In-situ Submesoscale observations during the formation of a mesoscale eddy in the ACC

KATE ADAMS [1], PHIL HOSEGOOD[1], JOHN R. TAYLOR[2], JEAN-BAPTISTE SALLEE[3]

[1] *SMSE, Plymouth University, United Kingdom*

[2] *DAMTP, University of Cambridge, United Kingdom*

[3] *L'Ocean, France*

Investigations within various large-scale current systems have shown the importance of submesoscale frontal dynamics on the vertical exchange between the atmosphere and the mixed layer. There is a dearth of observations, however, which resolve submesoscale variability along the strongly strained, eddy-rich frontal regions in the Southern Ocean. We present here observations from the Surface Mixed Layer Evolution at Submesoscales (SMILES) cruise conducted in May 2015 that constitute the first in-situ, submesoscale-resolving measurements of the formation and evolution of a closed core eddy within the ACC.

Our observations, primarily consisting of towed CTD (Seasoar), vessel-mounted ADCP, and drogued drifters, are concentrated on a prominent northward meander of the ACC within the frontal region east of Drakes Passage where the Subantarctic and Polar fronts converge. The Seasoar survey began at precisely the moment that the meander separated from the ACC and formed a closed, cold-core mesoscale eddy. The eddy crossed the Scotia Ridge through a narrow gap to the east of Burwood Bank and moved northwards towards the Falkland Island shelf sea. In conjunction with the towed CTD survey, a drifter triplet was released within a narrow ($<$5 km) cold water filament embedded within the front. The drifters completed three revolutions before being ejected from the eddy in a streamer that was clearly visible in a rare cloud-free SST image to emanate from the south-eastern sector of the eddy. Additional drifters released at various positions within the eddy also exited at a similar position suggesting a localized degradation in frontal integrity.

The ship-based measurements ultimately encompassed the entire eddy with an across-front horizontal resolution of O(2 km) down to 200-m water depth and thus, along with the drifter trajectories, provide insight into the variations in lateral frontal structure in different sectors. The northern sector where we began the survey was composed of the frontal region associated with the original meander and was defined by a strong cyclonic circulation and well-defined frontal system. The newly formed southern portion of the eddy was distinctly different, with decreased along-front velocities and a wider frontal zone composed of several filaments that further complicate the frontal dynamics within this sector of the eddy. We highlight the close correspondence of the drifter trajectories during the several revolutions around the eddy. Streamlines derived from geostrophic surface currents computed from sea surface height anomaly agree well with observed drifter trajectories.

Hysteresis Behaviour of the Antarctic Circumpolar Current Identifed in a Quasi-Geostrophic Model.

ADEKUNLE AJAYI[1]

[1] *Earth System Physics, The Abdus Salam International Centre for Theoretical Physics, Trieste. Italy*

In this research work, the hysteresis behavior of the Antarctic Circumpolar Current with respect to wind stress perturbation is investigated using an idealized eddy-resolving quasi-geostrophic wind driven model. The response of circumpolar transport, potential energy and kinetic energy to changes in wind is quantified. The model uses three quasi-geostrophic layers with variable wind stress forcing and no buoyancy effect. The analysis of the model results is divided into two stages with each stage having three regimes; eddy driven, eddy poor and wind driven in order to show the transition from an eddy saturated flow to a wind driven flow without strong eddy effects. The energy balance of the system is diagnosed and the mechanism behind the hysteresis behavior is proposed.

Observations of submesoscale features in the Canada Basin

Marion Alberty[1], Jennifer MacKinnon[1], Janet Sprintall[1]
[1] *Scripps Institution of Oceanography, University of California San Diego, USA*

The Canada Basin upper ocean heat budget is complicated by the unusual vertical distribution of the water properties, namely cold, fresh water lying over warm, salty water. Buoyancy forcing here is driven by solar radiation, ice melt in spring/summer, brine rejection in fall/winter, terrestrial freshwater inputs, and the advection of Pacific water eddies shed off of Point Barrow, Alaska. These mechanisms are inherently spatially patchy, resulting in complicated sea surface temperature and salinity fields of eddies and fronts. Additionally the surface velocity field can strain these mesoscale features and lateral gradients into thin filaments with short spatial and temporal scales making them challenging to observe. The resulting lateral gradients can potentially slump and restratify the surface layers or generate submesoscale instabilities and turbulence, enhancing local mixing. A cruise during the 2015 seasonal sea ice minimum to the Beaufort and Chukchi Seas of the Canada Basin made use of novel instrumentation with the intent of resolving the heat budget of the upper Arctic Ocean and observing the submesoscale processes that modulate vertical heat fluxes below the surface. We will present observations of submesoscale features in the upper 25 meters from a chain of thermistors deployed through undisturbed water with high spatial resolution, 1 m vertical and horizontal spacing. Simultaneously observed turbulent dissipation, background shear and stratification provide evidence of the potential mechanisms responsible for enhancing or suppressing both mixing at the halocline and vertical heat fluxes.

Measuring and modelling a shallow coastal sea area

Pekka Alenius[1], Simo Siiriä[1], Laura Tuomi[1], Antti Westerlund[1], Kimmo Tikka[1]
[1] *Finnish Meteorological Institute, Finland*

The Gulf of Finland (GoF) in the Baltic Sea is a shallow and narrow sea area that has very intensive longitudinal and transversal ship traffic. The end of the gulf receives the largest single fresh water river flow and the gulf opens to the Baltic Sea proper. There are coastal archipelagos and larger islands that affect the circulation in the gulf. The overall hydrography of the GoF is characterized by large horizontal and vertical variations in salinity and also seasonal variation in temperature. The dynamic scales of the GoF are rather small, some kilometres only. Furthermore, some of the deeper areas of the GoF suffer from oxygen depletion.

The challenge in the modelling of the 3D hydrodynamics of the GoF is its complicated dynamics that have been demonstrated in many numerical studies. The lack of sufficient validation data for model studies has hindered the development of models in this area. Though the gulf is only 400 km long and 60 - 120 km wide, the sea areas belong to territorial waters and economic zones of three countries and the routine monitoring observations are limited only to small number of stations. In 2013 and 2014 related to the Gulf of Finland Year, intensive measurement campaigns were done in the GoF by three countries. FMI organised three research cruises in the GoF to obtain good validation data sets for model studies.

Many model studies of the Gulf of Finland exists already. However, the resolution of the models has been too coarse to solve the mesoscale processes properly until recently. The meso-scale horizontal processes and strong vertical mixing are essential parts of the dynamics of the gulf. We used 3D ocean-ice model NEMO with Nordic configuration with 1 and 0.25 NM resolutions. Temperature validations of the high-resolution results seem to be better, as expected, but there is still developments to be done to properly model the study area.

Marine algae are taught the basics of angular momentum

JOHN ALLEN[1]
[1] *SOCIB, Palma de Mallorca, Spain*

Advanced modelling studies and high resolution observations have shown that 'sub-mesoscale' flows (5-20 km scale) may provide both the fertilisation mechanism for nutrient depleted (oligotrophic) surface waters and a subduction mechanism for the rapid export of phytoplankton biomass to the deep ocean. Here, a detailed multidisciplinary analysis of the data from an example of these studies, is presented. The data provide direct observations of the sub-mesoscale transport of phytoplankton. Furthermore, the data confirm that this transport is constrained by the requirement to conserve angular momentum, expressed in a stratified water column as the conservation of potential vorticity. This constraint is clearly seen to produce long thin streaks of phytoplankton populations strained out along isopycnal vorticity annuli associated with mesoscale frontal instabilities.

Water circulation inside the Bay of Calvi (Corsica, France): historical review and future perspectives

AIDA ALVERA-AZCARATE[1], ALEXANDER BARTH[1], ALAIN NORRO[2], SALIM DJENIDI[1], GENEVIÈVE LACROIX[3], SVETLANA KARIMOVA[1], PIERRE LEJEUNE[4], MICHÈLE LEDUC[4], SYLVIE GOBERT[5]

[1] *AGO/GHER, University of Liège, Belgium*
[2] *MARECO, OD Nature, Royal Belgian Institute of Natural Sciences*
[3] *REMSEM, OD Nature, Royal Belgian Institute of Natural Sciences*
[4] *STARESO, Corsica, France*
[5] *Laboratory of Oceanology, University of Liège, Belgium*

The bay of Calvi, located on the North Western coast of Corsica (Mediterranean sea) is a small bay (8 km wide) featuring complex bathymetry characterized by a submarine canyon with very steep side slopes, and an inner shallow zone with a gentle slope and that is home to an important ecosystem, notably Posidonia oceanica meadows. Submarine canyons act as a connection between coastal areas and the open sea, facilitating upwelling and downwelling events, and the exchange of nutrients and sediments between the shelf and the deep water masses. The effect of these cold and nutrient-rich waters in coastal ecosystems is of high relevance in the oligotrophic Mediterranean Sea ecosystem. Fronts and eddies also influence the marine ecosystem through upwelling and downwelling dynamics, from the large scale to the submesoscale.

The Bay of Calvi has been studied since the 1970s by researchers at the University of Liege thanks to the research station STARESO (Station de Recherches Sous-Marines et Océanographiques). Research at STARESO includes long-term monitoring of variables like sea water temperature, salinity, chlorophyll-*a* concentration, and meteorological variables. Ocean currents have been sparsely measured, and therefore our knowledge about the submesoscale dynamics within the Bay of Calvi and the influence of the submarine canyon on the ecology of the bay are not well known.

In this work a historical review of the ocean currents measured in the Bay of Calvi during the last 25 years is performed, with the aim of characterising the main patterns of variability as well as the spatial and temporal scales resolved so far with the existing measurements. This study will serve to optimise the locations inside the bay for future, long-term currents measurements efforts. Plans for increasing the infrastructure dedicated to the measurement of submesoscale currents in the Bay of Calvi will be presented.

Mechanisms of Eddy Formation in the Bay of Bengal

ANANDH T S[1], BIJAN KUMAR DAS[1], SUMIT DANDAPAT[1], J. KUTTIPPURATH[1], ARUN CHAKRABORTY[1]

[1] *Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology kharagpur, India*

Bay of Bengal (BOB) is a unique region in the Indian Ocean with seasonally reversing currents, large freshwater influx from several rivers and significant influence from both surface and remote forcings. Numerous eddies form in this region, playing a key role in productivity and weather of the coastal East India. In order to understand the mechanisms of eddy formation, a high resolution (1/12 degree) regional coupled model, the Coupled Ocean Atmosphere Wave Sediment Transport (COAWST) system, is set up for the BOB. The air-sea interactions and their influence on eddy generation in the BOB are studied using the coupling between Weather Research and Forecasting model (WRF) and Regional Ocean Modeling System (ROMS). Topographical effects are analysed using rossby radii of deformation. The coupled model results are then compared to stand-alone WRF and ROMS results and observations. It shows that the air-sea interactions are better captured in the coupled simulations. The mesoscale eddies start to appear during the pre-monsoon season with the onset of monsoonal winds. The results indicate that both wind forcing and bathymetry affect the formation and development of the eddies. Also, the number and strength of these eddies increase during monsoon, further develop by post-monsoon and decay during winter. It is found that uneven forcings weaken the central BOB gyre into numerous eddies. Also the remote forcings, through kelvin and rossby waves, are found to enhance/supress or even dissipate the eddies.

Optimizing wave run-up measurements by video imagery

UMBERTO ANDRIOLO[1], ELENA SANCHEZ-GARCIA[2], RAFAEL ALMAR[3], RUI TABORDA[1]

[1] *IDL, University of Lisbon, Faculty of Science, Lisbon, Portugal*

[2] *Polytechnic University of Valencia, Department of Cartographic Engineering, Geodesy and Photogrammetry, Valencia, Spain*

[3] *IRD-LEGOS - CNRS/CNES/Toulouse University, Toulouse, France*

Video remote sensing technique has been providing high resolution and continuous data to coastal engineers and scientists for the last three decades. Among all the coastal video applications, monitoring high frequency swash motion on the beach face has been improving the analysis and understanding of wave run-up processes. Hydrodynamic analysis at the shoreline is a crucial factor for assessing storm-related risk and designing coastal protection structures. Conventionally, maximum wave run-up excursions are marked manually or by image processing algorithms on space-time images (timestack). However, such practices require comprehensive human efforts, and much of digital signal processing codes are limited due to image noise induced by beach recreational activities.

This study presents a simple method of extracting wave run-up properties using statistical properties of timestack image. Video data set was derived by online-streaming high-definition cameras, which are installed at three exposed beaches on Portuguese west coast. Nine cross-shore profiles were considered for producing a series of several hundred timestacks with a range of different wave characteristics, tide elevation and beach slope. Relative standard deviation of pixel time series is found to determine horizontal location of maximum and minimum, along with mean and 98 percentile (R2%) wave run-up values over the transect. Wave run-up elevations were computed combining obtained horizontal locations with topographic surveys. The method was validated though the comparison of the results against manually digitalization of wave run-up, performed by different users, and an automated detection procedure based on threshold intensity value. The presented innovative methodology, which showed promising results, aims to optimize hydrodynamic analysis and direct measurements in the swash zone through video imagery.

High-resolution airborne observations of ocean color and thermal signatures of submesoscale eddies in the Southern California Bight

INGRID M. ANGEL-BENAVIDES[1], BURKARD BASCHEK[1], W. DAVID MILLER[2], GEOFFREY SMITH[2], RYAN P. NORTH[1], GEORGE. MARMORINO[2], RÜDIGER RÖTTGERS[1]

[1] *Institute for Coastal Research, Helmholtz-Zentrum Geesthacht, Germany*
[2] *Remote Sensing Division, Naval Research Laboratory, USA*

High spatial variability in phytoplankton distributions, from large scales down to submesoscales, has been long-observed in satellite ocean color data. Submesoscale eddies are one of the physical drivers of such variability, as they can alter phytoplankton distribution and growth conditions through horizontal stirring and vertical advection. However, their rapid dynamics (hours to days) and full range of spatial scales (0.1-10 km) are not properly sampled by traditional ocean color sensors on board of satellites at sun-synchronous near-polar orbits, such as MODIS and VIIRS. These satellites' typical spatial resolution of 1km and temporal resolution of 1 to 2 days, only provide snapshots and are limited to processes lying at the upper limit of the submesoscale length scales. During the Submesoscale Experiments (SubEx) in the Southern California Bight, we used airborne ocean color (VNIR) and thermal (IR) sensors to obtain high spatial (1m) and temporal (10 mins) resolution imagery of the surface signatures associated with submesoscale features. Our multi-platform sampling scheme also included rapid *in situ* measurements with a towed instrument array, which provided insight into the features vertical structure. Targeted cyclonic eddies were detected due to their sharp cold-core signature (L = 0.2 to 1 km) and sampled for several hours. The rotational currents, apparent in the sequence of IR images, extend to larger regions than the cold-cores, which, according to vertical *in situ* profiles, are most likely due to doming of subsurface isopycnals. The eddy signature in the chlorophyll concentration field, derived from the ocean color imagery, varied greatly and was sometimes lower and sometimes higher than the surrounding areas. For eddies with low-chlorophyll signatures, the spatial distribution of chlorophyll was highly correlated with temperature, and the gradients in both fields were nearly co-located. In contrast, higher chlorophyll eddies signatures were generally larger than the cold-core area. These results highlight the large variability in surface phytoplankton responses to the three-dimensional circulation of submesoscale features, and how these features introduce spatial heterogeneity into the ecosystem. The possible mechanisms and environmental conditions responsible for such contrasting responses will be discussed.

Exploring the small cyclones in the Malvinas Current

CAMILA ARTANA[1], CHRISTINE PROVOST[1]

[1] *Laboratoire d'Océanographie et du Climat: Expérimentation et Approche Numérique (LOCEAN), UMR7159, Université Pierre et Marie. Paris, France*

The Antarctic Circumpolar Current (ACC) is organized in three main fronts. From south to north: the Southern Antarctic Circumpolar Front (SACCF), the Polar Front (PF) and the Subantarctic Front (SAF). The last one penetrates 1800 km into the Western Argentinean Basin forming a major western boundary current, the Malvinas Current. This swift and relatively narrow current flows north along the Patagonian shelf break from 55°S up to 38°S providing a permanent injection of cold, fresh and nutrient-rich waters to the Southwestern Atlantic Ocean (SWA). The interaction of the MC with the sloping bottom is presumably responsible for generating upwelling along the shelf-break, which brings nutrients to the surface. As consequence, the SWA hosts a highly productive ecosystem that sustains one of the largest fisheries of the world. Apart from its regional influence, the MC contributes to the Meridional Overturning Circulation since it helps the exchanges of heat and salt.

The population of contrasted fronts, meanders, eddies and filaments in the SWA is rich and complex. The eddy kinetic energy (EKE) in this region can reach values as high as 1700 cm2/s2. However, the interior of the MC presents much lower values of EKE (around 200 cm2/s2) and mesoscale activity is considered to be low in comparison with the rest of the SWA.

High resolution Sea Surface Temperature (SST) data during the winter season reveal the presence of numerous persistent cyclonic eddies which had not been previously noticed in the interior of the MC. The SST data allow a precise description of these structures (size, shape, interaction with topography, coalescing and breaking apart), but cloud coverage prevents a systematic continuous examination. Even if summer images are less cloudy, the presence of a seasonal thermocline impedes a proper detection of cold eddies. We combined high resolution SST with satellite altimetry data to investigate the generation of these coherent structures and their propagation. Low resolution altimetry data allows a continuous examination, at the cost of loosing track of eddies with very small radii. Several generating processes have been identified. In particular, the recurrent generation of cyclonic eddies at the exit of Drake Passage (east Burwood Bank and the Shag Rocks Passage) is precisely described.

Influence of submesoscale eddies on chlorophyll distribution in surface layer of the White Sea

ATADZHANOVA O.A.[1,2], ZIMIN A.V. [1,2], KOPELEVICH O.V.[3], SAHLING I.V.[3], MOROZOV E.A. [4]

[1] *St. Petersburg Department of the P.P.Shirshov Institute of Oceanology RAS, St. Petersburg, Russia*
[2] *Russian State Hydrometeorological University, St. Petersburg, Russia*
[3] *P.P.Shirshov Institute of Oceanology RAS, Moscow, Russia*
[4] *Scientific Foundation "Nansen International Environmental and Remote Sensing Centre", St. Petersburg, Russia*

Previous studies of phytoplankton in the White Sea from satellite data showed a significant variability of the chlorophyll concentration for 1-2 days in some parts of the sea. It may be due to influence of submesoscale processes. To estimate the impact of hydrological conditions on phytoplankton distribution special hydrophysical observations with corresponding scales are need to be done. There has to be used in situ and satellite optic data. However in situ data are limited in time and space and also optic sensor often are inefficient due to the repeatability of clouds at high latitudes. The solution of this problem is using SAR-images (synthetic aperture radar images). So the aim of this paper is to investigate the influence of submesoscale eddies on chlorophyll distribution in surface layer of the White Sea using SAR-images Envisat ASAR 2010 with high resolution, optic and in-situ data for 2010 and 2015. According to analysis of SAR-images it was detected that submesoscale eddy structures are a widespread phenomenon in the White Sea. During May-September 2010 117 eddy structures were registered as forms of individual eddies, linear chains of spiral eddies and eddy dipoles. Including 90 eddies of cyclonic vorticity and 27 eddies of anticyclonic vorticity that had an average size of 4.5 km. Submesoscale eddy structures were more often detected near frontal zones and bottom irregularities In situ data showed that eddies were registered with tidal periodicity above bottom irregularities. Comparison of simultaneous SAR-images and satellite optic data revealed that large submesoscale eddies (diameter 8-10 km) of cyclonic vorticity appear as patches of cold water and low chlorophyll concentration. The opposite situation corresponds to anticyclonic eddies. Small submesoscale eddies (diameter < 6km) of cyclonic vorticity according in situ observations were also characterized as patches of cold water and low chlorophyll concentration. These submesoscale eddies may not be displayed in form of individual structures on chlorophyll concentration maps as they can be monitored in SAR-images. But they might be stably recorded in SST (sea surface temperature) maps. A similar situation corresponds to linear chains of spiral eddies. Submesoscale eddy structures influence on chlorophyll distribution but not all of them find their manifestations in current observations of satellite chlorophyll data. However eddy influence has been detected on the next images (1-2 days) as a variability of chlorophyll concentration fields.

Inter-annual variability of physical and biogeochemical dynamics in the South-East Atlantic Ocean, focusing on the Benguela upwelling System: Remote versus local forcing

Marie-Lou Bachèlery[1], Isabelle Dadou[1], Serena Illig[2]
[1] *LEGOS, France*
[2] *University of Cape Town, South Africa*

The respective contribution of equatorial remote (Equatorial Kelvin Waves) and local atmospheric (wind, heat fluxes) forcing on the South-Eastern Atlantic near-shore coastal physical and biogeochemical dynamics is investigated using a set of 4 sensitivity experiments based on a regional physical-biogeochemical coupled model. Model results show that over the 2000-2008 period, at sub-seasonal time-scales (10-100 day), the coastal physical and biogeochemical oceanic variability (currents, temperature, density, sea level, oxygen and nitrate concentration) is mainly driven by the local forcing, while at inter-annual timescales (13-20 months), it is dominated by the remote forced Coastal Trapped Waves (CTW) that propagate poleward along the African West coast up to the Northern part of the Benguela Upwelling System at 24°S. During their propagation, CTW induce significant temperature (±2°C), oxygen (±50 mmol.O.m-3), nitrate (±10 mmol.N.m-3), vertical (±5m.day-1) and alongshore currents (±5cm.s-1) anomalies with maximum values in subsurface. Tracer anomalies (Temperature, oxygen and nitrate concentration) are primarily driven by alongshore and vertical advection processes. Then, evidence is presented that most of the inter-annual variability of surface primary production and chlorophyll concentrations along the African West coast are also mainly forced by CTW. The currents associated with upwelling CTW induce an input of nutrients that trigger a substantial increase of primary production and phytoplankton in the Benguela Upwelling System while downwelling CTW induce a decrease of primary production and phytoplankton. Finally, we put in evidence that two triggering mechanisms limit the southward propagation of the CTW : the inter-annual variability of the equatorward Benguela current prescribed at the model Southern boundary (30°S) and the variability of the local forcing that modulates the magnitude of the observed coastal inter-annual events. When the local wind stress forcing is (out) in phase, the magnitude of the inter-annual event (decreases) increases.

Modelling Submesoscale Dynamics: A New Parameterization for Symmetric Instability

SCOTT BACHMAN[1], BAYLOR FOX-KEMPER[2], JOHN TAYLOR[1], LEIF THOMAS[3]

[1] *University of Cambridge, UK*

[2] *Brown University, USA*

[3] *Stanford University, USA*

Next-generation ocean models are expected to routinely resolve dynamics at 1/4 degree or smaller, offering new challenges in modelling subgridscale physics. These models are entering a regime where the unresolved turbulence is less constrained by planetary rotation, requiring a paradigm shift in the way modellers construct turbulence closures. Of particular importance is the representation of submesoscale turbulence, occupying O(1-10) km scales, which plays a leading role in setting the stratification of the surface mixed layer and mediating air-sea fluxes. This talk will introduce the submesoscale parameterization problem by presenting a few extant parameterizations, and will focus on a special type of fluid instability for which no parameterization has previously been developed: symmetric instability (SI). The theory and dynamics of SI will be discussed, from which a new parameterization will be proposed. This parameterization is dependent on external forcing by either surface buoyancy loss or down-front winds, which reduce potential vorticity (PV) and lead to conditions favorable for SI. Preliminary testing of the parameterization using a set of idealized models shows that the induced vertical fluxes of passive tracers and momentum are consistent with those from SI-resolving Large Eddy Simulations.

A study of surface semi-geostrophic turbulence

Gualtiero Badin[1], Francesco Ragone[2]
[1] *Institute of Oceanography, University of Hamburg, Germany*
[2] *Ecole normale supérieure de Lyon, Lyon, France*

In this study we give a characterization of semi-geostrophic turbulence by performing freely decaying simulations of the semi-geostrophic equations for the case of constant uniform potential vorticity, a set of equations known as surface semi-geostrophic approximation. The equations are formulated as conservation laws for potential temperature and potential vorticity, with a nonlinear Monge-Amp'ere type inversion equation for the streamfunction, expressed in a transformed coordinate system that follows the geostrophic flow. We perform model studies of turbulent surface semi-geostrophic flows in a doubly-periodic domain in the horizontal limited in the vertical by two rigid lids, allowing for variations of potential temperature at one of the boundaries, and we compare them with the corresponding surface quasi-geostrophic case. Results show that, while surface quasi-geostrophic dynamics is dominated by a symmetric population of cyclones-anticyclones, surface semi-geostrophic dynamics features a prominent role of fronts and filaments. The resulting distribution of potential temperature is strongly skewed and peaked at non-zero values at and close to the active boundary, while symmetry is restored in the interior of the domain, where small-scale frontal structures do not penetrate. In surface semi-geostrophic turbulence energy spectra are less steep than in the surface quasi-geostrophic case, with more energy concentrated at small scales for increasing Rossby number. Energy connected to frontal structures, lateral strain rate and vertical velocities are largest close to the active boundary. These results could be important for the lateral mixing of properties in geophysical flows.

SUBMESOSCALE DYNAMICAL INTERACTIONS IN COASTAL ZONE: NUMERICAL MODELLING AND SENSORS DATA ANALYSIS

ANDREI BAGAEV[1], VITALY IVANOV[2]

[1] *Atlantic branch of P.P.Shirshov Institute of Oceanology, Russian academy of Sciences, Russian Federation*

[2] *Marine Hydrophysical Institute, Russian Academy of Sciences, Sevastopol, Russian Federation*

Mixing processes on the continental slope with the scale of 1 to 10 km make an important contribution to the energy transfer (so called “cascade”) and various tracer fluxes, such as carbon dioxide. The issue of an explicit reproduction of these processes is on the cutting edge of the modern high-res hydrodynamical models. The appearance of enhanced mixing events has to be quantified and parameterized in order for them to be included in the biogeochemical models.

The area of interest for our study is the Southern Crimean Coast, due to anthropogenic overloading and as a pattern of multidisciplinary monitoring at Katsiveli oceanographic platform. The oscillation parameters were derived from in-situ data array collected from the platform in question (44°23’34.69”N, 33°59’4.22”E). Water temperature and salinity variations along with currents speed were analyzed with Fourier analysis with a special attention to a near-inertial range. Certain specific events were investigated with available information about turbidity and DOM concentration in water column to assess the coastal runoff influence. High-frequency internal waves were occasionally observed during the plume events. Energy transfer from lower to higher frequencies was demonstrated by means of spectrograms.

The operative Black Sea hydrophysical field monitoring system that was developed at Marine Hydrophysical Institute is used to simulate mesoscale and submesoscale features of internal near-inertial waves. The core of the system consists of the 3D numerical thermodynamic model written down in Lamb-Gromeka form for the Cartesian coordinate system. The fluctuations of kinetic energy, temperature and salinity are analyzed, interpreted and compared with the previous researches. A wide range of barotropic and baroclinic waves are distinguished, from the baroclinic seiches with the period of 2–10 hours to coastal-trapped waves of 30–70 hour-interval. Inventory of the barotropic and baroclinic oscillations, which were experimentally observed and numerically simulated, is performed.

