation [*Moum et al.*, 2001, *Thomson and Fine*, 2003]. However, no higher levels of dissipation were found at the surface. For shallow continental shelf areas vertical homogeneity due to wind shear plus increased bottom friction is expected. However, for the SBS, only a few profiles near the coast present full vertical mixing with no stratification. At the 23,5 kgm^{-3} isopycnal, which according to Möller et al., 2008 is the density limit of the plume, reduced levels of ε, about 10^{-8} Wkg^{-1} were observed. The highest dissipation levels where found at the shelf break, beneath the surface MLD, possibly result from enhanced vertical shear caused by the intrusion on the BC at the shelf slope and/or enhanced convective mixing, with reaching magnitudes of 10^{-6} Wkg^{-1}. The shelf slope steepness and roughness can be important factors to induce turbulence [*Tanaka et al.*, 2015]. Near the shelf break is expected to be found increased velocity shear due to depth reduction and bathymetric induced instabilities. This feature can be observed in areas where the Brazil Current approaches the shelf break [*Soutelino et al.*, 2013]. Also, convective mixing may occur at shelf break areas where large density gradients are observed.

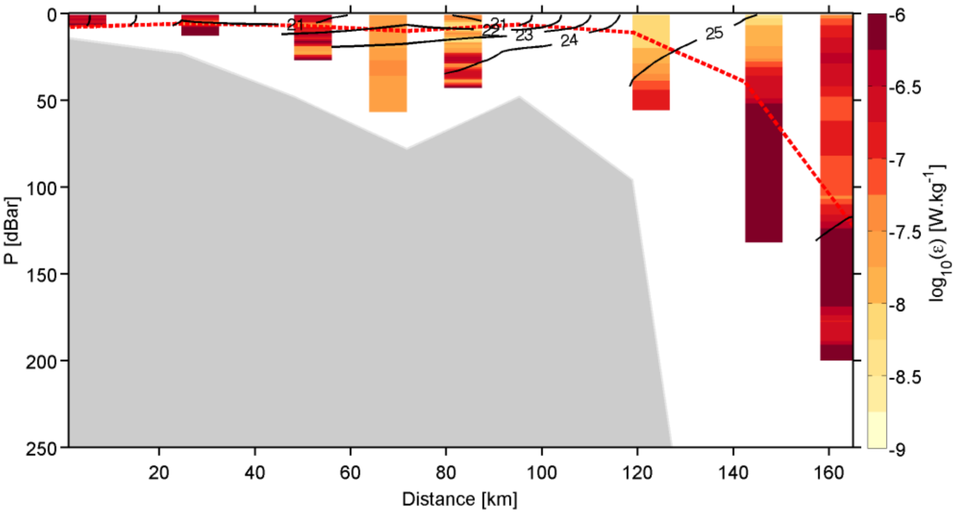

Figure 2. TKE dissipation profiles for the AL transect.

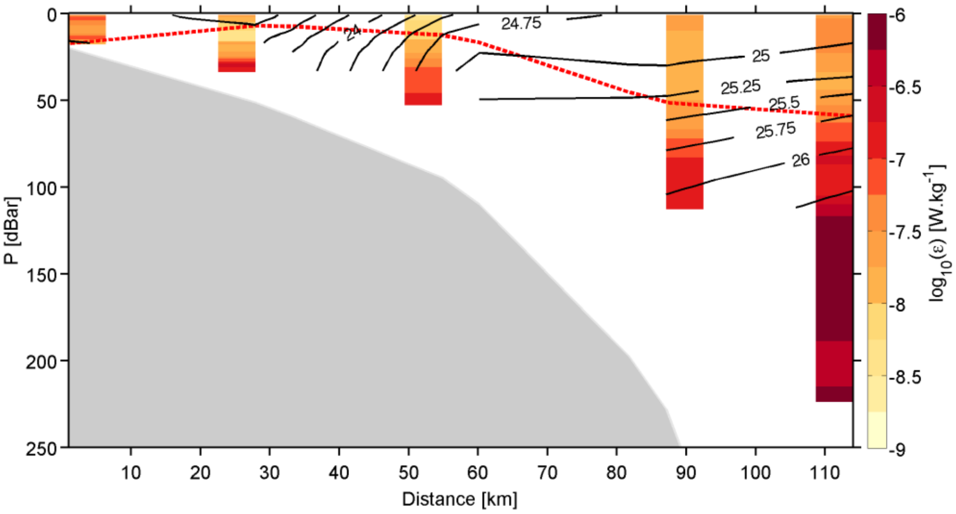

Figure 3. TKE dissipation profiles for the SM transect.

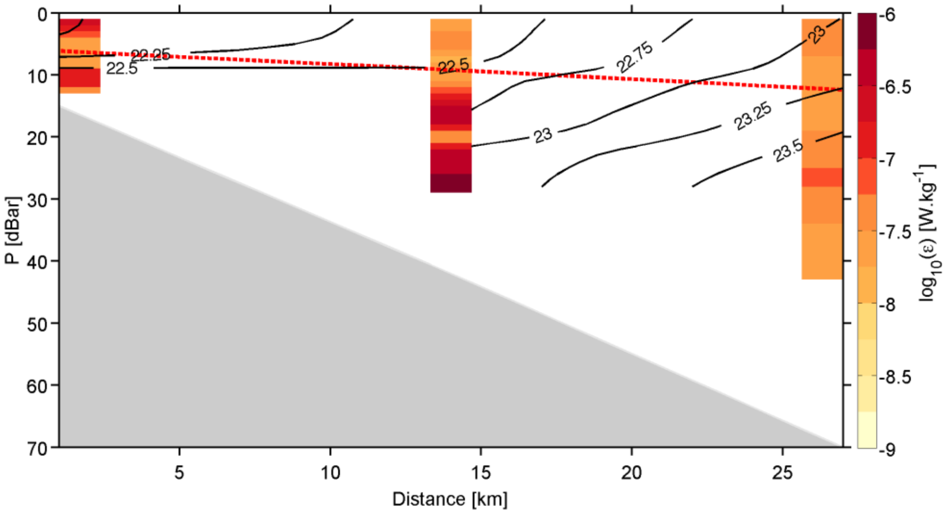

Figure 4. TKE dissipation profiles for the MO transect.

Conclusions

This study provided the first *in situ* turbulence measurements for this important continental shelf area, where large density gradients are observed. The presence of the La Plata River plume is a major factor controlling the density distribution in the continental shelf and, in some occasions, near the shelf break. In a general sense, the density distribution is a stable, as could be seen in the buoyancy frequency profiles, but convective mixing may occur at the shelf break. TKE dissipation in the continental shelf was inhibited due to strong stratification induced by the plume, being higher for the shelf break areas, possibly induced by shear instabilities that arise from the passage of the BC. Our study is the first of this kind for the area and presented relevant information. Nevertheless, more studies are necessary to elucidate the magnitude of dissipation in SBS and the influence of the plume. Also, the values calculated here are estimates from thermistor data, whose we expected to compare with data from shear sensors in the future for more robust results.

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No preference

Between Quasigeostrophic and Stratified Turbulence

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While it is well-established that the frequency disparity between vortical and wave motion is key to understanding the quasigeostrophic limit, i.e. strong rotation and stratification, the starting point for this work is that it has recently been established that there is no such frequency disparity in stratified turbulence without rotation. It remains to ask what happens in between these two limits, long held as the prevailing dynamics between deformation-scale eddies and the microscale where isotropy is recovered. Here, we explore numerically the nonhydrostatic Boussinesq equations starting from initial conditions that are "close" to our current notions of balance for a variety of Rossby and Froude numbers. It is found that evolution is spontaneously away from this balance in the small scales, and from steep to much more shallow spectra. The various generation mechanisms for spontaneous imbalance, wave drag and the shallow spectral range will be discussed. It will be argued that conclusions are robust to uncertainties in the definition of balance.

Oral preference

Submesocscale turbulence in the surface boundary layer: Fronts

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Submesoscale dynamics of fronts within the surface boundary layer are sensitive to the spatial structure of eddy viscosity that can modify the associated secondary circulations. An analytical solution is found for the turbulent thermal wind equation, a quasi-steady linear momentum balance that combines hydrostatic, geostrophic, and Ekman boundary layer dynamics. Implementation of spatially varying eddy viscosity structure requires a piecewise solution based on local mixing maxima. For that, an idealized two-dimensional front under varying forcing induced by e.g., up/down-front wind, surface heating/cooling, and surface straining is considered. Spatial mixing patterns are directly linked to the initial slopes of buoyancy gradient and overturning stream-functions triggered by the varying forcing that injects/extracts potential vorticity in the surface boundary layer. Physically motivated two-dimensional eddy viscosity structures are then used to obtain local solutions across the front. The parameter space is explored by changing width and location of the thermocline and the front along with the strength and direction of the forcing.

Oral preference

Impact of submesoscale turbulence in dissolved O2 in an upwelling system

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In this work, we explore the role played by physical-biogeochemical interactions at the submesoscale range in the distribution of dissolved O2 in an idealized upwelling system. We model a wind forced baroclinically unstable front in a period channel that gives rise to a field of mesoscale and submesoscale turbulence structures such as vortices and filaments that promote cross-frontal exchange of tracers. The submesoscale turbulence is characterized by the concentration of vorticity in thin filaments. Strong rotational cores are found with diameters of the order of 10 km. The biogeochemistry is modeled by a simple phytoplankton-zooplankton-dissolved O2 model. We compute biomass and O2 production and export for different wind regimes and water column stratifications. Eddy fluxes and streamfunctions are used to assess the impact of submesoscale motions on the sources, sinks and transport of dissolved O2.

Oral preference

Impact of different parameterisations for wind wave input and dissipation in ECMWF Earth System model

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The global analyses and medium range forecasts from the European Centre for Medium range Weather Forecasts rely on a state of the art atmospheric model. In order to best represent the momentum exchange at the surface of the oceans, it is tightly coupled to an ocean wave model (ECWAM). Recently, the ocean model NEMO has been included as part of the operational medium range forecasting system. In this context, a first set of sea state effects on Upper Ocean mixing and dynamics was successfully added to the system. Impact of sea-state dependent momentum forcing, the Stokes-Coriolis force and the enhanced mixing by breaking ocean waves were added. By far, the largest impact was found with the enhanced mixing by breaking ocean waves.

