A new insight on the Indo-Atlantic exchange achieved by Indian Ocean eddies assessed by satellite altimetry and Argo profiling float data.

RÉMI LAXENAIRE[1], SABRINA SPEICH[1], BRUNO BLANKE[2], ALEXIS CHAIGNEAU[3], CORI PEGLIASCO[3]

[1] *LMD, Ecole Normale Supérieure, France*

[2] *LPO, Université de Bretagne Occidentale, France*

[3] *LEGOS, Observatoire Midi-Pyrénées, France*

The Indo-Atlantic exchange achieved by mesoscale eddies formed in the Indian Ocean is investigated by means of 15 years (2000-2014) of daily satellite altimetry data and profiling floats.

A recently developed eddy identification and tracking algorithm is applied to daily maps of Absolute Dynamical Topography (ADT) to study the mesoscale activity from the Indian to the Atlantic oceans. The eddy-tracking algorithm has been further improved to account for merging and splitting events. These last two parameters are important because the study region is characterized by complex eddy dynamics where eddy formation, strong eddy interactions and influence of bottom topography are commonly observed.

Our results suggest that the origin and pathways of Agulhas Rings differ from previous analyses. The earliest positions of the eddies that achieve the Indo-Atlantic exchange are detected as far east as in the Mozambique Channel or southeast of Madagascar while the latest detection can occur in the South-West Atlantic, within the Brazilian Current or even the Zapiola Gyre.

The complex path associated with these eddies is also highlighted: every tracked eddy is shown to interact with other eddies and numerous merging and splitting events occur, especially in the Cape Basin. This affects the eddy trajectories across the Cape Basin: they are not straight and are characterized by a typical residence time between 1 and 2 years, with an actual covered distance 1.5 to 3 times larger than the beeline distance across this region.

Whereas the eddy detection from ADT allows the study of their surface properties along their trajectories, their collocation with Argo profiling floats gives a specific record of their internal structure over the water column. The evolution of the water masses trapped by eddies along their path from the Indian Ocean to Atlantic Ocean is consequently assessed.

Open-oceansubmesoscale instabilities from observations and a realistic global circulation model

AYAH LAZAR[1], ANDREW F. THOMPSON[1], DIMITRIS MENEMENLIS[2], CHRISTIAN E. BUCKINGHAM [3], GILLIAN M. DAMERELL[4], ALBERTO C. NAVEIRA GARABATO[3], KAREN J. HEYWOOD[4]

[1] *Environmental Science and Engineering, California Institute of Technology, Pasadena, California, United States*

[2] *Science Division, Jet propulsion Laboratory, California Institute of Technology, Pasadena, California, United States*

[3] *University of Southampton, National Oceanography Centre, Southampton, United Kingdo*

[4] *School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom*

Insight into submesoscale processes, including symmetric and baroclinic instabilities, has largely been achieved through numerical simulations of idealized model configurations (*Thomas et al. 2008*, *Mahadevan et al. 2010*, *Taylor Ferrari et al. 2010*). Studies with more realistic model configurations have tended to focus on regions that are susceptible to submesoscale motions, with strong, persistent fronts and/or strong surface forcing (*Mensa et al 2013, Rosso et al 2014*). Observations have focused on these areas, as well (*D'Asaro et al 2011, Thomas et al 2013*). As a consequence, much of our understanding of submesoscale instabilities is based on strong and persistent frontal gradients and forcing. However, the Ocean Surface Mixing, Ocean Submesoscale Interaction Study (OSMOSIS) provided direct observational evidence (*Thompson et al 2016*) (*Buckingham et al.*, submitted) that submesoscale motions are also active in a quiescent area of the ocean far from strong geost rophic fronts: the Northeast Atlantic. In this area the fronts, and their orientation relative to the surface forcing, are variable.

In this study we use a combination of observations and a realistic $1/48°$ global circulation model (llc_4320 MITgcm) to study instabilities of these variable fronts. We first demonstrate that the model, run only during late fall, produces qualitatively similar submesoscale field (e.g., buoyancy gradients, vorticity, mixed layer depth and potential vorticity) as observations in this time of year. A number of fronts from glider data and high resolution satellite image coincident with in situ measurements of density (*Buckingham et al.*, in preparation), are examined in the framework of the ageostrophic Eady problem (*Stone 1966*). We then compare with unstable fronts in the model, where we can follow the development of instabilities in time. The model does not directly resolve the convective and symmetric instabilities when the potential vorticity is negative (i.e., $\mathrm{Ri} < 1$ in the geostrophic approximation), but it nonetheless develops the basic state, bringing Ri to unity. When $\mathrm{Ri} > 1$ the dominant baroclinic instability is resolved, and can be seen to drive restratification of the mixed layer.

Global EOF analysis of NEMO OGCM output to constrain ocean interior from surface observations

Shaun Lee[1], Remi Tailleux[1], Keith Haines[1], Maarten Ambaum[1]
[1] *Department of Meteorology, University of Reading, UK*

Understanding to what extent surface information can constrain interior ocean properties is fundamental to data assimilation schemes which aim to incorporate observations into the model state, and more generally to establish the relative value of surface observations relative to interior ones in constraining the ocean state. Due to the limited spatial and temporal resolution of in-situ data, the exploitation of comparatively high resolution sea surface height and temperature (SSH and SST hereafter) observations to the constraining of the ocean interior is highly desirable. Previous theoretical work has generally assumed that the ocean variability projects onto vertical modes, which have been generally interpreted in terms of surface quasi-geostrophic modes for mesoscale or sub-mesoscale motions, or in terms of standard barotropic and baroclinic modes for large-scale motions. A similar strategy is pursued here, but for the use of empirical modes instead of theoretically determined ones.

With a focus on interior dynamics, we aim to quantify the amount of information contained in surface vs. interior observations and to identify the vertical structures of the variability. We use a high-resolution ocean model to construct timeseries of velocity at individual lat-lon points and calculate empirical orthogonal functions (EOFs) of these data. The aim is to characterise the complexity of the vertical structures of the variability as well as identify the minimum number of EOFs required to adequately describe it. The model used was the 1/12 degree NEMO ocean model run from 1978-2010 with ERA Interim-derived surface boundary conditions and fluxes; the data were sub-sampled to 1 degree to improve computational tractability.

To reach an explained variance of greater than 70%, many regions of the ocean require more than 2 modes. Regions such as the Antarctic Circumpolar Current and western boundary currents generally only require 1 or 2 modes to explain their variance whereas the strongly stratified tropical regions and the centre of gyres require around 5 or more.

For regions where a single vertical mode describes most of the data variance, projecting the surface geostrophic velocity value derived from the SSH provides a way to recover the interior dynamics. For regions where more than 1 mode is required, the problem becomes under-constrained. We therefore seek to identify whether at these locations different timescales have a different vertical structure. If they do, the SSH record can be similarly separated into different timescales and the data projected to the interior using the two different vertical modes generated.

To investigate the timescale-separability, the individual model timeseries data were time-filtered. This time-filter allowed the separation of the data into low-pass and high-pass filtered arrays. The correlation coefficient between the leading EOF of the two filtered data arrays was calculated. This was performed using a range of different cut-off frequencies from 2 weeks to 3 years and the frequency that produced the lowest correlation coefficient was taken to provide the clearest distinction of vertical modal structure.

Early results have shown that the regions previously requiring many modes to explain their variance are separable into distinct vertical structures but there does not seem to be a geographically consistent optimum cut-off frequency within these regions due to adjacent data point requiring different frequencies resulting in a 'noisy' image.

We next aim to reconstruct data using SSH observations from regions that require a single mode and for those which respond well to the time-filtering to investigate how successful this methodology proves in enhancing the information that can be extracted from surface observations.

Turbulent mixing and Chlorophyll maximum layer in the East China Sea

Jae Hak Lee[1], Chang-Su Hong[1], Hyoun-Woo Kang[1], Jae Kwi So[1]

[1] *Physical Oceanography Division, Korea Institute of Ocean Science and Technology, Korea*

The layered structure of the Chlorophyll concentration and vertical mixing in the northern East China Sea in summer is examined by analyzing data obtained in 2003-2007. The subsurface Chlorophyll maximum layer (SCML) appears in large parts of studied area. The SCML gets shallow toward the west and leads to the surface Chlorophyll maximum in the Changjiang bank where the low salinity water appears. The results of numerical simulation support that the lateral dependence of the SCML depth is a common summertime feature in the region. The turbulent energy dissipation rates estimated based on the microstructure profiler measurements show high within the thermocline, with typical value of O(10^{-7}W/kg) and occasionally close to 10^{-6}W/kg. Corresponding vertical eddy diffusivities reach to 10^{-2}m^{2}/s. Such high values of dissipation rate and vertical diffusivity match with the SCML. This implies that mixing within the thermocline is a key physical process to drive vertical nutrient flux into the SCML from the deep layer. The estimated daily vertical nitrate fluxes in the SCML are 0.12-8.6 mmol/m^2/day.

Energy exchange between near-inertial waves and balanced currents at ocean fronts

LEIF THOMAS[1]

[1] *Department of Earth System Science, Stanford University, USA*

In the ocean, wind-generated kinetic energy (KE) manifests itself primarily in balanced currents and near-inertial waves. The dynamics of these flows is strongly constrained by the Earth's rotation, causing the KE in balanced currents to follow an inverse cascade but also preventing wave-wave interactions from fluxing energy in the near-inertial band to lower frequencies and higher vertical wavenumbers. How wind-generated KE is transferred to small-scale turbulence and dissipated is thus a non-trivial problem. In this talk I will describe theoretical calculations and numerical simulations that demonstrate how some bizarre modifications to internal wave physics by the lateral density gradients present at ocean fronts allow for strong interactions between balanced currents and near-inertial waves that ultimately result in energy loss for both types of motion.

Hurricane Arthur and its effect on the short term variation of pCO_2 on the Scotian Shelf, NW Atlantic

J. LEMAY[1], H. THOMAS[1], S. CRAIG[1], B.J.W. GREENAN[2], K. FENNEL[1]

[1] *Dalhousie University, Canada*

[2] *Fisheries and Oceans Canada, Canada*

Variability of the CO_2 and pH system on the Scotian Shelf, NW Atlantic, has been investigated during the recent years at interannual, seasonal and diel time scales. However, a reliable understanding of the role of short term events and variability of the overall CO_2 and pH cycling has yet to be gained. Hourly measurements of pCO_2 and ancillary parameters were collected by an autonomous moored instrument (CARIOCA) stationed at Halifax Line 2 (HL2), roughly 30km off the coast of Halifax during the years 2007-2014. Complementary data from the 2007 deployment of the SeaHorse, an autonomous vertical profiler, was collected at the mooring location between April and July 2007. Focusing a the storm event, Hurricane Arthur, July 5^{th} 2014 triggered a significant drop in pCO_2. With the shelf revealing carbon rich deep water, this reduction of pCO_2 due to mixing went against current understanding. We show that just above the thermocline, yet underneath the shallow surface mixed layer, there is a sustained population of phytoplankton, decreasing CO_2 concentrations. When storm-driven mixing occurs, this intermediate, low-CO_2 layer is mixed into the well-lit surface, facilitating short term phytoplankton growth due to both favorable light and nutrient conditions. This growth then reduces pCO_2 for a short period of time until wind speeds slow down reducing mixing and allow for restratification of the water column.

Variability of submesoscale dynamics in the North Atlantic from a 1/60° ocean model simulation.

JULIEN LE SOMMER[1], JEAN-MARC MOLINES[1], BERNARD BARNIER[1], THIERRY PENDUFF[1], PATRICE KLEIN[2]

[1] *Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France*

[2] *Laboratoire de Physique des Oceans, Brest, France*

Several processes contribute to energize oceanic flows at scales smaller than the first baroclinic Rossby radius (frontogenesis, mixed-layer instabilities, current-topography interactions...). But the relative strength of these processes and their impact on energy cascades at basin scale is still poorly quantified. Likewise, little is known regarding how submesoscale dynamics actually affects larger scale flows at basin and global scales. Here, we use several years of an unprecedented sub-mesoscale-permitting, North Atlantic ocean/sea-ice model simulation performed at 1/60° resolution with 300 vertical levels. We describe the spatio-temporal variability of dynamical regimes at scales <100km at mid and high latitudes in the North Atlantic. Statistical properties of submesoscale dynamics across the basin are described in terms of wavenumber spectra and probability distributions of surface variables and discussed in the light of recent information collected during field experiments at submesoscales. Our results show in particular how the seasonal cycle of surface stratification in the subpolar gyre leads to a strong seasonal modulation of submesoscale activity at high latitudes. We finally discuss how the future wide-swath altimetric missions (SWOT) will sample these dynamical regimes.

Submesoscale control on marine ecosystems and diversity

Marina Levy[1]
[1] *LOCEAN, Université Pierre et Marie Curie, FR*

While meso and submesoscale nutrient fluxes and their relationship with primary production have received a great deal of attention over the last decade, we are know able to observe and model how such small scale dynamics might impact both higher levels in the marine ecosystems and the diversity of primary producers. In this presentation, I will overview some recent evidence of submesocale control on higher trophic levels as well as on phytoplankton diversity.

A statistical modeling of the Langmuir mixing effects on global climate

Qing Li[1], Adrean Webb[2], Baylor Fox-Kemper[1], Todd Arbetter[1], Anthony Craig[3], Gokhan Danabasoglu[3], William G. Large[3], Mariana Vertenstein[3]

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

[2] *Dept. of Ocean Technology, Policy, and Environment, The University of Tokyo, Kashiwa, Chiba, Japan*

[3] *National Center for Atmospheric Research, Boulder, Colorado, USA*

The effects of Langmuir turbulence on the surface ocean mixing and thereby the global climate are assessed in the NCAR earth system model CESM by adding a parameterization of Langmuir mixing to the K-Profile Parameterization (KPP). A global wave field is needed by this Langmuir mixing parameterization to provide the Stokes drift that drives Langmuir mixing. Both a prognostic wave model, WAVEWATCH III, and a climatological data wave model have been coupled with CESM and tested. Nearly identical and substantial improvements in the simulated mixed layer depth and intermediate water ventilation are found in both cases when Langmuir mixing is included. The greatest improvement occurs in the Southern Ocean. A climatological data wave model, which responds to simulated winds, but with fixed wind-wave relationships, can therefore reproduce the primary improvements of Langmuir mixing, but with much less computational cost than even a coarse-resolution prognostic wave model.

On the subsurface salinity maxima in the Gulf of Riga

TAAVI LIBLIK[1], MARIS SKUDRA[1,2], URMAS LIPS[1]

[1] *Marine Systems Institute at Tallinn University of Technology*

[2] *Latvian Institute of Aquatic Ecology*

Thermohaline structure in the Gulf of Riga (Baltic Sea) was investigated using an autonomous water column profiler and measurements onboard research vessel from May to September 2015. Stratification was mainly controlled by temperature while salinity had only minor contribution. The buoyant salt wedge with variable strength was occasionally observed in the intermediate layer of the Gulf of Riga. Salty water penetration to the gulf via Irbe strait was likely generated by wind forcing. South-westerly winds evoke an upwelling in the eastern part of the gulf and downwelling in the southern part of the Irbe strait. We suggest that upwelled deep layer water was compensated by the warm and salty downwelling water that originated from the Baltic proper. The salt wedge did not reach to the deeper ($>$ 35 m) part of the gulf, which remained untouched until convection and wind stirring destroyed stratification in autumn. Thus deeper part of the gulf remained isolated thorough summer and high oxygen utilization might lead to hypoxia in the deep layers of the gulf.