In general, this task was aimed at study of the mesoscale and sub-mesoscale oscillations variability in the Black Sea Crimean shelf. It is concluded that the domain dynamical instability is influenced by the basin-scale Rim current that encounters the continental slope and is modulated both by interannual and high frequency wind forcing variability. Lateral buoyancy flux might also be responsible for the short-period internal oscillations at the depth of a seasonal pycnocline.

The changes in currents intensity and direction caused by internal waves might produce upwelling events whose influence to biological productivity seems to be worthy of special attention in future research.

Consequences of Climate Change on the ecosystem in the ocean

ALPHA OUMAR BAH [1]
[1] *Ministère Environnement,des Eaux et Forets, Guinée*

Climate change has an increasing influence on all the components of the earth system. This contribution shows the evolution of global temperatures shows that climate change affects the biological and ecological systems of the planet, especially those of the North Atlantic Ocean and its adjacent seas. Biological changes attributed to climate change affect phytoplankton, zooplankton, fish and alter the dominance of many species and the structure, functioning and diversity of ecosystems. The changes are also seen on the biogeography and phenology of species and involved in some regions, abrupt ecosystem changes also called regime change. These changes reflect an adjustment of biological and ecological systems face of warming temperatures. The mechanisms involved are complex, having the split point and varying in time and space. The sensitivity vis-à-vis global agencies is high and low temperature fluctuations can have pronounced effects on the biological and ecological systems. It is urgent to put these systems under surveillance and to develop indicators coupled with statistical and mathematical tools adapted to detect, understand and anticipate the changes of biological and ecological systems in the face of global climate change. In conclusion:

- The Convention on Biological Diversity adopted in Rio de Janeiro in 1992, defines biodiversity as ”the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems ”. Marine biodiversity is important and includes both pelagic and benthic compartments. It relates therefore a wide variety of organisms (unicellular, protozoa, metazoa, invertebrates, vertebrates). However, this biodiversity is a large number of anthropogenic pressures (i) the exploitation of the environment and its resources (fishing, tourism, aquaculture) (ii) a direct impact of man on his environment (pollution and eutrophication local, extraction of materials, introduction of species via ballast water). If biodiversity is naturally resistant or resilient to natural variability of hydro-meteorological events, the effect of anthropogenic processes is still poorly reported and investigated. Since the late 1970s and the significant change in some ecoregions in the world, global climate change could be an additional factor impacting biodiversity.

- Although many remainest uncertainties and sometimes despite the absence of clearly identified intermediate mechanisms between climate variability and biological systems, a body of converging evidence suggests that the recent rise in temperatures began to influence the marine biosphere. The increase in global temperatures was however relatively low (0.8 ° C since the beginning of the 20th century) compared to that provided by the Intergovernmental Expert Group on Climate Change (between 1.4 ° C and 5.8 ° C by 2100 according to the different emission scenarios, demographic and technological change). This amplification of aquatic biological systems is worrying because if more substantial increase in temperatures between 1.4 and 5.8 ° C by 2100 is confirmed, unexpected changes and large magnitudes are not excluded. They can help increase the overall biodiversity loss, reduce services that the biosphere provides to humankind daily and have significant socioeconomic consequences. It is therefore essential to develop ways of monitoring these biological systems, in conjunction with mathematical methods of detection, modeling to anticipate changes. These are the macro-ecosystem approaches and bioclimatological which have so far gained the most unambiguous results. Such approaches should be encouraged, but this requires developing observation systems to large scales, comparable to systems developed in meteorology

Helmholtz decomposition of second order structure functions from Lagrangian ocean observations

DHRUV BALWADA[1], JOSEPH H. LACASCE[2], KEVIN G. SPEER[1]

[1] *Geophysical Fluid Dynamics Institute, Florida State University, USA*

[2] *Department of Geosciences, University of Oslo, Norway*

Second order structure functions are the physical space analogs of energy spectra in wave-number space. Different turbulence theories (2D, 3D, geostrophic, surface-quasi geostrophic, semi-geostrophic etc.) provide scaling laws for second and higher order structure functions (also energy spectra), which are a good way to test for the dominant dynamics using either observations or models. However, often divergent processes (gravity waves, internal waves, tides, inertial oscillations) and non-divergent processes (quasi-geostrophic motions) work on the same length scales (0-20km) causing contamination of the energy spectra by a variety of dynamical regimes. Lindborg, 2015 (also Buhler et al. 2014) developed a methodology to separate the total energy into corresponding divergent and non-divergent/rotational energies using along-track measurements (ship or air-plane tracks) of velocity. We apply this technique to Lagrangian velocity measurements from surface drifters in the Gulf of Mexico (GLAD experiment) and to deep ocean RAFOS floats in the Antarctic Circumpolar Current (DIMES experiment). The results from this decomposition will be presented at the colloquium.

The GLAD drifters provided reliable velocity measurements and statistics over the length scales from 10m-1000km. The total second order structure function has a slope close to 2/3, equivalent to a k$\hat{(}$-5/3) energy spectra, over 10m-100km, as has been noted by previous studies (Poje et al 2014). The Helmholtz decomposition shows that the total energy in the second structure function is dominated by divergent motions at scales smaller than 5km and by rotational motions above that, indicating the presence of strong vertical velocities at small scales. The divergent component of the second order structure function has a slope of 2/3 at scales smaller than 5km, which is in agreement with dominance of inertia-gravity waves. The rotational component of the second order structure function has a slope of 2/3 between 20 – 100km, possibly indicating the presence of an inverse energy cascade. Thus the slope of 2/3 over the entire range of length scales is due to an opportune overlap of these two regimes. The rotational energies below 20 km have a slope of 1.6 (energy spectra of k$\hat{(}$-8/3), which might be an indication of semi-geostrophic turbulence at work in the background at length scales where divergent motions are dominant. The third order structure functions are noisy but show a signs of forward cascade below 5km and an inverse cascade above those scales.

The DIMES RAFOS floats sampled the ACC between depths of 1000-2000m and are presumably unaffected by most of the submesoscale processes unique to the ocean surface. The separation into divergent and rotational components shows that the rotational component is greater than the divergent component over the entire range of sampled scales

(3-1000km), which is similar the decomposition seen in the atmosphere. However, at scales less than 10km the divergent component is comparable to the rotational motions and leads to a flattening of the second order structure function slope to 2/3.

Enhancement of Eddy Kinetic Energy Dissipation by Internal Waves

ROY BARKAN[1], KRAIG B. WINTERS[2], JAMES C. MCWILLIAMS[1]

[1] *Department of Atmospheric and Oceanic Science, University of California Los Angles, Los Angeles, California 90095-1565, USA*

[2] *Scripps Institution of Oceanography, University of California San Diego, 8622 Kennel Way, La Jolla, California 92037, USA*

The effect of internal waves (IWs), excited by high frequency (HF) wind forcing, on submesoscale dynamics and energy pathways is studied in high-resolution numerical simulations of an idealized wind-driven channel flow similar to the Antarctic Circumpolar Current. Three solutions are investigated: one forced by steady wind (LFW), one forced by HF wind (HFW) and one by a combination of both (LFHFW). We demonstrate that most of the HF wind work excites near inertial waves and that the frequency and wave number spectral slopes of the LFHFW solution are shallower than the LFW solution, indicating an enhanced energy transfer to smaller scales and higher frequencies. IWs stimulate submesoscale instabilities and extract energy from lower frequency motions by non-linear interactions. As a result, a 15% increase in HF wind work leads to a 23% increase in eddy kinetic energy dissipation.

High-resolution physical and optical observations of submesoscale eddies

BURKARD BASCHEK[1], INGRID BENAVIDES[1], RYAN NORTH[1], GEOFFREY SMITTH[2], DAVE MILLER[2]

[1] *Helmholtz-Zentrum Geesthacht*

[2] *Naval Research Laboratory*

High-resolution observations were carried out during the Submesoscale Experiments (SubEx) off Southern California. The measurements were taken from planes equipped with thermal and hyperspectral cameras and were complemented by in situ observations with a towed instrument chain, Acoustic Doppler Current Profiler (ADCP) and Radar Doppler Current Profiler (RDCP). Additional SAR, SST and ocean color satellite imagery is used to investigate the occurrence of submesoscale eddies in the coastal ocean. The high temporal and spatial resolution of 5 min and 1 min revealed the fast dynamics of submesoscale eddies in the coastal ocean with Rossby numbers > 10. The rapid mixing of surface water with the colder eddy core indicates the fast evolution and decay of the eddies. The observations suggest a close link between physical processes and phytoplankton concentrations.

Submesoscale Subduction in the central Baltic Sea

Berkay Basdurak[1], Hans Burchard[1], Volker Mohrholz[1], Ulf Gräwe[1], Peter Holtermann

[1] *Leibniz Institute for Baltic Sea Research, Germany*

Submesoscale dynamics in the upper layers (upper 50 m) of the central Baltic Sea were investigated, using towed instruments (T/S) and acoustic profiler along with a eddy-resolving numerical model. Data were collected in July 2012 by cruising in large meandering patterns about once per day during 14 days. The surveys covered an area of 28 by 28 km in hydrography mode using Scanfish, towed and ship ADCP, and in fine-structure mode using towed CTD-chain, towed and ship ADCP. In addition, a freefalling microstructure profiler was used over an area of 15 by 15 km. The observations demonstrated submesoscale intrusions of colder but less saline water around 20 m below the surface with varying thickness. Spatio-temporal variability of subducted water mass distribution was analyzed along with wind stress curls. The observations were then compared to numerical model results. For that, the General Estuarine Transport Model (GETM) with a horizontal resolution of 600 m was used. The model showed, consistent with the observations, salinity inversion in the upper surface layer. Major driving mechanisms behind the subduction were explored with the numerical model.

High-resolution airborne observations of ocean color and thermal signatures of submesoscale eddies in the Southern California Bight

INGRID M. ANGEL-BENAVIDES[1], BURKARD BASCHEK[1], W. DAVID MILLER[2], GEOFFREY SMITH[2], RYAN P. NORTH[1], GEORGE. MARMORINO[2], RÜDIGER RÖTTGERS[1]

[1] *Institute for Coastal Research, Helmholtz-Zentrum Geesthacht, Germany*
[2] *Remote Sensing Division, Naval Research Laboratory, USA*

High spatial variability in phytoplankton distributions, from large scales down to submesoscales, has been long-observed in satellite ocean color data. Submesoscale eddies are one of the physical drivers of such variability, as they can alter phytoplankton distribution and growth conditions through horizontal stirring and vertical advection. However, their rapid dynamics (hours to days) and full range of spatial scales (0.1-10 km) are not properly sampled by traditional ocean color sensors on board of satellites at sun-synchronous near-polar orbits, such as MODIS and VIIRS. These satellites' typical spatial resolution of 1km and temporal resolution of 1 to 2 days, only provide snapshots and are limited to processes lying at the upper limit of the submesoscale length scales. During the Submesoscale Experiments (SubEx) in the Southern California Bight, we used airborne ocean color (VNIR) and thermal (IR) sensors to obtain high spatial (1m) and temporal (10 mins) resolution imagery of the surface signatures associated with submesoscale features. Our multi-platform sampling scheme also included rapid *in situ* measurements with a towed instrument array, which provided insight into the features vertical structure. Targeted cyclonic eddies were detected due to their sharp cold-core signature (L = 0.2 to 1 km) and sampled for several hours. The rotational currents, apparent in the sequence of IR images, extend to larger regions than the cold-cores, which, according to vertical *in situ* profiles, are most likely due to doming of subsurface isopycnals. The eddy signature in the chlorophyll concentration field, derived from the ocean color imagery, varied greatly and was sometimes lower and sometimes higher than the surrounding areas. For eddies with low-chlorophyll signatures, the spatial distribution of chlorophyll was highly correlated with temperature, and the gradients in both fields were nearly co-located. In contrast, higher chlorophyll eddies signatures were generally larger than the cold-core area. These results highlight the large variability in surface phytoplankton responses to the three-dimensional circulation of submesoscale features, and how these features introduce spatial heterogeneity into the ecosystem. The possible mechanisms and environmental conditions responsible for such contrasting responses will be discussed.

River plume dynamics under erratic vs. persistent regimes: a satellite-based and numerical approach for the understanding of fate and distribution of the Po River suspended sediment load

BENETAZZO A.[1], BONALDO D.[1], BRAGA F.[1], BRANDO V.[2], CARNIEL S.[1], COLUCCELLI A.[1], FALCIERI F.M.[1], FALCINI F.[2], PITARCH J.[2], RUBINO A.[3], RUSSO A.[4], ZAGGIA L.[1], ZANCHETTIN D.[3]

[1] *Institute of Marine Sciences, Italian National Research Council (ISMAR-CNR), Venice, Italy*
[2] *Institute of Atmospheric Sciences and Climate, Italian National Research Council (ISAC-CNR), Rome, Italy*
[3] *Dipartimento di Scienze Ambientali, Informatica e Statistica-Università Ca' Foscari, Venice, Italy*
[4] *Università Politecnica delle Marche – Dipartimento di Scienze della Vita e dell'Ambiente (UNIVPM-DISVA), Ancona, Italy*

Suspended sediment load from river runoffs is the primary contributor for the maintenance of the coastal morphodynamic equilibrium [Fagherazzi et al., 2015]. During the last decade, several regions along the Italian coasts have been dramatically affected by intense flash floods and river runoffs [Borga et al., 2014], which delivered a significant amount of sediment off and along shore [Capello et al., 2015]. A crucial question that coastal geomorphologists and marine scientists need to face is about the fate and impact of this impulsive sediment load with respect to those persistent events that are characterized by a quasi-steady sediment and water discharge due to snow melting in springtime [Falcini et al., 2012; Basso et al., 2015]. A satellite-based analysis of these sediment discharges is a key ingredient for such a study since it represents the primary dataset for the recognition of coastal patterns of sediment load that may reflect erosional or depositional processes along the coats. We make use of turbidity (T) units derived from satellite imagery [Brando et al., 2015] to characterize Po River plume (Adriatic Sea) during two significant floods that are representative for an erratic and a persistent regime, respectively [Zanchettin et al., 2008]. The use of a multispectral approach, indeed, allows for the recognition of lithology and grain-size distribution of sediment. We also analyze the river plume dynamics from a coupled ocean-wave model to investigate fate and distribution of the sediment load, related to those two different regimes. Vorticity structure of the plumes and an ad hoc potential vorticity application [Falcini et al., 2010] are used as diagnostic tools to explore the efficiency of the plumes in depositing sediment along the coast rather than delivering it offshore. Our analysis gives some insights on the geomorphological impacts related to erratic vs. persistent events by means of a multi-disciplinary approach that accounts for sediment load retrieval of the river plumes from satellite, hydrological variability of the runoff, and fluid dynamic properties of the plumes.

REFERENCES

Basso, S., Frascati, A., Marani, M., Schirmer, M. and Botter, G., 2015. Climatic and landscape controls on effective discharge. Geophys. Res. Lett., 42(20), 8441-8447.

Brando, V.E., Braga, F., Zaggia, L., Giardino, C., Bresciani, M., Matta, E., ... and Bonaldo, D., 2015. High-resolution satellite turbidity and sea surface temperature observations of river plume interactions during a significant flood event. Ocean Sci., 11(6), 909-920.

Borga, M., Stoffel, M., Marchi, L., Marra, F. and Jakob, M., 2014. Hydrogeomorphic response to extreme rainfall in headwater systems: flash floods and debris flows. J. Hydrol., 518, 194-205.

Capello, M., Cutroneo, L., Ferretti, G., Gallino, S. and Canepa, G. (2015). Changes in the physical characteristics of the water column at the mouth of a torrent during an extreme rainfall event. J. Hydrol., doi:10.1016/j.jhydrol.2015.12.009.

Fagherazzi, S., Edmonds, D. A., Nardin, W., Leonardi, N., Canestrelli, A., Falcini, F., ... and Slingerland, R.L., 2015. Dynamics of River Mouth Deposits. Rev. Geophys., 53, 642–672, doi:10.1002/2014RG000451.

Falcini, F., Khan, N. S., Macelloni, L., Horton, B. P., Lutken, C. B., McKee, K. L., ... & D'Emidio, M. (2012). Linking the historic 2011 Mississippi River flood to coastal wetland sedimentation. Nature Geoscience, 5(11), 803-807.

Zanchettin, D., Traverso, P., & Tomasino, M. (2008). Po River discharges: a preliminary analysis of a 200-year time series. Clim. Change, 89(3-4), 411-433.

High resolution surface circulation of south western Indian Ocean and its coupling with biological productivity – A remote sensing perspective

Benny Peter[1], shenbakavalli Ranjan[2]

[1] *Kerala University of Fisheries and Ocean Sciences*

[2] *University of Technology Malaysia*

Surface circulation and its role in surface Chlorophyll distribution is analysed using remote sensing observations. High resoultion Eulerian mean velocity field has been derived by combining the available satellite tracked surface drifter data with satellite altimetry and ocean surface winds. The drifter data used in this study includes Argos and surface drifter data from Global Drifter Program. Maps of Sea Level Anomaly (MSLA) weekly files with a resolution of 1/3° in both Latitude and Longitude for the period 1993-2012 have been used. The weekly ocean surface mean wind fields derived from the scatterometers onboard ERS 1 / 2, Quikscat and ASCAT have been employed to estimate the wind driven component. The derived mean velocity field exhibits the broad flow of Antarctic Circumpolar Current with speeds up to 0.6 m/s. Anomalous field is quite significant in the western part between 20 ºE and 40 ºE. Eddy kinetic energy illustrates an increasing trend during 1993-2008 and the influence of high frequency Southern Annular Mode as well as the low frequency Antarctic Circumpolar Wave. The Chl-a concentration is determined by the advection of eastward current and associated zonal fronts. Mesoscale features like; eddies and meanders are modifying the Chlorophyll-a distribution especially, in the ARC region. The local maxima and minima is much owing to the measoscale features of the surface circulation.

Lagrangian reconstructions of tracers and three-dimensional flows in a model of surface ocean turbulence

STEFANO BERTI[1], GUILLAUME LAPEYRE[2]

[1] *Laboratoire de Mécanique de Lille, CNRS, Université de Lille, France*

[2] *Laboratoire de Météorologie Dynamique, IPSL, CNRS/ENS, Paris, France*

Ocean dynamics at submesoscales display strong variability giving rise to complex behaviors. Recent theoretical and numerical invsestigations suggest that submesoscale fluid motions exhibit intensified vertical velocities and they are considerably more energetic than previously hypothesized. Improving the knowledge of such small-scale dynamical features is essential to understand their impact on the global ocean properties. Direct measurements of fine structures over the world oceans, nevertheless, are at present severely limited by the spatial resolution of available satellite products. In addition, while satellites provide information on the ocean surface, subsurface information is considerably more difficult to retrieve, which makes the determination of the three-dimensional structure of submesoscales challenging.

In this study we examine the possibility to reconstruct tracer fields, like surface temperature, at small scales, from low-resolution data using a Lagrangian technique based on the properties of chaotic advection. Exploiting surface quasi geostrophic (SQG) theory, the reconstruction technique is also extended to obtain the velocity field in three dimensions when temperature is the tracer. Our main goal is to test the capabilities of the method in numerical simulations of upper-ocean turbulence, particularly focusing on the reconstruction of filamentary and frontal structures. The dynamical configuration we consider is obtained in the framework of the SQG model and it corresponds to a forced turbulent flow resembling, in its main features, real oceanographic systems at mesoscale and submesoscale.

By comparing the original (high-resolution) fields and their reconstructions, that use only low-resolution data, we find that spatial patterns are in overall good agreement, even in the presence of a large-scale forcing on the tracer dynamics. In particular, submesoscale filaments produced by the stretching by larger scale eddies are retrieved, although slightly shifted in space. The statistics of tracer gradients, which are relevant for assessing the possibility to detect fronts, are accurately reproduced. Reconstructions of the three-dimensional velocity field indicate that relevant features of dynamical quantities at small scales may be adequately deduced from only low-resolution temperature data. However, the ability to reconstruct the flow is found to be critically limited by the energetic level of submesoscales. We then discuss how the quality of reconstructions is affected by the dynamical properties of the advecting flow and the associated regime of Lagrangian dispersion.

Variability of the ocean mixed layer depth in Moroccan upwelling areas

ISMAIL BESSA [1,2], AHMED MAKAOUI [2], MOHAMMED IDRISSI[2], KARIM HILMI[2], AZIZ AGOUZOUK [2], JAMILA LARISSI [2], MOHAMED AFIFI[1]

[1] *Faculty of Sciences Ben M'sik, Hassan-II Casablanca University, Casablanca, Morocco*
[2] *Department of Oceanography, National Institute of Fishery Resereach, Casablanca, Morocco*

The main objective of this study is to create scripts using MATLAB to estimate the oceanic mixed layer depth (MLD) in relation with upwelling phenomenon. The determination of the MLD is important to a wide variety of oceanic investigations including ocean productivity, air–sea exchange processes, and long-term climate change. Many methods exist for the determination of the MLD using the Boyer Montegut and al.(2004) method of the threshold criteria and the general method of the gradient. In this work we use both approaches. The first approach based on an optimal threshold value 0.5 °C of the temperature relative to the SST. The second approach is based on a gradient criterion. The maximum gradient of each parameter (temperature, salinity, density) is determined depending on its profile with depth. The CTD data used in this work concern the winter season of 2011/12 and summer season of 2012, for the Atlantic coast of Morocco. The most important results reveal high seasonal variability of the MLD. During the winter season the MLD is generally much deeper than in summer season all over the Atlantic coast of Morocco following the spatial and temporal variability of the upwelling phenomenon.

Thermohaline intrusions observation using acoustic reflectivity

BERTA BIESCAS[1], BARRY RUDDICK[2], MLADEN NEDIMOVIC[3], VALENTI SALLARES[4], GUILLERMO BORNSTEIN[4], JHON MOJICA[4]

[1] *Istituto di Scienze Marine, ISMAR-CNR, Bologna, Italy.*
[2] *Department of Oceanograpy, Dalhousie University, Halifax, Canada.*
[3] *Department of Earth Sciences, Dalhousie University, Halifax, Canada.*
[4] *Department of Marine Geosciences, Institut de Ciencies del Mar, Barcelona, Spain.*

Acoustic reflectivity acquired with multichannel seismic reflection systems allow to detect and explore thermohaline structure in the ocean with vertical and lateral resolutions in the order of 10 m, covering hundreds of kilometers in the lateral dimension and the full-depth water column. We present acoustic data that image the thermohaline intrusions developed along the lateral front between the Mediterranean water transported by an eddy and the surrounding Atlantic water, in the Gulf of Cadiz, NE Atlantic Ocean. The inversion of temperature, salinity and potential density from time and space-coincident acoustic reflectivity and XBT data recovers low frequency content ($< 10Hz$) of the impedance from XBTs and the high frequency content ($> 10Hz$) from acoustic reflectivity, which results in 2D maps of temperature, salinity and potential density, with accuracies of $\delta T_{sd} = 0.1oC$, $\delta S_{sd} = 0.09$ and $\delta \rho_{sd} = 0.02kg/m^3$, respectively. Acoustic reflectors and inverted potential density are eventually compared to better understanding the contribution of the acoustic reflectivity to the multiscale observation of the physics of the ocean.

Sea Ice Monitoring and Correlation Analysis in the Liaodong Bay Based on Radarsat-2 Images

BING LEI[1,2,3], ZOU NANA[4], WANG BIN[5], XING QIANGUO[1], WU LINGLING[1,3], GUO RUIHONG[1,3]

[1] *Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003,China*

[2] *Yantai Maritime Safety Administration, Yantai 264000, China*

[3] *University of Chinese Academy of Sciences, Beijing 100049,China;*

[4] *Yantai No.5 Middle School, Yantai 264001,China*

[5] *General Office of State Oceanic Administration, Beijing 100860, China*

Sea ice plays an important role in maritime transport and safety production in winter. The Liaodong Bay is the most affected area in China. In this research, based on the backscatter and texture feature of sea ice on SAR images, some important information, such as sea ice area, sea ice extent and outer lines of sea ice were firstly detected from Radarsat-2 images acquired between 2012 and 2013. Then, three factors of four cities along the Liaodong Bay, including daily average temperature, daily range of the ground temperature and wind speed and direction, were selected to discuss the relationship between sea ice extent and these factors using principal components regression analysis. The results showed that, area of sea ice in the Liaodong Bay was negatively correlated with daily average temperature, and was greatly affected by south wind. This will provide a convenient and user friendly way for the public to predict trend of sea ice through weather forecast.

Keywords:

sea ice; Liaodong Bay; principal components regression analysis; Radarsat-2; temperature;

Physical and biogeochemical vertical structures in the Cabo Frio Eddy from glider measurements

CARINA STEFONI BÖCK[1], LUIZ PAULO DE FREITAS ASSAD[2], LUIZ LANDAU[3]
[1] *LAMCE/COPPE, Federal University of Rio de Janeiro, Brazil*
[2] *IGEO, Federal University of Rio de Janeiro, Brazil*
[3] *LAMCE/COPPE, Federal University of Rio de Janeiro, Brazil*

The Brazil Current (BC) is the Western Boundary Current flowing along the outer part of the Brazilian southeastern continental shelf and continental slope and is centred between the isobaths of 200 m and 1000 m. The BC flows with intense mesoscale activity, eddies, meanders and rings formation. One of the main oceanographic features is the Cabo Frio Eddy (CFE) representing a transient cyclonic coherent structure with approximately 100 km diameter frequently observed in the northern part of Santos Basin region (Brazil). Studies of eddies and mesoscale activities in this region can be divided into two main types: analysis with a theoretical or numerical approach, in order to analyze the formation and growth of meanders and eddies, and studies that use satellite images or hydrographic measurements to describe these features on the surface. Despite the connection between physical and biogeochemical processes in which, for example, vertical motion associated with mesoscale oceanic features is of fundamental importance for the exchanges of heat, fresh water and biogeochemical tracers between the surface and the inner ocean, studies that assess the relationship between physical and biogeochemical processes in the CFE are still rare and limited to numerical simulations. Only very few information about the vertical structure of these features, mainly the CFE, is available in literature. In this context, the aim of this work is to describe the vertical structure of physical and biogeochemical parameters of the CFE obtained through glider measurements and also to interpret biogeochemical responses to the physical forcing at mesoscales. Physical and biogeochemical measurements from gliders deployments along the Santos Basin are used in this study and were obtained from Projeto Azul (or The Ocean Observing System for Santos Basin also known as Project Blue). The Project Blue measurements span all four seasons over three years, between 2012–2015, including data from the deep-diving Seaglider vehicle, used for the first time in Brazilian waters, that operates at depths up to 1000 m. Gliders were deployed at a hydrographic section limited on the west by 42.3247º W and 23.6302º S and on the east by 41.6383º W and 25º S. This transect is approximately 100 Km wide, departing from the 200 m isobaths and crossing the shelf break. The glider's horizontal velocity is near 0.25 m/s and the whole section should be covered in five days approximately, permitting quasi-synoptic assumptions. Scientific measurements include depth, temperature and salinity (from a Seabird Free Flow CT-Sail), dissolved oxygen (DO, from Aanderaa oxygen optode), and optical parameters, chlorophyll-a and colored dissolved organic matter (C-DOM) from a WetLabs Eco Triplet sensor. The CFE presence was identified through the analysis of both sea surface temperature and chlorophyll-a maps obtained from remote sensing (MUR SST or Multi¬scale Ultra¬high Resolution Sea Surface Temperature and

MODIS/EOS Aqua data). The CFE signal was also identified through trajectories from SVP drifters deployed in the Project Blue. From this analysis, all high resolution physical and biogeochemical data acquired by the glider in these CFE vertical cross-sections were analysed and used to characterize the cross-shore structure and dynamics of the CFE and its associated physical and biogeochemical interactions.