So far, the implementation of the coupled system was done with ECMWF own wave physics parameterisation, an evolution of the original WAM cycle-4 physics. Research and development based on observations of waves and turbulence over the last decades have lead to two successful sets of parameterisation. Both initially implemented in the WaveWatch 3 (WW3) model, commonly referred to as ST4 and ST6. The ST4 physics has already been implemented in ECWAM and has been used successfully by Météo France in their standalone configuration. Tests have been carried out to assess how it performs in the coupled system. Plans are to also test the ST6 version in ECWAM.

An assessment of the different parameterisations will be discussed in the context of the fully coupled system.

Oral preference

Acquiring turbulence observations in oceanic stratified-sheared flows

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Turbulent mixing controls the distribution of contaminants, nutrients, temperature, and small organisms in the ocean, while also strongly influencing the global ocean circulation. Because of the challenges in obtaining direct mixing measurements at high Reynolds, circulation models rely on sub-grid mixing parametrizations derived from idealized engineering flows or from controlled experiments at length scales and turbulence intensities that are very different from those in the ocean. Historically, ocean mixing has been estimated with Osborn's model by measuring the rate of dissipation of turbulent kinetic energy ε and the background density stratification N, by assuming a value of the flux Richardson *Ri_f*. A constant *Ri_f* = 0.17 is typically assumed, despite mounting field, laboratory and modelling evidence that *Ri_f* varies. Here we present practical methods to obtain mixing rates without prescribing a value for *Ri_f*. Our methods were developed particularly to describe very energetic flows and for application to long term autonomous measurements, but can be applied to many existing instrumentation and datasets.

We applied the techniques to observations collected at two vastly different sites on the Australian North-West Shelf. The first dataset originates from a collaborative internal wave project where around 30 moorings were deployed for about three weeks in April 2012 over several hundreds of kilometers, clustered around four nodes. The turbulence observations originate from two moored turbulence packages located at 7.5 and 20.5 m ASB in 105 m of water. A microstructure shear and temperature profiler (VMP-500, Rockland Scientific) also collected more than 300 vertical profiles across the region. The second dataset originates from a separate project that examines the environmental implications of internal waves at Scott Reef in the Timor Sea. During this campaign, in April 2015, a Turbomap microstructure profiler collected more than 150 vertical profiles around the area. In both datasets, very strong tidally-driven flows dominate the dynamics. Applying the techniques to these two datasets resolved the vertical diffusivities that exceeded 10^{-2} $m^{2/s}$ during intense mixing events. The estimated flux Richardson *Ri_f* was also highly variable, and current work involves assessing its dependency on external turbulence parameters. Ongoing work also includes assessing various mixing models applied to these observations, while determining which parameters best predicts the observed mixing.

Oral preference

Microstruture turbulence profiles at the Gibraltar Strait

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The Strait of Gibraltar is the only connection between Atlantic and Mediterranean waters, where an inverse estuarine circulation is formed. Atlantic water flows above denser Mediterranean layer in order to compensate due to evaporation in the Mediterranean Sea. Mediterranean outflow is controlled on the Atlantic side by a topographic constriction, the Camarinal Sill. Several authors have focused their studies on this bathymetric feature due to large amplitude internal waves, which often generate there (e.g. *Bruno et al. 2002*). Turbulence rates at this emplacement have been depicted at the order of 10^{-5}W kg^{-1} (*Wesson and Gregg, 1994*), consequently intense vertical mixing is founded at this Atlantic area.

In the frame of the project MEGAN (mesoscale and submesoscale processes in the Strait of Gibraltar), microstructure profiles were carried out between the Gulf of Cádiz, through the Strait of Gibraltar and at the Alboran Sea emplacements. Data acquisition comprised 100 turbulence profiles during spring and neap tides. Whereas at the Strait of Gibraltar turbulence dissipation rates (ϵ) are in order of 10^{-5} – 10^{-6} $W{\cdot}kg^{-1}$, Alboran Sea profiles achieved values raging between 10^{-7} and 10^{-8}. At the Strait narrowest section (Tarifa Narrow) turbulence seems to be in agreement with the semidiurnal tidal cycle. When the outflow (westward currents) is established, the Atlantic-Mediterranean Interface is raised, Mediterranean Intermediate Water shallows, increasing the dissipation rates at the interface between the surface and the intermediate water mass. In the Alboran Sea the quasi-permanent western gyre (WAG) was broadly sampled. At the center of the gyre, the maximum turbulent value ($\sim 10^{-7}$) is located at 200 m depth.

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Final-scale dynamics and energy dissipation of the Lofoten Basin Eddy measured by Seagliders

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Located at high-latitude in the Norwegian Sea, the Lofoten Basin represents a large reservoir of warm and salty Atlantic Waters. The region is recognized as an area with substantial heat losses and intense mesoscale activity. A persistent, deep, anticyclonic vortex is located in the central part of the basin (the Lofoten Basin Eddy, LBE). The LBE is hypothesized to be energized by eddies shed from the boundary current and/or winter deep convection.

This eddy has been documented sporadically by shipborne measurements during the last decades. Since 2012, an intense sampling was carried out using autounomous Seagliders, including 7 completed and 1 ongoing missions (6-month average duration per mission). The data set is used to obtain a dozen realizations of the eddy, and detailed descriptions of its dynamical properties, in a period spanning from summer 2012 to winter 2017. The LBE is characterized by peak velocities at great depths of 800-900 m, about 15 km away from the center of rotation. The estimated cyclogeostrophic orbital velocities are very intense, ranging between 0.5 and 0.8 cm/s, leading to extremely negative values of vorticity close to -f.

Following Beaird et al (2012), we estimated the dissipation rate of turbulent kinetic energy based on water vertical velocities obtained from a glider hydrodynamic flight model. Under the PROVOLO project, full-depth ocean microstructure profiles were collected across the LBE in June 2016, thus allowing us to validate the method against state of the art turbulence measurements. The vertical and lateral distribution of the dissipation rates relative to the eddy core, and the probability distribution of dissipation compare well with the direct measurements, lending confidence on the indirect method. The application of the method to the entire glider data set provides a more complete description of the evolution of the LBE energy budget. Dissipation rates were significantly elevated within the intermediate pycnoclines separating the quiescent well-mixed cores formed in winter by deep convection. We observe energetic near-inertial variance within the LBE, and discernible interaction of the vortex and near-inertial waves. The low negative vorticity of the eddy core act as a near-inertial chimney that can explain the observed patterns of elevated mixing.

Oral preference

Mixing under internal tides: A Large-Eddy Simulation investigation

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In simple terms, the pycnocline is a sharp gradient of density (occurring over a small depth interval) which causes a distinct separation between the biologically active surface waters and the deep nutrient rich waters. Mixing across this region therefore dictates how much food phytoplankton, for example, can eat. Shelf seas experience significant density stratification in the summer months and hence a pronounced pycnocline. When the conditions are right, with the right topographic bumps and tidal currents, the pycnocline becomes a medium for the propagation of waves, known as internal tides.

Mixing at the pycnocline is poorly understood in regional numerical models. This is due to limiting depth resolution and a deficiency in knowledge about the driving mechanisms of turbulent mixing at the pycnocline, e.g. how internal tides feed energy into the mixing process.

A Large-Eddy Simulation (LES) has been utilised. LES is a method of solving the fully 3-dimensional Navier-Stokes equations, which means it is very well suited to modelling a turbulent flow. The LES is configured to resolve the fine scale processes directly and is forced by a prescribed internal tide supplied from observations.

We present correlations between energy dissipation rates and TKE from model output and from observations. Our work is a first step towards parameterising mixing associated with internal tides in regional models.

Oral preference

Submesoscale instabilities and enhanced dissipation at ocean fronts

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The ocean surface mixed layer (SML) is the critical interface across which ocean-atmosphere heat, trace gas and momentum exchange occurs. Recent high-resolution modelling studies have shown that oceanic processes occurring at small horizontal (0.1-10 km) and temporal (hours to days) scales play a critical role in these exchanges [**1-8**]. Cumulatively, these results suggest that ocean models that do not represent these processes do not accurately predict climate. To date, however, few observations exist at these scales, leaving model-based conjectures open to debate. Here, we use a novel dataset—a multi-month suite of mooring-based measurements collected in the North Atlantic* as part of the OSMOSIS year-long field campaign [**9**] together with ocean-atmospheric model reanalysis—to demonstrate that convective instabilities occurring at small scales play a leading-order role in upper ocean turbulence. In particular, we demonstrate that winds blowing down ocean fronts (i) reduce potential vorticity, (ii) catalyse a suite of gravitational and symmetric instabilities [**8**] and (iii) on average, enhance turbulence dissipation rates by an order of magnitude above background values and deepen the mixed layer. Importantly, this mechanism is found to dominate over surface buoyancy fluxes in terms of turbulence production, turning our understanding of ocean-atmosphere turbulence on its head. Given the SML's role in imparting deep/intermediate ocean properties to the atmosphere (and vice-versa), these results highlight the need for accurate representation of submesoscale instabilities in climate-scale ocean models. *Note: this rather "mundane" region allows us to study the physics in a regime not complicated by numerous factors present in strong boundary currents or coastal regions.

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Oral preference

In situ measurements of small scale turbulence at the air-sea interface

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The transfers of momentum, energy, mass and heat between the atmosphere and the ocean are important boundary conditions for weather, sea state, and climate predictions. These fluxes are largely controlled by small-scale turbulent processes at the air-sea interface. These include the generation and growth of waves under the action of the wind, the onset of wave breaking and the resulting dissipation of energy, the generation of marine aerosols under the action of wind and wave breaking. In spite of extensive past work on the topic, these processes remain improperly quantified and understood. This is due, in part, to the technical challenges involved in the measurement and modelling of the complex turbulent kinematics, within the coupled atmospheric and oceanic boundary layers, in the direct vicinity of the rapidly moving air-sea interface.
We present preliminary observations of the turbulent motions at the air-sea interface, obtained from a novel in situ measurement system, mounted on a single-pile platform in the Baltic Sea, in Germany. The platform is equipped with a high resolution, large field of view Particle Image Velocimetry system, specially developed for this study, and capable of capturing 2D velocity fields in the air directly above the wavy sea surface. In addition, the atmospheric boundary layer is further monitored using ultrasonic anemometers and temperature and relative humidity sensors, and the wave field is measured using stereo imaging of the water surface, along with single point ultrasonic wave gauges. Finally, turbulence measurements under the water surface will be achieved using Acoustic Doppler Velocimetry. We will discuss the technical aspects of this unique in situ measurement system, and present some of the initial data products.