Spectral characteristics of submesoscale variability of temperature and salinity observed in the upper northern South China Sea

HONGYANG LIN[1]

[1] *State Key Laboratory of Marine Environmental Science, and Department of Physical Oceanography, College of Ocean & Earth Sciences, Xiamen University, Xiamen, China*

Submesoscale processes are important for closing the oceanic energy pathway from large to dissipative scales and in communicating the upper and interior ocean with biophysical properties. Here we seek to disclose submesoscale (1–20 km) characteristics of the upper northern South China Sea using high-resolution underway hydrographic measurements. We focus on temperature-salinity compensation and horizontal wavenumber spectra of temperature. It is found that temperature and salinity are generally non-compensating at submesoscale with salinity dominating lateral density variability, even when it is temperature dominating at larger scales ($>$50 km). On the continental shelf/slope, the spectra of temperature follows a k^{-3} scaling at submesoscale in consistence with the quasi-geostrophic turbulence theory. In the deep basin, a dependence on mesoscale variability is observed; a near k^{-2} (k^{-3}) scaling is observed in coherent mesoscale structures (quiescent ambient flows). Difference in ambient flow and interference of unbalanced motions are presumably responsible for the discrepancy.

Tide- and wind-driven variability of water level in Sansha Bay, Fujian, China

HONGYANG LIN[1], JIANYU HU[1], JIA ZHU[1], PENG CHENG[1], ZHAOZHANG CHEN[1], ZHENYU SUN[1], DEWEN CHEN[2]

[1] *State Key Laboratory of Marine Environmental Science, College of Ocean and Earth Sciences, Xiamen University, Xiamen, Fujian 361102, China*

[2] *Marine Forecast Station of Xiamen, State Oceanic Administration 361012, China*

This study analyzes water-level variability in Sansha Bay and its adjacent waters near Fujian, China, using observed water-level data from seven stations along the coasts and wind data observed from a moored buoy near Mazu Island. At super- to near-inertial frequencies, tides dominate the water-level variations, mainly characterized by semi-diurnal(primarily M2, S2, N2) and diurnal tides(primarily K1, O1).The correlation coefficients between residual (non-tidal)water-level time series and the observed wind-stress time series exceed 0.78 at all stations, hinting that the wind acting on the study region is another factor modulating the water-level variability. A cross-wavelet and wavelet-coherence analyses further indicates (i) that the residual water level at each station is more coherent, and out-of-phase, with the alongshore winds mostly at sub-inertial time scales associated with synoptic weather changes, and (ii) that the residual water-level difference between the outer and inner bay is more coherent with the cross-shore winds at discrete narrow frequency bands, with the wind leading by a certain phase. The analysis also implies that the monsoon relaxation period is more favorable for the formation of land-sea breeze, modulating the residual water-level difference.

Multi-platform in-situ observations to resolve the sub-mesoscale in stratified estuaries (sub-basins of the Baltic Sea).

URMAS LIPS[1], TAAVI LIBLIK[1], INGA LIPS[1], VILLU KIKAS[1], NELLI RÜNK[1]
[1] *Marine Systems Institute, Tallinn University of Technology, Estonia*

Main physical forcing components for the non-tidal Baltic Sea system are the atmospheric forcing, exchange of heat energy and fresh water through the sea surface, and input of freshwater from rivers and saltier North Sea water through the Danish Straits. It was identified already in 1980s that the Baltic Sea has rich mesoscale variability with spatial scales of O(10) km through the whole water column. Recent results based on analysis of high-resolution in-situ, numerical modeling and remote sensing data showed that the sub-mesoscale features significantly shape the distribution pattern of tracers in this stratified sea. The layered structure of the Baltic Sea, with the seasonal thermocline and the halocline situated at different depths, is a challenge to be accurately described by numerical models, especially at the scales relevant for phytoplankton dynamics. In many cases, a proper validation of model results is difficult due to the absence of observational data with the required resolution and coverage in time and space. In order to fill this gap a number of autonomous devices, including moored profilers, ferryboxes, and a glider, in combination with research vessel based instruments are applied.

We present the results of analysis of high-resolution data collected since 2009 in the Gulf of Finland and other Baltic sub-basins, which demonstrate pronounced variability at the sub-mesoscale in the presence of mesoscale features, such as upwelling/downwelling events, fronts and eddies. The analysis showed that in these conditions, the horizontal wavenumber spectra of temperature variance in the surface layer as well as in the seasonal thermocline had slopes close to -2 between the lateral scales from 10 to 1 km (the internal Rossby radius of deformation is 2-5 km in the Gulf of Finland). It suggests that the ageostrophic sub-mesoscale processes could contribute considerably to the energy cascade in this stratified sea basin. Furthermore, we suggest that the sub-mesoscale processes could play a major role in feeding surface blooms in the conditions of coupled coastal upwelling and downwelling events in the Gulf of Finland. The ageostrophic sub-mesoscale processes could be responsible for the growth enhancement via re-stratification of the surface layer as well as by contributing to the vertical transport in the presence of pronounced lateral and vertical gradients at the mesoscale.

Turbulence on the Carolina shelf and at the Gulf Stream Cold Wall

IOSSIF LOZOVATSKY[1], JESUS PLANELLA MORATO[2], HJS FERNANDO[1], KIPP SHEARMAN[3], ALEJANDRA SANCHEZ[3]
[1] *University of Notre Dame, USA*
[2] *University of Girona, Catalonia, Spain*
[3] *Oregon State University, USA*

Results of the microstructure measurements collected in October-November of 2015 within the framework of CASPER project are discussed. The turbulent kinetic energy (TKE) and temperature dissipation rates were estimated using the multi-cast VMP data. Daily recurrent measurements were concentrated at two locations – about 1-2 and 30 miles from the coast. The surface layer stratification was dominated by highly variable salinity (28-31 psu near the coast) and (31-34 psu offshore) advected to the test area depending on the direction of local winds. The across-shelf ADCP transects depicted strong variability of shelf currents affected by tide, stormy winds and the near-bottom intrusions of warmer and saltier waters of the Gulf Stream origin. An exponential decrease of the dissipation rate ε(z)$\sim$ *exp*(-1.1z) with depth z, associated with the wave-induced turbulence in the upper mixed layer, has been detected down to ten meters from the sea surface (under moderate stormy wind). The S-shaped density inversions at the base of mixed layer, and the corresponding shear estimates, pointed to K-H instability as an important source of turbulence at the upper boundary of the pycnocline on the shelf. Below the surface layer, the dissipation rate varied in a relatively narrow range between 10^{-9} and 3x10^{-8} W/kg. Only once, after a day-long storm (hourly averaged winds 10-14 m/s), the entire 30 m water column became turbulent with a characteristic $\varepsilon \sim 10^{-7}$ W/kg at the depths $>\sim$ 5 m.

In the strongly stratified pycnocline of the Gulf Stream cold wall, the generalized extreme value distribution approximates more than 95% of the empirical probability function of the decimal logarithm of the dissipation rate. This finding corroborates with our recent studies of the dissipation rate distributions in strongly stratified waters of the East China Sea, Bay of Bengal, and around Sri Lanka. A more traditional log-normal distribution of the dissipation rate mostly dominates weakly stratified surface and bottom boundary layers. The log-Levy multifractal model of turbulence intermittency has been tested against the dissipation data that pertains to layers and patches with a clear identifiable inertial spectral subrange. The intermittency parameters of the well-developed ocean turbulence are consistent with those reported by other authors for atmospheric turbulence and laboratory experiments.

Observations of mesoscale frontogensis and submesoscale restratification from a multi-platform survey in the Bay of Bengal

ANDREW J. LUCAS[1], AMIT TANDON[2], JONATHAN NASH[3], EMILY SHROYER[3], AMALA MAHADEVAN[4], JENNIFER MACKINNON[1], DEBASIS SENGUPTA[5], M. RAVICHANDRAN[6], ERIC D'ASARO[7], ROBERT PINKEL[1]

[1] *Scripps Institution of Oceanography*
[2] *University of Massachusetts, Dartmouth*
[3] *Oregon State University*
[4] *Woods Hole Oceanographic Institution*
[5] *Indian Institute of Science, Bangalore*
[6] *INCOIS, Hyderabad*
[7] *Applied Physics Laboratory, University of Washington*

Convergence in the oceanic mesoscale can sharpen lateral density gradients; the processes that arrest this frontogenisis are ageostrophic, unbalanced, and proceed rapidly on small spatial scales. They are thus difficult to observe *in situ*, and few such observations have been collected. Here we present measurements of submesoscale frontal evolution in the Bay of Bengal, a basin with 1) strong lateral gradients in density resulting from buoyancy input at the boundaries and from the atmosphere, 2) very shallow mixed layers, and 3) energetic mesoscale and submesoscale variability. The observations, taken with two global class research vessels and by an assortment of autonomous platforms, provide a unique view of frontogensis, frontal slumping, and subsequent re-stratification. The ships' onboard instrumentation was augmented with rapid profiling systems and near-surface current meters, providing for the shallow, small-scale spatial and temporal evolution of the density and velocity field synoptically. The processes leading to the formation and subsequent destruction of a 2 km scale high salinity filament were strongly 3-dimensional and time-dependent and appeared to involve a combination of Ekman dynamics, mixed layer instabilities, and potentially near-inertial/frontal interactions. These processes ultimately influence air-sea interactions by creating strongly stratified and very thin oceanic boundary layers in the Bay of Bengal, allowing for the development of strong, persistent subsurface temperature maxima, and are not represented in mixed layer parameterizations of regional numerical models.

Evidence for energetic sub-mesoscale instabilities in the Bay of Bengal

JENNIFER MACKINNON[1], JONATHAN NASH[2], ANDREW LUCAS[1], AMIT TANDON[3], AMALA MAHADEVAN[4], EMILY SHROYER[2], DEBASIS SENGUPTA[5]

[1] *Scripps Institution of Oceanography, University of California San Diego*
[2] *Oregon State University*
[3] *University of Massachusetts Dartmouth*
[4] *Woods Hole Oceanographic Institution*
[5] *Indian Institute of Science*

Sub-mesoscale instabilities are thought to play a significant role in controlling upper ocean stratification globally. Such influence is particularly dramatic in the Bay of Bengal, where an energetic mesoscale eddy field combined with large sources of near-surface freshwater make for frequent occurrences of strong and potentially unstable fronts. The resultant frontal slumping may be one of the missing dynamical pieces explaining why regional models using only one-dimensional vertical mixing schemes predict sea-surface temperatures with a persistent cold bias. Here we present results from the ONR ASIRI project. A combination of small-scale ship surveys and large-scale statistics show clear evidence of lateral spectral peaks in the sub-mesoscale band, roughly 1-5 kilometers. In situ data suggests such peaks correspond with energetic vertically sheared motions that act to subduct heavier waters under light. These observations will be discussed in light of known and unknown potential dynamical causes.

Subduction by submesoscale processes

Amala Mahadevan [1], Mara Freilich[1,2], Ruth Curry[3,1], David Nicholson[1], Mariona Claret[4], Melissa Omand[5], Eric D'Asaro[6]

[1] *Woods Hole Oceanographic Institution*
[2] *MIT*
[3] *Bermuda Institute of Ocean Science*
[4] *McGill Univesrity*
[5] *University of Rhode Island*
[6] *APL, University of Washington, USA*

We examine the vertical fluxes of carbon and oxygen within a submesoscale eddying flow field using glider observations to characterize the biogeochemical distributions, and a model to trace advective pathways. We are able to quantify the vertical flux of properties by submesoscale processes, the spatio-temporal distribution of submesoscale injection events, and the resulting effect on biological distributions. We identify the mechanisms underlying such submesoscale vertical transport and estimate their contribution to the vertical flux of particulate carbon.

A Numerical Modeling of Deposition, Erosion, and Flux Cohesive Sediment In Mahakam Estuary, East Kalimantan, Indonesia

MANDANG I.[1], YUSUF B.[2], RUSDIN A.[3]

[1] *Computational Physics and Modelling Laboratory, Department of Physics, Faculty of Science, Mulawarman University ,INDONESIA*

[2] *Department of Chemistry, Faculty of Science, Mulawarman University ,INDONESIA*

[3] *Department of Civil Engineering, Faculty of Engineering, Tadulako University ,INDONESIA*

The Mahakam Delta, located on the east coast of Kalimantan, Indonesia, is an active delta system which has been formed in humid tropical environment under condition of relatively large tidal amplitude, low wave-energy, and large fluvial input. Tidal processes control the sediment distribution in the delta mouth and are responsible for the flaring estuarine-type inlets and numerous tidal flats. The tides in the Mahakam estuary are influenced by the complex delta formation, bottom topography, river discharge when the tides propagate from offshore area into the shallow estuary. The currents in the Mahakam delta waters are mostly affected by tides and river flow. During the flood tide the current flows to the delta waters, and vice versa in the ebb tide. Such tidal current occurs according to the tidal wave behavior in the Mahakam delta. The M4 tidal current amplitude distribution follows the M2 tidal current amplitude distribution with its peak at mid estuary (about 120 km from Sebulu), whereas M4 tidal elevation amplitude has another peak farther upstream (about 80 km from Sebulu). This is due to the shrinking of the cross-sectional area from 60 km to 80 km from Sebulu. In the Mahakam estuary, tidal elevation amplitude distortion (M4/M2) is less than 0.3. For tidal current amplitude, M4/M2 reaches a maximum of 1.85 at Tenggarong (about 40 km from Sebulu)due to the decrease of the cross-sectional area from Samarinda to Tenggarong. Factors such as friction and channel morphology generate the shallow water overtides such as M4 constituent. (Mandang and Yanagi, 2008)

Is this study the fully three-dimensional finite difference baroclinic modelling system ECOMSED (Estuarine Coastal and Ocean Modeling System with Sediment) was applied order to quantify the dynamics of the fine-grained sediment in the Mahakam Estuary. The model simulated the complex hydrodynamics including statification satisfactorily. The simulated suspended sediment concentration were a maximum at delta area, generally of 360 mg 1-1. The average deposition flux a maximum at delta area and offshore area is 0,000060 g m-2 s and 0,00003 g m-2 s respectively. The average erosion a maximum at delta area and offshore area is 0,000030 g m-2 s and 0,0002 g m-2s respectively...

References:

Mandang, I, and Yanagi, T., 2008. Tide and Tidal Current in the Mahakam Estuary, East Kalimantan, Indoensua. Coastal Marine Science., 32(1), 1-8.