Diagnosing frontal submesoscale dynamics during deep convection using autonomous gliders: a case study in the Gulf of Lions (NW Mediterranean)

ANTHONY BOSSE[1], PIERRE TESTOR[1], PIERRE DAMIEN[2], LOUIS PRIEUR[3], FABRIZIO D'ORTENZIO[3], CLAUDE ESTOURNEL[4], PATRICK MARSALEIX[4], LAURENT MORTIER[5]

[1] *LOCEAN-IPSL, Univ P et M Curie-CNRS-IRD-MNHN, Paris, France*
[2] *CICESE, Ensenada, México*
[3] *LOV, Obs de Villefranche, CNRS-Univ P et M Curie, Villefranche/mer, France*
[4] *LA, CNRS-Université Paul Sabatier, Toulouse, France*
[5] *ENSTA-Paristech, Palaiseau, France*

Since 2010, sustained observations of the circulation and watermass properties of the NW Mediterranean Sea have been carried out by gliders in the framework of MOOSE (Mediterranean Ocean Observatory System for the Environment: http://www.moose-network.fr/). In particular, they have regularly sampled the deep convection zone of the Gulf of Lions, as well as intense density fronts that run around it. In winter, the offshore mixed layer can reach the ocean floor at about 2300 m. Baroclinic fronts then become very intense and reveal a lot of variability at submesoscale in the upper 500 m. In terms of processes, we diagnose the potential vorticity (PV) from glider measurements showing that symmetric instability could occurr during strong wind events. We evaluate our PV estimation from gliders data thanks to a high-resolution regional model (dx=1km). Complementary analysis further highlight the prominent role of downfront winds in destroying PV in frontal zone. Important vertical exchanges of oceanic tracers approximately aligned with isopycnals can then occur in response to this strong atmospheric forcing. Finally, gliders measurements of Chl-a fluorescence show how this frontal instability seems to stimulate phytoplankton growth in frontal regions during harsh wintertime conditions.

A case study of physical processes controlling spatial variability of chlorophyll-a in a large lake (Lake Geneva)

DAMIEN BOUFFARD[1], ALFRED WÜEST[2]
[1] *EPFL Switzerland*
[2] *EAWAG Switzerland*

Analysis of chlorophyll-a map from remote sensing satellite data (MERIS) showed a consistent low concentration biomass in the middle of Lake Geneva for about two weeks in autumn 2009. A three dimensional hydrodynamic model (Delft3D-flow) validated with temperature and currents field data partly explains the observed horizontal phytoplankton patchiness. Our analysis suggests that physical mesoscale processes and in particular the large gyre observed in the middle of Lake Geneva plays an important role in the spatial heterogeneity of the biomass. This study finally emphasizes the benefit of using jointly remote sensing data, field observation together with numerical model to provide a better understanding of lake ecosystems.

Generation of halocline anticyclones at submesoscale fronts - a new twist on the Ekman spiral

LIAM BRANNIGAN[1,3], HELEN JOHNSON[1], CAMILLE LIQUE[2]

[1] *Department of Earth Sciences, University of Oxford, Oxford, U.K.*

[2] *Laboratoire de Physique des Ocans, UMR 6523 CNRS-Ifremer -IRD-UBO, Centre Ifremer de Brest, Plouzane,France*

[3] *Department of Meteorology, Stockholm University, Stockholm, Sweden*

Observations from the Arctic show the presence of submesoscale coherent vortices in the halocline. These vortices are predominantly anticyclonic and hydrographic analysis shows that some of the vortices originate from a shallow mixed layer under-ice front. However, previous numerical simulations of the ageostrophic baroclinic instability of such fronts with no surface stress produce cyclone - anticyclone dipoles rather than isolated anticyclones. New results presented here show that isolated anticyclonic halocline vortices can be produced by the baroclinic instability of such fronts in the presence of an upfront surface stress. It will be shown that the generation of anticyclones occurs because of a strong anticyclonic torque on the front due to the reversal of the Ekman spiral. The potential for the effect to occur more widely in the open ocean will also be considered.

An unstable submesoscale front in the open ocean

CHRISTIAN BUCKINGHAM[1], ZAMMATH KHALEEL[2], AYAH LAZAR[3], ADRIAN MARTIN[4], JOHN ALLEN[5]

[1] *University of Southampton, National Oceanography Centre, Southampton, United Kingdom*

[2] *Ministry of Environment and Energy, Malé, Maldives*

[3] *California Institute of Technology, Pasadena, California, United States*

[4] *National Oceanography Centre, Southampton, United Kingdom*

[5] *University of Portsmouth, Portsmouth, United Kingdom*

A single satellite image of an ocean front coincident with *in situ* measurements of density from a towed, profiling instrument is examined for evidence of submesoscale baroclinic instability (BCI). The image was taken on 19 September 2012 at 03:34 UTC by the Visible and Infrared Imaging Radiometer Suite (VIIRS) on Suomi/National Polar-orbiting Partnership (NPP) spacecraft and consists of brightness temperatures collected within the infrared band at 390-m pixel resolution over the Northeast Atlantic. The ocean front (i) is characterized by a 0.5–0.7°C change in temperature over a 10–25-km distance, (ii) appears to result from convergence of northern and southern waters by cyclonic and anticyclonic mesoscale eddies and (iii) is populated by several submesoscale vortices, or eddies, along the frontal boundary. While horizontal shear instability is one mechanism for generating such eddies (e.g., *Munk et al.*, 2000), here we consider an alternative hypothesis: that observed spiral eddies are the result of BCI within the ocean surface boundary layer (SBL; *Eldevik and Dysthe*, 2002). Vertical/lateral buoyancy gradients and SBL thickness are estimated from *in situ* measurements. Theoretical eddy sizes corresponding to the most unstable mode of an Eady model are then computed and compared with observed eddy sizes. Sensitivities to model parameters are discussed. In most cases, we find good agreement between predicted and observed eddy sizes. Growth rates were not estimated due to severe cloud cover before and after the event. Given Rossby numbers are less than 0.5, BCI might provide a better explanation for the occurrence of the observed submesoscale vortices than horizontal shear.

Frontal Instabilities in the South Atlantic Subtropical Front and their Impact on Phytoplankton Blooms

PAULO H. R. CALIL[1]
[1] *Laboratório de Dinâmica e Modelagem Oceânica - DinaMO - Instituto de Oceanografia - Universidade Federal do Rio Grande - Rio Grande-RS, Brazil*

Subtropical fronts are key regions in the world's oceans as they provide the connection between the dynamically and biogeochemically different subpolar and subtropical oceans. Understanding the mechanisms that modulate the exchange of properties between these regions is not only locally important but may also help explain long-term changes that affect the climate system and may be sensitive to such exchanges. In this study, focus is given to the importance of submesoscale processes in triggering phytoplankton blooms at the subtropical front in the South Atlantic Ocean. A basin-wide model configuration is nested with a higher resolution domain within the frontal region in order to study the exchange of physical properties as well biologically active tracers. On average, a stronger zonal baroclinic jet is observed in the high-resolution domain. Frontal instabilities generated by imbalances in the thermal wind induce rapid changes in the mixed layer depth and generates more episodic blooms with slighly larger biomass during periods when surface stratification is increased. Nonlinearities associated with the Ekman dynamics seem to be responsible for the generation of large vertical velocities and are more important in the high-resolution domain because of larger gradients in relative vorticiy.

A new high resolution tidal model in the Arctic Ocean

MATHILDE CANCET[1], OLE ANDERSEN[2], FLORENT LYARD[3], DAVID COTTON[4], JÉRÔME BENVENISTE[5]

[1] *NOVELTIS, France*
[2] *DTU Space, Denmark*
[3] *OMP/CNRS/LEGOS, France*
[4] *SatOC, UK*
[5] *ESA/ESRIN, Italy*

The Arctic Ocean is a challenging region for tidal modeling, because of its complex and not well-documented bathymetry, together combined with the intermittent presence of sea ice and the fact that the in situ tidal observations are rather scarce at such high latitudes. As a consequence, the accuracy of the global tidal models decreases by several centimeters in the Polar Regions. Accurate tidal models are highly strategic information for ever-growing maritime and industrial activities in this region. In addition, better knowledge of the tides improves the quality of the high-latitude satellite altimeter sea surface heights and of all derived products, such as the altimetry-derived geostrophic currents, the mean sea surface and the mean dynamic topography.

NOVELTIS and DTU Space, with the expertise support of LEGOS, have developed a regional, high-resolution tidal atlas in the Arctic Ocean, in the framework of the CryoSat Plus for Ocean (CP4O) ESA project. This atlas benefits from improvements in hydrodynamic modelling, high resolution unstructured grid and data assimilation of the most complete satellite altimetry dataset ever used in this region, including Envisat data up to 82°N and CryoSat-2 reprocessed data between 82°N and 88°N. The combination of all these satellites gives the best possible coverage of altimetry-derived tidal constituents. The available tide gauge data were also used for data assimilation and validation.

This paper presents the high performances of this new regional tidal model in the Arctic Ocean, compared to the existing global tidal models.

SMALL SCALE OCEAN DYNAMICS IN THE CAPE BASIN, SOUTH OF AFRICA, AND THE IMPACT ON THE OCEAN CIRCULATION

TONIA ASTRID CAPUANO[1], SABRINA SPEICH[2], XAVIER CARTON[1]

[1] *LPO-UBO, University of Western Brittany, France.*
[2] *LMD-ENS, École Normale Supérieure, France*

We investigate the role of meso-submesoscale features in the intensely turbulent activity characterizing the Cape Basin region, south-west of Africa, and its effect on the water mass exchanges and transformations, between the upper and intermediate layers, with a particular focus on the fate of Antarctic Intermediate Water. With this aim, realistic numerical simulations of the ocean circulation around Southern Africa have been run, at increasing horizontal and vertical resolutions, using different configurations of the Regional Ocean Model System. Validation of the runs output against observations (satellite and in-situ data) show that the model is able to reproduce the mean structure of the regional circulation, as well as the main characteristics, in the vertical and horizontal extents, of the water masses and currents present in the area (AAIW, NADW, Agulhas Current). Analysis of the major components of the Ertel Potential Vorticity budget,carried out with the output of the runs at highest resolutions (at 1/24° and at 1/48°), suggest that at the surface small scale instabilities (vortices, filaments and meanders) drive a highly ageostrophic flow, especially along the most prominent topographic features of the study region, while more quasi-geostrophic dynamics dominate at intermediate levels. The difference between these 2 dynamical regimes have been further explored looking at slopes of Kinetic Energy power spectra, which seem to confirm the preliminary results of the EPV analysis. Additional diagnostics have been set up to look at the nature of the meso-submesoscales processes, like the surface estimation of the Eddy Available Potential Energy, used as an indicator of the interior turbulence, and the Lagrangian Integration of Water particles, to statistically assess the impact of these instabilities on the pathways and mixing rates of the local watermasses.

Modeling physical - biological interactions in the ocean during the passé of the cyclone, Phailin

Kunal Chakraborty[1], Sourav Maity[1]

[1] *ESSO-Indian National Centre for Ocean Information Services (INCOIS)*

The significance of tropical cyclone in increasing the productivity of Bay of Bengal has been well studied by several researchers. Most of the studies are based on remote sensing techniques. Due to lack of data, biogeochemical variability of the ocean along the cyclone passé has often been less studied particularly, subsurface variability of the ocean. During October 9-12, 2013, a category-5 hurrican, Phailin, developed over Andaman & Nicober Islands and made a landfall at the Gopalpur coast of Odisha state in India. An eddy permitting coupled bio-physical model, Regional Ocean Modeling System (ROMS) integrated with an ecosystem model, simulated data has been used to study physical - biological interactions in the ocean along the cyclone passé. It is observed that thermocline is shoaled up after passing the cyclone and causes entrainment of nutrients. It is also observed that, on October 9th, subsurface chlorophyll maximum (SCM) was at the depth of 30-40 meters however, SCM was elevated to the sea surface on October 12th due to vertical upliftment of thermocline. Additionally, in presence of sufficient light after the passé, near-surface phytoplankton community utilized nutrients entrained from deeper waters which in turn enhanced primary productivity. It is to be concluded that the sea surface chlorophyll concentration (=6 mg/m3) is reaching to its peak approximately with time-lag of a week with respect to the increase in the nitrate concentration of the surface waters. The shoaling of oxycline and high biological productivity along the cyclone passé increase the oxygen concentration at the near surface and subsequently, there is a saturation observed in the oxygen concentration in the surface layer. It is further noted that there was a drop of 1°C in sea surface temperature (SST). Recorded cooling has enhanced the holding capacity of CO_2 in the surface water. On top of that entrainment of inorganic carbon from deeper layers increased the partial pressure of CO_2 almost 50 ppm. The subsequent effect of which is that ocean became source to atmospheric CO_2 during the cyclone.

Impact of horizontal resolution ($1/12^o$ to $1/50^o$) on Gulf Stream separation and penetration

ERIC CHASSIGNET[1], XIAOBIAO XU[1]

[1] *Center for Ocean-Atmospheric Prediction Studies, Florida State University*

The impact of horizontal resolution ($1/12^o$ to $1/50^o$) on Gulf Stream separation and penetration is analyzed in a series of identical North Atlantic HYCOM configurations. The $1/50^o$ simulation shows a significant improvement in the Gulf Stream representation (surface and interior)when compared to observations. The results will be discussed in terms of ageostrophic contributions and power spectra (2D versus surface QG turbulence).

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

CÉDRIC CHAVANNE[1], PATRICE KLEIN[2], HIDEHARU SASAKI[3]

[1] *Institut des sciences de la mer, Université du Québec à Rimouski, Canada*

[2] *Laboratoire de Physique des Oceans, IFREMER-CNRS-UBO-IRD, France*

[3] *Application Laboratory, JAMSTEC, Japan*

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 formulation for the adiabatic component departs from the classical surface quasi-geostrophic framework considered before since it takes into account the stratification within the surface mixed-layer that is usually much weaker than that in the ocean interior. To achieve this, the model approximates the ocean with two constant-stratification layers : a finite-thickness surface layer (or the mixed-layer) and an infinitely-deep interior layer. The surface layer 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. Summer conditions featuring shallow mixed-layers and weak mixed-layer instabilities are contrasted with winter conditions featuring deep mixed-layers and energetic mixed-layer instabilities.

Physical drivers of biogeochemical cycles in the North Atlantic Subtropical Gyre

HAIDI CHEN[1], GALEN A. MCKINLEY[2]

[1] *Department of Atmospheric and Oceanic Sciences, Princeton University*

[2] *Department of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison*

One fundamental challenge centers on a puzzle that nutrient supply from large-scale physical forcing in the North Atlantic Subtropical Gyre (NASG) can only support 50% of the estimated biological productivity. Episodic nutrient injection by mesoscale eddies and submesoscale fronts are potential mechanisms to balance the needed nutrients, but their large-scale impact has not been well explored with observations. With satellite observations, this study showed that 32.2% of the chlorophyll is caused by frontogenetic upwelling, 8.6% (eddy core) and 5.8% (eddy edge) by mesoscale eddy pumping, and the remaining 53% is caused by the large-scale forcing, which is consistent with previous studies. With in-situ observations from both Bio-Argo floats and bottle samples near Bermuda, this study further revealed that subduction of nutrient-poor but organic matter rich waters after spring bloom, along with the remineralization of these subducted organic matter, is the crucial mechanism for recharging the subsurface nutrient reservoir at shallow depths. The remineralization appears to enable effective nutrient injection by submesoscale dynamics during summer, and supports 30%-50% of the annual net community productivity (NCP) within the mixed layer. Therefore subduction, lateral advection and submesoscale process collaboratively explain the long-standing appearance of an imbalance between nutrient supply and productivity in the NASG.

Seasonal dynamics of suspended sediment concentration in the Korean coastal water identified from GOCI

JONG-KUK CHOI[1], YOON-KYUNG LEE[2]

[1] *KIOST-PML Lab, Korea Institute of Ocean Science and Technology, Plymouth, UK*

[2] *Korea Ocean Satellite Center, Korea Institute of Ocean Science and Technology, Ansan, Korea*

Analysis of suspended sediment concentration (SSC) is a key to understanding the turbulent quantities of sediment flow in the Koean coastal waters. The purpose of this study was to investigate intra-annual variability in remotely sensed SSC derived from the Geostationary Ocean Color Imager (GOCI) and sea surface temperature (SST) based on the Advanced Very High Resolution Radiometer (AVHRR), respectively, around the southern west coast of Korean peninsula over a period of 1 year (2013). Monthly composite SSC images showed pronounced seasonal changes in turbid water. The extent of turbid water increased during the winter season along Gomso Bay to Jangsado, whereas it decreased during the summer months from Yeonggwang to Sinan. A comparison of monthly composite SST images and wind data showed that the northwesterly winds of monsoons and net heat loss from the sea surface to the atmosphere resulted in vigorous vertical mixing of shallow coastal waters in winter. The tongue-shaped thermohaline front, monsoon winds, and bathymetry limited the spread of SSC at the southern part of the study area in winter. In conclusion, seasonal dynamics of sediment movement around the Korean coastal waters can be effectively detected using GOCI.

Gravity Wave Generation by Baroclinic Instability

MANITA CHOUKSEY[1], NILS BRÜGGEMANN[2], CARSTEN EDEN[1]

[1] *Institut für Meereskunde, Universität Hamburg, Germany*

[2] *Delft University of Technology, Netherlands*

We discuss the possibility of the generation of gravity waves during baroclinic instability for ageostrophic to quasi-geostrophic regimes. Previous results (Brueggemann and Eden, JPO, 2015) show a dominant forward energy cascade for a large Rossby number (Ro) and a small Richardson number (Ri) in an idealized channel model, while for Ro$\ll$1 and Ri$\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 higher for an ageostrophic regime than for a quasi-geostrophic regime. A linear modal decomposition into geostrophic and gravity wave modes indicates that there is surprisingly low energy in the gravity wave modes and much higher energy in the geostrophic mode even for super-inertial frequencies. Further, a non-linear decomposition of the balanced flow into geostrophic mode and linear and non-linear gravity wave modes also shows that most of the energy is contained in the geostrophic mode. A modal decomposition of the spectral fluxes of energy in wavenumber space provides more insight about how much energy is contained in which mode.

Multifractal characteristics of submesoscale eddies in the southwestern GIN Sea upper layer

PETER C. CHU[1]

[1] *Department of Oceanography, Naval Postgraduate School*

The Greenland Sea, Iceland Sea, and Norwegian Sea (GIN Sea) are key regions in the advective–convective system with various stages of modification that links the polar ocean with the North Atlantic. Because of the import and modification of water masses a large number of regional water types can be encountered. Convection in GIN Sea is seen as a globally important process in which air–sea interactions influence oceanic circulation through the production and ventilation of deep and intermediate waters. Submesoscale eddies are key dynamic elements in the GIN Sea upper layer.

Multifractal characteristics of the upper layer thermal structure in the southwestern GIN Sea are analyzed using high-resolution, digital thermistor chain data. The energy spectrum at 20 m depth (cold sublayer) shows the existence of a spike at the scale of approximate 3 km representing the scale of submesoscale eddies.

The power spectra for all the depths have multi-scale characteristics with the spectral exponent b in the range of (1, 2). This means the temperature field of the southwestern GIN Sea sublayer is nonstationary with stationary increments. The structure function has multi-fractal characteristics, i.e., the power of the qth-order structure function is monotonically and near-linearly increasing with q. However, the rate of such an increasing varies with depth: (a) slow increasing with q (surface layer, 0 m), (b) intermediate-rate increasing with q (second thermocline, 80 m), (c) fast increasing with q (first thermocline, 20 m; cold sublayer, 40–60 m; intermediate warm layer, below 100 m).

The graph dimension varies (multi-dimension structure) from higher values such as 1.89 (surface: 0 m), 1.78 (second thermocline: 80 m) to lower values such as 1.57 (first thermocline: 20 m), 1.52–1.53 (cold sublayer: 40, 60 m), and 1.44–1.50 (warm intermediate layer: 120, 140, 200 m). The decreasing order of the stationarity is: the ocean surface, second thermocline, first thermocline, cold sublayer, and warm intermediate layer. However, the information dimension varies slightly from 0.92 to 0.90. This indicates that singularity is very low.

C-Vector to identify Submesoscale Eddies in the Greenland Sea during the Northwind 1984 MIZEX Cruise

PETER CHU[1]
[1] *Department of Oceanography, Naval Postgraduate School, USA*

Mesoscale and submesoscale eddies belong to different dynamic regimes. The mesoscale eddies are geostrophic and the submesoscale eddies are ageostrophic. The flow field can be decomposed into geostrophic and ageostrophic parts. The geostrophic velocity is usually treated as the basic flow, the ageostrophic velocity is the motion relative to geostrophic flow, occurs often in the oceans such as convection and circulations driven by fronts and mesoscale eddies, and affects the general circulation and the mass, heat, salt, and energy balance. The submesoscale eddies can be identified by the C-vector method (Chu 2002, GRL) from in-situ observational data such as (T, S) profiles, surface wind stress, and buoyancy flux. Three-dimensional ageostrophic pseudovorticity and streamfunction, are calculated from the Conductivity-Temperature-Depth data collected during the Northwind 1984 MIZEX cruise in the Greenland Sea in August and September 1984, and are interpreted as submesoscale eddies.

Submesoscale vertical transport at the Eastern Alboran Front

Mariona Claret[1], Simón Ruiz[2], Ananda Pascual[2], Amala Mahadevan[3], Joaquín Tintoré[2,4], Baptiste Mourre[4], Antonio Olita[5], Antonio Tovar-Sánchez[2]

[1] *Earth and Planetary Sciences Dept., McGill University, QC, Canada*
[2] *Instituto Mediterráneo de Estudios Avanzados (IMEDEA, CSIC-UIB), Mallorca, Spain*
[3] *Physical Oceanography Dept, Woods Hole Oceanographic Institution, MA, USA*
[4] *Balearic Islands Coastal Observing and Forecasting System (SOCIB), Mallorca, Spain*
[5] *Institute for Coastal Marine Environment of the National Research Council (CNR-IAMC), Italy*

The strong front between Atlantic and Mediterranean waters in the Eastern Alboran Sea was sampled intensively during the ALBOREX multi-platform experiment in May 2014. Glider observations revealed subducted tongues of chlorophyll, oxygen, and temperature to depths of 100m. These large vertical excursions of tracers cannot be explained by quasigeostrophic dynamics inferred from the observations. To examine how submesoscale dynamics may have enhanced the vertical velocities in the vicinity of the large frontal buoyancy gradients, we initialized a Process Study Ocean Model with hydrographic data from gliders. We modeled the frontal instability and analyzed the vertical flux of tracers designed to mimic oxygen and nitrate. Our numerical results show that even in the absence of winds, the front triggers frontogenetic subduction that generates vertical tracer excursions similar to what was seen in the observations

Escape of frontally trapped near-inertial waves through wave-triad resonant interactions

Mariona Claret[1,2], Amit Tandon[3], Amala Mahadevan[2]

[1] *Earth and Planetary Sciences Dept., McGill University, QC, Canada*

[2] *Physical Oceanography Dept., Woods Hole Oceanographic Institution, MA, USA*

[3] *Mechanical Engineering Dept., University of Massachusetts Dartmouth, MA, USA*

Wind-generated inertial motions are largely modified by their interaction with strong ocean fronts that are dynamically 'submesoscale', with relative vertical vorticity of the order of the planetary vorticity. This occurs because the vertical vorticity of the balanced flow shifts the effective wave frequency from inertial f, to near-inertial. As a result of this front-wave interaction, near-inertial wave packets develop and propagate downward. Wave packets generated on the anticyclonic side of fronts are sub-inertial and experience trapping and amplification at critical depths.

Here, we propose a new mechanism by which these trapped sub-inertial wave packets escape from the anticyclonic region as super-inertial waves, with a continuum of frequencies in the f–$2f$ band, through wave-triad resonant interactions. Our inferences are drawn from the bispectral analyses of numerical solutions of a non-hydrostatic process study ocean model configured in two dimensions. The model is forced with a strong wind impulse and the resulting near-inertial wave field is analyzed over the ensuing inertial periods as the waves radiate downward. Observations from the North Wall of the Gulf Stream support the existence of this mechanism. The mechanism has implications for wave energy transfer from the surface to the deep ocean.

The Arctic Ocean as a laboratory for submesoscale dynamics

SYLVIA T. COLE[1], MARY-LOUISE TIMMERMANS[2], JOHN M. TOOLE[1]

[1] *Woods Hole Oceanographic Institution, United States*
[2] *Yale University, United States*

The dynamic and thermodynamic constraints imposed by ice cover in the Arctic Ocean make this environment a useful laboratory for investigating submesoscale dynamics. High-resolution observations of the mixed layer and upper 250 m were taken using Ice-Tethered Profilers with velocity. These systems observe profiles of temperature, salinity, and velocity with 1-3 km horizontal resolution, as well as vertical turbulent heat, salt, and momentum fluxes just beneath the ice-ocean interface. Together with observed wind and ice velocities, these systems provide a detailed view of submesoscale evolution on a seasonal timescale. In particular, three systems transited the Canada Basin from March through September 2014 while the mixed layer shoaled and the ice cover broke apart and melted. The thermodynamic constraint the ice cover imposed on the mixed layer lead to an absence of density compensated fronts in winter and early spring. Changes to horizontal density gradients occurred in spring when ice concentration first decreased below 100 percent, with the response differing beneath smoother first year ice versus rougher multi-year ice. The emergence of density-compensated gradients, and the slumping and mixing of density gradients were observed in the shallow (10 m) summer mixed layer. Beneath the mixed layer, temperature and salinity fluctuations along density surfaces are ubiquitous at the submesoscale, and are used to investigate horizontal stirring and submesoscale dynamics at depth. Observations in the Arctic Ocean, and especially under differing and observed surface forcing conditions, provide a detailed view of submesoscale processes and their influence on larger-scale ocean properties.

Impact of large scale topography on vertical fluxes of passive tracers in the Southern Ocean

JÉRÉMY COLLIN[1,3], STEVEN HERBETTE[1], JONATHAN GULA[1], PEDRO MONTEIRO[2], CHRIS REASON[3], ALAIN COLIN DE VERDIÈRE[1]

[1] *UBO/LOPS, Brest, France*

[2] *CSIR, Cape Town, South Africa*

[3] *Oceanography Department, UCT, Cape Town, South Africa*

Quantifying vertical fluxes of Iron in the Southern Ocean is a key question to better understand the carbon cycle. The following work investigates how enhanced (sub)mesoscale turbulence generated by current-topography interactions may impact the uplift of nutrients in the Antarctic Circumpolar Current.

We carry out idealized numerical simulations with a primitive equation model (ROMS) in an East-West periodic channel of an eastward jet encountering a large-scale plateau with different heights .