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Seamount induced turbulent mixing and their biological entrapment

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In the scope of the BIOMETORE project, several research campaigns helped characterize the hydrography of the Madeira-Tore submarine banks, in the NE Atlantic. The seamounts have different geomorphologies and were under the influence of different dynamical oceanographic systems: Gorringe is the shallowest bank (25m), close to the Iberian Peninsula and thus influenced by coastal filaments and on the direct path of the Mediterranean Intermediate Outflow (~300m); whereas the Seine bank is under the influence of the Azores front. Josephine and Seine summits lie 150 and 200m bellow the surface, in the lower-limit of the euphotic zone and thus in the threshold zone for photosynthetic organisms.

Located a stratified deep-ocean setting, these seamounts induced a ~60m isopycnic displacement pushing materials up- and down the mixed layer. A strong dissipation layer (10^{-7} to 10^{-6} W Kg^{-1}) is associated with the vertical (turbulent) mixing, which takes place above the seamount summits. Entrapment of biological materials in this turbulent layer occurs as a response to the flow modification induced by the seamount. Intermediate shear-layers (~600m), between two different water masses also induced intense dissipation rates (10^{-6} to 10^{-4} W Kg^{-1}) near and around the the banks.

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Multi-scale modeling of instabilities, internal waves and turbulence with SOMAR-LES

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The Stratified Ocean Model with Adaptive Refinement (SOMAR) [Santilli and Scotti, 2011, 2015] is a non-hydrostatic model that can adaptively refine the mesh in localized regions where nonlinearity transfers energy to finer scales, allowing it to capture both large-scale and small-scale features of the flow at a reduced computational cost. Localized grid refinement gives SOMAR access to small scales of the flow which are normally inaccessible to general circulation models (GCMs). These scales can be utilized to model turbulence with LES. Thus, a new tech- nique, called SOMAR-LES has been developed, whereby a large eddy simulation is performed on the finest grids of the adaptive mesh to model the effects of the unresolved small scale turbulence on the resolved scales of the flow.

In the case of internal tide generation, this tool is able to balance baroclinic energy budget and accurately model turbulence at a reduced computational cost. SOMAR-LES is most effective in reducing the computational cost in flow situations where the location of turbulence is not know a priori. For example, in the scenarios where internal waves radiate large distances and undergo mixing at remote locations, grid can be dynamically refined along the waves to capture remote mixing as the flow evolves in both space and time. In such scenarios, computational cost can be reduced by nearly two orders of magnitude compared to the traditional single grid solvers. Numerical simulations of internal tide generation, remote internal wave mixing, gravity currents and few other oceanic flow scenarios where this tool can be very efficient will be discussed.

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Oral preference

Diagnosing the Upper Ocean 3D Circulation from High-Resolution Surface Data in a Realistic Simulation of the North Pacific Ocean

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A new quasi-geostrophic model has recently been developed to diagnose the three-dimensional circulation, including the vertical velocity, in the upper ocean from high-resolution observations of sea surface height and buoyancy. The originality of the model is the diagnosis of the dynamics within the surface mixed-layer (ML), in particular in winter when ML instability is the main driver of the ML dynamics. The model is essentially an Eady model for the ML coupled to a surface quasi-geostrophic (SQG) model for the interior. The model further includes a diabatic dynamical contribution. Parameterization of diabatic vertical velocities is based on their restoring impacts of the thermal-wind balance that is perturbed by turbulent vertical mixing of momentum and buoyancy. The model skill in reproducing the three-dimensional circulation in the upper ocean from surface data is checked against the output of a high-resolution realistic simulation of the North Pacific Ocean. The skill in the ML is improved compared to that of the classical SQG model, while below the ML they are similar. Skill varies regionally and seasonally, performing in particular quite well for deep winter ML.

Oral preference

Gravity wave emission from balanced flow en route to turbulence

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Internal gravity waves are ubiquitous in the ocean interior and deposit their energy to small scale turbulence and mixing. Most ocean models do not resolve gravity waves explicitly and thus they need to be parameterized. For parameterization of gravity waves the specification of their sources is important. This includes the energy pathway(s) from balanced flows down to scales where energy is finally dissipated. We discuss, for a range of dynamical regimes from ageostrophic to quasi-geostrophic, if the balanced mesoscale flows can generate unbalanced gravity waves en route to dissipation.

Previous results (Brüggemann and Eden, JPO, 2015) show a dominant forward energy cascade for turbulent balanced flow at a small Richardson number (Ri) in an idealized channel model, while for Ri$\gg$1 the inverse energy cascade dominates. We discuss the role of gravity waves for the forward cascade of energy. A spectral analysis of energy in frequency-wavenumber space for different regimes characterized by a range of Ri, shows that energy contained in the super-inertial frequencies corresponding to gravity waves is much more pronounced for an ageostrophic regime than for a quasi-geostrophic regime. A modal decomposition into geostrophic and gravity wave modes indicates that the energy related to the super-inertial frequencies is indeed associated with gravity waves. Hence, gravity wave emission could be catalyzed by ageostrophic baroclinic instability. A modal decomposition of the spectral fluxes of energy provides more insight about energy distribution in different modes.

Oral preference

Hilbert-Huang Transform to Estimate Turbulent Diffusion Coefficient from Lagrangian Drifter Trajectory

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With the empirical mode decomposition (EMD) for the Hilbert–Huang transform (HHT), nonlinear and non-stationary signals from Lagragian drifters' trajectories are adaptively decomposed into a series of intrinsic mode functions (IMFs) with corresponding specific scale for each IMF. At each step of the EMD, the low-frequency component is mainly determined by the average of the upper envelope (consisting of local maxima) and the lower envelope (consisting of local minima). The high-frequency component (stochastic) is the deviation of the signal relative to the low-frequency component (deterministic). The stochastic component is diffusive, but not the deterministic. In this paper, a criterion is proposed to separate Lagrangian velocity into low-frequency (non-diffusive, i.e., deterministic) and high-frequency (diffusive) components. The diagonal diffusion coefficients are calculated using classical mixing length theory and general ideas of a theory of turbulent diffusion. Non-diagonal diffusion coefficients are calculated using the classical theory of the first passage boundary. The turbulent diffusion coefficients are obtained for several regional seas are presented using the data from surface floats of NOAA's Global Drifter Program.

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Oral preference

Lake Geneva as a natural laboratory for coastal transport processes

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Flow over sloping topography in a rotating environment is bound to follow the direction of constant depth, according to the Taylor-Proudman theorem. This result, which would rule out the possibility of any cross shore transport, holds only for linear, inviscid, stationary flows. Internal waves and, more recently, submesoscale structures are considered as the most plausible processes which, by being unsteady and/or non linear, can violate the theorem and lead to cross shore transport (Brink, 2016).

One of the main hindering factors when facing this problem is the limited amount of available observations. These processes are difficult to observe because they are sporadic in time and space, and have short duration (hours, days). An opportunity to make some progress on this front is offered by the study of a system like Lake Geneva. The lake is sufficiently large to host rich turbulent dynamics markedly influenced by Earth rotation, but it is small enough to be relatively easy to access in reality and to model numerically.

Despite its importance as a freshwater resource, transport phenomena in it are only partially understood. More in general, there has been very limited attention in the lake literature for the dynamics at the intermediate scales where rotation, stratification and turbulence have similar importance. This intermediate scale strongly resembles the "submesoscale" discussed in the oceanographic literature.

Here we present an effort, still in progress, to address the importance of such intermediate scales in Lake Geneva, in particular in terms of transport from and towards the shore. A high resolution numerical model (≈200m), based on MITgcm code, has been developed for the basin. A first campaign of observations has been conducted, providing a basis for model validation. Comparison with available observations shows that the model is capable of reproducing measured velocity fields and stratification. The latter results is somewhat surprising, given the simple one-equation turbulence closure used. The variability of these fields is also well captured, within the limits of the available resolution. The main limitation of the model is the use of an orthogonal grid, which leads to poor discretisation of complex bathymetry in some near shore areas.

Tracer release experiments, tracking the outflow of the main river entering the lake (Rhône river), show that the dispersion is highly inhomogenous in space and time, with spatial gradients remaining large for months after the initial release. Transport takes place mainly along boundary currents, but flow instabilities seem to determine the cross shore transport. The dispersion is also sensitive to the depth of the initial release, pointing to the importance of vertical shear and mixing for horizontal dispersion.

A systematic analysis of the results is underway, to link cross shore transport with the instabilities generated by wind forcing variability and topographic features. Interaction of internal waves with topography is also being investigated as a possible exchange mechanism between the coast and the centre of the lake. A larger observational effort is in progress, investigating the cross-- and along--shore dynamics using a distributed temperature sensor system combined with moored ADCPs. A systematic multi-instrument campaign is being defined, exploiting remote sensing from a balloon and from an autonomous aerial vehicle, and making use of high resolution Lagrangian drifters.

From a broader point of view, this contribution wants to draw attention on the possibility offered by lakes as a "natural laboratory" for fluid processes at scales up to the Rossby deformation radius.

A statistical look at ocean turbulence from high resolution Eulerian observations

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The study of turbulence in geophysical flows benefits from the growing amount of data available via modern sensor technologies. It is now possible to obtain detailed statistical characterisation of turbulence from field observations. By "statistical," we mean the description of a turbulent flow by precisely characterising the probability density function of quantities as the fluctuations of temperature or velocity, the increments of temperature in time and space, etc. This approach, common in laboratory and numerical studies, is only now becoming feasible when using field observations, since the size of datasets now enables converged estimates of high-order statistical moments (i.e. provide sufficient coverage of large deviations from the mean). Here, we provide an example of the value of such an exercise, with an application to deep ocean, wall bounded, stratified turbulence.