HydroQual, Inc., 2002. A primer for ECOMSED, Users Manual, Mahwah, N. J. 07430, USA

Understanding the multi-scale circulation in Lake Michigan: a Lagrangian view

MIAOHUA MAO[1], MENG XIA[1]

[1] *Department of Natural Sciences, University of Maryland Eastern Shore, Princess Anne, MD, 21853, USA*

In this study, five satellite-tracked surface current drifters deployed adjacent to the eastern shore of Lake Michigan on July 8th 2014 were used to investigate the dynamics of multi-scale lake-wide circulation. Additionally, an offline coupling system of wave-circulation-trajectory (SWAN-FVCOM-PTM) was applied to examine the relative effects of winds, waves, open boundary condition, river discharge, and baroclinicity on the circulation dynamics over the lake. Sensitivity experiments regarding the selection of wind field sources (e.g. atmospheric model winds (GEM and CFSv2) and observations-based NNM) were conducted, and the results indicated that models (FVCOM/PTM) using NNM winds yielded a slightly better statistical score than the atmospheric model winds when compared with the ADCP measured surface current velocity and satellite-tracked drifter trajectories adjacent to the eastern coast of the lake. Additional simulations revealed that the wind-driven and density-driven (i.e. temperature gradient) currents were more evident than that induced by wave forcing, lake-lake (i.e. Lakes Michigan and Huron) water exchange, and river discharge. By releasing 17 particles scattered around the lake perimeter and positioned in the deeper-water regions and being tracked from July to September 2014, we found that the coastal circulation in the eastern shore showed a signature of southerly alongshore current, whereas pronounced westerly offshore flows were presented in the western shore. The gyre-like circulation spirals with 0.1-10 km size prevailed in the deep water, and larger (10-100 km) cyclonic (anti-clockwise) eddy-like circulation pattern was detected in the northern and southern basin of the lake, respectively.

Influence of Island Mass Effect on Winter Chlorophyll-a bloom in the vicinity of Andaman-Nicobar Islands

M. V. Martin [1], Arun Chakraborty [1], J. Kuttippurath[1]

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

Island mass effect is the enhanced biological production around Islands, which is caused by factors such as input of nutrients from island runoff, contribution of benthic processes and lee eddies formed by flow disturbances or Ekman pumping. The flow disturbances in the wake of islands lead to the formation of submesoscale eddies. This study presents an investigation of influence of island mass effect on chlorophyll-a blooms occurring in the vicinity of the Andaman-Nicobar Islands during boreal winter. The Andaman-Nicobar Islands is located in the northeastern Indian Ocean. During boreal winter, a strong current with speed exceeding 0.4 m/s flows from the Andaman Sea into the Bay of Bengal across the Andaman-Nicobar Archipelago. This westward current is called the Winter Monsoon Current (WMC) and it appears during the period November-March with maximum strength during January-February. A significant increase in chlorophyll-a is observed along the path of WMC in the wake of Andaman-Nicobar Archipelago. In this study, we observe that the island mass effect is an important mechanism for the winter chlorophyll-a bloom in the study region, as analysed from 15 years (1997-2012) of satellite measurements. Our analysis reveals the presence of high concentration of chlorophyll-a, forming a pattern resembling submesoscale von Kármán vortex streets. This suggests that the submesoscale eddies generated due to the flow disturbance in the presence of the islands play a key role in upwelling nutrients and triggering the blooms.

Do ecological interactions at the submesoscale matter?

ADRIAN MARTIN[1], MARINA LÉVY[2], SIMON VAN GENNIP[1], SILVIA PARDO[3], MERIC SROKOSZ[1], JOHN ALLEN[4], STUART PAINTER[1], ROZ PIDCOCK[5]

[1] *National Oceanography Centre, UK*
[2] *Université Pierre et Marie Curie, France*
[3] *NEODAAS, UK*
[4] *SOCIB, Palma de Mallorca*
[5] *Carbon Brief, UK*

Whether uptake of nutrients, predation or fatal infection, biological and ecological processes are inherently non-linear. For situations where there is strong spatial variability, in organisms and their resources, this means that a knowledge of bulk properties, like mean abundance, does not necessarily allow us to predict what they will be in the future. The ocean submesoscale is such a patchy environment, with satellite images providing a constant reminder of the strong gradients in chlorophyll down to the kilometre scales they can resolve. Yet, the global biogeochemical models that we use for exploring future scenarios cannot resolve the submesoscale. This talk will use satellite and in situ observations to examine how significantly our models may be in error as a result.

Anoxia in the Eutrophic Cochin Estuary (Southwest Coast of India)

MARTIN G. D.[1,2], MURALEEDHARAN K. R.[1], REJOMON GEORGE[1,3], NAIR M[1], JERSON V. J [1]

[1] *National Institute of Oceanography, Regional Centre, Kochi-682018, India.*

[2] *Kerala University of Fisheries and Ocean Studies, Kochi - 682506, India.*

[3] *Cochin University of Science and Technology, Kochi-682016, India.*

Hydrographic observations in the Cochin Estuary (CE), southwest coast of India, during the summer monsoon delineated the spreading of an unusually anoxic (O2 = 0) water mass in the bottom layers, which have not been previously reported from any tropical estuaries. Monsoon driven upwelling in the Arabian Sea (AS) brought cool, high saline, oxygen deficient and nutrient-rich waters towards the coastal zone and bottom layers of CE during high tide. Intrusion of the AS waters found to be stronger in the estuary (upto15 km), than the previous reports. Diurnal observations in the lower reaches of CE reveals a low mixing zone with increased stratification, 3hrs after the high tide (highest high tide). The upwelled waters (O2 = 40μM) intruded in the estuary lose more oxygen during the neap phase (O2 = 4 μM) than spring phase (O2 = 10μM). Spatial observations reveals the severe oxygen depletion (O2 = 0), 2–6 km away from the estuarine mouth. Increased stratification and low ventilation in the region have resulted in severe oxygen depletion in the estuary. The expansion of oxygen deficient zone may lead to the destruction of biodiversity and increase the emission of green house gases from this region.

A numerical study of eddy generation at the island of Gran Canaria, Canary Islands

EVAN MASON[1], JEROEN MOLEMAKER[2], ANANDA PASCUAL[1], JAMES C. MCWILLIAMS[2]

[1] *IMEDEA, Esporles, Mallorca, Spain*

[2] *CESR, UCLA, Los Angeles, USA*

The Canary archipelago off the northwest African coast in the subtropical North Atlantic represents one of the better paradigms, along with Hawaii, for the study of deep water island wakes. The archipelago is embedded within the equatorward Canary Current, and a turbulent downstream wake is present all year. Island topography and wind stress shear are both directly implicated in eddy generation; a further contributor is baroclinic instability at the Canary coastal upwelling. Here we use aggressive grid nesting with ROMS to gain insight into eddy formation and evolution at Gran Canaria, one of the larger Canary Islands that is directly exposed to the Canary Current and has a nearly circular shape. The model is used to examine the expected sequence of near-island approach of the flow, bottom drag generation of vertical vorticity, current separation, wake instability, and coherent vortex roll-up that, taken as a whole, describes the eddy generation process.

Submesoscale dynamics under sea ice

J-A Mensa[1], M-L Timmermans[1]
[1] *Yale University, New Haven, CT, USA*

In an Arctic undergoing significant climate change and expansion of human activities, such as oil exploration, the study of Arctic Ocean dynamics is now, more than ever, a top priority. Measurements of ocean currents in the Arctic's Canada Basin suggest that upper-ocean dynamics under sea ice might be significantly different from that of the temperate oceans ([Timmermans et al., 2012]). In particular, observational evidence suggests that currents developing under sea ice present weak or absent submesoscale dynamics, in contrast with mid-latitude oceans characterized by energetic dynamics at these scales ([Capet et al., 2008; Mensa et al., 2013; Callies et al., 2015]). We present numerical model results of the upper ocean under sea ice, set in context with Arctic observations, to describe the submesoscale flow field and its evolution for a variety of sea-ice conditions.

Numerical simulations are performed with the MITgcm in an idealized configuration, and including sea-ice dynamics and thermodynamics. The domain is a 200 km by 400 km doubly-periodic channel initialized with hydrographic profiles from the Canada Basin. After the initial adjustment, a two-year long simulation is forced with ECMWF 3-hourly fluxes in the region. The model produces seasonal cycles of sea-ice and upper-ocean properties that are consistent with observations.

Based on the seasonal cycle of sea-ice thickness and concentration, we delineate seasonal intervals in which we separately investigate ocean dynamics. The summer season is divided into two periods. During the first half, ice melt generates a shallow mixing layer which isolates the surface from deeper, warmer and saltier waters. During the second half of the summer season, the sea ice becomes less concentrated resulting in a more dynamic ice pack (i.e., responsive to wind forcing) and subsequent upper-ocean mixing. During this period, shear driven instabilities are observed. During most of the winter season, sea-ice grows, convective cells form, and the mixed layer deepens in general. Convective plumes associated with sea-ice growth generate lateral density anomalies and baroclinic instabilities, in contrast to the shear-driven instabilities of the summer season. At the end of spring when both sea-ice thickness and concentration are maximal, there is a period of very little dynamic activity in the ocean prior to the onset of the summer season and rapid melt.

We show how numerical results characterizing the flow field are in broad accordance with upper-ocean density spectra from ice-tethered instrument platforms. Finally, Arctic submesoscale dynamics are compared and contrasted with those in the mid-latitudes.

REFERENCES

Callies, J., Ferrari, R., Klymak, J. M., & Gula, J. 2015. Seasonality in submesoscale turbulence. Nature Communications. 6, 6862.

Capet, X., McWilliams, J. C., Molemaker, M. J., & Shchepetkin, A. F., 2008.

Mesoscale to submesoscale transition in the California Current system. Part I: Flow structure, eddy flux, and observational tests. Journal of Physical Oceanography, 38(1), 2943.

Mensa, J. A., Garraffo, Z. D., Griffa, A., zgkmen, T. M., Haza, A. C., & Veneziani, M. , 2013. Seasonality of the submesoscale dynamics in the Gulf Stream region. Ocean Dynamics, 2013, 63(8), 923941.

Timmermans, M.-L., Cole, S., & Toole, J., 2012, Horizontal Density Structure and Restratification of the Arctic Ocean Surface Layer. Journal of Physical Oceanography.

The (So-Called) Stability Functions of Truncated Second-Order Turbulence Closure Models: Cause of Ill Behaviour and Remedial Measures

DMITRII MIRONOV [1], EKATERINA MACHULSKAYA [1]

[1] *German Weather Service, Offenbach am Main, Germany*

The problem of realizability of the second-order turbulence closure models (parameterization schemes) is addressed through the consideration of the so-called "stability functions" (Mellor and Yamada 1974, 1982). Stability functions appear within the framework of truncated turbulence closure schemes, where (i) the Reynolds-stress and scalar-flux (and possibly also scalar-variance) equations are reduced to the diagnostic algebraic formulations by neglecting the substantial derivatives and the third-order transport (diffusion) terms, and (ii) the linear parameterizations (in the second-order moments) of the pressure-scrambling terms are used. The stability functions are known to be ill-behaved over a part of their parameter space. They become infinite in the case of growing turbulence, where the actual value of the turbulence kinetic energy (TKE) is smaller than the equilibrium TKE corresponding to the steady-state production - dissipation balance. Helfand and Labraga (1988) analyzed the stability functions of the one-equation TKE scheme (the level 2.5 scheme in the nomenclature of Mellor and Yamada) that is very popular in geophysical applications. Using rather plausible physical arguments, they developed "regularized" stability functions that reveal no pathological behaviour over their entire parameter space. We extend the approach of Helfand and Labraga to the TKE - Scalar Variance (TKESV) scheme (the level 3 scheme in the nomenclature of Mellor and Yamada) that carries prognostic equations for the variances and covariance of scalar quantities (temperature and humidity in the atmosphere, temperature and salinity in the ocean) with due regard for the third-order transport. The cause of pathological behaviour of the stability functions of the TKESV schemes is analysed. The Helfand and Labraga regularization procedure is compared to some other realizability constraint techniques, and the physical interpretation of the various techniques is offered. The regularized stability functions for the TKESV scheme are developed that are well-behaved at any values of their governing parameters (gradient Richardson number, dimensionless velocity shear, and dimensionless scalar variances characteristic of the turbulence potential energy). We argue that a TKESV turbulence parameterization scheme with the well-behaved stability functions is a viable option for geophysical applications as it offers a good compromise between physical realism and computational economy. The TKESV scheme was successfully implemented into the limited-area numerical weather prediction model COSMO, where it clearly outperforms the TKE scheme at very low additional computational cost (Machulskaya and Mironov 2013).

References

Helfand, H. M., and J. C. Labraga, 1988: Design of a nonsingular level 2.5 second-order closure model for the prediction of atmospheric turbulence. J. Atmos. Sci., 45,113-132.

Machulskaya, E., and D. Mironov, 2013: Implementation of TKE–Scalar Variance mixing scheme into COSMO. COSMO Newsletter, No. 13, 25-33. (available from www.cosmo-model.org)

Mellor, G. L., and T. Yamada, 1974: A hierarchy of turbulence closure models for planetary boundary layers. J. Atmos. Sci., 31, 1791-1806.

Mellor, G. L., and T. Yamada, 1982: Development of a turbulence closure model for geophysical fluid problems. Rev. Geophys., 20, 851-875.

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

MAHDI MOHAMMADI-ARAGH[1], KNUT KLINGBEIL[2], NILS BRÜGGEMANN[3], CARSTEN EDEN[4], HANS BURCHARD[2]

[1] *Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Germany*
[2] *Leibniz Institute for Baltic Sea Research Warnemünde, Germany*
[3] *Section of Environmental Fluid Mechanics, Delft University of Technology, Netherlands*
[4] *Institute of Oceanography, University of Hamburg, Germany*

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

REFERENCES

Klingbeil, K., Mohammadi-Aragh, M., Gräwe, U. and Burchard, H., 2014. Quantification of spurious dissipation and mixing—Discrete Variance Decay in a Finite-Volume framework. J. Ocean Modelling, 81, 49-64.

Mohammadi-Aragh, M., Klingbeil, K., Brüggemann, N., Eden, C., and Burchard, H., 2015. The impact of advection schemes on restratifiction due to lateral shear and baroclinic instabilities. J. Ocean Modelling, 94, 112-127.

Do coupled sub-mesoscale – intraseasonal dynamics influence the seasonal cycle of surface ocean CO2: SOSCEX: a glider observations and model outputs experiment in the Sub-Antarctic Zone of the SE Atlantic Ocean

MONTEIRO, PMS[1], CHANG, N[1], LÉVY, M[3], SWART, S[1], THOMALLA, SJ

[1] *Ocean Systems & Climate, CSIR-CHPC, 15 Lwr Hope Rd., Rosebank 7700, Cape Town, South Africa*

[2] *Department of Oceanography, University of Cape Town, Rondebosch 7700, Cape Town, South Africa*

[3] *Sorbonne Université (UPMC, Paris 6)/CNRS/IRD/MNHN, Laboratoire d'Océanographie et du Climat, Institut Pierre, Simon Laplace, Paris, France*

The data sets from two spring – late summer deployments of CO2-equiped wave gliders and the output from a 2km resolution model (NEMO-PISCES) are used to investigate the response of CO2 to the interaction of synoptic scale storms with local sub-mesoscale gradients in the surface boundary layer. This work is part of the Southern Ocean Seasonal Cycle Experiment (SOSCEX) series of observations of the characteristics of the seasonal cycles of carbon and its drivers in the Sub-Antarctic zone.