An increase in topographic height results in jet and meanders intensification. The stronger stationary cyclonic circulation upwells dense waters and locally increases the available potential energy. As a consequence, baroclinic instabilities are more energetic in this area, leading to an increase in vertical velocity standard deviation up to 50%. Lagrangian particles are released near the topography using off-line experiments. This allows us to separate the impact of the Meridional Overturning Circulation $w = O(10^{-6}\text{m.s}^{-1})$, Eddy pumping $O(10^{-4}\text{m.s}^{-1})$ and ageostrophic velocities $O(10^{-3}\text{m.s}^{-1})$ on the observed vertical fluxes. The overturning cells are found to be slightly perturbed by topography. Vertical advection is controlled by eddy induced vertical stretching up to 200 m depth and by ageostrophic secondary circulation above. Particles entering the surface layer (100 m) exhibit a time residency larger than a month that enables phytoplankton blooms.

We conclude that large scale topographic obstacles in the Southern Ocean significantly impact the carbon cycle by providing nutrient supply.

Inverse and direct kinetic energy cascades in unforced upper ocean fronts

PABLO CORNEJO[1,2], AMIT TANDOM[3], HECTOR HITO SEPULVEDA[2]

[1] *Mechanical Engineering Departament, Faculty of Engineering, University of Concepcion, Concepcion, Chile*

[2] *Geophysics Department, Faculty of Physical and Mathematical Sciences, University of Concepcion, Concepcion, Chile*

[3] *Physics Department and Department of Estuarine and Ocean Sciences, University of Massachusetts, Dartmouth, North Dartmouth, USA*

A modified state of the art Computational Fluid Dynamics code was used to implement a highly resolved LES model of a mid-latitude upper ocean front. We investigated the spectral energy flux at the submesoscale/small-scale range in order to assess the inverse and forward kinetic energy cascades at these scales and inquire into the fluid dynamics processes which drive them in the absence of any atmospheric forcing. Near surface (25 m) we found submesoscale conditions ($Ro \sim 1$, $Ri \sim 1$) within baroclinic structures inducing a partially imbalanced frontogenetic activity in its vicinity. Furthermore in the upper ocean we also found zones where symmetric instability condition was satisfied. Calculations of spectral kinetic energy flux using alongfront transects predicted an intense direct kinetic energy cascade at the ocean surface. Previous studies of unforced density fronts have associated the high dissipation taking place near surface to the agesotrophic baroclinic instability induced frontogenetic activity. However an analysis of the spectral kinetic energy fluxes focused in specific zones dominated by frontogenesis and symmetric instability, indicates a predominance of an inverse kinetic energy cascade within the frontogenetic zone while a direct kinetic energy cascade dominates in the zone where symmetric instability was diagnosed.

Glider and satellite high resolution monitoring of a mesoscale eddy in the algerian basin: Effects on the mixed layer depth and biochemistry

YURI COTRONEO[1], GIUSEPPE AULICINO[1], SIMÓN RUIZ[2], ANANDA PASCUAL[2], GIORGIO BUDILLON[1,3], GIANNETTA FUSCO[1,3], JOAQUN TINTORÉ[1,4]

[1] *Università degli Studi di Napoli "Parthenope", Naples, Italy*

[2] *Instituto Mediterráneo de Estudios Avanzados, IMEDEA(CSIC-UIB), Esporles, Spain*

[3] *Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere, CINFAI, Tolentino (MC), Italy*

[4] *Balearic Islands Coastal Observing and Forecasting System (SOCIB), Palma de Mallorca, Spain*

Despite an extensive bibliography for the circulation of the Mediterranean Sea and its sub-basins, the debate on mesoscale dynamics and their impacts on bio-chemical processes is still open because of their intrinsic time scales and of the difficulties in their sampling. In order to clarify some of these processes, the "Algerian BAsin Circulation Unmanned Survey-ABACUS" project was proposed and realized through access to the JERICO Trans National Access (TNA) infrastructure between September and December 2014. In this framework, a deep glider cruise was carried out in the area between the Balearic Islands and the Algerian coast to establish a repeat line for monitoring of the basin circulation. During the mission a mesoscale eddy, identified on satellite altimetry maps, was sampled at high-spatial horizontal resolution (4 km) along its main axes and from the surface to 1000 m depth. Data were collected by a Slocum glider equipped with a pumped CTD and biochemical sensors that collected about 100 complete casts inside the eddy. In order to describe the structure of the eddy, in situ data were merged with next generation remotely sensed data: daily synoptic sea surface temperature (SST) and chlorophyll concentration (Chl-a) images from the MODIS satellites, as well as sea surface height and geostrophic velocities from AVISO. From its origin along the Algerian coast in the eastern part of the basin, the eddy propagated northwest at a mean speed of about 4 km/day,with amean diameter of 112–130 km, meanamplitude of 15.7 cm; the eddy was clearly distinguished from the surrounding waters thanks to its higher SST and Chl-a values. Temperature and salinity values over the water column confirm the origin of the eddy from the Algerian Current (AC) showing the presence of recent Atlanticwater in the surface layer and Levantine Intermediate Water (LIW) in the deeper layer. The eddy footprint is clearly evident in the multiparametric vertical sections conducted along its main axis. Deepening of temperature, salinity and density isolines at the center of the eddy is associated with variations in Chl-a, oxygen concentration and turbidity patterns. In particular, at 50 m depth along the eddy borders, Chl-a values are higher (1.1–5.2 µg/l) in comparison with the eddy center (0.5–0.7 µg/l) with maximum values found in the southeastern sector of the eddy. Calculation of geostrophic velocities along transects and vertical quasi-geostrophic velocities (QG-w) over a regular 5 km grid from the glider data helped to describe the mechanisms and functioning of the eddy. QG-w presents an asymmetric pattern, with relatively strong

downwelling in thewestern part of the eddy and upwelling in the southeastern part. This asymmetry in the vertical velocity pattern, which brings LIW into the euphotic layer as well as advection from the northeastern sector of the eddy,may explain the observed increases in Chl-a values.

Response of the North Atlantic Ocean carbon sink to climate change : role of submesoscale processes

DAMIEN COUESPEL[1], MARINA LÉVY[1], PATRICE KLEIN[2], CLAUDE TALANDIER[2]
[1] *LOCEAN-IPSL, CNRS/UPMC/MNHN/IRD, Paris, France*
[2] *LPO, CNRS/IFREMER/IRD/UBO, Brest, France*

In the North Atlantic, one of the largest oceanic carbon sink, both the biological pump (through primary production) and the physical pump (through subduction/obduction processes) are likely to be affected by climate change : earth system models predict a decline of primary production and changes in water mass formation. However, these models do not resolve submesoscale processes which have been shown to significantly modify both primary production and subduction at the scale of the basin. In order to examine how our current predictions of these changes are biased due to the absence of submesoscale processes, we carry a model study in which an idealized configuration of the North Atlantic ocean is run for several decades with 3 horizontal resolutions : 100km, 12km and 4km. Two scenarios are examined : a preindustrial scenario, with a seasonally repeating atmospheric forcing, and a climate change scenario where a constant temperature trend is added to the previous forcing. Comparing the results for the different horizontal resolution, we investigate the contribution of submesoscale processes to 1) the predicted decline of primary production, 2) the physical carbon fluxes in preindustrial conditions and 3) in climate change conditions.

Mixed Layer formation and restratification in presence of mesoscale and submesoscale turbulence

X. Couvelard[1], A.M. Treguier[2], F. Dumas[3], V. Garnier[1], A. Ponte[1]

[1] *Ifremer, Laboratoire d'Océanographie Physique et Spatiale, FRANCE*

[2] *CNRS, Laboratoire d'Océanographie Physique et Spatiale, FRANCE*

[3] *SHOM, French Hydrograhic and Oceanographic Service FRANCE*

Recent realistic high resolution modeling studies show a net increase of submesoscale activity in fall and winter when the Mixed Layer Depth (hereafter MLD) is at its maximum. This submesoscale activity increase is associated with the shallowing of the MLD when compared to similar configuration at lower resolution. Both phenomenon can be related to the development of Mixed Layer Instabilities (MLIs), which by slumping the horizontal density gradient in the mixed layer convert Available Potential Energy into submesoscale Eddy Kinetic Energy and contribute to a fast restratification. In the present work, the Mixed Layer formation and restratification is studied by uniformly cooling a fully turbulent zonal jet in a periodic channel at different resolution (eddy resolving -10km- to submesoscale permitting -2km). The effect of horizontal resolution is quantified in terms of MLD, restratification rate, buoyancy fluxes, and conversion of Available Potential Energy in Eddy Kinetic Energy.

Contrary to many idealized studies focusing on the restratification phase only, this study addresses a continuous event of mixed layer formation followed by its complete restratification. The robustness of the present results was established by ensemble simulations. The results show that, at higher resolution, when submesoscale starts to be resolved, the mixed layer formed during the surface cooling is significantly shallower and the total restratification is almost three times faster. Such differences between coarse and fine resolution models are consistent with the submesoscale upward buoyancy flux, which balances the convection during the formation phase and accelerates the restratification once the surface cooling is stopped. This submesoscale buoyancy flux is active even below the mixed layer. Our simulations show that mesoscale dynamics also cause restratification, but on longer time scales. Finally, the spatial distribution of the mixed layer depth is highly heterogeneous in the presence of submesoscale activity, prompting the question of whether it is possible to parameterize submesoscale effects and their effects on the marine biology as a function of a spatially-averaged mixed layer depth.

Focusing of Internal Tides by Near Inertial Waves

YANNIS CUYPERS[1], PASCALE BOURUET-AUBERTOT[2], JÉRÔME VIALARD[3]
[1] *1. LOCEAN-IPSL, Sorbonne Univ. (UPMC, Univ Paris 06)-CNRS-IRD-MNHN, Paris, France*
[2] *2. Pacific Marine Environment Laboratory, NOAA, Seattle, USA*

The refraction of internal waves by lower-frequency near-inertial waves has been predicted theoretically, but never observed before. Here, we report observations of semi-diurnal internal tides generated by the rough topography of the Central Indian Ridge, in the presence of a strong, lower-frequency near inertial wave field generated by a tropical storm. The semi-diurnal internal tide energy is trapped within upward-propagating bands with a periodicity close to the inertial period. A ray-tracing model suggests that this trapping results from the internal tide refraction by the shear associated with near-inertial waves. This yields a strong increase of the internal tide energy and shear in space-time regions where the background flow focuses the rays (caustics). The formation of internal waves caustics was studied theoretically and numerically by [Broutman, 1986] and [Broutman, 1997] but to the best of our knowledge it has never been observed before from in-situ oceani measurements. This mechanism may contribute to significantly increase vertical mixing generated by baroclinic tides in the vicinity of mid-ocean ridges in tropical regions.

Submesoscale dynamics of dissolved organic matter across the Northern Mediterranean Current revealed from a new glider-mounted optical sensor.

FRÉDÉRIC CYR[1], MADELEINE GOUTX[1], NAGIB BAIRHY[1], MARC TEDETTI[1], FLORENT BESSON[2], MARION MERY[2], ANDREA A. DOGLIOLI[1], ANNE PETRENKO[1]

[1] *Aix-Marseille Université, Université de Toulon, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 13288, Marseille, Cedex 09, France.*

[2] *ALSEAMAR, 9 Europarc, 13590 Meyreuil, France.*

Traditional measurements of dissolved organic matter (DOM) in natural environment implies the collection of water samples that need to be further analyzed in the laboratory. The workload associated with this task generally prevent the temporal and spatial resolutions to be sufficient to address DOM submesoscale dynamics. However, new techniques involving portable or submersible fluorometers have been employed in recent years to acquire real time and high frequency measurements of target DOM fluorophores in seawater. Data presented here are from one of these new generation sensors, the MiniFluo-UV, which is now fully operational on the European-built glider SeaExplorer. The two optical pathways used in the MiniFluo-UV target measurements of tryptophan-like (TRY-) and phenanthrenes-like (PHE-) compounds in natural environment that are interpreted using other standard physical and biogeochemical measurements on gliders such as temperature, salinity, Chlorophyll-a (Chl-a), turbidity, etc.

Data presented here were obtained in the Northwestern Mediterranean Sea between 28 October and 10 November 2015 as part of the OSCAHR (Observing Submesoscale Coupling At High Resolution) campaign. They consist of two transects across the frontal zone created by the permanent Northern Mediterranean Current. Results show that the new sensor is able to highlight new features of DOM dynamics. For example, near-shore low-salinity waters are associated with high turbidity, colored dissolved organic matter (CDOM) and high PHE-like concentrations (fluorescent DOM) suggesting anthropogenic influence, while offshore waters are associated with high Chl-a and high TRY-like concentrations marking higher biological production of DOM. Such distinction would be more difficult to assess without the MiniFluo-UV measurements, specially when looking only at Chl-a measurements. Specific improvements resulting from the use this new sensor for DOM characterization will be presented, together with preliminary results of submesoscale DOM dynamics in the NW Mediterranean Sea within OSCAHR campaign context.

Acknowledgments. This research was funded by the European Union's FP7 program for research, technological development and demonstration of the "NeXOS" project (grant agreement No 614102), and in collaboration with Alseamar.

Numerical simulation of the interannual variability of the Bay of Bengal upper ocean circulation characteristics by Regional Ocean Modeling System (ROMS)

SUMIT DANDAPAT[1], J. KUTTIPPURATH[1], ARUN CHAKRABORTY[1]

[1] *Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology Kharagpur, India*

The interannual variations of the Bay of Bengal (BoB) ocean circulation features have been investigated with the Regional Ocean Modeling System (ROMS) for the period of 2005-2010. The ROMS simulations for the BoB have been extended from 4°N to 25°N and 76°E to 100°E. We use a horizontal resolution of 9 km with 32 terrain-following vertical levels for these model runs. The initial and boundary conditions are derived from the HYCOM global data for 2005. The model is forced with the inter-annual forcing from the ECMWF Air-Sea fluxes. The interannual simulations are carried out with and without river input to estimate the relative importance of local and remote forcing. We discuss the model performance and analyze the trends and variability of temperature and salinity over the basin for the period 2005-2010. The simulations reveal that variations in wind stress can induce significant interannual changes in the circulation of the upper layers. The interannual response is more pronounced in the western BoB with the boundary currents Western Boundary Current (WBC) towards north and East India Coastal Current (EICC) towards south in this region. It is found that the influence of Indian Ocean Dipole (IOD) is more prominent than El Niño Southern Oscillation (ENSO) on the interannual variability in the BoB. The interannual changes of upwelling and downwelling signals become stronger during ENSO and IOD years in the western BoB. We also present the year-to-year changes in the occurrence, movement and lifecycle of the mesoscale and submesoscale eddies, and their influences on the strength of boundary currents in the western BoB during the IOD and ENSO years.

Impact of River and Tidal forcing in the Discontinuous Western Boundary Currents and associated Eddies of the Bay of Bengal

Bijan Kumar Das[1], Anandh T S[1], Sumit Dandapat[1], J. Kuttippurath[1], Arun Chakraborty[1]

[1] *Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology Kharagpur, India*

In North Indian Ocean (NIO), Bay of Bengal (BOB) shows very unique characteristics due to its parabolic basin shape, huge river input and monsoonal wind reversal. Previous studies have shown that the northward WBC during pre-Indian Summer Monsoon (ISM) and the southward East India Coastal Current (EICC) during post-ISM are continuous, whereas some studies have pointed out that the boundary current along the western coast of BOB during ISM is discontinuous. However, the mechanism behind the discontinuity of these currents is not well understood. Therefore, in this study, high resolution (9 Km $\times$ 9 Km) Regional Ocean Model System (ROMS), is used to investigate the effect of river discharge and tides on the Western Boundary Current (WBC) along the east coast of India during ISM. Two experiments are performed in the study region, with and without river and tidal forcing to understand the forcing impact. The results are compared with available satellite and reanalyzed datasets. It is seen that the ocean features along boundary are better captured in the simulation with river and tidal input. Huge amount of river discharge from various rivers in the east coast of India changes the Sea Surface Height Anomaly (SSHA), demarcates more specific upwelling and downwelling zones, and surfacing of the thermocline layer along the boundary. Model simulated geostrophic current pattern and eddies along the boundary are very clear and comparable with the observation. The model results with river and tidal forcing capture more eddies (e.g. tidal eddies) in mid-monsoon with cyclonic gyre in late monsoon. These simulations also indicate the effect of fresh water influx on the stratification of the cyclonic and anticyclonic flows along the boundary. In brief, the experiments with river and tidal forcing give a better understanding of the discontinuous WBC in the BOB.

Submesoscale Surface Dispersion Dynamics

Eric D'Asaro[1], Tamay Ozgokmen[2]

[1] *Applied Physics Laboratory and School of Oceanography, University of Washington, USA*

[2] *Rosenstiel School of Marine and Atmospheric Science,University of Miami*

A distinguishing feature of the submesoscale is their rich and complex structure at scales of meters to kilometers, intermingling balanced, internal wave and boundary layer processes. Quantitative measurement of such flows is notoriously difficult due to the small space and time scales. Here, we report on two recent attempts to make such measurements using large numbers of surface drifters: The GLAD experiment in July 2012, using 300 drifters, and the LASER experiment iin January/February 2016, using 1000 drifters. Both programs focussed on the dispersion of surface particles, motivated by questions about oil dispersion, but with an emphasis on using the dense sampling to address submesoscale dynamics. LASER added high resolution ADCP/CTD mapping to measure the subsurface flow. Measurements were made in deep water in the Northern Gulf of Mexico, in a region of weak mesoscale activity where submesoscale-permitting models predict the presence of a rich 'soup' of submesoscale motions. GLAD confirmed the accuracy of classic Richardson scaling laws at 200-m to 50-km scales and clearly indicated that second-moment dispersion at the submesoscales is local, driven predominantly by energetic submesoscale fluctuations. Submesoscale-permitting models could not reproduce the dispersion statistics at the smaller scales, perhaps because they had too little resolution. The 'turbulent' dispersive flow coexisted with strong inertial motions and with a strong antidispersive clumping of trajectories at km-scale, qualitatively consistent with surface convergence and downwelling predicted by the models. LASER, still underway as this abstract is written, shows similar phenomenology with the addition of much stronger and cyclic wind forcing as a series of fronts passed over the array of drifters. The talk will attempt to link the differing descriptions of these data based on statistical dispersion theory and submesoscale dynamics, with a special emphasis on the anti-dispersive clumping process.

Turbulance assesment in the southeastern part of the Baltic Sea

LINA DAVULIENE[1]
[1] *Environmental Reaseach Department, Institute of Physics, SRI Center for Physical Sciences and Technology, Vilnius, Lithuania*

The hydrodynamics of the south-eastern part of the Baltic Sea is scarcely investigated and described so far. In 2013 first attempts of conducting the drift experiments in the south-eastern part of the Baltic Sea at the Lithuanian coast were made. The group of three autonomous surface drifters was released about 2 km apart from the coast. Additional experiments were carried out last year. The meteorological conditions, the spreading rate and time dependence of the distance between drifters were analyzed. The data analysis showed that the distance between drifters is dependent on time and this trend in log-log scale has a threshold at about 400-700 m distance between drifters. The initial spreading to the threshold value is governed by the power law with the exponent close to 1 while for the larger distances exponent increases to about 1.5.

3D Dynamics of Freshwater Lenses, Double Diffusion, and Cabbeling in the Near-Surface Layer of the Ocean

CAYLA DEAN [1], ALEXANDER SOLOVIEV [1], ROBERT HELBER[2]

[1] *Nova Southeastern University, Halmos College of Natural Sciences and Oceanography, USA*

[2] *Naval Research Laboratory, USA*

Freshwater inflow due to convective rains or river runoff produce freshwater lenses in the near-surface layer of the ocean. These lenses are localized in space and involve salinity and temperature anomalies. The dynamics of freshwater lenses can be tied to the formation of the barrier layer and fronts, thus having an influence on large scale processes and contributing to the salinity field in the Aquarius and SMOS satellite footprints. Due to significant density anomalies, strong horizontal pressure gradients develop, which result in the lateral spreading of freshwater lenses resembling gravity currents in a lock exchange process. The gravity current head develops Kelvin-Helmholtz billows with vertical density inversions, which results in rapid mixing of the freshwater lens at its edges. The freshwater lens can either completely mix with the environment or achieve a compensated state when temperature and salinity anomalies compensate each other in the density field causing the horizontal pressure gradients to diminish and lateral spreading to cease. The compensated lenses then are subject to erosion by both double diffusion and cabbeling. In this work, we have simulated the evolution of freshwater lenses, including double-diffusion and cabbeling, with a 3D computational fluid dynamics model (CFD). During the process of spreading, freshwater lenses become progressively thinner, starting from the lens edges. Limited near-surface data from several field experiments in the tropical ocean (TOGA COARE) and the Gulf of Mexico (SCOPE) were used for verification of numerical simulations. In order to link the Aquarius/SMOS salinity retrievals with in situ sea surface salinity during rain, we have also simulated in CFD the process of rain drop penetration through the air-water interface and resulting vertical salinity profile in the upper few centimeters of the ocean. The results of this study indicate that 3D dynamics of the near-surface layer of the ocean are essential in the presence of freshwater inflow.

The role of Carbon cycle in the mangrove ecosystem south west coast of India

DEEPULAL PARENKAT MONY[1], CHANDRAMOHANAKUMAR N[1]

[1] *Inter University Centre for Development of Marine Biotechnology, School of Marine Sciences, Cochin University of Science and Technology,Foreshore Road, Kochi, Kerala, INDIA-682016*

Mangrove ecosystems are regarded as one of the most important coastal ecosystems in the world. Mangrove ecosystems along the coastlines are among the world most productive ecosystem with an average production of 2,500 mg cm per day. They are highly productive but extremely sensitive and fragile and are almost exclusively tropical. The present work deals with the role of dissolved greenhouse gases like, CO2 & CH4 in different mangrove ecosystems along the coastal regions of south west coast of India. Three mangrove ecosystems are discussed in this article. The carbon sequestration capacity of mangrove ecosystems is high while compared to other ecosystem. Each ecosystem has different mangrove plant species. So all the mangrove species are analysed for the presence of carbon concentration in its leaves, root and stem. The water samples are also collected from these locations and the pH, alkalinity, CO2, CH4 are analysed from all the locations. The results indicate the importance of mangrove ecosystem to the global carbon cycle.

Comparison of a satellite-derived high-resolution current map and numerical modelling of submesoscale eddies in a shallow-water domain

PHILIPPE DELANDMETER[1], WEI CHEN[2], ERIC DELEERSNIJDER[1,3], JONATHAN LAMBRECHTS[1], VINCENT LEGAT[1], GEORGE MARMORINO[2], ERIC WOLANSKI[4]

[1] *Université catholique de Louvain, Belgium*
[2] *Naval Research Laboratory, USA*
[3] *Delft University of Technology, The Netherlands*
[4] *James Cook University, Australia*

Interaction of flow with the reefs and islands that lie within the Great Barrier Reef (GBR) area of northeastern Australia create a rich submesoscale field of dipolar vortices, unsteady wakes, lee eddies, and free shear layers, all of which impact both the aggregation and dispersion of coral spawn, cyanobacteria and pollutants.

A unique and detailed view of the submesoscale variability in a part of the GBR having a number of small islands has been obtained by using a 'stereo' pair of 0.5 m-resolution visible-band satellite images that were acquired just 54 seconds apart. These were analysed using an optical-flow technique to extract the near-surface current, vorticity, and divergence fields.

To help understand features in the imagery and in the image-derived flow fields, an unstructured-mesh, finite-element model, SLIM (www.climate.be/slim), was used to simulate conditions at the time imagery was collected.

While aspects of the simulated flow field are in agreement with the observations, there are several unanticipated differences. These discrepancies are not expected to be a consequence of the mesh resolution, and so an analysis was made of the model sensitivity to formulations of bottom drag and eddy viscosity. Eventually, the way the model treats the separation flow was examined.

Chaotic stirring in surface quasi-geostrophic turbulence

AUDREY DELPECH[1], GUALTIERO BADIN[2]
[1] *ENSTA ParisTech, University of Paris-Saclay, France*
[2] *Institute of Oceanography, University of Hamburg, Germany*

We examine the chaotic stirring generated by forced and dissipative finite depth surface quasi-geostrophic (SQG) turbulence. The flow shows a transition from local dynamics at the surface to nonlocal dynamics in the interior. The finite depth further allows the control of the transition scale from large scale QG dynamics to small scale SQG dynamics. The effects of depth and the transition scale on the chaotic advection of a passive tracer are analyzed making use of Finite Time and Finite Separation Lyapunov Exponents (FTLEs and FSLEs respectively). The two effects (depth and transition scale) are then used to parametrize the passage from local to nonlocal turbulence.

A Lagrangian current perspective to surface drift and lateral mixing during an upwelling event in the Gulf of Finland, Baltic Sea

NICOLE DELPECHE-ELLMANN[1], TARMO SOOMERE[1,2], TOMA MINGELAITĖ[3]

[1] *Institute of Cybernetics at Tallinn University of Technology, Estonia*

[2] *Estonian Academy of Sciences, Estonia*

[3] *Department of Natural Sciences, Klaipėda University, Lithuania*

During the upwelling process, the presence of (sub)mesoscale disturbances (jets/squirts, filaments, eddies) has been suggested to play an important role in the lateral mixing of waters [Zhurbas et al., 2008]. However many of these studies have relied on an Eulerian framework of currents [Laanemets et al., 1994, Myrberg and Andrejev, 2003] with only a few studies investigating the drift and entrainment of various substances that was located in the 'original' surface water during the upwelling process. In this study a Lagrangian surface current perspective is presented, that combines different sources of in-situ data with satellite derived Sea Surface Temperature (SST) data. This combination allowed a detailed co-examination of the surface drift and lateral mixing during an upwelling event in the Gulf of Finland, Baltic Sea.

To identify the upwelling process the MODIS (Aqua) spectrometer satellite provided SST maps and transects. In addition three light weight in-situ surface drifters, designed to follow the current-driven flow in the uppermost layer of the sea (depths < 2 m) showed the drift and current velocities during the upwelling. Sea floor topography of the study area was also utilised to understand some of the spatial trends observed. Results show that once cold water reached the surface, transverse cold water jets (40–45 km from the coast) developed at distinct locations, thus transporting the cold water offshore rather than mixing. The drifters tended to stay within the original surface waters and avoided these transverse cold water jets. Lateral mixing was enhanced at a later stage of the upwelling and continued after the end of the event when the winds that have driven the entire process began to subside and intense (sub)mesoscale activity started to dominate.

References

Laanemets, J., Zhurbas, V., Elken, J., Vahtera, E., 2009. Dependence of upwelling mediated nutrient transport on wind forcing, bottom topography and stratification in the Gulf of Finland: model experiments, Boreal Environ. Res. 14, 213–225.

Myrberg, K., Andrejev, O., 2003. Main upwelling regions in the Baltic Sea–a statistical analysis based on three-dimensional modelling. Boreal Environ. Res. 8, 97–112.

Zhurbas, V., Laanemets, J., Vahtera, E., 2008. Modeling of the mesoscale structure of coupled upwelling/downwelling events and the related input of nutrients to the upper mixed layer in the Gulf of Finland, Baltic Sea. J. Geophys. Res.–Oceans 113, Art. No. C05004.