Deep ocean data was collected using a moored array of 144 thermistors, 100m tall, deployed above the slopes of a seamount in the North Eastern Atlantic Ocean from April to August 2013. The thermistors, built in-house at the Royal Netherlands Institute for Sea Research, provide a precision better than 1mK, very low noise levels, and measure temperature every second, synchronised throughout the moored array. The thermistor array ends 5m above the bottom, and no bottom mixed layer is visible in the data, indicating that restratification is constantly occurring and that a mixed layer is either absent or very thin. Intense turbulence is observed, and a strong dependence of turbulence parameters on the phase of the semidiurnal tidal wave (the dominant frequency in the power spectrum) is also evident.

We compute the statistical moments (generalised structure functions) of order up to 10 of the distributions of temperature increments. Strong intermittency and marked deviations from Gaussian behaviour are observed. We argue that these can be linked to different turbulence generation mechanisms (shear, convection) which dominate at different depths and during different tidal phases. High-order moments also show that the turbulence scaling behaviour breaks at a well-defined scale (of the order of the buoyancy length scale U/N), which is however dependent on the flow state. At larger scales, wave motions are dominant.

This complex scaling behaviour testifies the strong variability at this location, in terms of turbulence intensity and forcing mechanism. However, when long term averages are considered, this complex behaviour is associated with a surprisingly simple functional relation among vertical heat flux, vertical temperature gradient and distance from the seafloor. This can be described by a mixing length model derived from Balmforth (1998), which takes into account the vertical squeezing effect on turbulent eddies due to both stratification and distance from the seafloor.

Overall, the results suggest that surprisingly simple behaviour can be extracted from highly turbulent fields if sufficient averaging is performed. This is encouraging in terms of applications, as e.g. simple wall turbulence models may be effectively used in large scale ocean or climate models. However, the results do not explain how the simple average behaviour originates from the complex turbulence dynamics.

Is it possible to estimate KE transfers from HF radar?

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UQAR-ISMER

Input of kinetic energy by the winds in the ocean occurs at very large scales (order 1000km), whereas dissipation of this energy occurs at very small scales (0.01m). Understanding the complete pathways of energy from its input to its sink would be a milestone of physical oceanography. So far, energy transfer for scales larger than 100 km have been inferred from satellite altimeter observations. However, estimates for scales smaller than 100 km are still lacking due to the limited resolution of present-day altimeters. Regional estimates at scales ranging from tens to a few kilometers could in principle be obtained from high-frequency radars (HFR), provided that measurement limitations and noise do not introduce strong biases.

Our goal is thus to assess if new information about how the energy is transferred in this range of spatial scales can be gained from HFRs. To this end, we conduct a feasibility study using a two-layer quasi-geostrophic numerical model, for which the spectral kinetic energy fluxes are well known.From a reference setup with a doubly-periodic domain, we conduct a thorough examination of errors emerging from i) geometrical constraints (non-periodicity, domain size), and ii) measurement constraints (heterogeneous spatial averaging, noise and missing data).

Poster preference

Near-inertial waves in a Mid-ocean Deep Fracture Zone

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Mid-ocean deep fracture zones in the Brazil Basin funnel the densest bottom waters eastward towards the Mid-Atlantic Ridge. As those waters travel to the shallower Ridge, several mechanisms are responsible for their mixing with the shallower layer. To identify such mechanisms, two McLane Moored Profilers (MMPs) sampled 700 m within the canyon, one close to a sill and one away from it. A survey of Deep Microstructure Profilers also measured the dissipation rate of turbulent kinetic energy ε.

In addition to a mean two-layer exchange flow within the fracture zone, downward-propagating near-inertial waves predominantly modulate the shear away from the sill. The kinetic energy of those near-inertial waves intensifies at mid-depth within the canyon compared with the background field above the canyon. Away from the sill, the microstructure dissipation rate ε seems to be modulated by the internal wave field. Using the yearlong MMP, a shear-parameterized ε informs on the diffusive heat flux attributed to those near-inertial waves. We further investigate the interaction of those near-inertial waves with the two-layer mean flow, which is characterized by an increased shear and a reduced stratification. After estimating the internal wave characteristics, a ray tracing method is used to predict the evolution of those near-inertial waves within the background flow.

Comparison of in situ microstructure measurements to different turbulence closure schemes in a 3-D numerical ocean circulation model

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Turbulence closure schemes (TCS) play an essential role in the reliability of the results of physical and biogeochemical numerical models. In the present study, in situ measurements of both turbulent kinetic energy dissipation rate ε and vertical eddy diffusivity Kz are used to assess the ability of k−ε and k−l closure schemes to predict microscale turbulence in a 3-D numerical ocean circulation model of the Gulf of Lion (NW Mediterranean Sea).

Two different surface boundary conditions are considered in order to clarify their influence on each closure schemes' performance. The effects of two types of stability functions and the optical scheme on k−ε are also explored.

Overall, the 3-D model predictions appear to be much closer to the *in situ* data in the surface mixed layer as opposed to below it. Furthermore, k−l scheme's predictions of ε are closer to the observations than the k−ε schemes, in particular below the mixed layer depth. Above the mixed layer depth, the relative performances depend on the boundary conditions. The two closure schemes perform similarly in estimating Kz, with no strong influence of the boundary conditions. The value of the minimum allowed kinetic energy plays a key role in determining the accuracy of model's predictions.

Our study shows as the comparison with in situ microstructure data can effectively help in setting up the implementation of a TCS.

Oral preference

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The Effects of Turbulent Viscosity on Frontogenesis and Diffusion

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Fronts, or regions with large horizontal density gradients, are common features of the upper ocean. Ocean fronts are hotspots for air/sea exchange and marine life. Observations indicate elevated levels of small scale turbulence at fronts, which nevertheless often have a stable density stratification. The dynamical processes that govern this stratification are not well understood. We consider the evolution of an initially balanced front to an imposed turbulent viscosity and diffusivity. Over long times the dominant balance is found to be the quasi-steady Turbulent Thermal Wind (TTW) balance with time-evolution due to an advection-diffusion balance in the buoyancy equation. We use the leading order balance to analytically determine similarity solutions for the spreading of a front and compare our results with numerical simulations.

When the turbulent viscosity and diffusivity are relatively small, the horizontal density gradient intensifies at early times through frontogensis associated with the TTW flow, a result consistent with recent work by McWilliams [2015]. However, when the viscosity and diffusivity are sufficiently large, the front spreads through shear dispersion associated with the vertical diffusivity and the vertical shear of the cross-front velocity. The spreading rate is a function of the Ekman number, and the fastest spread occurs for moderate values of the Ekman number. Further, we find that the density evolves towards a piecewise linear profile in the cross-front direction with a relatively constant gradient inside the front and large curvature at the edges of the front (Fig. 1). The vertical velocity is intensified in the regions of large curvature at the edges of the front, consistent with the instantaneous TTW balance.

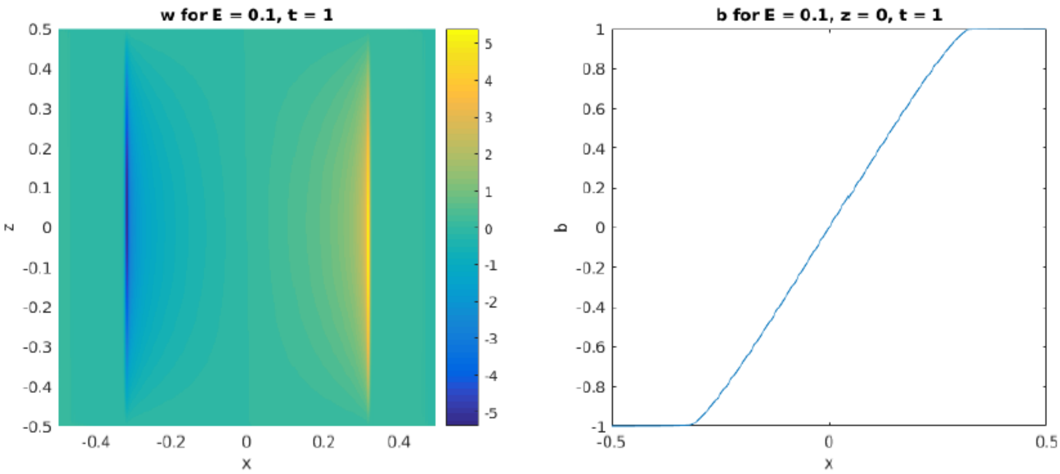

Fig. 1: Vertical velocity, w, and buoyancy, b, through z = 0 for E = 0.1, Ro = 0.025 and t = 1.

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High-resolution observations of wind-driven mixing in the Baltic Sea

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The deepening of the Baltic Sea surface boundary layer (SBL) by wind events is studied using high-resolution observations from winter 2010. A mooring equipped with a velocity profiler and 150 fast-response temperature sensors equally-spaced over the bottom 30 m of the water column (i.e., 20 cm vertical resolution) was deployed. Such unprecedented vertical and temporal resolution gives a new look at the mechanisms controlling the depth of the SBL and the erosion of the permanent halocline in the Baltic Sea. The mooring captured the winter storm Xynthia, which dramatically deepened the SBL. During more moderate wind events, observations also show an increase of the high frequency kinetic energy associated with the wind increase. Relatively high vertical velocities suggest the presence of convective-like motions during these periods. These motions reached the permanent halocline with possible consequences for the ventilation of the anoxic bottom boundary layer. High frequency internal waves propagating on the halocline were also observed and are believed to have been generated by the convective cells impinging upon the density interface. Implications of these findings will be discussed with respect to Langmuir circulation theory, wind-induced mixing parametrizations, and their effect on vertical transport in the Baltic Sea.