Earlier work glider data has demonstrated the importance of meso-scale – storm interactions (Thomalla et al., 2011; Swart et al., 2014) to understand the seasonal characteristics of primary productivity. More recently it has been shown that the seasonal cycle of CO2 and primary production comprise strong intra-seasonal modes (Memery et al., 2002; Thomalla et al., 2015; Monteiro et al., 2015). The energy and role that these sub-seasonal modes play in shaping the seasonal cycle makes them an important focus in understanding the climate sensitivity of the Southern Ocean carbon cycle.

Here we use the glider data and the high-resolution model output to examine how the interaction of storms with sub-mesoscale influences the seasonal evolution of the vertical transport fluxes of carbon.

Mémery, L., M. Lévy, S. Vérant, and L. Merlivat (2002), The relevant time scales in estimating the air–sea CO2 exchange in a mid-latitude region, Deep Sea Res. Part II, 49(11), 2067–2092.

Monteiro, P. M. S., L. Gregor, M. Lévy, S. Maenner, C. L. Sabine, and S. Swart (2015), Intraseasonal variability linked to sampling alias in air-sea CO2 fluxes in the Southern Ocean, Geophys. Res. Lett.,,42, doi:10.1002/2015GL066009.

Swart, S., S. J. Thomalla, and P. M. S. Monteiro (2014), The seasonal cycle of mixed layer dynamics and phytoplankton biomass in the Sub-Antarctic Zone: A high-resolution glider experiment, J. Mar. Syst., doi:10.1016/j.jmarsys.2014.06.002.

Thomalla, S. J., N. Fauchereau, S. Swart, and P. M. S. Monteiro (2011), Regional scale characteristics of the seasonal cycle of chlorophyll in the Southern Ocean, Biogeosciences, 8(10), 2849–2866, doi:10.5194/bg-8-2849-2011.

Observability of fine-scale ocean dynamics in the NW Mediterranean Sea

ROSEMARY MORROW[1], ALICE CARRET[1], FLORENCE BIROL[1], GUILLAUME VALLADEAU[2], FRANCOIS BOY[3], FERNANDO NINO[1]

[1] *LEGOS/OMP Toulouse, France*
[2] *CLS Space Oceanography, Toulouse, France*
[3] *CNES, Toulouse, France*

Technological advances in the recent satellite altimeter missions of Jason-2, Saral-AltiKa and Cryosat-2 have improved their signal-to-noise, allowing us to observe finer-scale ocean processes with alongtrack data. Here, we analyse the noise levels and observable ocean scales in the northwest Mediterranean Sea, using spectral analyses of alongtrack sea surface height from the three missions. Jason-2 has a higher mean noise level with strong seasonal variations, with higher noise in winter due to the rougher sea-state. Saral-Altika has the lowest noise, again with strong seasonal variations. Cryosat-2 is in SAR mode in the Mediterranean Sea but with lower resolution ocean corrections; its statistical noise level is moderate with little seasonal variation. These noise levels impact on the ocean scales we can observe. In winter, when the mixed layers are deepest and the sub-mesoscale is energetic, all of the altimeter missions can observe wavelengths down to 40-50 km (individual feature diameters of 20-25 km). In summer when the sub-mesoscales are weaker, Saral can detect ocean scales down to 35 km wavelength, whereas the higher noise from Jason-2 and Cryosat-2 blocks the observation of scales less than 50-55 km. This statistical analysis is verified by individual case studies, where filtered alongtrack altimeter data are compared with collocated glider and HF radar data. The glider comparisons work well for larger ocean structures, but observation of the smaller, rapidly moving dynamics are difficult to collocate in space and time (gliders cover 200 km in a few days, altimetry in 30 secs). HF radar surface current data at Toulon measures the meandering Northern Current, and its excellent temporal sampling shows promising results in comparison to collocated Saral altimetric currents. Techniques to separate the geostrophic component from the wind-driven ageostrophic flow need further development in this coastal band.

The impact of vertical eddy viscosity parameterizations on forced submesoscale eddy-resolving simulations

SONALJIT MUKHERJEE[1], SANJIV RAMACHANDRAN[2], AMIT TANDON[2], AMALA MAHADEVAN[3]

[1] *School for Marine Science and Technology, University of Massachusetts Dartmouth*

[2] *Dept. of Mechanical Engineering, University of Massachusetts Dartmouth*

[3] *Physical Oceanography, Woods Hole Oceanographic Institution*

We explore the spatial variability of the subgrid dissipation rate in a submesoscale eddy field using submesoscale-resolving simulations of an idealized mixed-layer front. We use the 3-dimensional non-hydrostatic Process Study Ocean Model (PSOM). The domain size is large enough to contain O(100km) eddies while the lateral and vertical grid resolution are 0.5km and O(1m) (near the surface) respectively. We compare the model results from three different subgrid vertical mixing schemes: the $k-\epsilon$, KPP and constant eddy-viscosity ($3 \times 10^{-2}\mathrm{m}^2\mathrm{s}^{-1}$) profiles. We simulate an idealized a 100m deep mixed-layer front initially in geostrophic balance with an along-frontal jet, forced by downfront winds. The front goes unstable to ageostrophic baroclinic instability and forms $\mathrm{O}(1\text{–}10\mathrm{km})$ submesoscale eddies. Regardless of the chosen subgrid mixing scheme, our simulations show that within the mixed layer, the regions with strong subgrid dissipation are characterized by downwelling, cyclonic relative vorticity, negative potential vorticity (PV) and frontogenesis. In such localized regions, the geostrophic shear production to the subgrid eddy kinetic energy exceeds the ageostrophic shear production, enhancing the subgrid dissipation. This is consistent with the strengthening of the lateral density gradients by frontogenesis. In contrast, when averaged over the eddying region, the ageostrophic shear production dominates the geostrophic shear production.

An analysis of the sensitivity of the resolved-scale EKE budget to different subgrid mixing schemes shows that stronger vertical diffusivities result in a weaker buoyancy flux associated with the ABI-induced restratification of the mixed-layer front. For $k-\epsilon$ and KPP, which dynamically estimate eddy viscosities based on the water column properties, the restratification reduces the eddy viscosities, thereby reducing the mixing and facilitating further restratification at later times. In the resolved-scale EKE budget, the $k-\epsilon$ and KPP produce an O(10m) deep shear-driven layer overlying a thicker buoyancy-driven layer. In contrast, we do not observe these two layers in the constant eddy viscosity simulation due to the dominance of the vertical pressure transport term in the resolved EKE budget. The subgrid EKE budget from $k-\epsilon$ mixing scheme contrasts the resolved EKE budget by showing a leading order balance between the subgrid shear production and subgrid dissipation throughout the mixed layer.

University of Massachusetts Dartmouth, 285 Old Westport Rd, North Dartmouth, MA-02747.

Three dimensional Chaotic Advection by Mixed Layer Baroclinic Instabilities

Daniel Mukiibi[1], Gualtiero Badin[1], Nuno Serra[1]

[1] *Institute of Oceanography, University of Hamburg, D- 20146 Hamaburg, Germany.*

Three dimensional (3D) Finite Time Lyapunov Exponents (FTLEs) are computed from high resolution numerical simulations of a freely evolving mixed layer (ML) front, in a zonal channel undergoing baroclinic instability. The 3D FTLEs show a complex structure, with features that are less defined than the two-dimensional (2D) FTLEs, suggesting that stirring is not confined to the edges of vortices and along filaments thus posing significant consequences on mixing. The magnitude of the 3D FTLEs is observed to be strongly determined by the vertical shear. A scaling law relating the local FTLEs and the nonlocal density contrast used to initialize the ML front is derived assuming thermal wind balance. The scaling law is found to only converge to the values found from the simulations within the pycnocline, while it displays significant differences within the ML, where the instabilities show a large ageostrophic component. The probability distribution functions of 2D and 3D FTLEs are found to be non Gaussian at all depths. In the ML, the FTLEs wavenumber spectra display -1 slopes, while in the pycnocline, the FTLEs wavenumber spectra display -2 slopes, corresponding to frontal dynamics. Close to the surface, the geodesic Lagrangian Coherent Structures (LCSs) reveal a complex stirring structure, with elliptic structures (vortices) detaching from the frontal region. In the pycnocline, LCSs are able to detect both submesoscale filaments and elliptic structures that are not captured by the Eulerian fields.

The interior submesoscale route to dissipation of balanced mesoscale energy

B.T. NADIGA[1]

[1] *LANL, Los Alamos, NM 87545, USA*

An estimate of interior dissipation of mesoscale energy in the world oceans is presented based on high-resolution simulations of the non-hydrostatic Boussinesq equations in an idealized domain. Analysis of such simulations reveals that a developing baroclinic instability can lead to secondary instabilities that cascade a small fraction of the energy forward to unbalanced scales. In particular, mesoscale shear and strain resulting from the hydrostatic geostrophic baroclinic instability drive frontogenesis, and the fronts in turn support ageostrophic secondary circulation and instabilities. These two processes acting together lead to a quick rise in dissipation rate which then reaches a peak and begins to fall slowly when frontogenesis slows down; eventually balanced and imbalanced modes decouple. Dissipation of balanced energy by imbalanced processes scales exponentially with Rossby number of the base flow. We expect that this scaling will hold more generally than for the specific setup we consider given the fundamental nature of the dynamics involved. A break is seen in the total energy spectrum at small scales: While a steep k^{-3} geostrophic scaling (where k is the three-dimensional wavenumber) is seen at intermediate scales, the smaller scales display a shallower $k^{-5/3}$ scaling, reminiscent of the atmospheric spectra of Nastrom & Gage. At higher Ro, the vertical shear spectrum has a minimum, like in some relevant obervations.

Evidence of enhanced double-diffusive convection below the main stream of the Kuroshio Extension

TAKEYOSHI NAGAI[1], RYUICHIRO INOUE[2], AMIT TANDON[3], HIDEKATSU YAMAZAKI[1]

[1] *Tokyo University of Marine Science and Technology*

[2] *Japan Agency for Marine-Earth Science and Technology*

[3] *University of Massachusetts Dartmouth*

In this study, a Navis-MicroRider microstructure float and an EM-APEX float were deployed along the Kuroshio Extension Front. The observations deeper than 150 m reveal widespread interleaving thermohaline structures for at least 900 km along the front, presumably generated through mesoscale stirring and near-inertial oscillations. In these interleaving structures, microscale thermal dissipation rates v are very high O($>10^{-7}$ K^{2}s^{-1}), while turbulent kinetic energy dissipation rates are relatively low O(10^{-10}-10^{-9}Wkg^{-1}), with effective thermal diffusivity Kh of O(10^{-3} m^{2}s^{-1}) consistent with the previous parameterizations for double-diffusion, and, Kh is two orders of magnitude larger than the turbulent eddy diffusivity for density K_ρ. The average observed dissipation ratio Γ in salt finger and diffusive convection favorable conditions are 1.2 and 4.0, respectively, and are larger than that for turbulence. Our results suggest that mesoscale subduction/obduction and near-inertial motions could catalyze double-diffusive favorable conditions, and thereby enhancing the diapycnal tracer fluxes below the Kuroshio Extension Front. In the presentation we will show numerical simulation results as well.

Instability of thin freshwater layers in the Bay of Bengal

JONATHAN NASH[1], DREW LUCAS[2], ANDY PICKERING[1], DEBASIS SENGUPTA[3]
[1] *Oregon State University, Corvallis, USA*
[2] *Scripps, UCSD, San Diego, USA*
[3] *Indian Institute of Science, Bangalore, India*

Heavy precipitation and high river flow in the northern Bay of Bengal creates extremely thin freshwater layers that trap heat and alter air-sea fluxes. During the 2015 summer monsoon, an intensive joint US-Indian effort was undertaken to understand the horizontal and vertical dispersion of these layers. Repeat surveys of the very near surface velocity and stratification were simultaneously obtained by 2 ships and a remotely operated kayak, obtaining data with 1-m horizontal and vertical resolution of a large-scale front that remained persistent over several inertial periods. Here we focus on details of the frontal structure in the upper 10 m, exploring (i) the turbulence and instabilities with horizontal scales of 20-2000 m that act to diffuse it, and (ii) larger scale convergence that acts to maintain it. By the time of this colloquium, we hope to understand the factors that differentiate periods of intense instability from periods without.

Coastal dynamics process in the Northeastern part of the Black sea

Ksenia Nazirova[1], Olga Lavrova[1]
[1] *Space Research Institute of Russian Academy of Sciences, Russia*

We present the results of the long-term experimental works, conducted in the shelf zone of the Black Sea near Gelendzhik in 2011-2015. The experimental works are included in-situ measurements (shipboard measurements - ADCP, CTD, termistors) and satellite data analyze (radar observation from Envisat, RADARSAT-2 and TerraSAR-X satellites and observation in the visible range using Envisat MERIS and MODIS Terra/Aqua, OLI Landsat-8 satellites). This area is very interesting from the point of view of intensity of dynamic processes. Because of the nature of the topography and climate of the region and the topography of the seabed in the studied area is observed frequently changing the direction of currents, caused by the passage of coastal eddies. The reasons of formation, peculiarities of the fine structure and quantitative characteristics of these vortices is one of the main goals of our work. Our experiments of previous years showed that submesoscale vortices influence on hydrological and hydrodynamic structure of water. So, often after the passage of the vortex, we recorded the generation of internal waves of different amplitudes and frequencies. Also, eddies could influence on transport of pollution (biological or anthropogenic). The problem of pollution of marine waters and little knowledge of small submesoscale structures is the importance and relevance of this work. The presented results bring some clarity to the understanding of coastal dynamic processes, obtained in a joint analysis of subsatellite measurements and remote sensing data. As well as open many questions for further work in this area and in the region. The study was completed with financial support from the Russian Science Foundation grant #14-17-00555.

Multi-platform synergies for the direct investigation of ocean fronts: a case study in the North-western Mediterranean

FRANCESCO NENCIOLI[1,2], ANNE PETRENKO[2], ANDREA DOGLIOLI[2], FRANCESCO D'OVIDIO[3]

[1] *Remote Sensing Group, Plymouth Marine Laboratory, United Kingdom*

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

[3] *Sorbonne Université (UPMC, Paris 6)/CNRS/IRD/MNHN, Laboratoire d'Océanographie et du Climat (LOCEAN), Institut Pierre Simon Laplace (IPSL), Paris, France*

In the last decade, high-resolution numerical models have highlighted the key contribution of (sub)mesoscale dynamics to the ocean energy budget, tracer transport and biogeochemical cycles. At the same time, direct and quantitative observations of submesoscale processes are still particularly challenging, and many of the theoretical hypotheses and model results remain virtually untested in the field. Due to the ephemeral and localized nature of eddies, fronts and filaments, key aspects in the design of field experiments for their direct investigation include *a*) the implementation of sampling strategies optimized in near-real time to target a specific structure; *b*) the integration of multi-platform observations to contextualize the localized high-resolution observations into a larger dynamical context.