Mesoscale to Submesoscale variability during the OUTPACE cruise: Contrasting Biological and Physical regimes in the oligotrophic SW Pacific

ALAIN DE VERNEIL[1], ANDREA DOGLIOLI[1], ANNE PETRENKO[1], PASCALE BOURUET-AUBERTOT[2], GILLES ROUGIER[1], SOPHIE BONNET[1], THIERRY MOUTIN[1]

[1] *Aix-Marseille Université, CNRS/INSU, Université de Toulon, IRD, Mediterranean Institute of Oceanography (MIO) UM 110, Marseille, France*

[2] *Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques, Institut Pierre Simon Laplace (LOCEAN-IPSL), Sorbonnes Universités, UPMC Univ. Paris 06, Paris, France*

In the past decades, both modeling and theoretical studies have identified the submesoscale as a dynamical regime with large consequences for planktonic ecosystems. These impacts relate primarily to altered light and nutrient fields, brought about by rapid restratification, vertical advection of nutrients to the surface, and/or mixing, all occurring on timescales similar to planktonic growth. Despite the ubiquitous nature of mesoscale and submesoscale features in the ocean, most physical studies naturally focus on vigorously forced, energetic mixed layers in the context of temperate latitudes, coastal transition areas, and/or wintertime conditions. How do submesoscale structures arise for plankton in more quiescent regions, such as the margins of subtropical gyres? Additionally, what impact does submesoscale motion have upon phytoplankton and subsequent biological production?

Here we present results from the OUTPACE campaign (https://outpace.mio.univ-amu.fr), undertaken from February 18 to April 3, 2015, across the SW Pacific from Noumea to Tahiti onboard the French R/V L'Atalante. Using a combination of in situ and remote sensing data, we assess how both physical and biological variability manifests from the regional to the submesoscale. Understanding the drivers of biological variability in these regions has become imperative in light of both historical undersampling and to better understand the role they may play in time with ongoing climate change.

Acknowledgements: This is a contribution of the OUTPACE (Oligotrophy from Ultra-oligoTrophy PACific Experiment) project (doi:10.17600/15000900) funded by the French national research agency (ANR), the LEFE-CyBER program (CNRS-INSU), the GOPS program (IRD) and CNES. The OUTPACE project was managed by MIO (OSU Institut Pytheas, AMU) from Marseilles (France). The authors thank the crew of the R/V L'Atalante for outstanding shipboard operation. L. Bellomo and M. Picheral are warmly thanked for their efficient help in CTD rosette management and data processing.

Three dimensional structure of chlorophyll biomass in Senegalese Mauritanian upwelling

IBRAHIMA DIACK[1]

[1] *Laboratoire de Physique de l'Atmosphere et de l'ocean Simeon Fongang, Ecole superieur Politechnique Universite Cheikh Anta Diop de Dakar/Senegal*

Chlorophyll (chl-a) is fluorescent pigment assimilating photosynthetic plant. In the marine area these pigment essentially carried by phytoplankton i.e. the original plant plankton. Thus species of r strategy are too sensitives to environmental conditions fluctuations. However they play too important role on the marines ecosystems dynamic where they from the basis of food web. Survival and development of aquatic species is highly depending of thus micro organisms existence. Our study aims to understand the chlorophyll biomass structuring in the water column as well as thus spacial-temporal distribution observed during "varget" oceanographic campaign to 1996, 1997, and 1999.

The physical mixing layer, via the physic of upwelling coast, as well as the depth of the euphotic layer, governs the surface enrichment in nutrients (minerals) and largely determines biomass phytoplankton chl-a. Data used analysis shows that upwelling is low in 1997 whence the hight temperatures, whereas upwelling 1999 is characterized by intense upwelling. It then results hight phytoplankton productivity express as chl-a concentration. According to the depth and the maximum values of chl-a, we distinguish five (5) shapes of chl-a profiles but which differ in their structure on the vertical. These profiles can be classified in two groups. Those whose maximum is subsurface and those whose maximum arrives surface (met only en 1999).

We express hypothesis which resurgence intensification of cold water into 1999 observed both on times series of CUISST (Coastal upwelling Index "based on the Sea Surface Temperature SST") as phytoplankton productivity express as in-situ chl-a Concentration is probably one of consequences of La Niña 1998-1999 on the tropical Atlantic ocean and particularly in Senegalese.

Key words : Chlorophyll, CTD profile, Upwelling, Phytoplankton, ENSO, ”El Niño”, ”La Niña”

Investigating the termination regime of the East Madagascar Current and the influence of Southern Indian Ocean's westward-propagating eddies on the local currents.

FEHMI DILMAHAMOD[1]

[1] *Department of Oceanography, University of Cape Town, South Africa.*

The East Madagascar Current (EMC) and its surrounding waters in the Indian Ocean are of particular interest because it is one of the three major source regions of the Agulhas Current. Variability of EMC is also known to influence the timing of ring formation at the Agulhas Retroflection and, ultimately, the strength and stability of the Atlantic overturning circulation due to the leakage of warm Indian Ocean water into the Atlantic Ocean. However, the termination regime of the EMC and its variability, after passing the southern tip of Madagascar, has not been completely resolved. Whether or not a possible non-persistent retroflection exists, it is however known that nearly symmetric dipolar vortex pairs joins the Agulhas Current from the southern tip. Also occurring south of Madagascar is the start of the South Indian Ocean Countercurrent (SICC), a permanent shallow eastward flow, fed by a possible retroflection of the EMC. It breaks into 3 distinct branches as it flows towards the Australian coast. This region is also home to westward propagating eddies, travelling from the Australian coast towards Madagascar, covering the vicinity of the SICC. Interaction between these two oceanic features can create disturbances, influencing the variability of the SICC as well as the physical mechanisms driving the eddies. On reaching the Madagascar coast, eddies will also interact with the EMC, causing changes in the flow of the EMC, hence possibly affecting the termination regime. This whole oceanic system is being investigated using a high-resolution regional model to better understand the variability of the termination regime of the EMC and the interaction between the westward-propagating eddies and the main local oceanic currents.

Mixed and barrier layers variabilities in tropical Atlantic

DJOIRKA MINTO DIMOUNE[1]
[1] *ICMPA, Faculty of Sciences and Technics (FAST), University of Abomey-Calavi, Benin*

Daily re-analysis of temperatures and salinity records, from MERCATOR GLORYS2V3, are used to analyze the variabilities of Density Mixed Layer Depth (MLD), Isothermal Layer Depth (ILD) and Barrier Layer Thickness (BLT) at PIRATA buoys locations in tropical Atlantic Ocean from 2000 to 2008. Seasonal cycles have gone from 1993 to 2013 to validate data results with previous studies. The presence of significant barrier layer is noticed at 8 positions, where correlations between the Isotherm Layer Depth and density Mixed Layer Depth are significants, but with coefficients less than 0.90, except at 0°N-35°W. At 19°S-34°W, we noticed a strong vertically Compensated Layer (CL), especially in summer-autumn in the northern hemisphere. Study of intra-seasonal variability shows the influence of Tropical Instabilities Waves (TIWs) on Isotherm Layer Depth variability at 4°N-38°W. Correlations between density Mixed Layer Depth and Isotherm Layer Depth show that seasonal variability of Barrier layer (BL) is linked with Isotherm Layer Depth at 20°N-38°W, 15°N-38°W and 4°N-38°W. At 8°N-38°W, the influence of North Equatorial Counter Current (NECC) which transports Amazon fresh water, on Sea Surface Salinity (SSS) is the main mechanism that explains seasonal variability of Barrier Layer (BL). Inter-annual variability of the Isotherm Layer at positions 12°N-38°W, 4°N-38°W, 4°N-23°W and 0°N-35°W is associated to sea level variability, and especially the intensification of westward wind at 0°N-35°W.

Internal waves and mixing in northern Baffin Bay from moored hydrographic observations, 2003-2006

G. Djoumna[1], D. M. Holland[1,2]

[1] *Center for Sea level Change, NYU Abu Dhabi, United Arab Emirates*

[2] *New York University, New York , USA*

The spatiotemporal variability of the energetics and turbulent dissipation of internal tides in Nares Strait is examined using hydrographic data from conductivity-temperature-depth, temperature and salinity and Acoustic Doppler current profilers (ADCP) moorings, and LADCP spanning from August 2003 to August 2006. Nares Strait is a major conduit for the southward exchange of Arctic water and ice into Baffin Bay and the Atlantic Ocean. How the fluxes associated with the small-scale processes affect fluxes through Nares Strait remain poorly understood. Temporal variations of mixing rates in the strait likely occur at different spacial scales including large-scale motions influenced by rotation, geometric scales due to topography (presence of two sills), and scales related to vertical and lateral boundary layer processes. For example, the internal Rossby radius of deformation in Nares Strait is $\sim$ 10 km, two to five time the width of the strait {Münchow et al., 2006}.

Here, we focus on internal waves induced mixing and double-diffusive instabilities in the permanent pycnocline in Nares Strait. It is shown that the warming of the bottom waters in Nares Strait is accompanied by thermohaline staircase in the temperature and salinity profile, and this could enhanced vertical heat transports in the pycnocline. We use the first two Empirical Orthogonal Function (EOF) to detect internal waves by analyzing the scatter diagram of the first EOF projection coefficient versus the second EOF projection coefficient. Mixing rates were inferred from density inversions (Thorpe scale method) and from internal wave fine-scale parametrizations {Gregg, 1989} to hydrography and current data.

REFERENCES

Münchow, A. and Melling H. and Falkner K.K., 2006. An observational estimate of volume and freshwater fluxes leaving the Arctic Ocean through Nares Strait. J. Phys. Oceanog., 36, 2025-2041.

Gregg, M.C., 1989. Scaling turbulent diffusion in the thermocline J. Geophys. Res., 94, 9686-9698.

Mapping the planktonic community across submesoscale physical features: the 2015 OSCAHR cruise in the NW Mediterranean

A. M. Doglioli[1], G. Grégori[1], M. Thyssen[1], T. Wagener[1], P. Marrec[1], G. Rougier[1], N. Bhairy[1], J. Fenouil[2], A. de Verneil[1], L. Rousselet[1], F. Cyr[1], A. A. Petrenko[1], J.-M. André[1], L. Berline[1], F. d'Ovidio[3], A. Pietri[3], F. Nencioli[1,4], L. Jullion[1], C. Pinazo[1], C. Yohia[1], P. Marsalaix[5]

[1] *Aix-Marseille Université, CNRS/INSU, Universit'e de Toulon, IRD, Mediterranean Institute of Oceanography, Marseille, France*

[2] *Genavir, La Seyne sur Mer, France*

[3] *Sorbonne Université/CNRS/IRD/MNHN, Laboratoire d'Océanographie et du Climat, Institut Pierre Simon Laplace, Paris, France*

[4] *Plymouth Marine Laboratory, Plymouth, UK*

[5] *Laboratoire d'Aérologie, CNRS and Toulouse University, Toulouse, France*

In the past decade, submesoscale dynamics have been predominantly investigated through the analysis of numerical models. These studies suggest that submesoscale variability and the associated horizontal and vertical fluxes play an important role in ocean dynamics and physical-biogeochemical coupling. Modelers also generally highlight the need for in situ measurements at the submesoscale. Nevertheless, this represents a big challenge due to the ephemeral nature of submesoscale structures. Moreover, in order to study physical-biological coupling at the submesoscale it is crucial to perform biological measurements at high frequency.

The scientific objective of OSCAHR (Observing Submesoscale Coupling At High Resolution) is to characterize the structuring effect of a submesoscale-active region on the first trophic levels and the associated biogenic elements. Additionally, the OSCAHR dataset allows the validation of remote sensing measurements (altimetry, ocean color, reconstitution of planktonic assemblages). The cruise strategy utilizes an adaptive approach based on both satellite and numerical modeling data to identify the dynamical features of interest. Our methodology also includes the use of novel platforms of observation for sampling the ocean surface layer at a high spatial and temporal frequency. In particular, a MVP (Moving Vessel Profiler) is deployed with CTD, Fluorescence and LOPC (Laser Optical Particle Counter) sensors. Furthermore, a new version of automated flow cytometer is installed for real-time, high-throughput sampling of phytoplankton functional groups, from micro-phytoplankton down to cyanobacteria (including Prochlorococcus). Two sources of seawater have been used in OSCAHR: along with the onboard surface water intake, a new pumping system is developed and tested in order to sample the upper water column to one meter resolution.

The OSCAHR cruise has been conducted from 29 October to 6 November 2015 in the North-West Mediterranean Sea. The first leg sampled the coastal waters near the Côte d'Azur, characterized by the presence of the along-shore Northern Mediterranean Current. During the second leg, an offshore region characterized by strong temperature and chlorophyll gradients has been sampled in the middle of the Gulf of Genoa.

Acknowledgments.

The authors are grateful to the CNFC and to the crews of R/V T'ethys II.

OSCAHR is supported by the MIO (AT COUPLAGE program) and by the following projects: CHROME (M.Thyssen, AMIDEX), SeaQUEST (O.Ross, UE FP7-People), BIOSWOT (F.d'Ovidio, CNES), CETSM (V. Rigaud, R'egion PACA) and FOCEA (M.Zhou & F. Carlotti, ANR-09-CEXC-006-01).

Global variability in submesoscale density variability from historical thermosalinograph data

KYLA DRUSHKA[1]

[1] *Applied Physics Laboratory, University of Washington*

Temperature and salinity measurements are routinely collected from numerous research vessels and volunteer observing ships using thermosalingraph (TSGs), which generally have seawater intake ports at 3 to 10 m depth. With typical sampling rates of 1 to 5 minutes and ship speeds of 8 to 20 kt, TSGs provide continuous along-track, near-surface temperature and salinity measurements at spatial scales of $\sim$0.5 to 3 km. Recent and ongoing efforts to quality-control historical TSG data (notably by the Global Ocean Surface Underway Data (GOSUD) Project) have produced a wealth of high quality, high resolution near-surface measurements, providing a unique opportunity to characterize near-global, year-round submesoscale variations of near-surface density.

Here, we use TSG observations from around 40 ships, collected from 1989 to 2015, to characterize variations in surface temperature, salinity, and density at spatial scales of 2 to 50 km. The density ratio, a metric for quantifying the compensation of thermohaline fronts, is computed at different spatial scales. We find strong seasonal and regional variability in the relative importance of temperature and salinity in controlling the dynamics of submesoscale fronts: in general, fronts tend to be compensated during winter; the dominance of temperature versus salinity varies widely between regions. Spectral slopes of temperature, salinity, and density provide new insight into global patterns of the mesoscale–submesoscale potential energy cascade at the ocean surface.

Mesoscale resolution capability of along-track satellite altimetry: present and future

Claire Dufau[1], Marion Orsztynowicz[1], Gérald Dibarboure[1], Rosemary Morrow[2], Pierre-Yves Le Traon[3]

[1] *CLS, France.*
[2] *LEGOS, CNRS, France*
[3] *IFREMER, France*

Wavenumber spectra computed from along-track Sea Surface Height Anomalies exhibit linear slope between large and small scales linked to the geostrophic turbulence and its energy cascades in the mesoscale band (Le Traon et al., 2008). At small scales, altimeter measurements are affected by instrumental noise preventing the observation of small scales processes. This paper determines the length scales of ocean dynamics following SQG theory reachable with along-track 1hz altimeter data. It relies on a joint analysis of (1) the spectral slope in the mesoscale band and (2) the noise level observed for scales lower than 20km. Maps of mesoscale capability of the on-flight altimeter missions (Jason-2, SARAL/Altika, Cryosat-2) are discussed at global scales. Finally, a prediction of the future 2D mesoscale resolution capability of the SWOT mission is computed using a simulated SWOT error level.

Characterising the atmospheric interactions on the submesoscale instability in the Southern Ocean and their impacts on mixed layer stability

Marcel du Plessis[1], Seb Swart[2], Amala Mahadevan[3], Isabelle J Ansorge[1]

[1] *University of Cape Town*
[2] *Southern Ocean Carbon and Climate Observatory*
[3] *Woods Hole Oceanographic Institution*

The exchange of CO2 and heat between the atmosphere and the ocean is a fundamental process in regulating Earth's climate. The movement of these properties away from the surface, where they can potentially be re-released into the atmosphere is therefore an important process. This study looks at the role of submesoscale processes in characterising the variability of the upper ocean from in situ observations. In the Atlantic Subantarctic Zone, the energetic Antarctic Circumpolar Current provides the location of the deployment of two ocean gliders as part of the third Southern Ocean Seasonal Cycle Experiment (SOSCEx III). We make use of a sampling strategy that monitors a single location (within 20 km) for one seasonal cycle (winter to end of summer), providing a unique, high-resolution dataset of temperature, salinity, surface and depth-mean currents and fluorescence. We provide evidence of how in the presence of a down-front wind stress along a large horizontal density front, a strong destratifying Ekman buoyancy flux exists. Initial findings indicate this flux to erode the mixed layer stratification and deepen the mixed layer depth. Conversely, synoptic scale reversals to up-front winds interact with fronts to promote a stabilising flux. The strong restratifying flux that is driven by the strength of the horizontal buoyancy gradient and the mixed layer depth is able to override mixing and increase the mixed layer stratification. Observations of chlorophyll within the mixed layer suggest that phytoplankton production follows the stabilising and destabilising fluxes, by increasing and decreasing respectively. Along with these findings, calculations of Ertel potential vorticity indicate a highly unstable mixed layer during deepening phases, while a restratification of the mixed layer returns the potential vorticity to a stable state. These results indicate that horizontal buoyancy fronts are likely important in determining the stability of the mixed layer and can have an important influence on the biogeochemistry in the Southern Ocean.

Numerical modeling of the dispersion of the Bay of Bengal freshwater plume in a hierarchy of unstructured-grid ocean circulation models

FABIEN DURAND[1], YANN KRIEN[1], XAVIER BERTIN[2], LAURENT TESTUT[1], FABRICE PAPA[3]

[1] *LEGOS, Toulouse, France*

[2] *LIENSs, La Rochelle, France*

[3] *IRD/CEFIRSE, Indian Institute of Science, Bangalore, India*

The Bay of Bengal is a semi-enclosed tropical basin in the north-eastern Indian ocean. It receives an excess freshwater from three rivers among the world's top fifteen: the Brahmaputra, the Ganges and the Irrawaddy. This freshwater supply is highly seasonal, as it is associated with the summer monsoon. It results in a well defined freshwater plume that builds up during summer and fall close to the rivers mouths, and subsequently extends all along the northern periphery of the basin. It retains its identity until the following spring. The freshwater plume overlays a very strong density stratification located at only a few meters depth. This pycnocline has profound implications in air-sea local interactions, as it inhibits the vertical mixing of the warm surface waters with the underlying cooler thermocline waters. Despite recent initiatives to observe and decipher the mechanisms of the freshwater plume dispersion in the deep part of the Bay of Bengal (see e.g. OMM/ASIRI programs), hardly anything is known about the processes responsible for its evolution in the costal domain (on the shelf as well as in the estuaries). This area also suffers from a drastic lack of observations. Our poster presents an attempt to implement a suite of three different configurations of the three-dimensional SELFE/SCHISM circulation model over the northern Bay of Bengal, with horizontal resolutions ranging from eddy-permitting (25 km) to eddy-resolving (8 km) and sub-mesoscale-resolving (1 km). The model grid is unstructured but the the resolution is prescribed as roughly uniform throughout the oceanic shelf. We present preliminary results of the impact of the finer scales on the spatio-temporal evolution of the freshwater plume.

3D reconstruction of mesoscale flows using observations of satellite high resolution data: twin experiments with a numerical model of the Solomon Sea

MARINA DURAN MORO[1], JEAN-MICHEL BRANKART[1], PIERRE BRASSEUR[1], JACQUES VERRON[1]

[1] *LGGE, Grenoble, France*

Satellite sensors are increasingly providing high resolution observations of the oceans and this will become even more true in the future, especially for dynamic topography (altimetry) and for tracers (ocean color for example). In particular, the NASA/CNES SWOT (Surface Water Ocean Topography) mission will provide in 2020, high resolution Sea Surface Height measurements giving unprecedented information on the meso and submesoscale dynamics.

In this study, the focus is on the feasibility to use these measurements to improve and correct the numerical model behavior at these scales, especially on the vertical. Since such high resolution SSH observations are not yet available, simulations from a fine resolution regional model are used [Djath et al., 2014]. The region of interest is the Solomon Sea where high energetic dynamics occur and where the Rossby radius of deformation is large, allowing a significant range for meso- and submeso-scales to develop. Twin experiments are carried out using these simulations. Using Finite Size Lyapunov Exponents (FSLE) from the velocity fields, a 3D reconstruction of the flow is performed. A cost function minimisation method is applied following Gaultier et al. [2013]. This technique succeeds in making a first guess velocity field to converge towards the true velocity state and hence, it is able to correct meso-scale dynamics using the structure information contained in the velocity signal. This correction allows us to extend the analyses on the vertical using the 3D multivariate EOFs and in the studied cases, this approach provides useful information below the surface.

The next step will be to establish a closer link between this minimization method and the future SSH observations. Several options will be explored : (i) geostrophic velocities can be calculated from SSH observations to constrain the FSLE structure and consequently, the minimisation method could be applied ; (ii) a Kalman filter can be applied to precondition the background state of the minimization method using SSH or the Laplacian of SSH as observed variables.

References : Djath B., J. Verron, L. Gourdeau, A. Melet, B. Barnier, J. M. Molines, 2014: Multiscale analysis of dynamics from high resolution realistic model of the Solomon sea. Journal of Geophysical Research, 119 (9), 6286-6304. Gaultier L., Verron J., Brankart J.-M., Titaud O. and Brasseur P., 2013 : On the use of submesoscale tracer fields to estimate the surface ocean circulation, Journal of Marine Systems, 126, 33–42.

Modeling meso- and submeso-scale dynamics in the marginal ice zone of the Bering Sea shelf.

SCOTT M. DURSKI[1], ALEXANDER L. KURAPOV[1]
[1] *CEOAS, Oregon State University, USA*

A 2-km resolution coupled ice/ocean model has been developed to study mesoscale circulation in the Eastern Bering Sea. Comparison of simulations of winter 2009-10 with satellite-derived estimates of sea-ice areal coverage and extent confirm that the model accurately captures both the rapid Fall/Winter advance of sea ice, southward and westward over the shelf, and the subsequent Spring retreat (northward and eastward). As the ice edge either advances or retreats, fronts with mesoscale variability develop in the marginal ice zone. Depending on the mechanism responsible (advective or thermal) and the relative proximity of the ice edge to the shelf break, these fronts may alternately exhibit positive or negative cross shelf density gradients. Spatial variability in the model, in these regions, rapidly approaches the limitations of its mesoscale resolution (<O(10km)), then persists at these scales, raising the question whether submesoscale processes ultimately contribute to the dynamic balances. (High-resolution MODIS imagery has shown similar scales of variability in the marginal ice zone of the Bering Sea). To explore this, 1-month simulations are run at 250m-resolution in a 100km x 100km subdomain representing the central outer portion of the Bering Sea shelf, west of St. Matthew Island. By varying the initialization time, the inclusion or exclusion of surface fluxes and the inclusion or exclusion of an active ice model, we explore under which conditions energy cascades into the submesoscale , and how inclusion of submesoscale processes may influence the mesoscale circulation.

The coastal impact of the 2015-2016 El Niño off Peru : preliminary results from a glider cruise and regional modelling experiments

ECHEVIN V.[1], COLAS F.[1,2], CORREA D.[2], GUTIERREZ D.[2], POUS S.[1], AUMONT O.[1], ESPINOZA D.[2], TESTOR P.[1], FUDA J-L[3], BENABDELMOUMENE H.[3], BACHELIER C.[3], ORTLIEB L.[1], SIFEDDINE A.[1]

[1] *LOCEAN, UPMC/IRD/CNRS, France*
[2] *IMARPE, Peru*
[3] *Division Technique INSU, France*

The El Niño phenomenon has had a profound impact on the coastal circulation and ecosystems off the Peruvian coasts (e.g Barber and Chavez, 1982). When equatorial Kelvin waves reach the coasts of South America, the thermocline/nutricline deepens abruptly, which halts the nearshore upwelling of nutrient-replete waters and the associated primary productivity, triggering huge modifications at all levels of the trophic chain. The nearshore circulation is strongly modified due to the presence of an intense surface poleward current transporting anomalously warm, nutrient-depleted waters. The 2015-2016 El Niño event being one of the most intense ever recorded, we describe the impact of this event on environmental conditions (hydrology, productivity and oxygen concentration) in the north Peru shore. We investigate the meso an submesoscale processes which occur during the event using both recent glider measurements and high-resolution, regional model simulations (e.g. Colas et al., 2008). The recent El Niño event is contrasted with the previous, very intense El Niño event, which occurred in 1997-1998.

REFERENCES

Barber, D., and F. P. Chavez, 1982. Biological Consequences of El Niño. Science, 222, 4629, pp.1203-1210.

Colas, F., X. Capet, J.-C. McWilliams, A. Shchepetkin, 2008. 1997-1998 El Niño off Peru: a numerical study. Progress in Oceanography, 79, 138-155.

Gravity wave drag in the ocean

Carsten Eden[1], Dirk Olbers[2]
[1] *Institut für Meereskunde, Universität Hamburg, Germany*
[2] *Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany*

When gravity waves are propagating in a vertically sheared geostrophic (eddying or mean) flow, they exchange energy with the (eddying or mean) flow and can even break due to critical layer absorption, transferring their energy to small-scale turbulence. A novel concept to parameterise gravity wave-mean flow interaction in the ocean is demonstrated, based on the description of the entire wave field by the wave-energy density in physical and wavenumber space, and its prognostic computation by the radiative transfer equation. The IDEMIX (Internal wave Dissipation, Energetics and MIXing) concept enables to simplify the radiative transfer equation with a few but reasonable assumptions, and to derive simple but consistent parameterisations in terms of spectrally integrated energy compartments which are used as prognostic model variables.

The effect of the waves on the mean flow in the concept is in accordance with the non-acceleration theorem by Andrews and McIntyre (1976) and figures as a divergence of a vertical eddy momentum flux in the residual momentum equation, similar to vertical friction, but can accelerate and decelerate the mean flow. Using the new parameterisation in realistic ocean models it will be shown that the energy transfer between waves and large-scale mean flow is present, but globally amounts to only a fraction of, e. g., the energy transfer from mean flow to meso-scale eddies. It is the effect of critical layers where waves break and contribute to density mixing which appears to be the more important effect in the ocean.

Combined DINEOF reconstruction of SEVIRI SST and HF-Radar surface current data aided with WRFDA winds. A case study in the Bay of Biscay during winters with a surface signal of the Iberian Poleward Current.