Oral preference

Bioturbulence Produced by Diel Vertical Migration of Zooplankton

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Diel vertical migration (DVM) of zooplankton is the largest animal migration on Earth [*Andersen et al.*, 1991] with approximately 15% of all zooplankton biomass undergoing this migration [*Ianson et al.*, 2004]. In certain nutrient-rich areas, up to 30,000 organisms/m^3 of zooplankton can undergo migration [*Hamner*, 1984]. DVM may be a source of fine-scale turbulent mixing on local spatial and temporal scales, though details about the hydrodynamics of this process are still unknown. Kunze et al. [2006] reported an increase of dissipation rate of turbulent kinetic energy by four to five orders of magnitude during DVM of zooplankton over background turbulence in Saanich Inlet, British Columbia, Canada. However, in the same location, this effect was not observed by Rousseau et al. [2010]. In this work, we simulate the effect of turbulence generation by DVM using a 3D non-hydrostatic computational fluid dynamics model with Lagrangian particle injection (a proxy for migrating organisms) via a discrete phase model. We have tested a range of organism concentrations from 1000 to 10,000 organisms/m^3 based on measurements by Greenlaw [1979] and Mackie and Mills [1983] in Saanich Inlet. The simulation at a high concentration of organisms showed an increase in dissipation rate of turbulent kinetic energy by two to three orders of magnitude during DVM over background turbulence (10^{-9} W kg^{-1}), while the simulation conducted with a low concentration of organisms showed almost no turbulence generation above the background level. These results suggest that zooplankton concentrations were larger during the measurements by Kunze et al. [2006] than during the Rousseau et al. [2010] measurements. In addition, an 11-month data set obtained from a bottom-mounted acoustic Doppler current profiler (ADCP) in the Straits of Florida revealed strong sound scattering layers undergoing DVM. There was a small decrease in northward current velocity profiles during migration times after averaging over the 11 months of ADCP observations. In the simulation with an extreme concentration of particles (10,000 org/m^3), 25 minutes after injection, there was a small decrease in current velocity qualitatively similar to that seen in the field data. Quantitatively, the decrease observed from the ADCP measurements is an order of magnitude smaller than that modeled, which can be explained by the much smaller average concentration of zooplankton in the Straits of Florida than in the simulation. Comparison of the model and average ADCP velocity profiles is also complicated by their substantial dependence on the environmental conditions that are not directly related to DVM including wind/wave mixing, meandering of the Florida Current and tides. In principle, diurnal cycles, breezes, and tides can have an effect on the velocity field even at 20–30 m depth.

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Using the age to diagnose the evolution of turbulence kinetic energy and, possibly, other variables unrelated to the concentration of a constituent

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Timescales such as the age, the residence time or the exposure time have proven to be of use to diagnose reactive transport processes in complex geophysical and environmental fluid flows. In this respect, the Constituent-oriented Age and Residence time Theory (CART, www.climate.be/cart_flyer) provides partial differential equations from which the aforementioned timescales may be derived, taking into account the impact of advective and diffusive transport as well and reactive processes without having recourse to crude simplifying assumptions.

So far CART has been applied to dissolved or particulate constituents, or aggregates thereof such as seawater. It is suggested that similar ideas may be applied to quantities of another nature such as the turbulence kinetic energy (k). The age of the latter may be defined as the time elapsed since production by shear occurred. Then, inhibition by stratification, viscous dissipation (whose rate is ε) and transport phenomena are taken into account much in the same manner as for a tracer subject to transport and destruction phenomena. Idealised situations leading to analytical solutions are tackled that tend to lend credence to this approach. Then, numerical simulations are carried out, addressing more complex flows. It is seen that, unsurprisingly, the age of the turbulence kinetic is generally of the order of k/ε. Deviations therefrom are possibly caused by hysteresis or diffusive processes.

An attempt is made to apply similar ideas to functions that, unlike concentrations or the turbulence kinetic energy, are not positive definite, such as the perturbation of a variable (e.g. temperature, pressure) due to changing environmental or climatic conditions. The first step is to define an associated positive definite quantity governed by the relevant reactive transport equation. Then, idealised and realistic situations are considered, allowing for a preliminary assessment of the well-foundedness of the application of the age concept to such variables.

Poster preference

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The effect of stratification and topography on internal waves in a continental shelf sea

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Internal gravity waves (IWs) have been recognised to be of immense importance on a variety of temporal and spatial scales - as a driver of the climate controlling circulation, sustaining fisheries in shelf seas and CO2-pump system. High frequency IWs are particularly important to internal mixing in the shelf seas, where they contain an enhanced fraction of the available baroclinic energy. The origin, generation mechanism, propagation and spatial distribution of these waves are unfortunately still poorly understood since they are difficult to measure and simulate, and are therefore not represented in the vast majority of ocean and climate models.

In this research we aim to increase our understanding of IWs dynamics over different topographies and with different stratifications in a continental shelf seas through a combination of observational (from moorings and ocean gliders) and modelling methods (MITgcm). Our analysis of two separate sites from observational data, both situated ~20km from the continental shelf break, shows that the energetics of low frequency IWs differs slightly between sites, which can be explained through variable local and remote forcing, however baroclinic energy distribution at high frequencies has a significant difference between sites, one being enhanced by ~60%. To identify the generation hotspots and propagation of IWs in a regional shelf sea we used a new high-resolution (50m horizontal) MITgcm configuration. Our model suggests that under increasing stratification, the IW field becomes more energetic at all frequencies, however the increase in energy is not evenly distributed. While energy in the dominant low frequency IWs increase by 20-40 per cent, energy associated with high frequency waves increases by as much as 90 per cent. These model results are compared to varying stratification scenarios from observations made during 2012 and 2013 to interpret the impact on continental shelf sea IW generation and propagation. We use the results from a turbulence enabled ocean glider to assess the impact that this varying wave field has on internal mixing, and discuss the implications this might have on future climate scenarios.

Oral preference

Estimating turbulence from Seagliders

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The dissipation of turbulent kinetic energy is estimated using observations of Seaglider vertical water velocity in the subtropical North Atlantic. The method is based on the large-eddy method utilised by [*Beaird et al.*, 2012]. This approach relies on the assumption that the flux of turbulent energy between scales is steady, allowing the energy at relatively large scales (O(1-10m)) to be used to estimate the energy lost through viscous processes. The Seaglider observations used here were made in a region of relatively high stratification. Previous application of the large-eddy method relied on a high-pass spatial filter to remove signals larger than 30m. This filter was designed to remove unwanted internal wave variability in the vertical water velocity. In regions of high stratification, this approach is not sufficient to remove internal wave variability. In order to target fluctuations not associated with internal waves, the method developed here uses a high pass filter based on the local buoyancy frequency. This approach naturally removes variations in vertical water velocity due to internal waves in regions of both high and low stratification. Using this method, we produce a depth-time series of dissipation spanning the top 1000 m and several months at sub-daily resolution. Independent verification of the method is achieved using a time series of dissipation from a moored 600 kHz ADCP [*Lucas et al.*, 2014].

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Poster preference

The dissipation of kinetic energy in the Lofoten Basin Eddy

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The Lofoten Basin of the Norwegian Sea acts as a reservoir for the warm Atlantic Water. The region is recognized as an area with substantial heat losses and intense mesoscale activity. A long-lived, deep anticyclonic vortex is located in the central part of the basin (the Lofoten Basin Eddy, LBE), energized by eddies shed from the boundary current over the adjacent continental slope. Under the PROVOLO project, full-depth ocean microstructure profiles were collected in June 2016, to study the turbulent structure of the LBE in unprecedented detail. A set of two free-fall, deep vertical microstructure profilers (VMP5500 and VMP6000, Rockland Scientific) was utilized, supplemented by hydrographic and velocity measurements from the ship. Dissipation rate of turbulent kinetic energy per unit mass is measured to a noise level of 10^{-11} W kg^{-1}, down to 50-100 m above the sea bed in 3200 m depth.

During the cruise period the LBE was characterized by a radius of 20 km, upper 500-m averaged anticyclonic azimuthal peak velocity of 0.8 m s^{-1}, and core relative vorticity of -0.8f (f is the local Coriolis parameter). Contrasting the dissipation profiles from the energetic LBE environment with a typical reference station in the basin reveals that the LBE site is significantly turbulent between 750 and 2000 m, exceeding the dissipation values in the reference station by up to two orders of magnitude. We observed a multi-layer core structure where 500-m thick well-mixed layers were separated by pycnoclines. While each pycnostad had negligible dissipation levels (< 3x10^{-11} W kg^{-1}), the interfaces were associated with substantial background velocity shear and high dissipation rates reaching 10^{-8} W kg^{-1}. Near the rim of the eddy, the velocity profile shows a subsurface maximum near 1000 m, reaching 0.9 m s^{-1}. The depth of the velocity maximum has negligible shear production and dissipation rates, however, the strong shear layer below the velocity maximum is turbulent with dissipation rates above 10^{-8} W kg^{-1}. We hypothesize that the source of energy to maintain the observed rates of dissipation of kinetic energy is the near-inertial energy trapped by the negative vorticity of the eddy.

Oral preference

Mean flow generation by an intermittently unstable boundary layer over a sloping wall

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Although the steady Ekman boundary has been extensively studied in the literature, the less attention has been paid to an unsteady boundary layer when the wall is not perpendicular to the rotation axis. In oceanography this case is representative of the tidal motion over the continental shelf. In this work we show that the unsteady boundary layer has properties of the Stokes (a kind of damped wave or evanescent wave) and Ekman (mass flux parallel to the wall) boundary layers, and study the development of intermittent turbulence and generation of a mean flow. The boundary layer is generated using a variable frictional stress provided by time periodic variation of the rotation rate (longitudinal libration) of an inclined wall annulus. According to the inclination angle of the inclined wall, librational forcing and Coriolis force are realized to have different contribution to the boundary layer dynamics. Three flow regimes i) libration dominated regime (Ghasemi et al. 2016), ii) libation-rotation dominated regime and iii) rotation dominated regime are identified. For high enough libration amplitude, the boundary layer becomes intermittently unstable, generating Gortler vortices as a discrete event. Direct numerical simulations (DNS) of the fluid flow in an annular container with librating inner inclined wall showed explosive radial propagation of the vortices into the fluid interior and generation of a zonal mean flow. We show that the vortices which are generated due to the Stokes property of the boundary layer are deflected due to a mass flux within the boundary layer which is the Ekman property of the boundary layer. In fact, we will show how the two forces compete and enhancing or inhibiting the mean flow generation in the fluid interior. To see how the boundary layer dynamics is changed in terms of the dominating force, the Reynolds-averaged Navier-Stokes (RANS) equations as a diagnostic tool is used to investigate generation mechanism of the zonal mean flow in the bulk.