The Latex10 campaign (September 1-24, 2010) adopted an adaptive sampling strategy that included satellite, ship-based and Lagrangian observations to collect a series of sections across a thermal front in the western Gulf of Lion (NW Mediterranean). AVHRR imagery of pseudo-SST showed that the front originated from the mesoscale-induced stirring of coastal (colder) and open (warmer) waters. Their movement was tracked in-situ through the optimized deployment of a series of Lagrangian drifter arrays. The trajectories were used to localize the front axis and to define the ship route for the cross-sections. Ship-based observations identified the TS signature of the water masses across the front and provided a direct estimate of the associated currents.

Our analysis integrated the datasets from the various platforms to investigate different aspects associated with the front dynamics: i) Dispersion patterns of the drifter arrays identified and tracked in-situ Lagrangian coherent structures associated with the front. These were compared to the ones from remote sensing, evidencing limitations of satellite altimetry in the coastal region [*Nencioli et al.*, 2011]. ii) Cross-front profiles from the ship-mounted thermosalinograph were combined with strain rates from the drifter arrays to compute in-situ estimates of submesoscale horizontal diffusivity across the front, providing an important term of comparison for numerical model parametrizations [*Nencioli et al.*, 2013]. iii) Near-inertial currents retrieved from the drifter trajectories were used to correct the instantaneous currents measured by the ship-mounted ADCP. These were used to estimate the cross-shelf fluxes associated with the front, suggesting that 3 to 4 of such events are sufficient to completely renew the surface waters of the Gulf of Lion [*Nencioli et al., Submitted*].

Future (sub)mesoscale-focused field experiments can further improve the approach developed for Latex10 by extending the high-resolution observations to the first few hundred meters of the water column (e.g. through ship-towed profilers), and by including biological and biogeochemical parameters (e.g. through optical and acoustic sensors). This type of strategy and design will be crucial to provide the in-situ observations required to better understand the physical and ecological impact of (sub)mesoscale processes in the oceans, and to contribute and support the further development of numerical models and future high-resolution satellite missions.

Acknowledgments. The LATEX project was supported by the programs LEFE/IDAO and LEFE-/CYBER of the INSU-Institut National des Sciences de l'Univers and by the Region PACA-Provence Alpes Côte d'Azur. F.N. acknowledges support from the FP7 Marie Curie Actions of the European Commission, via the Intra-European Fellowship (FP7-PEOPLE-IEF-2011), project "Lyapunov Analysis in the COaSTal Environment" (LACOSTE-299834). AVHRR data were supplied by Météo-France. The DT-INSU is thanked for the treatment of the thermosalinograph data. We thank the crews and technicians of the *R/V Le Suroît* and the *R/V Téthys II* and all the LATEX collaborators for their assistance at sea.

REFERENCES

Nencioli, F., F. d'Ovidio, A. M. Doglioli, and A. A. Petrenko (2011), Surface coastal circulation patterns by in-situ detection of Lagrangian coherent structures, *Geophys. Res. Lett.*, *38*(17), L17,604, doi:10.1029/2011GL048815.

Nencioli, F., F. d'Ovidio, A. M. Doglioli, and A. A. Petrenko (2013), In situ estimates of submesoscale horizontal eddy diffusivity across an ocean front, *Journal of Geophysical Research: Oceans*, *118*(12), 7066–7080, doi:10.1002/2013JC009252.

Nencioli, F., A. A. Petrenko and A. M. Doglioli, Front-associated cross-shelf transport in the Gulf of Lion: a case study combining remote sensing, ship-based and Lagrangian observations, *Submitted to Journal of Geophysical Research: Oceans*.

Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK

Morphological changes in the Phu Yen province - the representative case in the Central Vietnam

KIM-CUONG NGUYEN, TIEN-GIANG NGUYEN, NGOC-ANH TRAN, THO-SAO NGUYEN, NGOC-VINH TRAN, DINH-DUC DANG

[1] *VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam*

Recently, in the Centre of Vietnam, the situation of morphological change causes a series of trouble for marine activities. The tendency is quite similar for the provinces. For some provinces with important ports or beaches, the situation is becoming more seriously and need to raise the solutions. In this paper, the measurements, remote-sensing data and numerical results are presented and analyzed for long-term and short-term changes in morphology in the Phu Yen beach. A dataset of remote sensing images was gathered and analyzed to show the generations of shoreline. A field survey with 8 stations was deployed for both river and coastal zone included two river mouths. A numerical model was applied to provide new insight into the physical processes involved in the near-shore circulation and sediment transport. The results show the significant short-term and long-term changes. It is really important to find the solutions for several river mouths in the provinces in the Centre of Vietnam.

Understanding the dynamics of a 1 km submesoscale coastal eddy using in situ and aerial observations

Ryan P. North[1], Burkard Baschek[1], Geoffrey B. Smith[2], Ingrid M. Angel-Benavides[1], Dave Miller[2], Rolf Riethmüller[1], Ruben Carrasco[1], Marius Cysewski[1], George O. Marmorino[2]

[1] *Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Germany*
[2] *Remote Sensing Division, Naval Research Laboratory, Washington, D.C., U.S.A*

A novel experiment combining high-resolution aerial and in situ measurements allowed, for the first time, tracking of the vertical and horizontal evolution of a ca. 1 km diameter submesoscale eddy. The Submesoscale Experiment (SubEx) took place along the southern California coast, and required the joint effort of several international research institutes. The experiment was designed to allow the rapid and concurrent use of multiple measurement platforms in order to account for the small spatial-scales and short time-scales of submesoscale eddies. Here we focus on the analysis of aerial SST and ocean color images and in situ temperature and current velocity profiles to quantify the rapid changes of a cyclonic spiral-armed eddy. Although the origin of the eddy is not captured, its proximity to the tip of Santa Catalina Island and the direction of the background currents suggest it is an island-wake eddy. Over a period of 5.5 hours, observed changes in the eddy's properties are contradictory: while the size of the surface temperature signature and the maximum rotational speed of the eddy remain fairly constant, temperature gradients along the edges increase and deepen, velocities outside the eddy core decrease, and the underwater dome of cold water drops and narrows. Implications for the dissipation of the eddy, local energy cascades, and transport within the eddy and the region are discussed.

Upstream control of the frontal jet regulating plankton production in the Alboran Sea (Western Mediterranean)

TEMEL OGUZ[1,2], BAPTISTE MOURRE[1], JOAQUÍN TINTORÉ[1]

[1] *SOCIB, Balearic Islands Coastal Observing and Forecasting System, Spain*

[2] *Middle East Technical University, Institute of Marine Sciences, Turkey*

Using a coupled physical-biological model, we investigate the impact of the 40km wide meandering jet on the biological production of the Alboran Sea (Western Mediterranean). Our results suggest that the jet constitutes a major source of biological enrichment even in the absence of wind forcing and tidal dynamics. The level of enrichment is shown to vary markedly during the year depending on the upstream characteristics of the jet as it exits from the Gibraltar Strait. When its intensity is sufficiently low and characterized by weak cross-frontal density gradients during winter-spring, the jet is weakly nonlinear and may not fulfill the necessary conditions for frontogenesis and remains weakly productive. In the case of stronger jet intensity accompanied by stronger cross-frontal density and velocity gradients in summer-autumn, the frontal jet becomes strongly nonlinear and ageostrophic due to large anticyclonic to cyclonic cross-frontal vorticity changes on the order of planetary vorticity. Under these conditions, relatively strong upward vertical velocities supply nutrients into the euphotic layer and support high level phytoplankton production on the anticyclonic side of the main jet axis due to the frontogenesis. A strong eddy pumping mechanism also provides a comparable level of plankton production within strongly nonlinear elongated cyclonic eddies along the outer periphery of the frontal jet. The plankton biomass is advected partially by the jet along its trajectory and dispersed within the basin by mesoscale eddies and meanders.

Submesoscale, depth-resolved primary production from glider observations across an intense density front

ANTONIO OLITA[1], ARTHUR CAPET[2], MARIONA CLARET[3], AMALA MAHADEVAN[4], SIMON RUIZ[5], JOAQUIN TINTORÉ[5], ANTONIO TOVAR SANCHEZ[5], ANANDA PASCUAL[5]

[1] *CNR, Italy*
[2] *OGS, Italy*
[3] *McGill, Canada*
[4] *WHOI, USA*
[5] *IMEDEA (CSIC-UIB), Spain*

Quasi-synoptic glider observations, performed during a process-oriented experiment (ALBOREX) in the Eastern Alboran sea, sampled an intense density front ($\Delta\rho$? about $1kgm^-3$ in $10km$) between Atlantic and Mediterranean waters. The observations have a horizontal resolution of $\sim 600m$ at surface, and capture the submesoscale variability of biological features. Fluorometrically-derived, and calibrated, measurements of chlorophyll-a across the front show a deep chlorophyll maximum (DCM) with values up to $5mgm^-3$. Patches of high-chlorophyll also observed are not related to the mixed layer depth (defined by a density threshold) but appear to be associated with the relative lows in buoyancy frequency within the DCM depth range (30-60 m). To estimate Gross Primary Production (GPP), an empirical function, derived from Argo PAR profiles, is used to model instantaneous PAR in the glider temporal and spatial frame. Standard bio-optical model (Morel, 1991) is applied to assess the instantaneous and integrated primary production rates. Integrated primary production maxima are detected in the veins of Atlantic water intercepted by the glider. Depth-resolved primary production estimates locate the highest production patches where upwelling is suggested by hydrographical data. The deeper Chl patches are unproductive and are probably shaped by the passive transport or subduction of productive waters. By exploring the estimated primary production rates in relation to oxygen, we find that the slope and shape of the AOU-GPP curves change as a function of the two water masses, suggesting the presence of different phytoplankton communities on the two sides of the front.

Lagrangian studies of particle source cones following the North Atlantic spring bloom.

MELISSA M. OMAND[1], JINBO WANG[2], ERIC A. D'ASARO[3], CRAIG M. LEE[3], MARY JANE PERRY[4], NATHAN BRIGGS[5], IVONA CETINIC[6], AMALA MAHADEVAN[7]

[1] *Graduate School of Oceanography, University of Rhode Island*
[2] *Scripps Institution of Oceanography, University of California San Diego*
[3] *Applied Ocean Physics Laboratory, University of Washington*
[4] *Darling Marine Center, University of Maine,*
[5] *Laboratoire d'Océanographie de Villefranche*
[6] *NASA/GSFC*
[7] *Woods Hole Oceanographic Institution*

Export of particulate organic carbon (POC) from the surface ocean to depth may occur through subduction by an eddying flow field. Lagrangian float and glider observations from the North Atlantic Bloom experiment (NAB08) are presented alongside analysis of Lagrangian particles released in a high-resolution process study model. Repeated model runs connect deep intrusions of POC with the horizontal source 'radius' and patchiness of the particle origins within the euphotic zone. Identical flow fields seeded with sinking particles allow comparison of the scales of the source cones above virtual sediment traps with those relevant to eddy subduction.

Coexistence of multiscale processes in the Brazil-Malvinas Confluence region

DORLETA ORUE-ECHEVARRIA[1], MIKHAIL EMELIANOV[1], JORDI ISERN-FONTANET[1], SERGIO RAMÍREZ[1], MARC GASSER[1], MIQUEL ROSELL-FIESCHI[1], VERÓNICA BENÍTEZ-BARRIOS[2], JOSEP L. PELEGRÍ[1]

[1] *Physical Oceanography,Institut de Ciències del Mar, CSIC, Barcelona, Spain*

[2] *Oceomic, Marine BioandTechnology, S.L., Fuerteventura, Spain*

The Brazil-Malvinas Confluence (BMC), the encountering site of waters of subtropical and subantarctic origin, is one of the most energetic regions in the world ocean. During March 2015, the R/V Hespérides carried out the TIC-MOC cruise, with 14 days of measurements in the BMC region. Field and remote-sensing data collected during the TIC-MOC cruise clearly illustrate the presence of mesoscale and submesoscale structures of different sort on top of the very energetic large-scale Brazil and Malvinas Currents. These two meridional currents, each of the order of 100 km wide, collide frontally before diverting east, leaving behind vortices of opposite sign near the collision region, but also much farther away, as well as multiple submesoscale structures. Here we characterize the spatial structure of the two colliding currents and of three (one cyclone and two anti-cyclones) vortices found in the near field (at distances less than 500 km from the collision point). We use the satellite images to identify several submesoscalar structures at the frontal system and in the margins of both the main currents and the mesoscalar structures. We also employ high resolution field data to study two different types of submesoscale structures observed in the frontal system. These are a very shallow (5-20 m), thin (5-50 km) and intense (velocities close to 2 m s-1) filament that flows east over the frontal system, carrying brackish waters from Rio de la Plata, and a number of relatively small thermohaline intrusions (thickness 10-100 m and width of the order of 10 km) that intrude several tens of km into both sides of the frontal system. An energy analysis of the frontal system shows that the flux of kinetic energy into the confluence region,associated with the two large scale currents,is of the order of 10 GW while the mesoscalar structures in the near field contain some 107-108 GJ of kinetic energy, giving a residence time of the order of 10-100 days. While some of these mesoscalar structures may flow away from the BMC region during these time intervals, others remain in the area for longer periods, hence requiring substantial energy transfer from the meso- to the submesoscale.

Deep ventilation of aerobic zone in the NE Black Sea due to vertical turbulent mixing

ALEXANDER OSTROVSKII[1], ANDREY ZATSEPIN[1]

[1] *P.P.Shirshov Institute of Oceanology, Russian Academy of Science*

We present new data indicating that deep ventilation events of the aerobic zone extending across the upper part of the permanent pycno-halocline may sporadically occur in the Rim Current area, even in relatively warm seasons when the seasonal thermocline is still notable. The strongest event of this type was observed in November 2014, off the continental shelf break near Gelendzhik Bay. The vertical profiles of the dissolved oxygen were measured to a high accuracy using a SBE 52-MP CTD equipped with a fast-response SBE 43F sensor that was mounted on the moored automatic mobile profiler Aqualog. The analysis of the profiling data from October 6 through December 16, 2014, between 35 m and 215 m, revealed an anomaly on November 6-7. The amount of dissolved oxygen exceeded the background levels in the oxycline at isopycnals 14.9-15.7 kg/m3 by more than 0.3 ml/l (or even by approximately 1 m/l for short periods). Noticeably at isopycnal 15.9 kg/m3 the peak absolute value of the dissolved oxygen attained an exceptionally high absolute value of about 0.3 m/l. This event led to the rise of the sea temperature by 0.2°C in the Cold Intermediate Layer at 120-160 m depths. The simultaneous observations of both the thermohaline stratification and the ocean currents allow us to suggest that the ventilation event was associated with a more intensive vertical turbulent exchange in the Rim Current area near the continental slope. In particular, the event could be linked to intensification of the current speed in the cyclonic meander above the continental slope and, consequently, to generation of the vertical turbulent exchange. The ventilation of the pycno-halocline when the overlaying upper ocean is stably stratified sharply differs from the convection reaching the Cold Intermediate Layer during extensive cooling offthe sea surface. The traces of such ventilation events were found in the Aqualog mooring data archive of 2012-2014.