GANIX ESNAOLA[1], ALEXANDER BARTH[2], AIDA ALVERA AZCÁRATE[2], JON SAENZ[3,4], GABRIEL IBARRA-BERASTEGI[5], SANTOS J. GONZÁLEZ-ROJÍ [3]

[1] *University of the Basque Country, Engineering College of Gipuzkoa, Department N. E. and Fluid Mechanics, Donostia-San Sebatian, Spain,*

[2] *GeoHydrodynamic and Environmental Research (GHER), University of Liège, Liège, Belgium*

[3] *University of the Basque Country, Fac. Sciences and Technology, Applied Physics II, Leioa, Spain*

[4] *Plentziako Itsas Estazioa (PIE), University of the Basque Country, Plentzia, Spain*

[5] *University of the Basque Country, Engineering College of Bizkaia, Department N. E. and Fluid Mechanics, Bilbao, Spain*

Two HF-Radar antennas located in the Basque coast provide hourly surface current data since late 2009 over the corner of the Bay of Biscay. Over the same area and period, hourly SEVIRI Sea Surface Temperature (SST) data is also available. For the use of these datasets in the study of processes affecting SST or surface currents, the reconstruction of missing data present in both datasets can be a deal of great interest. Assuming that the causes of the presence of missing data in the different datasets are a priory independent, a mutual benefit could be obtained combining both datasets in a single data reconstruction technique.

An experiment is proposed here to test the feasibility of combining hourly SEVIRI SST and HF-Radar surface current datasets in the context of the DINEOF technique. After checking the independence of the sources of missing data, the reconstruction technique is applied to the SST and surface current datasets separately, first, and combining then after. Part of the initially non-missing data is reserved to test the performance of the different experiments by means of cross-validation. In addition, a third source of information that does not contain missing data is added to the combined reconstruction experiments in the form of hourly surface wind fields, and the impact in the quality of the reconstructions is checked. These surface winds are obtained from a WRF model run nested in ERAInterim that covers the Iberian Peninsula and surrounding areas. A 15km x 15km grid with 60 vertical levels is used, and a 3DVAR assimilation is run every 6 hours using the same observations that were used in the case of ERAInterim.

A SST signal related to the Iberian Poleward Current (IPC) can be observed during some winters within the slopes and shelves of the Bay of Biscay, and some influence has also been reported in HF-radar surface current data. The slope current is characterized by its baroclinicity, and the associated fronts and meanders, amongst others. Two 4 month-long (November to February) winter-time periods corresponding to the 2010-2011 and 2011-2012 transitions, and that have been reported to show an IPC related SST signal, were

selected for the experiments. The effect of the different reconstruction strategies is then checked in terms of the spatial and temporal characterization of the surface IPC signal, both in the reconstructed SST and HF-Radar data. An special attention is paid to the higher order EOFs retained in the reconstruction technique, as expected to be related to mesoscale and submesoscale processes.

Observations of Vorticity and Strain From Drifters in the Ocean

SEBASTIAN ESSINK[1,2], ANDREW LUCAS[3], VERENA HORMANN[3], LUCA CENTURIONI[3], AMALA MAHADEVAN[1]

[1] *Woods Hole Oceanographic Institution, Woods Hole, MA, USA*

[2] *Massachusetts Institute of Technology, Cambridge, MA, USA*

[3] *Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA*

Lagrangian velocity estimates from a large, but closely-spaced, drifter array in the Bay of Bengal are used to calculate vorticity and strain. The along-trajectory vorticity signal reveals complex patterns, supposedly generated by tides, inertial oscillations, and mesoscale and submesoscale flow. In particular, banded structures of alternating positive and negative vorticity are observed, where trajectories are parallel to the coastline. This work aims at a mechanistic understanding of the contributing factors that generate the observed vorticity patterns. By understanding the role of tides, inertial oscillations and the mesoscale circulation, estimates for the vorticity generating effect of submesoscale flows will be retrieved. The footprint of submesoscale dynamics is evidenced from a) positively-skewed distributions of vorticity, b) regions, in which high strain and high vorticity co-occur and c) a correlation between vorticity and lateral density gradients or fronts.

UK Environmental Prediction – integration and evaluation at the convective scale

JOACHIM FALLMANN[1], HUW LEWIS[1], JUAN CASTILLO[1], DAVID PEARSON[1], CHRIS HARRIS[1], ANDY SAULTER[1], LUCY BRICHENO[2], ELEANOR BLYTH[3], ALBERTO MARTINEZ DE LA TORRE [3]

[1] *Met Office, FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom*
[2] *National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool L3 5DA, United Kingdom*
[3] *Centre for Ecology & Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, United Kingdom*

Traditionally, the simulation of regional ocean, wave and atmosphere components of the Earth System have been considered separately, with some information on other components provided by means of boundary or forcing conditions. More recently, the potential value of a more integrated approach, as required for global climate and Earth System prediction, for regional short-term applications has begun to gain increasing research effort. In the UK, this activity is motivated by an understanding that accurate prediction and warning of the impacts of severe weather requires an integrated approach to forecasting. The substantial impacts on individuals, businesses and infrastructure of such events indicate a pressing need to understand better the value that might be delivered through more integrated environmental prediction. To address this need, the Met Office, NERC Centre for Ecology & Hydrology and NERC National Oceanography Centre have begun to develop the foundations of a coupled high resolution probabilistic forecast system for the UK at km-scale. This links together existing model components of the atmosphere, coastal ocean, land surface and hydrology. Our initial focus has been on a 2-year Prototype project to demonstrate the UK coupled prediction concept in research mode. This presentation will provide an update on UK environmental prediction activities. We will present the results from the initial implementation of an atmosphere-land-ocean coupled system, including a new eddy-permitting resolution ocean component, and discuss progress and initial results from further development to integrate wave interactions in this relatively high resolution system. We will discuss future directions and opportunities for collaboration in environmental prediction, and the challenges to realise the potential of integrated regional coupled forecasting for improving predictions and applications.

Microstructure observations of turbulent heat fluxes around a warm-core eddy in the Beaufort Gyre

Effie Fine[1], Jennifer MacKinnon[1], Matthew Alford[1], John Mickett[2], Madeleine Hamann[1], Olavo Marques[1], Gunnar Voet[1], Gregory Wagner[1], Marion Alberty[1], Algot Peterson[3],

[1] *Scripps Institution of Oceanography, USA*
[2] *APL, University of Washington, USA*
[3] *University of Bergen, Norway*
[4]

Recent years have seen dramatic reduction of summer Arctic sea ice coverage, particularly in the Western Arctic. Due to this reduction of sea ice, large areas of the Beaufort Sea are now exposed to direct wind forcing during the summer and autumn months. Understanding potentially increased turbulent heat and salt fluxes in this new regime is crucial for accurate climate prediction.

On a 28-day cruise in September 2015 that included direct microstructure measurements, high-resolution lateral tows and a turbulence-measuring profiling mooring, we conducted multiple process studies in the Beaufort Sea aimed at observationally constraining turbulent heat and salt fluxes in the upper ocean, and at developing an understanding of the dynamics that set ocean stratification in the Canada Basin. Of particular interest are subsurface intrathermocline eddies with core temperatures of 6 C, which may be a pathway for advection of warm Alaskan Coastal Water into the basin interior. One such eddy was sectioned with both a towed CTD and a microstructure profiler. High dissipation was apparent at the edges of the eddy, and density variations suggest that trapped internal waves could contribute to mixing at the eddy edges. Heat flux from such subsurface eddies to the surface may have a dramatic effect on overlying sea ice.

Effects of ocean surface gravity waves: on turbulence, instabilities, and frontogenesis

BAYLOR FOX-KEMPER[1], NOBUHIRO SUZUKI[1], QING LI[1], SEAN HANEY[2]

[1] *Dept. of Earth, Environmental, and Planetary Sciences, Brown University, USA*

[2] *Scripps Institution of Oceanography, University of California San Diego, USA*

High resolution simulations and observations of the near-surface ocean have revealed 100m to 10km frontal and filamentary structures in temperature and other properties worldwide. The formation and evolution of these features, through frontogenesis, instability, and frontolysis is an important and often poorly-simulated part of the climate system, because fronts and filaments affect the ocean surface layer and the transport of energy, momentum, and gasses through this layer. These features also dominate the transport of oil spills and pollutants over a wide range of scales.

These fronts and their instabilities coexist in the upper ocean where boundary layer turbulence and surface gravity waves are active. The interaction between fronts and surface gravity waves strongly resembles the dynamical interaction between Langmuir turbulence and waves, and through these interactions the effects of surface waves on frontal instabilities can also be understood. Analysis of a multi-scale, non-hydrostatic, large eddy simulation spanning 20km fronts to 5m turbulence will be presented, where interactions of surface gravity waves with turbulence, fronts, instabilities, and tracers will be explored. The theory of the interactions of the fronts with turbulence and surface waves will be illustrated, and the consequences of these interactions on frontal strength and tracer transport will be demonstrated.

Biological and Physical Fine Structure at Fronts: Thin Layers from Submesoscale Patches

PETER FRANKS[1], ALAIN DE VERNEIL[2]
[1] *Scripps Institution of Oceanography, UCSD, USA*
[2] *Aix-Marseille Université, France*

Dense CTD/fluorescence sampling across a front in the California Current System revealed fine-scale anomalies in salinity and fluorescence. When viewed in frontal cross-sections, these anomalies were seen to be parts of thin layers extending across the front, suggestive of subduction at the front. Further analysis, however, showed that the most likely mechanism of formation was the vertical shearing of existing horizontal patches to form thin layers. The scales and angles of the layers relative to density surfaces are consistent with a cross-frontal shear driven by an ageostrophic secondary circulation, set up through upstream frontogenesis. We use this information to estimate the horizontal scales of the original salinity and Chlorophyll-a patches that formed the thin layers. The hypothesized layer-formation mechanism provides a source of biological variability within a front, and a means of subducting material at the front.

Lagrangian exploration of submesoscale vertical transport

MARA FREILICH[1,2], AMALA MAHADEVAN[1]
[1] *Woods Hole Oceanography Institution, USA*
[2] *Department of Earth, Atmospheric, and Planetary Sciences, MIT, USA*

Advective exchange of nutrients and biomass between the ocean surface and the permanent thermocline is an important process for both new biological production at the surface and particle export from the surface to the deep ocean, processes which could be enhanced by intense submesoscale circulation cells. We explore vertical motion at a front in the Lagrangian framework to examine how the evolution of the strain and vorticity fields of frontal meanders and eddies relate to vertical motion of water parcels. We estimate the importance of frontogenesis and rapid submesoscale vertical velocities for biological production as a function of biological uptake and growth timescales.

Long-range transport of biogeochemical tracers by coherent eddies in the ocean interior

Ivy Frenger[1], Daniele Bianchi[2], Andreas Oschlies[1]

[1] *Biogeochemical Modelling, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany*

[2] *Atmospheric and Oceanic Sciences, University of California Los Angeles, CA, United States*

We investigate the impact of subsurface coherent (sub)mesoscale eddies on the distribution of biogeochemical tracers in the ocean. Our focus is on eddies shedding from the poleward undercurrents of the oxygen minimum zones which subsequently propagate westward deep into the subtropical gyres. These eddies trap and transport waters with characteristic oxygen anomalies over long distances across dynamical and tracer fronts. They are known to exist but are sparsely observed as they are "hiding" in the ocean interior, oftentimes undetectable at the ocean surface. To this end, eddies are tracked in a high resolution model simulation based on isopycnal layer thickness anomalies, and their long-range transport is estimated from the evolution of their oxygen (and nutrient) properties. Their transport will be compared to other processes based on a budget analysis to quantify the role of the subsurface eddies for the oxygen and nutrient distribution of and exchange between the oxygen minimum zones and the subtropical gyres.

A next generation altimeter for mapping the sea surface height variability: opportunities and challenges

LEE-LUENG FU[1], ROSEMARY MORROW[2]

[1] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*

[2] *Centre de Topographie des Océans et de l'Hydrosphère LEGOS, Toulouse, France*

The global observations of the sea surface height (SSH) have revolutionized oceanography since the beginning of precision radar altimetry in the early 1990s. For the first time we have continuous records of SSH with spatial and temporal sampling for detecting the global mean sea level rise, the waxing and waning of El Niño, and the ocean circulation from gyres to ocean eddies. The limit of spatial resolution of the present constellation of radar altimeters in mapping SSH variability is approaching 100 km (in wavelength) with 3 or more simultaneous altimetric satellites in orbit. At scales shorter than 100 km, the circulation contains substantial amount of kinetic energy in currents, eddies and fronts that are responsible for the stirring and mixing of the ocean, especially from the vertical exchange of the upper ocean with the deep. A mission currently in development will use the technique of radar interferometry for making high-resolution measurement of the height of water over the ocean as well as on land. It is called Surface Water and Ocean Topography (SWOT), which is a joint mission of US NASA and French CNES, with contributions from Canada and UK. SWOT promises the detection of SSH at scales approaching 15 km, depending on the sea state. SWOT will make SSH measurement over a swath of 120 km with a nadir gap of 20 km in a 21-day repeat orbit. A conventional radar altimeter will provide measurement along the nadir. This is an exploratory mission with applications in oceanography and hydrology. The increased spatial resolution offers an opportunity to study ocean surface processes to address important questions about the ocean circulation. However, the limited temporal sampling poses challenges to map the evolution of the ocean variability that changes rapidly at the small scales. The measurement technique and the development of the mission will be presented with emphasis on its science program with outlook on the opportunities and challenges.

Mesoscale dynamics in the Western Indian Ocean (Focus on the Southern Gyre): A numerical investigation using ROMS.

MAJAMBO GAMOYO[1], CHRIS REASON[1], ISSUFO HALO[2]

[1] *Department of Oceanography, University of Cape Town, Cape Town, South Africa*

[2] *Department of Conservation and Marine Sciences, Cape Peninsula University of Technology, Cape Town, South Africa*

The southern Gyre (SG) is a persistent mesoscale eddy that is observed seasonally in the northwest Indian ocean during the southwest monsoon at quasi-steady location. Its dynamics remain unclear due to sparse in-situ data in the region. Hence modelling provides an alternative means of examining the dynamics in this region. Realistic regional numerical experiment using Regional Ocean Modelling System (ROMS) is performed to investigate the generation process, characteristics and life span which is not well resolved by sparse available measurements in the region. By comparison with satellite observations, the results show that the model possesses reasonable skill to be useful in this work. According to model data, the most energetic place in the domain, is located off the eastern coast of Somalia, with maximum energy of about 1200 cm2 s−2 associated with the strong, annually reversing Somalia Current.

(Sub-)Mesoscale processes in North-western Mediterranean Sea : Observations and Modeling.

PIERRE GARREAU[1], VALÉRIE GARNIER[1], IVANE PAIRAUD[2]
[1] *IFREMER/LOPS, Ifremer, France*
[2] *IFREMER/LERPAC, Ifremer France*

The Northern Current (NC) is a branch of the general North-Western Mediterranean cyclonic circulation extending from the Ligurian to the Catalan Sea (Millot, 1991). In winter and early spring, instabilities of this slope current are intense and can generate eddies, meanders and filaments. The mesoscale activity is also enhanced just after a deep convection event in the Gulf of Lions. The study of mesoscale structures is thus crucial, because of their physical and biogeochemical impact on ecosystems.

Results from an observational effort put forth in March 2012 during the IMEDIA cruise dedicated to eddy and filament tracking are presented. A Water column profiling was performed using a Moving Vessel Profiler (MVP200 http://www.brooke-ocean.com/mvp_main.html) equipped with a CTD and capable of profiling down to 400m depth at a speed of 4 knots with a horizontal resolution less than a half nautic miles. The combined use of data from the MVP and the ship-based ADCP measurements reveals the presence of an instability of the NC north of the Corsica Island. A meander close to a detached anticyclonic eddy with a diameter of 40 km is deeply and synoptically investigated. The very high resolution of the sampling exhibits sub-mesoscale dynamics like layering inside the eddy core and probably subduction at the periphery. Less intensive measurement at different position in the NC current reveals that multi-layer structures are common in this area that could be a fruitful experimental field.

Using a two-way nesting facility (http://www-ljk.imag.fr/MOISE/AGRIF/), a very high resolution numerical modelling of the Ligurian Sea and of the Gulf of Lions has been performed to simulate this kind of structure. A primitive equation model of about 400 m horizontal resolution and 60 vertical levels in generalized sigma coordinates is able to reproduce the thin observed layering and explain the eddy dynamics in the Ligurian Sea, north of Corsica Strait. In the Gulf of Lions, the effect of the mesoscale structures after a deep convection events on the dynamics is also numerically investigated (estimation of vertical velocity and fluxes, Eddy Kinetic Energy (EKE) enhancement after convection) and compared with available measurement performed in the framework of HYMEX/ASICS experiment during winter 2013.

(Millot, 1991) Mesoscale and seasonnal variabilities of the circulation in the Western Mediterranean. Dynamics of Atmospheres and Oceans, vol. 15, p 179-214)

Dynamics of the Dense Water Formation in the Northwestern Mediterranean during the HyMeX/ASICS Experiment: A PV-Perspective

H. GIORDANI[1], C. LEBEAUPIN-BROSSIER[1], F. LEGER[1]

[1] *CNRM/GAME (Météo-France/CNRS), 42 av. G. Coriolis, 31057, Toulouse, France*

Mode water formation has long been treated as a buoyancy flux problem, however this approach fails to explain the spatial distribution and variability of dense water in the Northwestern Mediterranean. This paper proposes to adopt a PV-perspective (PV: Potential Vorticity) rather than the usual surface flux approach to identify the processes of dense water formation during the HyMeX/ASICS experiment. The PV-budget is diagnosed from an ocean simulation performed with the NEMO-WMED36 ocean model (1/36°-resolution $\approx$ 2.5 km), driven in surface by the hourly air-sea fluxes from the AROMEWMED forecasts atmospheric model (2.5km-resolution) during winter 2012-2013. If a large part of dense water is produced at the centre of the cyclonic gyre, a significant amount of dense water (ρ ¿29 kg/m3) is also produced along the rim of the cyclonic gyre where the current (North Current) and gradients of density are strong. The dense waters are well collocated with the PV-destruction associated with the surface frictional and buoyancy PV-fluxes. This suggests that surface PV destructions by winds are sources of destratification and are relevant forcings of dense water formation. The negative PV created around the gyre forces a cross-front ageostrophic circulation which subducts subsurface low-PV into interior and obducts high-PV from the thermocline to the surface. The horizontal and vertical advections of PV associated with the 3D ageostrophic circulation in the frontal region are positive and plays a role of PV-refueling destroyed by surface winds. Finally eddies formed by baroclinic instability are expulsed from the cyclonic gyre and transport the low-PV produced in the frontal region towards the centre of the gyre. It is suspected that this non-local process contributes to modify the stratification in the convection area. Forcings of the cross-front ageostrophic circulation in the cyclonic gyre is identified by using the generalized ω-equation. A particular attention is paid on the sources of vertical velocity associated with the turbulent fluxes because they strongly structure the vertical dynamics in the frontal mixedlayer. More generally it is shown that the ω-turbulent momentum forcing which represents the interactions between the surface wind and the submesoscale structures much better explain the upper layer vertical dynamics than the Ekman pumping.

An Embedded, Low-Cost, GPS-Enabled Lagrangian Smart Drifter Platform Design for Use in the Nearshore Area of the Gulf of Finland.

ANDREA GIUDICI[1]
[1] *Tallinn University of Technology, Institute of Cybernetics*

The design of a novel embedded, compact and low-cost Lagrangian drifter platform is described. The platform is intended to be mounted on floating drifters which operate confined in the nearshore environment, over time scales of up to several weeks, and represents a new low-cost alternative tuned for applications which do not rely on drifters with full ocean-going capabilities. The platform supports GPS positioning, radio communication with the mainland, on-device data logging and multiple sensing devices for measuring several physical quantities.

Investigating SWOT capabilities to detect submesoscale eddies in the Canary Islands: application of the SWOT simulator

LAURA GÓMEZ-NAVARRO[1], EVAN MASON[2], ANANDA PASCUAL-ASCASO[2]

[1] *University of Western Brittany, France*

[2] *Instituto Mediterráneo de Estudios Avanzados, Consejo Superior de Investigaciones Científicas, University of the Balearic Islands, Spain*

The joint National Aeronautics and Space Administration (NASA), Centre National d'Études Spatiales (CNES) and Canadian Space Agency (CSA) [Alsdorf et al., 2011] Surface Water and Ocean Topography (SWOT) satellite mission is now planned to be launched in 2020. It will be able to measure wide-swath Sea Surface Height (SSH) at a higher spatial resolution than present day satellites [Fu and Ferrari, 2008]. The SWOT simulator is a recently developed numerical tool that provides statistically reliable SSH outputs of what the satellite should be able to measure. Therefore, the existence of the simulator makes it possible to start optimization of information retrieval protocols/procedures for the processing of future SWOT data. [Gaultier et al., 2016].

In this study we use the SWOT simulator with the objective of not only understanding the future data from the SWOT satellite, but also we make an attempt to detect a number of particular eddies identified in a submesoscale resolving ROMS solution. These eddies have been observed in the outputs of simulations of the Canary Islands region [Mason et al., 2010]. The eddies are shed by a cape (La Isleta) at the northeast of the island of Gran Canaria. These eddies may explain nutrient and planktonic distributions in the area.

Several SWOT simulations were carried out using the daily ROMS sea surface height fields as inputs. A range of optimum parameters to carry out these simulations were explored, leading to a total of 13 experiments. The SSH ROMS outputs were analyzed to determine the temporal and spatial occurrence of these eddies.

Outputs of the SWOT simulator were obtained for the Canary Islands region, a preliminary step in trying to detect the submesoscale eddies of interest. In future work, other submesoscale eddies around the islands could be studied, the time shift and other parameters of the simulator could be varied in order to detect these submesoscale features more often, and interpolation techniques like the dynamic interpolation proposed by Ubelmann et al. [2015] could be put into practice.

ACKNOWLEDGEMENTS

The authors acknowledge the help of L. Gaultier for implementing the SWOT simulator and her insight when problems were encountered.

REFERENCES

Alsdorf, D. E., Mognard, N. M., Lettenmaier, D. P. and SWOT Virtual Mission Team, 2011. Remote Sensing of Surface Water and Recent Developments in the SWOT

Mission. AGU Fall Meeting Abstracts, page J6.

Fu, L. L. and Ferrari, R., 2008. Observing Oceanic Submesoscale Processes From Space. Eos Trans. AGU, 89(48), 488-488.

Gaultier, L., Ubelmann, C. and Fu, L. L., 2016. The challenge of using future swot data for oceanic field reconstruction. J. Atmos. Oceanic Technol., 33, 119–126.

Mason, E., Molemaker, J., Shchepetkin, A. F., Colas, F., McWilliams, J. C. and Sangrà, P., 2010. Procedures for offline grid nesting in regional ocean models. Ocean modelling, 35, 1–15.

Ubelmann, C., Klein, P. and Fu L.L., 2015. Dynamic Interpolation of Sea Surface Height and Potential Applications for Future High-Resolution Altimetry Mapping. Journal of Atmospheric and Oceanic Technology, 32, 177-184.

SEASTAR: a new satellite mission concept to observe submesoscale ocean surface currents and atmosphere/ocean coupling processes

CHRISTINE GOMMENGINGER[1], BERTRAND CHAPRON[2], ADRIEN MARTIN[1], JOSE MARQUEZ[3], SAM DOODY[3]

[1] *Satellite Oceanography, National Oceanography Centre, United Kingdom*

[2] *IFREMER, France*

[3] *Airbus Defence & Space Ltd, United Kingdom*

The demand for ocean surface current observations from space has never been greater. From ship routing to pollution dispersal to fisheries management to coastal erosion, the list of applications in need of ocean current information is endless. There is also a well-recognised urgent scientific need for new ocean current observations to support research in upper ocean dynamics at the submesoscale and the impact of small scales on air-sea coupling, oceanic productivity and marine ecosystems. Improved understanding and parameterisations of these small-scale effects on larger scales are critical to improve ocean, atmosphere and climate forecasting, and are therefore high impact with significant societal benefits.

SEASTAR is a new satellite mission concept that aims to deliver high-precision high-resolution two-dimensional maps of total ocean surface current vectors and wind vectors at a spatial resolution of 1 km over a swath of at least 50km, supported by coincident directional wave spectra measurements. The mission is being prepared for submission to the European Space Agency in June 2016 as an Earth Explorer 9 (EE9) candidate. The SEASTAR instrument is an active microwave radar that uses single-pass squinted SAR along-track interferometry with dual-polarisation capability. Dual-beam configuration makes it possible to measure both components of the surface current and wind vectors in a single pass, and because the instrument senses directly the displacement of the ocean surface, it estimates the TOTAL ocean surface current, including ageostrophic contributions.

This paper will present the SEASTAR mission concept, review the scientific motivation and objectives that underpin it and summarise the status of the mission proposal. It will present results from a highly successful airborne demonstration of the concept during a campaign in the Irish Sea that provides estimates of current retrieval performance against in situ ADCP and HF radar data. SEASTAR is a reduced version of a larger original mission concept known as “Wavemill”, with mission reductions driven by unexpected additional constraints in EE9 on budget, launcher volume and development schedule. The paper will outline the instrument and mission design, the impact on spatial and temporal sampling capabilities and possible mission operations and acquisition scenarios. We will highlight the strong complementarity of SEASTAR with other satellites and programmes, such as the Surface Water and Ocean Topography (SWOT) mission, ESA GlobCurrent ocean surface current products, Sentinel-1 high-resolution wind and radial velocity data and high-

resolution ocean colour and sea surface temperature from Sentinel-3.

Role of Coastal Submesoscale dynamics in the Landfall Pattern of Tropical cyclones across Indian Coast

K C Gouda[1], S K Nahak[1], P Goswami[2]

[1] *CSIR Fourth Paradigm Institute (C-MMACS),Bangalore, India*

[2] *CSIR National Institute of Science, Technology and Development Studies, New Delhi, India*

India being a country surrounded by oceans along three sides i.e. Bay of Bengal (BoB) in eastern, Arabian sea(AS) in the western and north India Ocean in the southern part is always vulnerable to the tropical cyclones and associated storm surges. The role of submesoscale dynamics particularly in the coastal region plays an important role in the landfall pattern of the tropical cyclones. In this work basically the ocean dynamics on the wake of tropical cyclone is studied and the influence of the wind induced coastal upwelling, bathymetry structure and the river plume & freshwater inputs in the ocean basins are studied using the satellite remote sensing and in-situ data along the east and west coast of India. About 20 cyclone cases in both the ocean basins i.e. BoB and AS are considered. The observed wind data from NCEP and ERA-40 and the cyclone heat potential as well as altimetry derived sea surface height are analysed and related with the cyclone track estimation. Finally the impact of the submesoscale dynamics on the cyclone landfall pattern is quantified and it can be used for the better prediction of cyclone track along the Indian coast.

Analysis of a nested North Sea -Baltic Sea model setup with an enhanced resolution in the Danish Straits

SEBASTIAN GRAYEK[1], EMIL STANEV[1]
[1] *Helmholtz-Zentrum Geesthacht, Max-Planck-Straße 1, Geesthacht, Germany*

The performance of a coupled North Sea - Baltic Sea model with an enhanced resolution model nest in the Danish Straits area is analyzed, where the focus of the evaluation is on the integrated transport through the Danish Straits and its representation using different spatial model grids. The reference setup for the study uses the same configuration as the nested model but without the enhanced resolution nest in the Danish Straits. The second setup includes three nested areas: one for the North Sea, one for the Baltic Sea and one for the Danish Straits. The horizontal resolution for the North Sea and the Baltic Sea nests is 5 nm. In the vertical the North Sea model uses 21 terrain-following sigma-levels . The Baltic Sea model uses 35 z-levels in the vertical. For the Danish Straits a finer spatial resolution with 0.5 nm in the horizontal and 31 terrain-following sigma-levels in the vertical is set up. The two coarse resolution models include the entire area of the fine resolution model. Temperature and salinity fields are exchanged between the three models. The coarse resolution model runs are segmented in a one day hindcast and a one day forecast phase. During the hindcast phase the coarse resolution models receive the enhanced fine resolution information via a nudging approach. During the forecast phase of the coarse resolution model no nudging is applied and the models run in a free prognostic mode. In the next cycle of coupling procedure the fine resolution model is rerun for the whole hindcast-forecast period of the coarse resolution models using interpolated coarse resolution output as boundary condition.