Oral preference

Conservation laws and inertial-symmetric instability

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Submesoscale oceanic density fronts are structures in geostrophic and hydrostatic balance, but are more prone to instabilities than mesoscale flows. We here present two-dimensional (x, z) Boussinesq numerical experiments of submesoscale baroclinic fronts on the f-plane. Mixed inertial-symmetric instabilities (ISI) (the actual name varies across the literature) develop, with the absence of along-front variations prohibiting baroclinic instabilities. Two new salient facts emerge. First, contrary to pure inertial or pure symmetric instability, the potential energy budget is significantly affected, ISI extracting significant available potential energy from the front. Second, in the submesoscale regime, the growth rate of ISI is sufficiently large that significant radiation of near-inertial internal waves occurs. Although energetically small compared to e.g. local dissipation within the front, this process might be a significant source of near-inertial energy in the ocean.

Oral preference

Preliminary comparison of microstructure data collected from Seaglider and Slocum glider platforms

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A Kongsberg Seaglider and Teledyne-Webb Slocum glider, both equipped with Rockland Scientific microstructure sensor systems, were deployed in Loch Linnhe, on the west coast of Scotland, to compare the performance of the sensors and suitability of the glider platforms. The Slocum glider was equipped with a top-mounted MicroRider self-contained microstructure system with twin shear probes, twin fast-response thermistors, and a micro-conductivity sensor. The Seaglider was equipped with a compact MicroPods system with a single shear probe and single fast thermistor mounted either side of the glider's conductivity-temperature sail. The gliders were operated in the deepest part of the loch, diving to approximately 180 m every hour, and reasonably co-located (within 1.5 km) for 18 hours.

Turbulent kinetic energy dissipations rate (ε), derived from the shear probe data, are qualitatively similar for the two platforms. Patches of high ε are observed both near-bottom and mid-depth during salinity-compensated temperature inversions associated with the loch exchange circulation. Despite the short timeseries, there is evidence of tidal modulation of ε in the lower layer. There are no significant differences between profiles of ε measured during the Seaglider descents and ascents. A detailed, quantitative comparison of the two datasets is in progress.

No preference

Isoneutral control of effective diapycnal mixing in numerical ocean models with neutral rotated diffusion tensors

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The current view about the mixing of heat and salt in the ocean is that it should be parameterised by means of a rotated diffusion tensor based on mixing directions parallel and perpendicular to the so-called local neutral vector. An important difficulty with this approach, however, arises from the impossibility to construct a density variable in the ocean that is exactly neutral because of the coupling between thermobaricity and density-compensated temperature/salinity anomalies. Therefore the use of neutral rotated diffusion necessarily implies that the effective diapycnal diffusivity experienced by any possible density variable is partly controlled by isoneutral diffusion. Here, this effect is quantified for five density variables: Jackett et al. 1997 γ_n, Lorentz reference state density ρ_{ref} [*Winters* et al. 1996], and three potential density variables σ_0, σ_2 and σ_4, using the World Ocean Circulation Experiment climatology, assuming either a uniform value for isoneutral mixing or spatially varying values inferred from an inverse calculation. Effective diapycnal mixing values larger than 10^{-3} $m^{2/s}$ are systematically found in the deep ocean for all density variables, with γ_n suffering the least from the isoneutral control of diapycnal mixing, and σ_0 the most. These high values are due to spatially localised large value of non-neutrality, mostly in the deep Southern Ocean. Removing only 5% of these high values on each density surface reduces the effective diapycnal diffusivities to less than 10^{-4} $m^{2/s}$. This work highlights the potential pitfalls of estimating diapycnal diffusivities by means of Walin-like water masses analysis or in using Lorenz reference state for diagnosing spurious diapycnal mixing.

Poster preference

Evolution of turbulence in a rotating gravity current descending on a topographic slope

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The Baltic Sea is a system of shallow brackish basins, connected to the salty waters of the North Sea by the danish Sound and belts. The density difference between the North Sea and the Baltic Sea intermittently triggers bottom gravity currents (so called Major Baltic Inflows, MBI) that may travel over hundreds of kilometers along the bottom topography towards the deep central basins of the Baltic Sea. This configuration, and the relatively easy accessibility with oceanic instrumentation, makes the Baltic Sea an ideal natural laboratory for the study of rotationally influenced bottom gravity currents.

In March 2015, one of the largest oxic dense-water inflows of the last 50 years entered the anoxic deep layers of the central Baltic Sea, with a water volume large enough to replace and oxygenate the deep water body. During this event turbulence microstructure and velocity (ADCP) transects across the bottom gravity current have been obtained. In addition to the ship-based measurements an autonomous profiling system was deployed in the Gotland Basin, the deepest part of the central Baltic sea and the location where the gravity current finally settles. This mooring was equipped with standard sensors as CTD and velocity meters as well as a temperature microstructure turbulence package. This sensor combination made it possible to estimate turbulent parameters like the temperature variance decay (χ) and the dissipation of turbulent kinetic energy (ε) during the pre-inflow phase, the inflow, and the time after the main inflow.

During the active inflow phase, our data reveals a vigorously turbulent bottom gravity current of 10-20 m thickness, traveling, strongly affected by rotation, along the slope of one of the main basins, finally merging with its lower flank into a pre-existing pool of dense bottom waters. The inflow reached the central part of the basin in a front-like pattern with cold intrusions interleaving with warm ambient waters. These large-scale temperature variabilities were, however, not reflected in an increase of temperature microstructure. This surprising result indicates that, after the detachment of the gravity current from the basin boundary on its way to the central part of the basin, turbulence levels decreased to those typically observed during a stagnation (non-inflow) period. The buoyancy Reynolds numbers calculated from ε, the buoyancy frequency N^2, and the viscosity ν, $Re_b = \varepsilon/(\nu N^2)$ was most of the cases well below 2, which can be considered a threshold for turbulent activity. Generally, the majority of the measurements with $Re_b > 2$ was within the range of 2 to 50, where strong anisotropy of turbulence is expected. A consequence of the low interior turbulence levels, even during such an intensive inflow, is the importance of boundary mixing processes for basin scale mixing rates.

Oral preference

Fast-ice control of TKE dissipation rate on the West Antarctic Peninsula shelf

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The ocean-to-atmosphere heat budget of the West Antarctic Peninsula is controlled in part by the upward flux of heat from the warm Circumpolar Deep Water (CDW) layer that resides below ~200 m to the Antarctic Surface Water (AASW), a water mass which varies strongly on a seasonal basis. Recent fine structure analysis [Brearley et al., 2017] estimates mean upward heat flux of ~1 W m^{-2}, with the largest heat fluxes occurring shortly after the loss of winter fast ice when the water column is first exposed to wind stress, without being strongly stratified by salinity. Here we report on new shear microstructure observations made at the same site during both summer ice-free and winter fast-ice conditions. In late summer (February 2016) the water column above the CDW is temperature stratified in the upper 75 m (above the temperature minimum of the preceding winter's mixed layer) and salinity stratified throughout. Stratification is maximum just above the temperature minimum at about 75 m (s_q = 27.0). Mean epsilon (47 profiles) is elevated in the upper layer, and falls by an order of magnitude between ~80 m and 100 m, remaining at that lower level down to the maximum measurement depth (300 m). By way of contrast, in mid-winter (July 2016) and in the presence of continuous fast-ice, temperature is homogeneous at freezing point to ~45 m and weakly salt stratified below 15 m. Beneath ~45 m T and S increase monotonically with depth, with a weak broad stratification maximum at ~100 m (marking the perennial halocline). Winter epsilon levels in the uppermost 15 m are the highest measured in the winter water column and, though marginally lower, are, unexpectedly, statistically indistinguishable from summer values. Beneath this shallow under-ice boundary layer, epsilon levels fall to near-detection limits down to the maximum measurement depth (~300 m). From 15 m to 100 m epsilon values under winter fast-ice are an order of magnitude lower than the summer ice-free mean values (statistically significant). From 100 m to 300 m the winter epsilon values are lower than summer, but

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with weaker statistical significance. The deep upward heat flux from the CDW is confirmed to be ~1 W m^{-2} in both late summer and mid-winter, with a slight reduction in winter. The effect of isolating the shelf waters from wind during times of fast-ice cover, though, fundamentally changes the turbulent state of the upper water column. Concurrent wind speed and current profile measurements are used to scale the dependence of epsilon in these contrasting regimes on atmospheric and oceanic energy input.

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Poster preference

Enhanced vertical mixing by internal tides in the northern East China Sea in summer

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The East China Sea (ECS), a marginal sea of the North Pacific Ocean, is one of the most important regions for internal wave generation and associated turbulence mixing. Here we present observed evidence of intense turbulence dissipation near the thermocline and in the bottom boundary layer (BBL) in the northern ECS during summer, based on microstructure profile measurements in Augusts of 2005 and 2006. The 25-hour long timeseries measurement of the microstructure in the northern ECS in summer reveals that the enhanced turbulence dissipation rate along the thermocline occurs at almost every six hours, indicating influence of internal tide stirred by semi-diurnal tide (M2) that is dominant in the observed area. The intrusions of enhanced near-bottom turbulence into the upper layers are also observed. This intrusion, together with oscillation of the BBL height, strongly suggests influence of the semi-diurnal tide (M2) on strong vertical mixing in the BBL. The elevated vertical mixing by the internal tide would enhance nutrients supply into the thermocline from the deep waters, and thus support elevated chlorophyll-a (Chl-a) that has been frequently observed within the thermocline in the northern ECS during summer. Our findings suggest that internal-tide induced vertical mixing may play an important role in nutrient budget and thus Chl-a concentration in the continental shelf in the northern ECS.

Poster preference

Submesoscale Turbulence in a Mixed Layer Front: Observations, Dynamics and Implications

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Submesoscale turbulence is an important pathway in the energy transfer from mesoscale flows to small-scale dissipation, yet observations of these processes are rare due to the challenges of resolving the relevant spatial and temporal scales. Here, a neutrally buoyant, subsurface Lagrangian float was deployed in a small mixed layer front within the California Current System as part of the Assessing the Effect of Submesoscale Ocean Parameterizations (AESOP) program. Its trajectory was acoustically tracked, allowing the region surrounding the drifting float to be intensely surveyed by a ship towing a Triaxus profiler. The survey lasted 30 hours as the float traveled approximately 50km along the front. This Lagrangian approach provides uniquely detailed measurements of the frontal structure and evolution within and below the boundary layer. The frontal evolution can be divided into two stages. Initially, downfront winds incite mixing and the float repeatedly traverses the 15m deep boundary layer. Directly below, but above the stratified pycnocline, lies a distinct 15m-thick layer of stably-stratified fluid with negative potential vorticity, evidence of symmetric instability. As winds relax and vigorous mixing subsides, the front continues to evolve and the system enters a different regime en route to mixing. Fields of salinity and chlorophyll reveal intrusive features, implying cross frontal exchange and subduction of water masses. Buoyancy flux estimates and inferred vertical velocity from the float are compared with theoretical scalings of submesoscale dynamics. Initially, buoyancy flux estimates are consistent with the expected response to downfront winds, but as the front evolves, observational estimates deviate from theoretical predictions. During this stage, tracer distribution and inferred circulation provide insight into mechanisms at play. These results affirm the role of small fronts in mixing tracers in both the forced and unforced upper ocean.