Optimal Transient Growth of Ageostrophic Baroclinic Instabilities

PIERRE-YVES PASSAGGIA[1], BRIAN WHITE[1]

[1] *Department of Marine Sciences, University of North Carolina, Chapel Hill, NC, USA*

Submesoscale instabilities are analyzed using a transient growth approach to determine the optimal perturbation for a rotating Boussinesq fluid initially in thermal wind balance. We consider a base flow with uniform shear and stratification and consider the non-normal evolution over finite-time horizons of linear perturbations in an ageostrophic, non-hydrostatic regime. Stone (1966, 1971) showed that the stability of the base flow to normal modes depends on the Rossby and Richardson numbers, with instabilities that include geostrophic ($Ro \to 0$), ageostrophic (finite Ro), symmetric ($Ri < 1$, $Ro > 1$), and Kelvin-Helmholtz ($Ri < 1{=}4$). However, non-normal transient growth, initiated by localized optimal wave packets, can provide a faster mechanism for the growth of perturbations and may provide a link between large-scale balanced flows and dissipation scales via submesoscale instabilities. Here we consider two- (symmetric) and three-dimensional optimal perturbations, by means of direct-adjoint iterations of the linearized Boussinesq Navier Stokes équations to determine the form of the optimal perturbation, the optimal energy gain, and the characteristics of the most unstable perturbation.

The effects of curvature on hydrodynamics and sediment dynamics in a partially stratified estuary

JOHANNES PEIN[1], EMIL STANEV[1]
[1] *Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Germany*

Topographic features like meanders "disturb" the along-channel dynamics in a tidal channel or an estuary. Still curvature is common to most estuaries. It is well-known do drive the circulation in a plane normal to the main axis of flow, i.e. the secondary circulation. Although being per definition of secondary importance compared to the dominant dynamics, it can be shown that the secondary circulation feeds back on the along-channel dynamics. This modelling study explores the effects of channel curvature on along-channel flow, mixing and secondary circulation using idealized cases of a straight and a meandering channel. It is demonstrated that the along-channel distribution of tracers like salinity and sediment depends to a significant degree on the secondary flow.

The role of submesoscale processes in enhancing kinetic energy in the Caribbean Sea.

JUAN G. C. PÉREZ[1], 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*

In this study we use a regional model with different spatial resolutions (6 km, 3 km and 1 km), focusing the Guajira Upwelling and the Lesser Antilles in the Caribbean Sea. The upper ocean dynamics in this region ranges from large-scale currents to coastal upwelling filaments. The interaction of North Brazil Current rings with the Antilles may lead to the formation of submesoscale vorticity filaments leeward of the islands, transferring kinetic energy (KE) from large to small scales and allowing the advection of potential vorticity (PV). The Caribbean Upwelling System (CUS) in the coasts of Venezuela and Colombia interacts with the mesoscale flow allowing the formation of submesoscale filaments, small eddies and the vertical exchange of physical properties that may supply KE to larger scales. The ageostrophic velocities and large vertical velocities are evidenced by O(1) Rossby number, the shoaling of the KE spectra in large wavenumbers (k) and affect the eddy flux divergence of tracers which demonstrate the importance of processes such as surface frontogenesis in the areas of study. Finally, the KE budget exhibits the dominance of dissipative terms near the islands and an injection of KE over the Guajira Upwelling Region. This demonstrates that submesoscale processes in the Caribbean Sea could be potentially important in the large-scale dynamics in the region.

Air-sea interaction in the southwest of Africa: a study of mesoscale process using satellite data

X. PERROT[1], S. SPEICH[1], G. LAPEYRE[1]
[1] *LMD, ENS, France*

The exchanges of momentum and heat between ocean and atmosphere play a key role for the climate regulation. Consequently it is important to address properly the basis mechanism of those interactions. In the past years some studies showed that the oceanic mesoscale and submesoscale had an impact on the dynamics of the PBL (Planetary Boundary Layer) and on the localization and intensity of the precipitation [*Small et al.* 2008; *Minobe et al.* 2008; *Bryan et al.* 2010].

The types of mechanism occuring are not yet sorted. There are mainly two different hypotheses. The first one [*Wallace et al.* 1989] is based on the destabilization of the PBL above SST anomalies, the second one [*Lindzen and Nigam* 1987] is based on the pressure anomalies linked to the atmosphere temperature adjustment to the SST.

Recently we showed with numerical model that the intensity of the wind in the PBL could influence the mechanism which is acting. We propose to test that hypothesis by using data from satellites and argo floats. We concentrate our effort on the Cap basin because of its strong mesoscale activity. To perform an interesting study we are identifying and following some Agulhas Rings (using the work by Remy Laxenaire). Then, we could characterize, by using the satellite data from METOP-B, SARAL and SMOS, the motion and heat flux on the PBL over those rings depending on the wind regime.

Acknowledgments: X. Perrot's research is supported by a CNES Grant.

REFERENCES

Small, R.J., deSzoeke, S.P., Xie, S.P., O'Neill, L., Seo, H., Song, Q., Cornillon, P., Spall, M. and Minobe S., 2008. Air-sea interaction over ocean fronts ans eddies. *Dynam. Atmos. Océans*, 45, 274-319.

Minobe, S., Kuwano-Yoshida, S., Xie, S.P. and Small R.J. 2008. Influence of the Gulf Stream on the troposphere., *Nature*, 452, 206-210.

Bryan, F.O., Tomas, R., Dennis, J.M., Chelton, D.B., Loeb, N.G., and McClean J.L. 2010. Frontal scale interaction in high-resolution coupled climate models. *J. Climate*, 23, 6277-6291.

Wallace, J.M., Mitchell, T.P., and Deser, C. 1989. The influence of sea-surface temperature on surface wind in the eastern equatorial Pacific: Seasonal and Interannual variability. *J. Climate*, 2, 1492-1499.

Lindzen, R.S., and Nigam, S. 1987. On the role of sea-surface temperature-gradients in forcing low-level winds and convergence in the tropics. *J. Atmos. Sci.*, 44, 2418-2436.

Meso and Submeso-scale Vertical Velocity Estimations in Different Dynamical Regimes in Preparation for the High Resolution Observations of the SWOT Altimetry Mission

A. PIETRI[1], X. CAPET[1], F. D'OVIDIO[1], J. LE SOMMER[2], J.M. MOLINES[2], A.M. DOGLIOLI[3], H. GIORDANI[4]

[1] *LOCEAN-IPSL, CNRS/IRD/UPMC, Paris, France*

[2] *LGGE, Univ. Grenoble-Alpes / CNRS, Grenoble, France*

[3] *Mediterranean Institute of Oceanography, Marseille, France*

[4] *Météo-France, CNRM-GAME/GMGEC/NEMO, Toulouse, France*

Upper ocean vertical transport associated with meso and submesoscale processes plays an essential role in ocean dynamics and physical-biological coupling through the upwelling of nutrient in the photic zone and the subduction of water masses modified by surface fluxes. However, it is very difficult to measures vertical velocities (w) because of their small intensity compared to horizontal motions and their important variability in space and time. Estimations are thus usually inferred using a generalized approach based on frontogenesis theories. The choice of the method used to calculate w generally depends on the data available and on the dominant processes in the region of study. A widely used approach is to solve the Q-vector version of the omega equation.

We will present a comparison of the results obtained by solving different expressions of the omega equation from the simple quasi geostrophic formulation to the generalized one. We aim to provide a statistically robust evaluation of the scales at which the vertical velocity can be resolved with confidence in a variety of flow and data availability conditions. The spatial and temporal resolution of the data as well as its synoptic character will constrain the formulation of the equation that can be used and the uncertainty on estimated w. To simulate the possible data sets a high resolution simulation (dx=1-1.5 km) of the North Atlantic was used. We compare the different reconstruction of w to the modelled vertical velocity. The simulation encompasses regions with different regimes of atmospheric forcing, mesoscale turbulence intensity, seasonality and thermohaline structure, allowing us to explore and contrast several different dynamical contexts.

In a few years the SWOT mission will provide bi-dimensional images of sea level elevation at a significantly higher resolution than available today. The wide-swath altimeter should capture wavelength down to 10 to 20 km, which in combination with high-resolution satellite imagery and in situ data could provide very valuable information on the vertical circulation. This work helps assess the possible contribution of the SWOT data to the understanding of the submesoscale circulation and the associated vertical fluxes in the upper ocean.

The Structure of Southwest Monsoon Current past Southern Sri Lanka

A. Pirro[1], H.W. Wijesekera[2], T.G. Jensen[2], L. R. Centurioni[3], W. J .Teague[2], H.J.S. Fernando[1,4]

[1]*Department of Civil & Environmental Engineering and Earth Sciences, University of Notre Dame, USA*

[2]*Naval Research Laboratory, Stennis Space Center, USA*

[3]*Scripps Institution of Oceanography, University of California, USA*

[4]*Department of Aerospace and Mechanical Engineering, University of Notre Dame, USA*

Detailed observations of oceanic circulation structure of the Bay of Bengal (BoB) are rare, yet BoB is a critical region where air-sea interactions play a critical role in regional monsoon dynamics. ASIRI-EBOB initiative was conceived realizing this need, under which several cruises and mooring programs were conducted. The ADCP data collected onboard of R/V Roger Revelle in August 2015 during successfully recovery of an array of 6 deep moorings are the basis of this presentation. They indicate the presence of north - flow in the upper layer (z < ~ 150m) over the region 80°E – 84.6°E and 5.62°N - 6.25°N, which is a signature of the Southwest Monsoon Current (SMC). Observations suggest that SMC flows north-eastward at least up to 8°N and 85.5°E with a velocity of about 0.7 m/s. Data collected along the zonal transect 8°N, 85.5°E – 88.5°E show eastward flow is mostly in the western half of the transect. Thereafter, the flow gradually turns southwestward at the eastern end of the transect passing through the south of Sri Lanka while slightly increasing its magnitude. This indicates the presence of large anticyclonic mesoscale structure in the study area. We hypothesize that this surface manifestation is generated by SMC interacting with the southern boundary of Sri Lanka as well as East Indian Coastal Current. Drifter observations and sea surface anomalies of the study area as well as numerical simulations support

the hypothesis. The CTD structure at a location within eddy will be described based on 24 hour CTD experiment conducted at a fixed point ($\varphi = 6.42°N$, $\lambda = 85.21°E$) up to 250 meters on August 11-12 of 2015 during the same cruise. The analysis includes CTD, shear instabilities and internal waves in the upper thermocline.

Intermittency of near-bottom turbulence in a tidal flow: Trace moments of the TKE dissipation rate

JESUS PLANELLA-MORATO[1], ELENA ROGET[1], XAVIER SANCHEZ-MARTIN[1], IOSSIF LOZOVATSKY[2]

[1] *Physics Department, University of Girona, Catalonia, Spain*

[2] *Department of Civil $\&Environmental Engineering$& Earth Sciences, University of Notre Dame, USA*

The ADV measurements in the bottom boundary layer of the East China Sea were used to study turbulence intermittency in a reversing tidal flow. To the best of our knowledge, it is the first time that the multifractal analysis of intermittency is applied by computing the trace moments of the TKE dissipation rate ε_r, where r is a variable length of the averaging segments. The scaling exponents $K(p)$ of the p-order moments of ε_r were used to estimate parameters C_1 and α of the log-Levy multifractal model, which in turn allows to evaluate the intermittency exponent $\mu = K(2)$ of the log-normal intermittency model. For high microscale Reynolds numbers, $R_\lambda >\sim 300$, $C_1 \sim 0.25$ and $\mu \sim 0.4$. These estimates, however, are higher than those reported for fully-developed turbulence, $C_1 = 0.15$ and $\mu = 0.25$. The discrepancy could be associated with insufficient spatial resolution of the measurements at high R_λ.

It was also found that for low Reynolds numbers, $R_\lambda <\sim 100$, C_1 and μ tend to increase with decreasing R_λ, up to ~ 0.35 and ~ 0.55, respectively. The results are consistent with those obtained in our previous study with the same dataset by using the structure function method [*Lozovatsky et al.*, 2010] and with laboratory experiments [*Hao et al.*, 2008].

REFERENCES Lozovatsky, I. , Roget, E., Planella, J., Fernando, H. J. S., and Z. Liu 2010. Intermittency of near-bottom turbulence in tidal flow on a shallow shelf.. J. Geophys. Res., 115, C50006, doi: 10.1029/2009JC005325.

Hao, Z., Zhou, T., Zhou, Z., and Mi, J., 2008. Reynolds number dependence of the inertial range scaling of energy dissipation rate and enstrophy in a cylinder wake, Exp. Fluids, 44, 279289, doi:10.1007/s00348-007-0400-5.

Seasonal variability of mixed layer depth over Gulf of Aden

ABDULLA C POYIL[1], ALAA AL-BARAKATI[1], MUHAMMED ALSAAFANI[1], THURKY ALRADDADI[1]

[1] *Department of Physical oceanography, King Abdulaziz University, Saudi Arabia.*

Interminable energy exchange between Atmosphere and underlying ocean, makes the upper layer of ocean to quasi-uniform state with nearly uniform temperature, salinity and density. Strength and behavior of interaction between the two spheres can be read from this layer, often called as mixed layer. Depth of mixed layer, usually represented by MLD (Mixed layer Depth) is crucial in understanding the physics of the heat distribution, acoustic propagation, biological changes, etc. Threshold difference method is the most common approach, used for MLD estimation on global basis. Other than threshold difference method, gradient and curvature approach are the two widely used techniques. We analyzed ability of threshold difference, gradient and curvature methods to identify MLD over the Gulf of Aden region for both temperature and density profiles. Our close evaluation of profiles reveals the limitation of each approaches in both space and time, with under or over estimation. Threshold and gradient method fails for more than 70% of profiles in winter, especially in western part of the gulf. Curvature approach is better to threshold and gradient approaches, still incapable to detect real MLD for more than 50% of profiles. Understanding the failure of these conventional methods over the Gulf of Aden, we came up with a new approach to estimate MLD, using gradient, curvature and standard deviation of the profile. New approach detects MLD in better way for more than 95% of the profiles. MLD estimated with new approach at gulf region shows significant seasonal variability in mixed layer, with deeper values during winter. Eddies of the region plays substantial role in the mixed layer pattern, especially during summer.

Time variability on hydrology and biogeochemistry induced by mesoscale eddies in the Algerian Basin: a one year high resolution and multiplatform experiment.

PUILLAT[1], TAUPIER-LETAGE[2], FUDA[3]
[1] *Ifremer, Centre de Brest, France*
[2] *MIO-OPLC, Antenne de Toulon, France*
[3] *DT-Insu, Antenne Ifremer Toulon, France*

In the framework of the ELISA project (1997-1998, MAST-3/MTP/MATER program) 1-year high frequency time series were acquired at fixed points in the Algerian Basin, an open sea area of the Mediterranean sea (3000m). This multidisciplinary and multiplatform experiment was dedicated to study the algerian eddies and their influence on general circulation and on biological phenomena. During 3 main cruises, 2 specific Anticyclonic Eddies (AEs) tracked by satellites images during 4 years were mainly studied by mean of vertical sections, performed inside AEs and in the surrounding smaller structures such as sub-mesoscale filaments and small-scale shear eddies. These sections helped describing the hydrological and biogeocheminal structures of eddies according to the seasons and the surrounding dynamics, knowing their historical circulation in and/or out of the Algerian Current. With benefit of this first stage of the study, when an AE flowed throughout a 9-mooring network (lines 50 km-spaced), including 50 currentmeters down to the bottom, it is possible to comprehend its signature at fine spacio-temporal scale. The presented analysis will focus on the temporal signal induced by these eddies recorded on 4 autonomous CTD/Fluorometers, located in the central mooring of the network, in the upper layer. The temporal analysis will apply recent analysis methods like the Empirical Mode Decomposition that works with gappy records, and help filtering the data as well. This study will show how much the seasonal signal and the (sub)mesoscale-induced time variability can be comparable in this area. It will also explain how eddies history can play a role in the observed signature at a given time.