Topographic Generation of Submesoscale Centrifugal Instability and Energy Dissipation

JONATHAN GULA[1]
[1] *LOPS, Université de Bretagne Occidentale, France*
[2] *University of California, Los Angeles, USA*

Most of the ocean kinetic energy is contained in the large scale currents and the vigorous geostrophic eddy field, at horizontal scales of order 100 km. To achieve equilibrium the geostrophic currents must viscously dissipate their kinetic energy at much smaller scale, and the pathways of energy toward dissipation are still in question. Here we show that the interaction of a large scale geostrophic oceanic current with topography can generate unbalanced submesocale turbulence, and lead to significant energy dissipation and mixing outside the oceanic boundary layers. Interior regions of high energy dissipation, with the implication of strong vertical mixing of material properties across stably stratified isopycnal surfaces, is of great interest for its potential significance for the energy budget of the general circulation and the maintenance of the density stratification. The sequence of processes comprises the generation of large negative vertical vorticity values in the turbulent bottom boundary layer, and the onset of intense centrifugal instability. This mechanism is exposed in the context of the Gulf Stream, by means of realistic simulations of the ocean with very high resolution. We show that these processes lead to large energy dissipation rates, which are comparable to the rates observed in highly energetic frontal regions in the surface layer of the ocean.

Numerical study on the shoaling process of internal solitary waves in the southern Red Sea

DAQUAN GUO[1], JIESHUO XIE[2], PENG ZHAN[1], IBRAHIM HOTEIT[1]

[1] *King Abdullah University of Science and Technology, Saudi Arabia*

[2] *University of Chinese Academy of Sciences, China*

Satellite observations recently revealed trains of internal solitary waves (ISWs) in the off-shelf region between 16.0°N and 16.5°N in the southern Red Sea. Analysis of satellite images shows that the amplitude of these ISWs could be 50 to 75 meters. The shoaling and breaking of these ISWs could bring a significant source of turbulence, leading to mixing and particle transport on the boundaries, which is with great importance to the ecosystem. With a three-dimensional, non-hydrostatic and high resolution MIT general circulation model, the fate of the ISWs in the southern Red Sea had been simulated and explored. Based on this simulation, we discuss about the different stages of the interaction process between ISWs and topography. As observed by the satellite images, some ISWs were obstructed and reflected by the steep slope on the boundaries with a lot of mixing and dissipating over the slope. Two types of instabilities, convective instability and shear instability, that lead to ISWs' breakings have been studied and identified in the southern Red Sea. The breaking of internal waves has been identified as a plankton pump for the coral reef. In this simulation, we applied particle tracer method to explore how the transport of plankton or larvae could be influenced by the breaking of the ISWs.

A review of submarine currents and mesoscale eddies of the Arabian Sea and the Gulf of Oman by using satellite sensors

Samad Hamzehei[1,2], Abolhassan Gheibi[2], Hossein Malakooti[2]
[1] *Department of Physics, Payame Noor University, Tehran, Iran*
[2] *Department of physical oceanography, Hormozgan University, Bandarabbas, Iran*

Indian Ocean winds the names of the southwest monsoon (SW) and the northeast monsoon (NE) are very effective on the Gulf of Oman and the Arabian Sea. In the Arabian Sea and the Gulf of Oman is constantly changing seasonal currents regime the Indian Ocean monsoons flow due to changes in buoyancy force due to the high salinity of the Persian Gulf and the Red Sea. The Arabian Sea is a unique environment for the study of oceanic strong currents regimes that formed the mesoscale eddies. MODIS and MERIS sensors satellite data used on ocean temperature and ocean color, which in this study have been used. In this study, using appropriate algorithms changes in temperature and color of the waters of the Gulf of Oman and the Arabian Sea, has been investigated for seasonal currents have been identified and the changes it has been evaluated. MODIS data show that in the north of Gulf of Oman phenomenon Upwelling occurs in the winter and mesoscale eddies as well as in central and southern Gulf of Oman by changing seasonal positions are formed.

The Wake of Internal Gravity Waves Behind Groups of Surface Gravity Waves

SEAN HANEY[1], WILLIAM YOUNG[1]

[1] *Scripps Institution of Oceanography, UC San Diego, USA*

Surface gravity waves have been of increasing interest in submesoscale dynamics as they induce a Stokes drift current as well as the associated Stokes Coriolis, and Stokes shear forces. Theory and modeling studies have shown that these forces drive Langmuir turbulence, and influence symmetric and baroclinic instabilities. Many such studies consider a horizontally uniform wave state. Here we find solutions to the wave-averaged Boussinesq equations with horizontally varying Stokes drift, as is the case in an amplitude modulated wave group. Wave groups have convergent Stokes drift in front of the group driving water downward, while lifting it up behind the group where the Stokes drift diverges. In this case, the vertical forcing due to the horizontal divergence of Stokes drift is greater than that of the Stokes shear or Stokes Coriolis forces. Furthermore, this vertical forcing penetrates deeper than the Stokes forces, which decay very steeply with depth. This “Stokes pumping” induces a return flow with equal mass transport, but in the opposite direction of the mass transport by the Stokes drift. The return flow is attenuated by vertical density stratification, and if the stratification is sufficiently strong, internal gravity waves are radiated from the passing surface wave group. The phase of the buoyancy perturbations underneath the surface wave group is always the same (isopycnals depressed in front of the group, and lifted behind it), so the phase of the radiated internal waves must match this. Therefore, the stratification must be strong enough so that the phase speed of the radiated internal waves is fast enough to match the group speed of the internal waves. A few examples of different stratification profiles, and the ensuing internal wave radiation, as well as computation of the energy flux from surface to internal waves will be presented.

Meso- and submeso-scale nutrient fluxes and their relationship with primary production

Victoria Hemsley[1,2], Adrian Martin[1], Xiaolong Yu[1,2], Stuart Painter[1], Eleanor Frajka-Williams[2], Alberto Naveira Garabato[2], Tim Smyth[3]

[1] *National Oceanography Centre*
[2] *University of Southampton*
[3] *Plymouth Marine Laboratory*

We present twin year-long time-series of nitrate fluxes resolving meso- and submeso-scale processes respectively. These data were collected using a nested array of moorings at the Porcupine Abyssal Plain Sustained Observatory site in the North East Atlantic as part of the NERC UK Ocean Surface Mixing, Ocean Sub-mesoscale Interaction Study (OSMOSIS). We simultaneously collected depth-resolved profiles at the same high temporal resolution of primary production using a novel glider approach. We contrast the mesoscale and submesoscale resolving time-series of nitrate fluxes and how these relate to the variability seen in primary production.

Instabilities in river plumes

ROBERT HETLAND[1]
[1] *Texas A&M University - Dept. Of Oceanography, USA*

Baroclinic instabilities are ubiquitous in many types of geostrophic flow, however, they are seldom observed in river plumes despite strong lateral density gradients within the plume front. Plumes may form in complex shapes that may appear to have formed from instabilities, but these shapes may also be formed by changes in river discharge or changes in wind direction. Many numerical and laboratory studies of rotating plumes with no wind forcing show that the plume is stable over many rotational periods and does not develop instabilities along the plume front. Unlike other river plumes, the Mississippi-Atchafalaya River plume displays large instabilities over the Texas-Louisiana shelf in summer. A criterion based on the plume width compared with the deformation radius suggests for energetic baroclinic instabilities to form, the plume must be wide enough to support eddies of approximately three deformation radii. The instabilities in the Mississippi-Atchafalaya plume greatly enhance dispersion of particles on the shelf, and influence regional biogeochemistry.

High-definition Oceanography: Observing the submesoscale with ocean gliders

KAREN HEYWOOD

[1] *Centre for Ocean and Atmospheric Sciences, School of Environmental Sciences, University of East Anglia, Norwich, UK*

I will discuss submesoscale processes from the observational perspective, focusing on the opportunities offered by ocean gliders. Ocean gliders can obtain profiles of physical and biogeochemical properties on horizontal scales of hundreds of metres to a few kilometres depending on the depth range. This can give us high resolution sections in regions where observations are challenging using conventional techniques such as moorings, for example at shelf breaks and on continental slopes.

I will illustrate the talk primarily with examples from Antarctic continental slope, where ocean glider sections have shed light on exchange across the shelf break. Submesoscale and mesoscale processes enable the relatively warm subsurface water offshore to cross the Antarctic Slope Front and reach the continental shelf. This brings heat towards the Antarctic ice shelves where it can contribute to basal melting. It is important to understand (and in future parameterise in climate models) the exchange processes at the shelf break; observational campaigns at the submesoscale are the first step towards that goal. Carefully designed moored arrays, instrumenting of marine mammals, and autonomous vehicle deployments are needed. I will also touch upon glider deployments in the North Atlantic and the Sea of Oman, where gliders have revealed complex and intricate water mass structure and instabilities.

Daily to seasonal CO2 variation in the Bay of Fundy

Rachel Horwitz[1], Helmuth Thomas[1], Alex Hay[1]
[1] *Department of Oceanography, Dalhousie University, Canada*

Anthropogenic CO2 emissions acidify the oceans and have potentially adverse effects for ecosystems, living marine resources, and the fisheries and mariculture industries that depend on them. Assessing the vulnerability of these resources to ocean acidification requires a detailed understanding of the system's responses to both natural variability and the trend of lowering pH conditions as a consequence of the ocean's uptake of anthropogenic CO2. A cabled-to-shore observatory is installed in Grand Passage, a tidal channel in the Bay of Fundy, Nova Scotia. Measurements from a CO2 sensor, CTD, and ADCP provide year-long time series of pCO2, temperature, salinity, and currents. Preliminary analyses demonstrate the dominant seasonal cycle of pCO2 is modulated by a large diel signal in summertime, and by equal contributions from diel and tidal variation in winter. Further analysis aims to identify the physical and biogeochemical drivers of the observed short and long timescale pCO2 variation and to link observations in this tidal channel to the larger Bay of Fundy – Gulf of Maine carbon system.

Frontal interactions with a near-inertial wave in the Antarctic Circumpolar Current

Phil Hosegood[1], Kate Adams[1], John Taylor[2], Jean Baptiste Sallee[3]

[1] *School of Marine Science and Engineering, Plymouth University, Plymouth, PL48AA, UK*

[2] *DAMTP, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WA, United Kingdom*

[3] *Laboratoire d'Océanographie et du Climat: Expérimentations et approches numériques. Unité Mixte de Recherche 7159 CNRS / IRD / Université Pierre et Marie Curie/MNHN.*

Observations are presented from the Surface Mixed Layer Evolution at Submesoscales (SMILES) cruise conducted at the Subantarctic Front (SAF) in the Scotia Sea during May 2015. The cruise aimed to measure with submesoscale-resolving resolution the evolution of a strongly strained front within the ACC and a weaker front to the north within the region overlying the water subducted at the subantarctic front.

The cruise timing was opportune as the sampling of the strong frontal region within which the subantarctic and polar fronts converged coincided with the evolution from a frontal meander to a closed core eddy. The eddy was surveyed extensively with towed CTD, vessel mounted ADCP and Lagrangian drifters. The eddy translated northwards into the Falklands Chasm where it dissipated comparatively rapidly, within 3 months of its generation. This location coincided with the study site that was first sampled during the cruise where a relatively weak filament extended westward following the northward deflection of the SAF to the east of the Falklands. A total of 32 cross-front transects were completed across the comparatively weak front that defined the northern boundary of the filament with the Moving Vessel Profiler, a towed CTD that enables measurements to be made at 300 m horizontal resolution to a depth of 200 m. The measurements were made in a Lagrangian reference frame whilst following a float drogued at mid depth within the 100 m deep mixed layer within which the front was embedded. The drifters oscillated with a near inertial periodicity indicating the presence of inertial motions that were likely generated by the strong winds that prohibited the ship's departure from the Falklands by a day. The inertial motion was replicated by the front that repeatedly slumped and returned to the vertical with a 15 hour periodicity, with horizontal current velocities exhibiting upward phase propagation consistent with a downward propagating near inertial wave. We discuss the interaction between the wave and front, drawing upon microstructure data acquired over an inertial cycle to demonstrate the extent to which the dissipation of turbulent kinetic energy may have been elevated by the interaction.

Observations and modelling of multi-scale processes in Qatar's marine region, Central Arabian Gulf

Y. Sinan Husrevoglu[1], Ebrahim S. Al-Ansari[1], Ibrahim A. Al-Maslamani[1], M. Alaa Abdel-Moati[2]

[1] *Environmental Science Center, Qatar University, Qatar*

[2] *Environmental Assessment Department, Ministry of Environment, Qatar*

Modern oceanographic studies carried out in Qatar's marine region over the last two decades indicate that variability of the water column structure and circulation in this shallow and wide continental shelf area is driven by multi-scale dynamics and interactions. Locally motivated observations over this period have separately reported the existence and importance of various mesoscale and submesoscale phenomena driving the circulation and controlling the vertical and lateral distribution of water masses in the region. While the physical dynamics of relatively deeper offshore areas of Qatar's marine region are predominantly driven by opposing effects of large scale wind (Shamal wind versus southwest monsoon) and stratified mesoscale flow (oceanic surface inflow versus dense, deep outflow) patterns, shallow coastal areas are affected by submesoscale dynamics such as frontal formations, front-eddy interactions, gravity currents, inverse estuarine circulation, mixed-layer instabilities, and topographic and coastline interaction. Reported multi-physics processes are claimed to affect the supply and redistribution of nutrients and dissolved oxygen, thus impacting productivity and dynamics of pelagic and benthic ecosystems.

Although there have been numerous studies focusing on local dynamics and processes, a comprehensive observational and modelling study framework encompassing the whole Qatari marine region is yet to be established. A recent study is thus designed to collect high-frequency, high-resolution hydrographic and flow data and to implement a multi-scale, nested numerical modelling framework for the region. This study aims to identify the dominant dynamics at various time and space scales, the interactions among these dynamics, and implications of such interactions on the functioning of various shallow water ecosystems. Preliminary data analysis and modelling results will be presented.

Deep Coherent Vortices and Their Sea-Surface Expressions

FEDERICO IENNA[1,2], IGOR BASHMACHNIKOV[3,4], JOAQUIM DIAS[1,2], ÁLVARO PELIZ[1]

[1] *Instituto Dom Luiz, University of Lisbon, Portugal*

[2] *Marine and Environmental Sciences Centre, University of Lisbon, Portugal*

[3] *Laboratory of Oceanography, Institute of Earth Science, St. Petersburg State University, Russia*

[4] *NIERSC, 14th Line 7, Office 49, Vasilievsky Island, 199034 St. Petersburg, Russia*

Mediterranean Water eddies (Meddies) are long-lived ocean phenomena regularly observed at mid-depths in the Northeast Atlantic Ocean. Meddies are sometimes referred to as Submesoscale Coherent Vortices (SCV's), and their dimensions range from the upper submesoscale to the mesoscale. Although their cores are found far below the sea-surface (at around 1000 meter depth), a number of recent works have focused on studying their sea-surface expressions, observed in remote sensing data-sets. During the lateral propagation of a Meddy, the underlying core compresses the water column above it. As a response to the decrease in absolute vorticity, an anti-cyclonic rotation of the water column above often reaches the sea surface, making them often observable in sea-surface height data. The surface expressions of Meddies, at times, can be distinguished in satellite sea-surface temperature records (Bashmachnikov et al., 2013), which permits observation of their surface expre ssions at high resolution and study of the related fine-scale effects. This work presents statistical relationships between the high-temperature, high-salinity, rotating Meddy cores and the characteristics of the generated surface signatures. Observations of the the cores are made using historically available in-situ data (XBT, CTD, Argo), and are compared with their corresponding surface signatures by use of remote sensing. Remote sensing data includes merged altimeter data to observe the geostrophic effects at the surface, as well as high-resolution sea surface temperature data, allowing for the observation of entrainment of surrounding surface waters and finer scale processes occurring in the submesoscale realm. The results can be applied to other types of eddies of finer scales (i.e. Labrador Sea Eddies, Persian Gulf Eddies, and Red Sea Eddies, among others; see Ciani et. al., 2015), as well as for submesoscale phenomena and mechanisms (D'Asaro, 1988) and to future studies of Meddies at any scale.

References:

Bashmachnikov, I., Boutov, D., & Dias, J. (2013). Manifestation of two meddies in altimetry and sea-surface temperature. Ocean Science, 9(2), 249-259.

Ciani, D., Carton, X., Bashmachnikov, I., & Chapron, B. (2015, April). Influence of deep vortices on the ocean surface. In EGU General Assembly Conference Abstracts (Vol. 17, p. 5775).

D'Asaro, E. A. (1988). Generation of submesoscale vortices: A new mechanism. Journal of Geophysical Research: Oceans (1978–2012), 93(C6), 6685-6693.

Characterization of ocean submesoscale turbulence regimes from satellite observations of Sea Surface Temperatures

JORDI ISERN[1], ANTONIO TURIEL[1], ESTRELLA OLMEDO[1]
[1] *Institute of Marine Sciences of Barcelone, CSIC.*

Satellite infrared radiometers can be used not only for the evaluation of Sea Surface Temperature (SST), but have also the potential of characterizing the distinct turbulence regimes present in the upper ocean. These regimes, own to submesoscale, have different contributions on the vertical transport of nutrients, heat, and gases between the oceanic upper layers and the ocean interior, and contain key information about the dynamics of the mixed layer. However, the different regimes do not always leave a clear footprint on surface scalars as SST, unless an adequate data processing technique based in the theory of turbulence is applied on them.

In this study, we will present evidence that infrared SST provided by the AATSR sensor (Envisat) can be processed to characterize the underlying turbulence regime. As a first step, data have been divided into granules adapted to the observed cloud coverage with a maximum size of 512 by 512 pixels (i.e. 512 km by 512 km). These granules have been classified into two groups: one characterized by the presence of submesoscale instabilities (5-10 km) and one characterized by the presence of vortices and filaments. Then, for all the granules of each group we have analyzed classical statistical descriptors such as the spectral slope associated to power spectra, and also new descriptors emerging from the use of singularity analysis (curvature of singularity fronts, singularity spectra), which is based on multifractal theory of turbulent flows.

Our results show that both groups of images are characterized by similar spectral slopes, what would indicate a similar cascade process in both cases. On the contrary, the singularity spectra and the characteristics of front curvatures in both groups were neatly different, what allows to separate both dynamical regimes. We will discuss the implications of our work under the perspective of assessing submesoscale ocean turbulence at global scale.

Spring chlorophyll changes in relation with mixed layer variability in the East Sea (Japan Sea)

CHAN JOO JANG[1], HYOUN-WOO KANG[1], JAE KWI SO[1], SINJAE YOO[1]
[1] *Korea Institute of Ocean Science & Technology, Republic of Korea*

The East Sea, a semi-enclosed marginal sea in the western North Pacific, shows two peaks in chlorophyll concentration (CHL) in response to spring stratification and fall destratification: one stronger peak in spring and the other weaker peak in fall. In this study, we investigate year-to-year variability of spring CHL concentration in association with ocean mixed layer depth (MLD) changes in the East Sea (Japan Sea). MLD data were estimated from 1/12° Global HYbrid Coordinate Ocean Model (HYCOM) for the period (2004-2010). For CHL concentration, Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate-Resolution Imaging Spectroradiometer (MODIS) data were used. The spring CHL concentration shows substantial year-to-year variability. In 2008, CHL concentration in the Ulleung basin in April reaches a maximum (8 times larger than the other years) for the period (2004-2010). The increase of the spring CHL concentration in 2008 is attributed to considerable deeper winter mixed-layer (about 2 times larger than in normal years) that probably entrains more deep-ocean nutrients into the upper ocean, making favourable spring bloom condition. The larger winter MLD in 2008 is caused by intensified wind and ocean surface cooling that are associated with strengthened Siberian high and Aleutian low. On the other hand, spring CHL in 2004 is not elevated significantly, although the winder MLD deepens considerably. Deeper mixed layer in spring seems to limit phytoplankton bloom in 2004 through unfavourable light condition. Different responses of spring CH to winter MLDs in two years (2004 and 2008) suggest that springtime stratification also plays a crucial role in phytoplankton bloom in the East Sea (Japan Sea).

Submesoscale interaction of fronts and internal tides in a high-resolution coupled atmosphere-ocean-wave model of the Bay of Bengal

T.G. Jensen[1], H.W. Wijesekera[1], W. J. Teague[1], E. Jarosz[1]

[1] *Naval Research Laboratory, Oceanography Division, Stennis Space Center, USA*

A coupled atmosphere-ocean-wave model is used to model the weather, ocean circulation and wave field in the Bay of Bengal. Horizontal resolution in the atmosphere is 6 km, 13 km for the surface waves, but submesoscale permitting in the ocean with a 2 km resolution and a vertical resolution of 0.5 m in the upper 10 m. The model has been run during two field experiments in 2013 and 2014 and continuously since June 2015 until now. Intense solitary-like waves are generated by semi-diurnal tides in the Andaman Sea and interact with mesoscale flows and fronts and generate submesoscale features. Convective cells in the atmosphere and associated intense down drafts with rainfall produce submesoscale current, temperature and salinity anomalies in the oceanic mixed layer. A third source of submesoscale variability is found in the vicinity of rivers. Examples of all three generation mechanisms are shown. These mesoscale and submesoscale features affect the vertical mixing in the upper ocean; in particular, the solitary internal waves, produce sporadic mixing events on submesoscales that reach below the thermocline and also interact with strongly sheared flows along fronts. Model runs without diurnal and semi-diurnal tides show less vertical mixing and suggest an indirect impact of tides on submesoscale features.

Global Estimates of Lateral Springtime Restratification

LEAH JOHNSON[1], CRAIG M. LEE[1], ERIC A. D'ASARO[1]
[1] *Applied Physics Laboratory, University of Washington, USA*

Ageostrophic motions at submesoscale fronts are thought to be leading order importance for stratifying the upper ocean by slumping horizontal density gradients to produce vertical stratification. This mechanism competes with processes that keep the upper ocean vertically homogenous in the winter and could dominate in spring as winter forcing weakens but before the ocean is heated at the surface. The prevalence of submesoscale fronts suggests these motions have significant influence on large-scale patterns of upper ocean stratification. This work takes a global approach to identify these large-scale signatures of frontal induced stratification during the transition into spring. Observations from global Argo database are contrasted with predictions from a 1-D mixed layer model to assess where lateral processes influence mixed layer evolution. Relationships between vertical and horizontal gradients of temperature and salinity are used to isolate regions where this excess stratification can be attributed to the slumping of horizontal density fronts. Enhanced stratification from frontal tilting occurs in regions of strong horizontal density gradients (e.g. mid-latitude subtropical gyres), with a small fraction in regions of deep mixed layers (e.g. high latitudes). These patterns are discussed in context of instabilities and frictional effects in order to understand the large-scale implications of these small-scale dynamics.

Source of nutrients within mesoscale eddies in the upwelling system off Peru

YONSS JOSE[1], HEINER DIETZE[1], ANDREAS OSCHLIES[1]
[1] *GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany*

Ocean eddies can both trigger mixing (during their formation and decay) and effectively shield water encompassed from being exchanged with ambient water (throughout their life time). These antagonistic effects of eddies complicate the interpretation of synoptic snapshots as typically obtained by ship-based oceanographic measurement campaigns. Here we aim to explore the biogeochemical dynamics within anticyclonic eddies in the Eastern Tropical South Pacific ocean, using a coupled physical-biogeochemical model. The goal is to understand the diverse biogeochemical patterns observed at the subsurface layers of the anticlyclonic eddies in this region.

Formation of Loop Current Frontal Eddies : the impact of the coastal-trapped waves.

JULIEN JOUANNO[1], JOSE OCHOA[2], JULIO SHEINBAUM[2], ENRIC PALLAZ-SANZ[2], FERNANDO ANDRADE-CANTO[2], JULIO CANDELA[2], JEAN-MARC MOLINES[3]

[1] *LEGOS/IRD, Toulouse, France*
[2] *CICESE, Ensenada, Mexico*
[3] *LGGE, Grenoble, France*

Velocity data, from moored arrays of current profilers, deployed during one year northeast of the Campeche Bank, show the presence of 6-10 days period velocity fluctuations within the core of the northward flowing Loop Current. These fluctuations are associated with the presence of surface intensified Loop Current Frontal Eddies (LCFEs), with cyclonic vorticity and diameters below 100 km. These eddies are well reproduced by a high resolution (1/36) numerical simulation of the Gulf of Mexico. An eddy tracking procedure of model LCFEs suggests that most of the LCFEs originate along and north of the Campeche Bank, their main energy source being the mixed baroclinic-barotropic instability of the northward flow along the shelf break. Model results show that the wind variability associated with winter cold surges favors the emergence of LCFEs in a narrow band of periods (6-10-day) in the region of the Campeche Bank. The dynamical link between the formation of LCFEs and the wind variability is not direct. It is shown that the large scale wind perturbations generate sea level anomalies on the Campeche Bank, and first mode, coastal trapped waves in the western Gulf of Mexico which propagate anti-clockwise along the coast with a phase speed of 3.3 m s-1, also producing anomalies at the Campeche Bank. It is the interaction of these anomalies with the Loop Current what triggers the cyclonic vorticity anomalies that grow in intensity as they propagate downstream, on the cyclonic side of the Loop Current.

On the summer distributions of N-P-Z-D in an anticyclonic eddy in the East Sea simulated using a physical-biogeochemical coupled model

HYOUN-WOO KANG[1], OK HEE SEO[1], JAE KWI SO[1], CHAN JOO JANG[1]
[1] *Korea Institute of Ocean Science and Technology*

Mesoscale eddies appear frequently in the East Sea (Japan Sea) and they have significant effects on the distributions of nutrients (N), phytoplankton (P), zooplankton (Z) and detritus (D) resulting in changes of carbon export into the deep layer, especially in summer. In this study, we have analysed three kinds of nutrients (phosphate, nitrate, silicate), diatoms, three size-classed phytoplankton and zooplankton functional groups, as well as dissolved and particulate organic carbon in an anticyclonic eddy simulated by a coupled system. It is based on three-dimensional baroclinic ocean circulation model, POLCOMS (Proudman Oceanographic Laboratory Coastal Ocean Modelling System) and a lower trophic biogeochemical model, ERSEM (European Regional Seas Ecosystem Model). The phytoplankton uses the entrained nutrients at the rim of warm eddy as the light is available for photosynthesis resulting in subsurface chlorophyll maximum layer, which is formed just on top of the euphotic depth. The distributions of phytoplanktons inside the eddy are locally different and characterized by their types. Diatoms are the major source of total chlorophyll-a blooming at the subsurface rim of the eddy and the pico-phytoplankton has the second largest biomass along the slope of the euphotic depth lowered to the center of the eddy. Nano-phytoplankton, the least biomass though, blooms on top layer of the diatoms in the rim area and also in the central region of warm core eddy even to the slightly deeper layer than the euphotic depth. It is noticeable that the micro-phytoplankton blooms on top of the nano-phytoplankton in the center of the eddy and has the third largest biomass. The biomass of the meso-zooplankon is very low inside the eddy and the dominant zooplankton type is the micro-size one grazing all three phytoplankton groups except for the diatoms at the rim of the eddy. Particulate organic carbon produced at the subsurface area on top of the eddy rim flows into the center of the eddy and sinks there. Dissolved organic carbon increases in the central water column of the eddy as well. Changes and links between these lower trophic ecosystem variables inside an anticyclonic eddy are also discussed in the context of eddy strength changing by time.