Oral preference

Effects of vertical mixing on low trophic ecosystem in the Ulleung Basin, East Sea

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Ulleung basin (UB) in the southwestern East Sea shows relatively high primary productivity even in summer. The high productivity is probably associated with nutrient supply by vertical mixing, horizontal transport by ocean currents, or eddy-induced upwelling. In this study we investigated effects of vertical mixing on low trophic ecosystem in the UB using a one- dimensional physical-biological model (1D GOTM-ERSEM), focusing on timing and intensity of phytoplankton bloom. Stratification in the model was given by three different cases with different degree of reality. We found that proper representation of stratification plays a crucial role in timing of phytoplankton bloom by controlling nutrient supply in winter. However, the diatom, a dominant phytoplankton in spring bloom in the UB, was poorly simulated both in timing and strength of bloom, indicating importance of horizontal transport of silicate supply.

Poster preference

A numerical study of wind and tidal mixing in Maryland Coastal Bays

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The wind and tidal induced mixing in the Maryland Coastal Bays System (MCBs) during September 2004 were simulated using a three-dimensional unstructured-grid based hydrodynamic model. Sensitivity experiments were then carried out to investigate the impact of wind forcing and tidal forcing on vertical mixing conditions based on the calibrated model. Potential energy anomaly and turbulent kinetic energy were applied to evaluate the vertically mixed conditions of the MCBs, especially around the two inlet areas (Ocean City Inlet and Chincoteague Inlet), where deeper than the overall shallowness of bathymetry inside of the MCBs. In this shallow bay, both winds and tides contribute to vertical mixing, of which, the effects of tides were found to be more significant on vertical mixing of inlet areas. Wind forcing is the key role for the vertical mixing in the northern part of the MCBs due to the narrow entrance of Ocean City Inlet. Meanwhile, the vertically mixed conditions of the MCBs were examined from the aspects of inlet existence. Sensitivity tests involving closure of either inlet elucidated that closing either inlet results in a significant effect on the vertical mixing conditions of the MCBs. It was found that tidal forcing from Chincoteague Inlet is the major source to the mixing of Chincoteague Bay. With the only entrance of narrow Ocean City Inlet, the average potential energy anomaly of the MCBs enhances by approximately 20%.

Poster preference

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Ocean mixing beneath Pine Island Glacier ice shelf, West Antarctica

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We present the first measurement of turbulence beneath an ice shelf cavity. Ice shelves around Antarctica are vulnerable to an increase in ocean-driven melting. Melting of ice shelves will result in reducing the basal traction of ice sheets resting upstream, thereby mediating the ice sheet's contribution to sea-level rise. The melt rate of ice shelves depends on ocean temperature and the strength of circulations inside the ice-shelf cavities. We present measurements of velocity, temperature, salinity, turbulent kinetic energy dissipation rate and thermal variance dissipation rate beneath Pine Island Glacier ice shelf, West Antarctica. These measurements were obtained by CTD, ADCP and turbulence sensors mounted on an Autonomous Underwater Vehicle (AUV). The highest turbulent kinetic energy dissipation rate is found near the grounding line, where the floating ice shelf is joined to its tributary ice streams. The thermal variance dissipation rate increases closer to the ice-shelf base, with a maximum value found ~0.5 m away from the ice. The observed turbulent kinetic energy dissipation rate near the ice is used to estimate basal melting of the ice shelf. The dissipation-rate-based melt rate estimates is sensitive to a parameter in the linear approximation of universal function of the Monin-Obukhov similarity theory for stratified boundary layers. We argue that our estimates of basal melting from dissipation rates are within a range of previous estimates of basal melting.

Presentation : No preference

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Vertical structure of the turbulence intensity and power density in an asymmetrical tidal flow : turbulence measurements in the Eastern English channel

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The present study demonstrates the time-depth variation of the mean current, turbulence intensities, Reynolds stresses and power densities for a 30-m depth tidal energy site in the Eastern English Channel. The variables were derived from two-week of high-frequency ADCP measurements, which covered calm and storm periods. The direct turbulence measurement data were revisited with aim of assessing of a tidal energy site.

The study site is located in the tidal strait that exhibits quasi semi-diurnal tidal current characteristics with a streamwise tidal velocity varied from 1.1 m s^{-1} on the north-eastward flood flow to 0.7 m s^{-1} on the south-westward ebb flow, and turbulence intensity varied from 0.10 to 1.0 depending on the magnitude of mean current and weather conditions.

Being nearly bi-directional flood and ebb flow directions with higher magnitude during flood tide, the tidal current skews the power production towards the flood tide period, where maximum power density reached about 0.15 kW m^{-2} while, on the ebb, average power density does not exceed 0.1 kW m^{-2}. In addition to factors inherent to the tidal site studied, the asymmetry of turbulence was revealed to be strongly tied with wind and wave variabilities and their interaction with tidal turbulence.

During the calm period, the minimum of streamwise turbulent intensity, on the flood and ebb peaks, decreased to about 0.1 - 0.15 within the layer of 5 – 15 meters above the bottom (m.a.b.). During the storm period, the turbulence intensity significantly enhanced when sustainable southwesterly winds blown oppositely to the ebb current. In such coincidence, the overall level of the turbulence intensity increased. Its magnitude minimum of 0.23 locating near the bottom sharply increased away from the bottom. On the flood, depth range where the turbulent intensity decreasing to its minimum of about 0.12 extended to 5 m, from 5 to 10 m.a.b.

The study suggests that the observed site is suitable as a power energy site in a very narrow range of depth, from 5 to 8 m.a.b., beyond of which the ebb-flood asymmetry and wind/wave-induced turbulence appear to cause unsteady blade loads and premature failures of tidal turbines. Moreover, for this particular site on the ebb tide in periods of strong sustainable southwesterly winds (> 10 m s^{-1}), the turbulence intensity will grow significantly throughout the water column presuming that an operation of tidal turbines is likely to be unsafe and insecure.

Oral preference

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Turbulent cooling of a UCDW eddy on the Antarctic Continental Slope

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Water mass transformation of Upper Circumpolar Deep (UCDW) upwelling in the Southern Ocean is a critical driver for the Meridional Overturning Circulation that in turn mediates global climate. How the warm salty UCDW encroaches and then is transformed onto the Antarctic continental shelves where it can impact the sea-ice processes driving Antarctic Bottom Water (AABW) formation remains a key question. Recent observations provide evidence that mesoscale and sub-mesoscale eddies contribute to the overturning by fluxing CDW across the Antarctic Peninsula and Weddell Sea Continental slopes [*Thompson et al, 2014, Stewart et al., 2016, Ericksen et al., 2016*]. We present EM-APEX float observations of a UCDW bolas propagating along the Antarctic continental slope north of the Antarctic Peninsula. The float captures direct heat exchange between a parcel of UCDW and Lower Circumpolar Deep Waters (LCDW) at mid-depths over the course of several days. Heat fluxes peak across the top and bottom boundaries of the UCDW parcel and peak diffusivities across the bottom boundary are associated with shear instability. Estimates of diffusivity from shear-strain finestructure parameterisation and heat fluxes are found to be in reasonable agreement. The two-dimensional Ertel potential vorticity is elevated both inside the UCDW parcel and along its bottom boundary, with a strong contribution from the shear term in these regions and instabilities associated with gravitational through symmetric forcing arising from the interaction of the eddy with the barotropic tide. Hence waters mix vertically across the bottom boundary of the UCDW parcel, injecting heat at mid-depths and transforming as heat, mass and buoyancy are lost from UCDW to LCDW. This has implications for our understanding of rates of upwelling and ocean-atmosphere exchange of heat and carbon at this critical location.

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Oral preference

Spatial distribution of turbulent mixing in the upper ocean of the South China Sea

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The spatial distribution of the dissipation rate and diapycnal diffusivity in the upper ocean of the South China Sea (SCS) is presented from a measurement program conducted from April 26 to May 23 2010. In the vertical distribution, the dissipation rates were predominantly high in the thermocline where the shear and stratification were strong. In the regional distribution, high dissipation rate and diapycnal diffusivity were observed in west of the Luzon Strait with an averagedand of 8.3×10^{-9} W/kg and 2.7×10^{-5} m^2/s, respectively, almost one order of magnitude higher than those in the central and southern SCS. In the west of the Luzon Strait, the water column was characterized by strong shear and weak stratification. Elevated dissipation rates ($>10^{-7}$ W/kg) and diapycnal diffusivity ($>10^{-4}$ m^2/s) induced by shear instability occurred in the water column. In the central and southern SCS, the water column was characterized by strong stratification and weak shear and the turbulent mixing was weak. The observed dissipation rates were found to scale positively with the shear and stratification, which was consistent with the MacKinnon-Gregg model used for the continental shelf, but different from the Gregg-Henyey scaling used for the open ocean.