Reconstructability of 3-Dimensional Upper Ocean Circulation from SWOT Sea Surface Height Measurements

Bo Qiu[1], Shuiming Chen[1], Patrice Klein[2], Clement Ubelmann[3], Lee-Lueng Fu[3], Hideharu Sasaki[4]

[1] *Dept of Oceanography, University of Hawaii, USA*
[2] *Laboratoire de Physique des Oceans, Ifremer/CNRS/UBO/IRD, France*
[3] *Jet Propulsion Laboratory, California Institute of Technology, USA*
[4] *Application Laboratory, JAMSTEC, Japan*

Utilizing the framework of effective surface quasi-geostrophic (eSQG) theory, we explored the potential of reconstructing the 3D upper ocean circulation structures, including the balanced vertical velocity (w) field, from high-resolution sea surface height (SSH) data of the planned SWOT satellite mission. Specifically, we utilized the 1/30$\circ$, submesoscale-resolving, OFES model output and subjected it through the SWOT simulator that generates the along-swath SSH data with expected measurement errors. Focusing on the Kuroshio Extension region in the North Pacific where regional Rossby numbers range from 0.22 to 0.32, we found that the eSQG dynamics constitutes an effective framework for reconstructing the 3D upper ocean circulation field. Using the modeled SSH data as input, the eSQG-reconstructed relative vorticity (ζ) and w fields are found to reach a correlation of 0.7–0.9 and 0.6–0.7, respectively, in the 1,000m upper ocean when compared to the original model output. Degradation due to the SWOT sampling and measurement errors in the input SSH data for the ζ and w reconstructions is found to be moderate, 5–25\% for the 3D ζ field and 15-35\% for the 3D w field. There exists a tendency for this degradation ratio to decrease in regions where the regional eddy variability (or Rossby number) increases.

Extensive under-ice turbulence microstructure measurements in the central Arctic Ocean in 2015

Benjamin Rabe[1], Markus Janout[1], Rainer Graupner[1], Jens Hoelemann[1], Hendrik Hampe[1], Mario Hoppmann[1], Myriel Horn[1], Bennet Juhls[2], Meri Korhonen[3], Anna Nikolopoulos[4], Sergey Pisarev[5], Achim Randelhoff[6,7], John-Philippe Savy[8], Nicolas Villacieros[9]

[1] *Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeres forschung, Bremerhaven, Germany*

[2] *GEOMAR Helmholtz-Zentrum für Ozeanforschung, Kiel, Germany*

[3] *Finnish Meteorological Institute, Helsinki, Finland*

[4] *AquaBiota Water Research, Stockholm, Sweden*

[5] *Shirshov Institute of Oceanology, Moscow, Russia*

[6] *Norwegian Polar Institute, Tromso, Norway*

[7] *UiT The Arctic University of Norway, Tromso, Norway*

[8] *LEGOS/CNRS, Toulouse, France*

[9] *LOCEAN, Universite Pierre et Marie Curie, Paris, France*

The Arctic Ocean is a strongly stratified low-energy environment, where tides are weak and the upper ocean is protected by an ice cover during much of the year. Interior mixing processes are dominated by double diffusion. The upper Arctic Ocean features a cold surface mixed layer, which, separated by a sharp halocline, protects the sea ice from the warmer underlying Atlantic- and Pacific-derived water masses. These water masses carry nutrients that are important for the Arctic ecosystem. Hence vertical fluxes of heat, salt, and nutrients are crucial components in understanding the Arctic ecosystem. Yet, direct flux measurements are difficult to obtain and hence sparse.

In 2015, two multidisciplinary R/V Polarstern expeditions to the Arctic Ocean resulted in a series of under-ice turbulence microstructure measurements. These cover different locations across the Eurasian and Makarov Basins, during the melt season in spring and early summer as well as during freeze-up in late summer. Sampling was carried out from ice floes with repeated profiles resulting in 4-24 hour-long time series.

2015 featured anomalously warm atmospheric conditions during summer followed by unusually low temperatures in September. Our measurements show elevated dissipation rates at the base of the mixed layer throughout all stations, with significantly higher levels above the Eurasian continental slope when compared with the Arctic Basin. Additional peaks were found between the mixed layer and the halocline, in particular at stations where Pacific Summer water was present. Vertical eddy diffusivity was lowest below the base of the mixed layer and in the upper halocline where Pacific Summer water was present, gradually increasing toward the lower halocline.

This contribution provides first flux estimates and presents first conclusions regarding the impact of atmospheric and sea ice conditions on vertical mixing in 2015.

The effect of high frequency atmospheric variability on Lagrangian transport in the southern Benguela

NATALIE RAGOASHA[1,2,3], STEVEN HERBETTE[2], GILDAS CAMBON[1], CLAUDE ROY[1], CHRIS REASON[3], CHRISTOPHE LETT[4]

[1] *IRD/LOPS, Brest, France*
[2] *IRS/UBO,Brest, France*
[3] *Oceanography Department, UCT, Cape Town, South Africa*
[4] *IRD/UMMISCO, Sète, France*

This study analyses the physical mechanisms that impact on Lagrangian transport in the southern Benguela upwelling system, an environment in which currents are key components of many important ecological processes, including the dispersal of marine larvae. Our study wishes to disentangle the combined roles of mesoscale turbulence, highly present in the region, and of short-period (less than 10 days) wind variability.

A validated interannual simulation of the region, using ROMS, over the period 1990-2010, provides the mean dispersal patterns. Sensitivity of these patterns to the atmospheric variability and to the synoptic oceanic circulation is considered by carrying a series of simulations with different initial conditions and low-passed time-filtered atmospheric forcing. Results highlight the contribution of high frequency atmospheric forcing on the variability of larval transport from the south coast to the west coast of South Africa.

Submesoscale stirring in shallow, stratified layers in the Bay of Bengal: Observations during the winter Monsoon.

Sanjiv Ramachandran[1], Amit Tandon[1], Jennifer Mackinnon[2], Amy Waterhouse[2], Andrew Lucas[2], Robert Pinkel[2], Jonathan Nash[3], Emily Shroyer[3], Amala Mahadevan[4], Robert Weller[4], Tom Farrar[4]

[1] *Department of Mechanical Engineering, University of Massachusetts, Dartmouth, USA*
[2] *Scripps Institute of Oceanography, San Diego, USA*
[3] *College of Earth, Ocean and Atmospheric Science, Oregon State University, Corvallis, USA*
[4] *Woods Hole Oceanographic Institution, Woods Hole, USA*

We explore submesoscale instabilities in the Bay of Bengal during the winter monsoon. Earlier observational and numerical studies have established the importance of submesoscale dynamics at fronts within O(100m) mixed layers during winter-time conditions. Here, we assess the potential for these instabilities at fronts in shallow stratified boundary layers with strong horizontal and vertical density gradients. Such conditions are typical of the Bay during the winter monsoon, when the mixed layers are O(5–30m) and the lateral buoyancy gradients can be as large as O(10^{-6}s^{-2}) over scales O(1km). We use observations from three high-resolution frontal process studies, conducted during two cruises in November and December 2013. The data spans a wide array of in-situ measurements, resolving lateral scales from O(100m) to O(10km), allowing us to seek signatures of submesoscale instabilities in the bay. We center our analysis on the central-bay process study which was forced by downfront winds, had the strongest gradients and was marked by strong frontogenesis. At this site, our analysis shows the presence of several dynamic signatures indicative of submesoscale instabilities, such as, O(f) relative vorticity with positive skewness (f is the Coriolis parameter), negative potential vorticity and subduction of near-surface water masses. We find the flow conditions during this survey satisfy the necessary conditions for forced symmetric instability derived in earlier studies, opening the possibility for energy pathways previously unknown in the bay. We conclude by contrasting these results with the other two process studies, where similar markers of submesoscale activity are absent. The evidence presented here supports a strong dynamical role for lateral processes at submesoscales, even at locations far from the coast.

Observing submesoscale currents from high resolution roughness images

NICOLAS RASCLE[1], BERTRAND CHAPRON[1], FREDERIC NOUGUIER[2], AURELIEN PONTE[1], ALEXIS MOUCHE[1], JEROEN MOLEMAKER[1]

[1] *Laboratoire d'Oceanographie Physique et Spatiale, Institut Francais de Recherche pour l'Exploitation de la Mer, Plouzane, France*

[2] *Universite de Toulon, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), La Garde, France*

At times, high resolution sea surface roughness variations can provide stunning details of submesoscale upper ocean dynamics. As interpreted, transformations of short scale wind waves by horizontal current gradients are responsible for those spectacular observations. Here we present two major advances towards the quantitative interpretation of those observations.

First, we show that surface roughness variations mainly trace two particular characteristics of the current gradient tensor, the divergence and the strain in the wind direction. Local vorticity and shear in the wind direction should not affect short scale roughness distribution and would not be detectable.

Second, we discuss the effect of the viewing direction using sets of quasi-simultaneous sun glitter images, taken from different satellites to provide different viewing configurations. We show that upwind and crosswind viewing observations can be markedly different. As further confirmed with idealized numerical simulations, this anisotropy well traces surface current strain area, while more isotropic contrasts likely trace areas dominated by surface divergence conditions.

These findings suggest the potential to directly observe surface currents at submesoscale by using high resolution roughness observations at multiple azimuth viewing angles.

Seasonal dynamics of phytoplankton pigments and associated community structure over the Eastern Arabian Sea: HPLC-CHEMTAX approach.

RASIQ.K.T[1,2], KURIAN.S[1], NAIK.H[1], GAUNS.M[1], NAQVI.S.W.A[1]

[1] *Chemical Oceanography Department, CSIR-National Institute of Oceanography, Goa, India.403004.*

[2] *Marine Chemistry Department, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia, 21589.*

Marine phytoplankton plays an important role in the CO2 sequestration and forms the basis of the food web and biological pump in the oceans. HPLC derived phytoplankton pigments that provide class level information is being used as biomarkers of specific phytoplankton functional groups for the last years. Here we report seasonal and spatial variations of phytoplankton pigments (sampled up to 200m depth) and their associated class abundance along the west coast of India (seven transects includes 41 stations; 11°-18°N and 72°-75°E) during 2011-2012. The HPLC-CHEMTAX analyses lead to the qualitative and quantitative estimation of 13 pigments corresponding to 8 major groups of phytoplankton. Strong spatial and seasonal variability was observed in pigment's distribution and phytoplankton community structure. Fucoxanthin followed by zeaxanthin was the major pigments in the southwest monsoon (SWM) and spring intermonsoon seasons (SIM), whereas zeaxanthin was dominant during northeast monsoon (NEM). CHEMTAX analysis showed the dominance of diatoms during the SWM season along the coast, however, the diversity of other classes increased towards the offshore. This was more pronounced at the southern transects. Seasonal changes noticed in phytoplankton community possibly be driven by the differences in nutrient supply, the levels of dissolved oxygen and/or due to grazing pressure is yet to be ascertain. Nonetheless, our study clearly demonstrates seasonal changes in phytoplankton composition along the west coast of India with reference to the environmental conditions.

Key words: Phytoplankton pigments, HPLC, CHEMTAX, Community structure, Eastern Arabian Sea.

Seasonal dynamics of phytoplankton pigments and associated community structure over the Eastern Arabian Sea: HPLC-CHEMTAX approach.

RASIQ.K.T[1,2], KURIAN.S[1], NAIK.H[1], GAUNS.M[1], NAQVI.S.W.A[1]

[1] *Chemical Oceanography Department, CSIR-National Institute of Oceanography, Goa, India.403004.*

[2] *Marine Chemistry Department, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia, 21589.*

Marine phytoplankton plays an important role in the CO2 sequestration and forms the basis of the food web and biological pump in the oceans. HPLC derived phytoplankton pigments that provide class level information is recently being used as biomarkers of specific phytoplankton functional groups. Here we report seasonal and spatial variations of phytoplankton pigments and their associated class abundance along the west coast of India (11-18°N) during 2011-2012. The HPLC-CHEMTAX analyses lead to the qualitative and quantitative estimation of 13 pigments corresponding to 8 major groups of phytoplankton. Strong spatial and seasonal variability was observed in pigment's distribution and phytoplankton community structure. Fucoxanthin followed by zeaxanthin was the major pigments in the southwest monsoon (SWM) and spring intermonsoon seasons (SIM), whereas zeaxanthin was dominant during northeast monsoon (NEM). CHEMTAX analysis showed the dominance of diatoms during the SWM season along the coast, however, the diversity of other classes increased towards the offshore. This was more pronounced at the southern transects. Seasonal changes noticed in phytoplankton community possibly be driven by the differences in nutrient supply, the levels of dissolved oxygen and/or due to grazing pressure is yet to be ascertain. Nonetheless, our study clearly demonstrates seasonal changes in phytoplankton composition along the west coast of India with reference to the environmental conditions.

Baroclinic Dynamics of the Adriatic-Ionian system: a process study

MARCO REALE[1,2], RICCARDO FARNETI[2], ALESSANDRO CRISE[1], RENZO MOSETTI[1]
[1] *OGS,Trieste,Italy*
[2] *ICTP,Trieste,Italy*

The decadal reversal of the Ionian upper layer circulation has recently raised a sparkle discussion in the Mediterranean scientific community. It has been suggested that it can be driven either by variation in wind stress curl over the basin or by baroclinic mechanisms acting within or outside the Adriatic-Ionian System.

In this framework, a coarse resolution primitive equation numerical model based on the MIT general circulation model (MITgcm) , has been used to assess the relative importance of remote forcings (wind stress and thermohaline fluxes, thermohaline open boundary conditions) on the vorticity and energy budget of the Ionian Sea.

Our experiments show that the wind stress role appears to be marginal in the vorticity/energy budget of the Ionian Sea: it is able to reinforce/weaken the circulation but not to induce changes in sign in the circulation. Its role become dominant only in absence of inflows through the Sicily channel/Kythira Strait/Cretan Passage. On the other hand the reversal of the upper layer circulation of the Ionian Sea take place only in presence an active boundary in the Ionian Sea (on the Aegean Sea side) and appears to be correlated with substantial exchange of APE (Availaible Potential Energy) between these two basins (as happened at the end of the East Mediterranean Transient). Thus AIS dynamics can be explained only if the role of the Aegean Sea is explicitly considered.