Satellite observations of submesoscale eddies in the Western Mediterranean

SVETLANA KARIMOVA[1], MARTIN GADE[2]
[1] *GHER, University of Liege (ULg), Belgium*
[2] *University of Hamburg (UHH), Germany*

Despite significant attention paid to mesoscale circulation in the Western Mediterranean and especially to anticyclonic gyres of the Alboran Sea and Algerian Basin, which have been intensively studied by satellite and in situ observations [*Millot*, 1999], properties of submesoscale eddies in this area are still quite unknown. So far some consideration have got only submesoscale vortices in the Gulf of Lion observed by satellite synthetic aperture radar (SAR) imagery [*Redondo et al.*, 2013]. In the present work such an analysis of submesoscale eddies has been performed for the entire Western Mediterranean.

Mostly Envisat Advanced SAR (ASAR) images obtained in 2009-2011 have been used in the analysis. Despite strong dependence of visibility of hydrodynamic features in SAR imagery on the near-surface wind speed, such imagery is still a unique tool for observation of submesoscale eddies both in the near-coastal and open-sea areas of marginal seas due to ubiquitous availability of surfactant films and occurrence of wave/current interactions both contributing to manifestation of eddies in SAR imagery. Additionally a number of visible range imagery sensed by the Medium Resolution Imaging Spectrometer (MERIS) has been used. During extensive phytoplankton blooms visible-range imagery, similar to SAR images, can also provide precious information about turbulent processes in the surface waters.

As a result of the observations performed well-developed submesoscale circulation features (mostly cyclonically rotating coherent vortices) have been observed in both types of imagery. Analysis of spatial distribution of the vortices visible due to accumulations of surfactant films revealed a tendency for such eddies to be more frequently found in the near-coastal area rather than in the open sea. Thus, the areas of especially frequent observation of small-scale eddies were ones in the vicinity of the north-eastern coast of Corsica and southern coast of the Balearic Islands. Presumably it is intensive wind forcing and resulting mixing which prevent full development of submesoscale turbulence in the open-sea area. Eddies manifested due to wave-current interactions were typically found further offshore; especially high density of such eddies was discovered in the Balearic Sea. Despite the presence of strong turbulent currents in the Alboran Sea and in the Algerian Basin, just a few manifestations of wave-current interaction were noticed there. The reasons of such a peculiar distribution of eddy manifestations require further consideration. This research is supported by the University of Liege and the EU in the context of the FP7-PEOPLE-COFUND-BeIPD project. The SAR data were obtained under the grant of the European Space Agency # 14120 ”Spiral eddy statistical analyses for the Mediterranean Sea using Envisat ASAR Imagery (SESAMeSEA)”.

REFERENCES

Millot, C., 1999. Circulation in the Western Mediterranean Sea. *J. Marine Syst.*, 20, 423-442.

Redondo, J.M., Matulka, A., Platonov, A., Sekula, E., and Fraunie, P., 2013. Eddy measurements, coastal turbulence and statistics in the Gulf of Lions. *Ocean Sci. Discuss.*, 10, 55–81.

Waves Effect On Exchanges Across Gravity-Stratified Shallow Flow

SHOOKA KARIMPOUR[1], VINCENT H. CHU[1]

[1] *Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada*

Waves are produced by the shear instability in gravity-stratified shallow flow as the instability is concurrently affected by the emitted waves. The exchanges of mass and momentum across the shear flow are altered by the presence of the waves. Numerical simulations are conducted to study this waves' effect in the nonlinear transition of the gravity-stratified shear flow to turbulence. The simulations start from a hyperbolic-tangent velocity profile covering a wide range of convective Froude numbers. The mass and momentum exchanges across the flow at high convective Froude numbers are governed by processes not describable by the conventional theory of turbulence. Gravity waves modify the advection and diffusion of vorticity as the surge waves modify the flow through additional energy dissipation.

The simulations are carried out using a fifth-order WENO (Weighted Essentially Non Oscillatory) scheme for spatial interpolation and a forth-order Runge Kutta method for the integration in time. The computationsl algorithm has been independently verified by numerical simulations of similar problems. Karimpour & Chu (2014, 2015) have employed the method to study the supercritical to subcritical transition in transverse dam-break waves, and to calculate the development of the instability in subcritical flow. The present series of simulations is an extension to cover the nonlinear transition to turbulence in both subcritical and supercritical flows. A refined grid of 265 nodes over one wave length are employed in the simulations. Wave radiation, vorticity evolution and energy dissipation are analyzed using the simulation data to reveal the structural evolution at key stages of the nonlinear transition for 4 convective Froude Numbers $\mathrm{Fr_c}$ = 0.1, 0.8, 1.1 and 1.4. At low convective Froude number, the vorticity in the base flow rolls up to form eddies. At high convective Froude number, beyond a value of $\mathrm{Fr_c} \simeq 0.8$, the vorticity is confined within elongated elements known as eddy-shocklets; surge waves are observed to radiate intermittently from the eddy-shocklets. The intriguing details of the wave's effect on the nonlinear transition will be reported in a full paper at the colloquium.

REFERENCES

S. Karimpour & V. H. Chu (2014) Transverse dam-break waves. Journal of Fluid Mechanics, R2 (12 page); doi:10.1017/jfm.2014.562.

S. Karimpour & V. H. Chu (2015) High-order Interpolation Schemes for Shear Instability Simulations. International J. for Numerical Methods for Heat and Fluid Flow, Vol. 25(6), pp. 1340-1360.

Sub-mesoscale features of the Eastern Ionian Sea as derived from Argo floats operating during 2014-2015

DIMITRIS KASSIS[1,2], GERASIMOS KORRES[1], LEONIDAS PERIVOLIOTIS[1]

[1] *Institute of Oceanography, Hellenic Centre for Marine Research, PO Box 712 Anavyssos, Attica GR-190 13, Greece*

[2] *Department of Naval Architecture and Marine Engineering, National Technical University of Athens, Heroon Polytechniou 9, Athens 15773, Greece*

One of the strategic targets of the newly-formed Euro-Argo ERIC (www.euro-argo.eu) is the expansion of the existing European Argo Network into Regional Seas. In this framework, float deployments carried out by the Greek Argo Infrastructure (www.greekargo.gr) during 2014-2015, provided the opportunity for more enhanced studies of the mesoscale and sub-mesoscale dynamic processes that dominate semi-enclosed sea basins. With focus on the Ionian Sea, data analyses of the acquired profiles from the recent deployed floats show the variability of different origin water masses at subsurface, intermediate, and deeper layers and the interaction with the adjacent basins. At the northern, and central parts of the Ionian, float trajectories indicate a northward flow of water masses, at intermediate and deeper layers, towards the Otranto strait along the western Hellenic Arc. The dynamics of the Levantine Intermediate Water (LIW) core signal and the spatio-temporal variability of the other major water masses like Eastern Mediterranean Deep Water (EMDW) and Adriatic Deep Water (AdDW) interacting between Ionian and Adriatic are also highlighted. In the south, 2 floats were trapped south of Peloponnese by the Pelops anticyclone gyre which exhibits a strong signal, following a south-eastward displacement. A study of the gyre's characteristics is presented through the combined analysis of the profiles with the satellite sea surface topography. Furthermore, one of the floats deployed in the Cretan Sea, exited the Western Cretan Straits indicating an outflow of Cretan Intermediate Water (CIW) into Ionian. In general, the analysed datasets highlight the variability of the physical properties in the area and confirm the transitional characteristics of the region where water masses of the Western Mediterranean meet and interact with water masses formed in the Levantine, Aegean and Adriatic Seas.

The influence of the changes in SST boundary conditions in Regional Climate Model simulations with RegCM4 in West Africa monsoon

Kenfack Sadem Christian[1]

[1] *University of Dschang, Faculty of Science, Department of Physics, Mesoscopic and Multilayer Structure Laboratory , Cameroon. Po Box: 67 Dschang - Cameroon*

Effects of the increased sea surface temperatures (SSTs) in the Gulf of Guinea on the west and central Africa precipitation are investigated through sensitivity simulations using a state-of-the-art regional climate model, RegCM4. We run the simulation for two years: weak and strong SST years. It was verified that all SST changes clearly influenced the simulated precipitation, with the most significant impact during summer. The changes affected rainfall in the Sahel and West Africa coastal region. These analyze support the hypothesis that when the region shows positive anomalies an extreme dry event is observed in some West Africa regions during summer. We showed that changes of Sea surface temperature in the Gulf of Guinea significantly affect West African monsoon.

Energy spectra of submesoscale coastal ocean currents

Sung Yong Kim[1]
[1] *Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Republic of Korea*

This paper describes submesoscale kinetic energy spectra of coastal ocean currents observed from multiple platforms of satellite altimeters, shore-based high-frequency radars, and shipboard acoustic Doppler current profilers. One-dimensional wavenumber energy spectra of coastal currents decay with a slope of approximately k^{-2} at a wavenumber (k) of 0.5 km^{-1}. The spatial covariance of surface currents, equivalent to two-dimensional wavenumber spectra, has an anisotropic exponential shape with decorrelation length scales of *O*(10) km close to the shore and *O*(100) km offshore and principal axes nearly parallel with the shoreline, exhibiting coastal boundary effects on surface currents. The exponentially decaying spatial covariance function is consistent with submesoscale wavenumber spectra of a k^{-2} decay slope.

Observations of coastal sub-mesoscale variability and implications for across-shelf exchange.

ANTHONY KIRINCICH[1], STEVE LENTZ[1], IRINA RYPINA[1],

[1] *Woods Hole Oceanographic Institution*

2

This work investigates the characteristics and implications of sub-mesoscale variability over the continental shelf in order to understand the relative importance of lateral mechanisms of exchange and stirring on the total across-shelf transport. Within the study area south of Martha's Vineyard, USA, observations of high-resolution HF radar surface currents allow lateral scales as small as 1.5 km to be resolved within a 30x30 km domain. Coupled with dense observations of subsurface velocity and hydrography for a 6-month period spanning both stratified and weakly stratified conditions, these observations were used to document horizontal and vertical scales, occurrences, and drivers of spatially-variable circulation. Coherent vortices, or eddies, driven both by density intrusions and tidal processes were observed at rates up to 4 per day during the stratified period, with locations and length scales dependent on wind forcing. Despite being temporally short, with mean durations of 5 hours, these features caused exchange equivalent to 1/3 of the wind-driven depth-dependent exchange, but in the opposite direction.

Observations of submesoscale vortices on strong oceanic fronts

JODY KLYMAK[1], ERIC D'ASARO[2], ANDREY SHCHERBINA[2], KIPP SHEARMAN[3], TAMAY M. ÖZGÖKMEN[4]

[1] *School of Earth and Ocean Sciences, University of Victoria, Victoria, Canada*

[2] *Applied Physics Laboratory, University of Washington, Seattle, WA, USA*

[3] *College of Earth, Ocean, and Atmospheric Science, Oregon State University, Corvallis, OR, USA*

[4] *Rosentiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA*

Here we present subsurface observations of small-scale lateral vortices in the Gulf Stream and a front in the Gulf of Mexico. In the strongly strained front of the Gulf Stream these vortices are formed from water that has been partially mixed on the north wall. The vortices are highly strained and are stretched laterally along-stream so that they have a shallow aspect ratio. In the Gulf of Mexico, the front was a buoyant plume of shelf water extruding into the main basin. As it moved off shelf, it developed cusps that rolled up into cyclonic vortices. These vortices were also sampled with a dense array of surface drifters, and the vortices accumulated a substantial number of drifters within a very small area, indicating that the vortices were entraining fluid and then subducting it from the surface. Both features clearly exchange fluid across the fronts, with the Gulf Stream features having close to the salt water loss needed to explain the large-scale salinity budget of Gulf Stream.

Dynamics of sub-mesoscale frontal eddies over a broad shelf and their implications for mixing and bottom oxygen variability

DAIJIRO KOBASHI[1], HUI WU[2], MARTINHO MARTA-ALMEIDA[3], ROBERT HETLAND[1]
[1] *Texas A&M University*
[2] *State Key Laboratory of Estuarine and Coastal Research, East China Normal University*
[3] *Universidade de Aveiro*

On the Texas-Louisiana Shelf in the northwestern Gulf of Mexico, there are numerous eddies generated along the fronts associated with the Mississippi and Atchafalaya rivers. These eddies are 'submesoscale' with the spatial resolution ranging from several km to 50 km. Our preliminary analysis suggests that the eddies may play a role in transport of freshwater and nutrients on the shelf and also in mixing in the absence of storms especially in summer, when hypoxic water is often established near the bottom. We implemented a high-resolution ocean model and investigated phenomena of such sub-mesoscale eddies and further how they influence mixing and consequent variability of bottom dissolved oxygen (DO). The eddies move downcoast (westward) during non-summer seasons at the speed of approximately 8 cm/s and the direction is reversed during summer consistent with seasonal wind patterns. The eddies generate patches of strong stratification resulting in quasi-periodic oscillations of pycnocline and out-of-phase cross-shore current profiles between the upper and lower layers influence oxygen fluxes in the bottom mixed layer (BML) depending on the locations of the eddies. The sub-mesoscale eddies also generate stronger vertical velocity, which modifies pynocline depth; salt diffusivity and TKE correspond to bottom DO. The finding suggests that bottom oxygen variability depend on mixing and advection in the BML. A comparison between the eddy behavior and in-situ bottom DO confirms that the fluxes associated with eddies correspond to in-situ bottom oxygen distribution suggesting that the eddies influence the distribution of bottom DO. Thus, these eddies may play a significant role in seasonal hypoxia.

Frontal structures in the North Adriatic as observed by a Slocum glider

Zoi Kokkini[1], Riccardo Gerin[1], Elena Mauri[1], Pierre Marie Poulain[1]
[1] *OGS, National Institute of Oceanography and Experimental Geophysics, Italy*

A 200 m Slocum glider was used in the Northern Adriatic Sea in February 2015. The glider was deployed at the entrance of Kvarner Bay on 24 February 2015 and it was recovered on 27 February 2015, after having performed around 540 yos (dive/climb cycles). The glider provided high resolution measurements of temperature, conductivity, dissolved oxygen concentration and saturation, chlorophyll fluorescence and optical backscatter. During the glider mission, the Istrian front was clearly detected in salinity, temperature and density and it was crossed twice. During this short mission the glider was able to observe this shallow frontal area (with a maximum depth around 50 m) while it was under the influence of an intense cooling due to cold jet-like Bora winds. This resulted in a very sharp and highly contrasted front, between the denser and warmer Adriatic Water (salinity around 38.4 and temperature around 12 ^oC) to the south, and the lighter and colder North Adriatic Water to the north, and also including water from the inside of Kvarner Bay (salinity around 37.4 and temperature around 10.5 ^oC). The glider crossed a second time this front, two days after the Bora event, when the wind had weakened. The frontal pattern was changed. It appeared to be much smoother and more inclined. A small thermohaline intrusion was also found. It was approximately 20 m thick and it was horizontal elongated, from the smoother and weak Istrian front, and for about 1.5 km. The structure of this front and its response to the wind changes are described using the new glider observations and the results are compared with older observations collected in the same area during the DolceVita experiment in 2003.

Synoptic timescale sea level fluctuations in the White Sea according to observations in 2007 – 2014

ALEXEY KONDRIN[1]

[1] *Lomonosov Moscow State University, Faculty of Geography, Rissian Federation*

Abstract. Residual sea level (RSL) oscillations in the White Sea are investigated using the data of observations at four points located in the Gorlo (Throat), Dvina Bay, at Solovetskiy Archipelago and in Kandalaksha Bay. Focus is given to the study of the RSL oscillations in the synoptic timescale. The RSL fluctuations were obtained by excluding tidal component from the measurement data and then applying the Butterworth filter. A number of significant RSL rises and their relation to the synoptic conditions is considered. Storm surges in the White Sea arise when deep cyclones formed on the Arctic and Polar climate fronts pass over the Barents and White seas. Storm surges are the result of three factors: changes in atmospheric pressure, causing the static response of the ocean level in accordance with the ”inverse barometer” law; dynamic effects on ocean water of moving pressure systems; wind impact. RSL rising due mainly static reaction of the ocean took place rarely enough. Such raising (about 0.2 m) occurred when the White Sea for a long time was within the vast stable areas of low atmospheric pressure. The wind factor often prevails since when surge reaches its greatest height, White Sea usually is located in the rear part of the cyclone where dominate surge winds of the northern points of the compass. The third type of surge is in fact the passage of the solitary surges wave formed outside the White Sea because of the dynamic effects of a moving cyclone. The height of the surges in the points under consideration ranged from 0.20 to 0.6 - 0.7 m, and the duration - from 1 to 10 days. Key words: residual sea level, White Sea, static response of the ocean level, wind surges, solitary surge wave, synoptic conditions

Estimating contribution of coastal-trapped internal waves to primary production: a case study of Lastovo Island (Adriatic Sea)

ZARKO KOVAC[1], JADRANKA SEPIC[1], GORDANA BEG PAKLAR[1]
[1] *Institute of Oceanography and Fisheries, Croatia*

The effect of internal waves on primary production has not been studied extensively, with only a minor number of publications on the topic, all of which conclude that internal waves can increase daily primary production by a factor of less than 10%. Here we examine a special case of resonant excitation of internal waves around specific topographical features, like islands and its effect on primary production. The entrapment of these waves due to resonance can last for a considerable amount of time, ranging from a few days to weeks. First we explore the physical setting which leads to generation and resonant endurance of island trapped internal waves. Then we proceed to investigate mathematical formulations of biological models suitable for dealing with this phenomenon and our research. The analysis reveals that enhancement of primary production occurs if internal waves and the diurnal cycle of irradiance are in phase, whereas weakening of primary production occurs in case of internal waves and the diurnal cycle of irradiance being out of phase. Biomass accumulation is in accordance with literature values on the daily scale, but is stronger the longer the wave resides around the island. In this sense, geometry of some islands can localy increase primary production due to resonant excitation of internal waves. One of locations where long-lasting entrapment of gravity waves is known to happen is Lastovo Island, in the Mid Adriatic Sea, where internal gravity waves can persist up to a week. The theoretical model is further developed for Lastovo Island, and validated using coupled ocean-biology Regional Ocean Modelling System (ROMS) and available data.

Nonlinear internal waves and submesoscale eddies in the ice-free Arctic as observed by spaceborne SAR

IGOR KOZLOV[1,2], EVGENIA ZUBKOVA[1], OKSANA ATADZHANOVA[1,3], ALEXEI ZIMIN[3,1], VLADIMIR KUDRYAVTSEV[1], BERTRAND CHAPRON [4,1]

[1] *Russian State Hydrometeorological University, St.Petersburg, Russia*

[2] *Department of Natural Sciences, Klaipeda University, Lithuania*

[3] *P.P. Shirshov Institute of Oceanology RAS (Saint-Petersburg Branch), Saint-Petersburg, Russia*

[4] *Institute Français de Recherche pour l'Exploitation de la Mer, Plouzané, France*

High-frequency nonlinear internal waves (NIW) and submesoscale eddies (SE) are important dynamical features significantly impacting the hydrology of the upper ocean through enhancement of vertical and horizontal exchange, surface and deep water mixing, and transfer of marine organisms, sediments and pollutants. In the Arctic Ocean they are particularly important for sub-marine navigation, formation of the water structure and the maintenance of the life activity in marine ecosystems. However, these dynamic processes still remain largely unexplored and poorly investigated in the ice-free Arctic Ocean. In this work taking the advantage of high resolution spaceborne synthetic aperture radar (SAR) data we present joint results of NIWs and SEs observations in the ice-free Arctic including the Greenland, Barents, Kara, Laptev and East-Siberian seas. The study is based on analysis of ENVISAT ASAR images for summer-autumn months in 2007-2011. More than 4000 packets of high-frequency NIWs and about 3400 surface manifestations of SEs were identified in about 3000 SAR images. Detailed maps of NIWs and SEs observational frequency and their spatial and kinematic properties for the selected Arctic seas helped to identify main hot-spots of their activity. It is shown that hot-spots of NIWs occurrence do not spatially correlate with those of SEs suggesting they play a different role over continental and deeper parts of the Arctic Ocean, as well as having different mechanisms of their generation. We also point out the regions where large-scale intensive nonlinear IW packets are regularly observed. The work is supported by RFBR, research projects No. 16-29-02106 mol_a_dk and 15-05-04639 A.

Observing mesoscale eddy dynamics in Bay of Bengal with satellite and Argo

K. Muni Krishna[1]
[1] *Dept of Meteorology and Oceanography, Andhra University, Visakhapatnam, India*

Oceanic eddies have warm or cold temperatures and high or low sea surface height (SSH) at the center depending upon the direction of rotation. However, since the Bay of Bengal waters are highly stratified, sea surface temperature (SST) gradients may not be detectable even though the subsurface temperature sections and the SSH show prominent eddy signatures. In this investigation, SSH observations from satellite altimeter data and the Argo observations have been analyzed to study the Bay of Bengal eddies. Several cyclonic and anticyclonic eddies are identified from the satellite altimeter observations. These eddies located at the Argo float locations and have significant variations in amplitudes and show good qualitative agreement with the subsurface isotherm features of the in situ temperature profiles. The thermal structure observed across the eddy indicates that it was confined to a level well below the mixed layer, between 50 and 300m. A temperature drop of 3-5°C as compared with the surroundings was observed at the center of the eddy.

Sub-mesoscale instabilities in the frontal region of a non-meandering Agulhas Current

MARJOLAINE KRUG[1,2], SEBASTIAAN SWART[3]

[1] *Ecosystem Earth Observation, CSIR, P.O. Box 320, Stellenbosch 7599, South Africa*

[2] *Department of Oceanography, Nansen-Tutu Center for Marine Environmental Research, University of Cape Town, South Africa*

[3] *Southern Ocean Carbon and Climate Observatory, CSIR, P.O. Box 320, Stellenbosch 7599, South Africa*

In April 2015, two Seagliders were deployed for the very first time in the Agulhas Current region as part of the Shelf Glider Agulhas Current Experiment (SAGE) and to investigate processes of interactions between the Agulhas Current and shelf waters. Six weeks of continuous observations from the gliders in water depths of 100-1000m reveal the impact of sub-mesoscale eddies on the mean structure of the cross-shelf circulation. Glider and wind observations collected in a non-meandering Agulhas Current state suggest that sub-mesoscale cyclonic eddies generated at the inshore boundary of Agulhas Current are symmetric instabilities initially triggered by changes in the along-front component of the winds. The sub-mesoscale cyclonic eddies extend to water depth of 100-150m and interact with the sea-bed over the shallower regions of the continental shelf. The cumulative impact of the frontal instabilities is to create a counter current at the northern edge of the Agulhas Current whose width matches the length-scale of the frontal instabilities.

Geospatial Strategy for Adverse Impact of Urban Heat Island via surface topography using LANDSAT ETM+ Sensors

AMIT KUMAR[1],

[1]*Haryana Institute of Public Administration, Gurgaon, India*

We are living in the age of rapidly growing population and changing environmental conditions with advance technical capacity. This has been resulting in wide spread land cover change. Among several human induced environmental and urban thermal problems are reported to be negatively affecting urban residents in many ways. Urban Heat Islands exist in many large cities especially metropolitan cities and can significantly affect the quality of life in affected areas. The adverse effect of urban heat island has become the subject of numerous studies in recent decades and is reflected in many major cities around the world. The built-up structures in urbanized areas considerably alter land cover thereby affecting thermal energy flow which leads to development of elevated surface and air temperature. The Urban Heat Island (UHI) for the temporal period is estimated using geospatial techniques which are then utilized for the impact assessment on climate of the surrounding regions and how it reduce the sustainability of the natural resources like air, vegetation (Wang, 1990). Rapid growth of industries in peri-urban areas results in excessive warming and variations in weather conditions. Remotely sensed data of thermal infrared band in the region of 10.4-12.5 μm of EMR spectrum, available from LANDSAT-7 Thematic Mapper and Enhanced Thematic Mapper (TM and ETM+) with 60 m resolution is proved to be very helpful to identify urban heat islands using surface topography. Thermal infrared data acquired during the daytime and night time can be used to monitor the heat island associated with urban areas as well as atmospheric pollution. To ascertain the influence of land use and land cover categories and vegetation density on surface temperature LANDSAT 7 ETM+ and ASTER Advanced Space-borne Thermal Emission and Reflection Radiometer with 90 meters resolution data sets can be used (Kim, 1992; Weng, 2001).The present paper describes the methodology and resolution dynamic urban heat island change on climate using geospatial approach for Haridwar district of Uttrakhand. NDVI were generated using day time LANDSAT ETM+ image of 1990, 2000 and 2005. Temperature of various land use and land cover categories was estimated. In Haridwar district the temperature is inversely related and negatively correlated with NDVI value. The present study has showed that heat island effect need not be limited to a particular temperature epoch which signals towards the increasing dominance of anthropogenic heat emissions in rapidly developing cities such as Haridwar District in Uttrakhand, India. For compensation of the adverse effect of UHI, the urban built up cover should be reduced to an extent but in real, it is not possible due to proclivity of the human towards urbanization.

REFERENCES

Wang, W. C., Zeng, Z. and Karl, T. R.,1990. Urban heat islands in China. *Geophysical Research Letters* 17, 2377-2380.

Weng, Q., 2001. A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *International Journal of Remote Sensing*, 22, 1999-2014.

Kim, H.H., 1992. Urban heat island. *International Journal of Remote Sensing*, 13, 2319-2336.

[1] Haryana Institute of Public Administration, Gurgaon-122015, India

Modeling variability in the slope flows along the US West Coast

ALEXANDER KURAPOV[1]
[1] *College of Earth, Ocean, and Atmospheric Sciences, Oregon State University*

A multi-year (2009-2014) simulation using a 2-km resolution ocean circulation model of the entire US West Coast is analyzed to understand transport, temperature and salinity variability on the 26.5 isopycnal surface. This isopycnal surface is suppressed near the coast in winter, crossing the slope at depths between 200-400 m and is rising in summer. Velocities, temperature and salinity are sampled on this surface and Lagrangian particles are tracked to understand continuity and eddy variability in the poleward slope current (esp. in winter), as well as its connectivity with the interior ocean. The effect of coastal trapped waves on the placement depth, and transport of salinity and temperature anomalies are also analyzed. Contour tracking on the isopycnal surface is used to estimate eddy diffusivity values appropriate for low-resolution climate models.