Poster Preference

Underwater Glider Measurements and Simulations of Storm-Induced Abrupt Upper Ocean Mixing

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Within the framework of the Canadian Ocean Tracking Network (OTN) program, two Teledyne Webb Research Slocum electric gliders (OTN200 and OTN201) were deployed near-continuously along the Halifax Line, running from Chebucto Head to approximately 250 km offshore from Nova Scotia. On mission 34, during the period between 2014-06-26 15:47:00 and 2014-07-15 13:32:13, the glider OTN200 captured the ocean temperature and salinity responses to the fast-moving North Atlantic storm: Hurricane Arthur. The glider collected data for the high spatial and temporal ocean vertical structure, thus providing a unique opportunity to investigate the ocean environment and test the 1D dynamical processes, such as the current shear and wave-induced turbulence, under hurricane force winds. The hurricane winds and wave forcing are provided by model simulations: Rutgers RuWRF and WAVEWATCHIII simulations. These were shown to validate well against measurements from three moored NDBC buoys 44258, 44137 and 44150, which are located close to the track of the glider. Based on an application of the one-dimensional General Ocean Turbulence Model (GOTM) *k*-epsilon equations, inclusion of the surface waves effects by wave breaking, Coriolis-Stokes force (CSF) and Langmuir turbulence (represented as the Stokes shear in Turbulent Kinetic Energy (TKE) equation), the temperature and salinity evolution is simulated and compared with the glider observations. *It is found* that the surface wave effects, wave breaking (momentum and energy) and Langmuir turbulence play an essential role in improving the performance of GOTM simulations. In detail, without considering the Langmuir turbulence, the SST cooling is underestimated by the model by about 0.7 degree, as detected by the data. Furthermore, inclusion of the Langmuir turbulence significantly improves and dominates the surface wave impacts on the upper ocean cooling and the warming of the upper thermocline water in the forced-stage of the storm. Without the Langmuir turbulence effects, in the upper 25 meters, temperature is underestimated by an average of 0.5 degree, whereas in the range from 25 to 40 meters, the overestimate is an average of 0.7 degree. The surface wave breaking is parameterized as (i) a source of energy fluxes at the surface in TKE equation and (ii) a body force in the present study. It is shown that the body force scheme is more effective than that of an energy flux, which has an effect that is limited to the uppermost portion of the ocean. The simulation results also indicate that the CSF effect might be negligible under severe storm conditions, since it takes more time to affect the lower depth currents. The present study provides a unique opportunity to test the various processes in setting up the ocean response to fast-moving storms for one-dimensional processes, and helps understand the surface wave role in the ocean response to strong winds.

Oral preference

Assessment of the impact of the turbulence closure schemes on the nutrient availability in shelf sea models.

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Simulating the North West European shelf seas using the NEMO Atlantic Marginal Model configuration with 7km resolution (AMM7), coupled with ecosystem model ERSEM, we examine 5 different subgridscale turbulent closure schemes on the ability to reproduce observed turbulence and ecosystem characteristics. We will compare profiles of modelled dissipation rate of turbulent kinetic energy, velocity shear and nutrients (nitrate and phosphate) to data measured in the Celtic Sea. The impact of nutrient availability on the vertical distribution of phytoplankton will be explored by comparing modelled chlorophyll-a with observed profiles to gauge the impact of the different turbulence closure schemes on the existence and location of the sub-surface chlorophyll maximum.

We discuss effects of nonlinear internal tides, wind-induced near- inertial waves and anisotropy, that arise from non-traditional Coriolis force to explain deficit of turbulence and weak correlations between predicted and observed dissipation rate of TKE. We propose a closure for structural functions with effects of non-traditional Coriolis force and estimate these effects in the mixed layer and pycnocline.

Oral preference

Mesoscale Eddy Induced Nutrient pumping and its Biological Response in the North Eastern Arabian Sea during Winter-Spring Transition

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A Cold Core Eddy (CCE) induced nutrient pumping in the North Eastern Arabian Sea (NEAS) is explained based on *in situ* measurments during March 2013 onboard FORV *Sagar Sampada* which was not reported earlier in the area. Samples for physical, chemical and biological parameters were collected in 5 stations along the diameter of the eddy and following standard protocols. The core of this mesoscale CCE is identified at 21°20.38'N; 66°30.68'E with a diameter of 120Km. Earlier studies [Smitha, 2013], explaining the process and the forcing mechanism of the particular eddy records that, the eddy is short term (1-3 months) and is regular during the season. Surface waters were well oxygenated (>4.8 ml L^{-1}) in the core. Mesoscale eddies modulate nutrients into the euphotic zone through vertical and horizontal transport and the surface values of nutrients viz., Nitrate, Nitrite, Silicate and Phosphate in the core regions was 0.9µM, 0.01 µM, 0.5 µM and 0.7 µM respectively indicating upwelling in the core.

Spring intermonsoon (SIM) is generally termed as a transition period between the active winter and summer seasons and as per earlier studies, high biological production and the regularly occurring *Noctilica* bloom is supported by the nutrient loading due to convective mixing during winter as well as regenerated production. However, present observations shows that, nutrient pumping due to the upwelling associated with the CCE also contributes for sustaining high biological production and are evident in the Chl *a* and mesozooplankton biovolume which records values of 4.35mg/m^3 and 1.09ml/m^3 respectively in the core. An intense Noctiluca blooms observed in the western flank of the eddy (Chl *a* 13.25 mg/m^3; cell density 5.8×106 cells/litre), where Nitrate concentration records 1.04µM explains the role of such mesoscale processes in the sustenance of the HAB events. While eastern flank of the CCE showed typical open ocean condition of the season showing Nitrate 0.08µM; Chl *a* 0.23mg/m^3; and phytoplankton cell density as 421 cells/litre.

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Poster preference

Turbulence induced by overturning breaking waves: from small scale mixing to large scale overturning circulation

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Turbulent mixing in the abyssal ocean, where stratification is relatively weak and shear is strong in vicinity of rough topographic features, is facilitated by continuous formation and breaking of large overturns which can arise in different forms such as shear instabilities or convectively breaking internal waves, among others. We will connect the fluid dynamical basis of such breaking events to their corresponding mixing rates as diagnosed from models or inferred from observations. We will highlight the significant contribution to mixing of the phase of turbulence in which large scale overturns and small scale isotropic turbulence coexist. Such phase is often systematically ignored in parameterization schemes used to infer mixing from observations and is frequently left out of analysis of direct numerical simulations in favor of better agreement with assumptions made in the aforementioned parameterization schemes: this poses a circular problem. We attempt to quantify the inaccuracies that such assumptions and systematic biases introduce in estimates of mixing. We finish by putting our findings in a big-picture perspective by showing that such errors are leading order insofar as the diagnosis of the rate of overturning of the mixing-induced abyssal branch of global meridional overturning circulation is concerned.

Oral preference

Measurements of the Rate of Dissipation of TKE in a High Reynolds Number Tidal Channel Using ADCPs and Shear Probes

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The rate of dissipation, ε, of turbulent kinetic energy at mid-depth in a high speed tidal channel is estimated using measurements from both a standard acoustic Doppler current profiler (ADCP) and shear probes mounted on an underwater, streamlined buoy "flown" at 10 m above the bottom. The investigation was carried out in Grand Passage, Nova Scotia where the depth-averaged flow speed reaches 2 m/s and the water column is well-mixed. Speed-bin averaged dissipation rates estimated from the ADCP data agree with the shear probe data to within a factor of two. Furthermore, both the ADCP and the shear probe measurements indicate a linear dependence of ε on the cube of the flow speed during flood tide, whereas on the ebb tide the dissipation rate is lower and comparatively independent of flow speed. Possible sources of bias and error in the ADCP estimates are investigated, and the most likely cause of the discrepancy is the 40 m cross-channel separation of the instruments and the high degree of spatial variability in the passage.

Oral preference

The impact of advection schemes on restratification due to lateral shear and baroclinic instabilities

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Despite the progress in computing technology and the development of new advection schemes, the role of advection schemes in oceanic flow formation and its evolution is not well verified. In addition, a host of studies has recognized that truncation errors of the discretized advection terms lead to spurious mixing and dissipation and may interact nonlinearly with turbulent mixing and transport. To investigate the impacts of spurious mixing and dissipation, we implemented some of the most novel advection schemes into the General Estuarine Transport Model (GETM). We quantified spurious dissipation [*Klingbeil*, 2014] and mixing of the advection schemes in idealised experiments of lateral shear and baroclinic instabilities ranging from mesoscales to sub-mesoscales. Such analyses help to choose between highly accurate but complex schemes and lower order less complex schemes balancing accuracy and computational costs. The analyses show that the WENO advection scheme minimizes the absolute numerical dissipation more than the majority of other used advection schemes. In addition, the MP5 scheme and the SPL-max- 1/3 scheme (a TVD scheme) provide the best results concerning best energy conservation. In terms of computational costs, the MP5 scheme is approximately 2.3 times more expensive than the SPL-max- 1/3 scheme in our implementation. While the advection schemes behave similarly for sub-mesoscale dynamics, the differences between the impacts of the schemes are apparent for mesoscale dynamics. The major outcome of the present study is that both, numerically induced dissipation (leading to a decrease of kinetic energy) and numerically induced mixing (leading to an increase of background potential energy), artificially delay the restratification process [*Mohammadi-Aragh*, 2015], an effect that needs to be taken into account if parameterizations for eddy induced mixing and dissipation are compared with numerical model simulations.

Poster preference

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Buoyancy fluxes in stratified flows: observations and parameterizations

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We present a synthesis of observations of turbulent buoyancy fluxes made at five sites where flows and turbulence are primarily associated with internal waves, both breaking and non-breaking. In four of the cases, buoyancy fluxes were calculated from the covariance of velocity and density whereas in the fifth case, it was inferred from the rate of temperature variance dissipation, χ.

Overall, our data show a dependence of the flux Richardson number, Ri_f, on the Gibson number, $Gi = \varepsilon/\nu N^2$, such that when $Gi < 100$, $Ri_f \approx 0.36$, and when $Gi > 100$ $Ri_f \approx 2.4\ Gi^{-0.5}$, in agreement with the functional relationship found originally by Shih et al (2005) using direct numerical simulation (DNS). Our observations do not match well other DNS-derived models that parameterize Rif in terms of the gradient Richardson number, Ri, or the turbulence Froude numbers, Frk and Frt. Similarly, $Ri_f(Gi)$ is found to be the same for all the covariance data sets, despite the fact that these 4 flows produce turbulence that falls in different regimes defined by several pairs chosen from the 5 non-dimensional numbers that the Buckingham Π theorem shows may affect Ri_f .

This view of our data is complicated by several issues: (1) Most of the data show turbulent mixing taking place when $Ri > 1$ and when turbulence production is weaker than turbulence dissipation; (2) Our χ based data constitute most of the data with $Gi < 100$ whereas our covariance based data make up nearly all of the $Gi > 100$ data; and (3) In each case, the various non-dimensional numbers such as Ri and Gi appear to be related to each other, albeit in different ways depending on the data

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