Multi-Scale analysis of Ocean Colour and Sea Surface Temperature images of MODIS-Aqua: statistical characterization using turbulence tools

P.R. RENOSH[1], FRANCOIS G. SCHMITT[2], HUBERT LOISEL[3]

[1] *University of Lille, Laboratory of Oceanology and Geosciences, 28 Avenue Foch, 62930 Wimereux, France*

[2] *CNRS, Laboratory of Oceanology and Geosciences, 28 Avenue Foch, 62930 Wimereux, France*

[3] *ULCO, Laboratory of Oceanology and Geosciences, 32 Avenue Foch, 62930 Wimereux, France*

Satellite remote sensing is a powerful tool for understanding many of oceanic processes synoptically. The scaling and multi-scaling properties of these satellite products have hardly been studied in the framework of the turbulence theory. The main objective of the present study is to understand the multi-scaling and multifractal properties of the satellite images of ocean colour and sea surface temperature for various oceanic regions using tools borrowed from the turbulence theory. For this purpose, we have selected satellite ocean colour products of Remote sensing reflectance (R_{rs}), Chlorophyll-a (Chl-a) and thermal infra-red Sea Surface Temperature (SST). For understanding the spatial scaling associated with turbulence, it is important to have a daily imagery of these products. As far as ocean colour remote sensing is considered, it is very difficult to have a cloud free images for the understanding of scaling behavior.

For that purpose, we have identified seven contrasted regions of the global ocean, characterized by high spatial heterogeneity in Chl-a and SST. Power spectral analysis, a widely used tool in the marine environment and marine ecology to assess the scaling properties of these scalars, especially in connection with turbulence have been used for the present study. Here we use 1D and 2D Fourier power spectra to understand the spatial scaling of Chl-a and SST. The 2D spectral slope β is derived from the 2D power spectrum using radial sum of the power spectrum. The multi-scaling properties of these images are also studied using the Structure Function (SF) method. Using a lognormal fit, we have derived the multifractal parameters (Hurst exponent H and intermittency parameter μ) of these images using SF method. The β derived through power spectra and SF method show good agreement except SST images. The derived multifractal parameters show variability in their values depending upon the region. The scatter plot of μ versus H shows some clustering of these parameters. The SST is showing low intermittency, R_{rs} high, and Chl-a shows intermittency in between SST and R_{rs} for all the regions.

Cumulant scaling of these images is also performed for deriving H using lognormal intermittency model. The H values derived through the SF method and the cumulant scaling method also show good agreement with Chl-a data.

A Shallow Waters Oil-Fate Model

JUAN M. RESTREPO[1], SAEED MOGHIMI[2], SHANKAR VENKATARAMANI[3]
[1] *Department of Mathematics, Oregon State University, USA*
[2] *Civil and Environmental Engineering, Portland State University, USA*
[3] *Mathematics Department, University of Arizona, USA*

I will introduce a model for the dynamics of oil in suspension, appropriate for shallow waters, including the nearshore environment. This model is capable of oil mass conservation and does so by evolving the oil on the sea surface as well as the oil in the subsurface. Oil spills from point sources will typically leave the ”large-eddy-simulation” scales, reaching the submesoscale regime in a matter of a day or 2. The longer term forecast of an oil spill thus depends crucially on understanding how the complexities of the submesoscale ocean dynamics impact the transport of oil.

The shallower portion of the continental shelf poses compounding unique modeling challenges, associated with bathymetry and complex coastal boundaries. However, the two most challenging modeling issues are (1) the inherent multi-scale nature of the oil dynamics, from the microscopic to the macroscopic; (2) that advection, diffusion, dispersion, and petro-chemical transformations require fidelity in capturing the effects of oceanic waves, current, wind, and turbulence.

The description of the model as well as some of the multiscale strategies my team has developed to capture oil transport will be followed by a description on how submesoscale phenomena affect transport and where opportunities arise in contributing to our effort to create a significantly better forecast tool for ocean oil spill management.

Exploring ocean dynamics in the Western Mediterranean Sea, to reconstruct 2D sea surface height from future SWOT data

MARINE ROGÉ[1], ROSEMARY MORROW[2], CLÉMENT UBELMANN[3], GÉRALD DIBARBOURE[3]

[1] *LEGOS/CLS, France*

[2] *LEGOS/CNES, France*

[3] *CLS, France*

The main oceanographic objective of the future SWOT mission is to characterize the ocean mesoscale and submesoscale circulation by observing the fine range of ocean dynamics (from 15-300 km). However it will not capture the time evolution of short mesoscale signals. Despite the very high spatial resolution of the future satellite, the temporal resolution is compromise (exact repeat cycle of 21 days, with near repeats around 5-10 days, depending on the latitude). High resolution SWOT sea surface height snapshots alone will not allow us to follow the dynamics of ocean variability at these scales, such as the formation and evolution of small eddies.

Here, we investigate a mean to reconstruct the missing SSH signal in time between two satellite revisits. We use a shallow water quasi-geostrophic model developped by Ubelmann et al (2015). Based on potential vorticity conservation, it advects dynamically the SSH field, assuming that the quasi-geostrophic dynamics are principally captured by the first baroclinic mode. This model has been tested in energetic open ocean regions such as the Gulf Stream and the Californian Current, and has given improved results. Here we test this model in the Western Mediterranean Sea. In this regional basin the technique provides a small improvement over linear interpolation in the boundary current systems. The simple dynamical model is missing some physical mechanisms, needed to correctly represent the mesoscale circulation in this region, where the first radius of deformation of Rossby is small (5-15km), where the dynamics have a strong topographic control and strong spatial and seasonal variability. We propose to identify which vertical modes are dominant in this zone, and to investigate a two-layer advection model taking into account the barotropic mode.

Frontal variability and submesoscale structures in the White Sea according to spaceborne and shipboard data

DMITRII ROMANENKOV[1], ALEXEI ZIMIN[1,2], ANATOLII RODIONOV[1], OKSANA ATADZHANOVA[1,2], IGOR KOZLOV[1,3]

[1] *St. Petersburg Branch of P. P. Shirshov Institute of Oceanology RAS, St. Petersburg, Russian Federation*

[2] *Russian State Hydrometeorological University, St. Petersburg, Russian Federation*

[3] *Klaipėda University, Klaipėda, Lithuania*

We present the study of intraseasonal, synoptic and mesoscale dynamics of major hydrological fronts in the White Sea based on the high-resolution spaceborne and shipboard observations performed during 2009-2014. The correlation between frontal dynamics and peculiarities of distribution of the submesoscale structures and short-lived phenomena (such as small eddies and short-period internal waves) is found. The White Sea, the smallest of the Arctic seas, is a unique marine basin in a sense. Firstly, there exist regions with sharply different hydrological conditions due to the nearby location of the fronts of different origins under the influence of river inflow and tidal mixing. Secondly, the semi-diurnal tide is the most important factor controlling the dynamics and variability of the thermohaline structure of the sea. The complex morphometry of bottom and coastline of the White Sea and the strong tidal currents (up to 2 m/s in the Gorlo Strait) provide the conditions for generating the internal wave in stratified areas of the Sea. However, reliable observations in situ of internal tidal waves in the White Sea are not enough and also the model estimates of characteristics of such waves are inconsistent. In order to study the spatiotemporal variability of surface manifestations of fronts, the MODIS images with a spatial resolution of about 1 km acquired from Terra and Aqua satellites were analyzed. Sea surface temperature and its gradient data during the summer 2010 revealed the features of considerable dynamics of river plume and tidal mixing fronts on synoptic timescales, as well as areas of mesoscale frontal activity. Direct measurements in the frontal areas in 2009, 2012, 2014 showed the relative importance of vertical and horizontal variations of the thermohaline structure for forming submesoscale phenomena under the influence of tide and wind. The observed variability ranged from several hours to days. Moreover frontal zones of different origins can transform each other and spaceborne data suggest that this interaction is observed throughout the summer. As a result of processing and analyzing of ENVISAT ASAR images of high spatial resolution, a large number of surface manifestations of submesoscale structures were found in the White Sea during warm season 2010. Among them there were 117 eddies of 1 to 12 km in diameter, as well as 190 packages of short-period internal waves, with the package width of 0.1 to12 km and leading wave‘s crest length of 2 to 89 km. The areas where these structures were observed cover a large space of the Sea, but more than half of them were detected in/near the frontal zones. Hydrological field inhomogeneity generated by such eddies and waves contributes significantly to the dynamics and mixing. Submesoscale eddies occur more in the first half of summer when the fronts are more dynamic and seasonal warming of

the upper layer does not reach its peak yet. Short-period internal waves are observed more in the second half of summer when the horizontal and vertical temperature gradients in well formed fronts reach the highest value. The factors that determine the features of spatial and seasonal distribution of small eddies and short-period internal waves in the areas of frontal activity are discussed. The reported study was funded by RFBR according to the research projects No. 15-05-04639_a.

A 3D view of the Brazil-Malvinas frontal system

MIQUEL ROSELL-FIESCHI[1], JORDI ISERN-FONTANET1[1], MIKHAIL EMELIANOV[1], MARTÍN SARACENO[2], DANIEL VALLA[3], JOAQUIN SALVADOR[1], FERNANDO PÉREZ[1], JOSEP L. PELEGRÍ[1]

[1] *Institut de Ciències del Mar, ICM-CSIC, Barcelona*

[2] *Consejo Nacional de Investigaciones Científica y Técnicas, Universidad de Buenos Aires*

[3] *Departamento Oceanografía, Servicio de Hidrografía Naval y Consejo Nacional de Investigaciones Científicas y Técnicas, SHN/CONICET*

In March 2015, the R/V Hespérides carried out the TIC-MOC cruise, a 14-day oceanographic expedition in the Brazil-Malvinas Confluence (BMC) region. One principal objective of this cruise was to characterize the fine structure of the frontal system (or front) between the subtropical and subantarctic waters. The surface position of the front (sea-surface front) was determined in near-real time using sea surface temperature (SST), color and altimetry data, as well as daily outputs from the operational Mercator global-ocean analysis and forecast system at 1/12 resolution. A total of 66 hydrographic stations were carried out and nine drifters were deployed. Additionally, seven Argo profilers (vertical cycles of either 5 or 10 days) were launched, which meant an additional 19 conductivity-temperature-depth (CTD) profiles down to 2000 m simultaneous with the cruise, and another two APEX profilers were left to drift in the region before their recovery, representing another 42 CTD profiles sampling the top 300-800 m of the water column. The vessel also sampled continuously the sea-surface temperature, salinity and fluorescence, and the velocity fields down to about 600 m, during a total of 11 crossings of the surface front. Here we pay special attention to the description of the front, with 37 hydrographic stations along six cross-frontal sections about 100 km long and down to at least 400 m plus all the CTDs from the APEX profilers, which are combined with a sequence of simultaneous high-resolution (1 km) SST images. The front is formed by the subantarctic waters intruding below the subtropical waters, with horizontal gradients of up to 20 degrees C in about 10 km at 50 m depth. The front steepens as both the Malvinas and Brazil Currents get deflected east, reaching a maximum slope of about 200 m in 50 km at distances less than 150 km from the initial colliding point. We observed numerous thermohaline intrusions (thickness about 10-50 m and width of the order of 10 km) that intrude several tens of km into both sides of the frontal system. The sea-surface front is very sharp in temperature but appears distorted in salinity because of the presence of a filament that carries brackish waters from Rio de la Plata. On its onshore end, the filament is rather wide (up to 100 km) and lays on the subtropical side of the front but, as it moves further offshore, it thins out (down to only a few km), moves towards the surface front and accelerates, reaching speeds close to 2 m s-1, much faster than expected if the flow was in geostrophic balance.

Sub-mesoscale impact on iron fluxes in the Southern Ocean

Isabella Rosso[1], Andrew McC. Hogg[2], Richard Matear[3], Peter G. Strutton[4]

[1] *SIO, University of California San Diego, USA*

[2] *RSES, The Australian National University, Australia*

[3] *CSIRO Marine and Atmospheric Research, Australia*

[4] *IMAS, University of Tasmania, Australia*

Phytoplankton growth in the Southern Ocean is limited by the availability of iron. Natural fertilization events are fundamental to trigger the phytoplankton activity in this region. The Kerguelen Plateau, in the Indian sector of the Southern Ocean, is one of the regions where this iron fertilization occur, which results in a large phytoplankton bloom extending above and downstream the plateau.

Several mechanisms have been taken into account to explain the presence of iron in the euphotic layer of this region. However, these processes are not wholly understood.

Our hypothesis is that the mechanisms occurring at the sub-mesoscales, which can generate large vertical velocities and transport of tracers, may contribute to supply iron in the Kerguelen Plateau region. To investigate this hypothesis, we model the evolution of dissolved iron concentration and apply it to a set of Lagrangian particles, released into a mesoscale- (1/20° resolution) and a sub-mesoscale-resolving (1/80°) simulation of the ocean circulation in this location. We find that vertical velocities are dramatically enhanced in the highest resolution model, which consequently affect the vertical transport of the Lagrangian particles. Finally, results show that sub-mesoscale flows can enhance the vertical flux of iron to the base of the mixed layer, by a factor of 2.

Tracer Spectra at Submesoscale in the Shelf Seas

Meike Rotermund[1], Gualtiero Badin[2], Jonathan Sharples[3]
[1] *School of Integrated Climate System Sciences (SICSS), CliSAP, University of Hamburg, Germany*
[2] *Institute of Oceanography, University of Hamburg, Germany*
[3] *School of Environmental Sciences, University of Liverpool, United Kingdom*

Tracer statistics at the submesoscale are evaluated from high resolution observations in the Celtic Sea. The high resolution sections encompass different dynamical regions ranging from tidal fronts, shallow coastal waters, the shelf break front and the open ocean. Of particular interest is the comparison between the statistics in the open ocean and in the coastal regions, where topography and wind mixing are expected to play different roles. The analysis is thus made separating the shallow from the deep parts of the sections. A passive tracer, the spice, is calculated from the linear equation of state for seawater and statistics are analysed along isopycnals. Compensation and alignment between temperature and salinity along isopycnals are analysed making use of the Turner angle. Temperature, salinity and spice display Gaussian probability density functions (PDFs) in the separate coastal and deep ocean regions. In both regions, the slopes of spice spectra are studied along different isopycnals, and the consequences of ageostrophic dynamics at the submesoscale are discussed.

A tale of two eddies: The bio-physical characteristics of two contrasting cyclonic eddies in the Tasman Sea

MONINYA ROUGHAN[1], PAULINA CETINA HEREDIA, DAVID GRIFFIN, SHANE KEATING, CARLOS ROCHA, AMANDINE SCHAEFFER, IAIN SUTHERS

[1] *University of New South Wales, Sydney Australia*

Mesoscale cold core eddies are known to be highly productive regions of the ocean due to their cyclonic rotation which drives upwelling at the core. Lesser known however are the dynamics and productivity of smaller frontal eddies that form on the inside edge of western boundary currents. In this study we investigate the physical and biogeochemical properties of two contrasting cyclonic eddies in the Tasman Sea. The first being a frontal eddy that formed from a shelf water billow at 32S on the continental shelf of SE Australia and was advected offshore along the EAC front. The second is a larger mesoscale cyclonic eddy that formed at 28S and remained topographically trapped, blocking the southward flow of the EAC. We present results from a dedicated research voyage on the RV Investigator to study the biophysical interactions and productivity in two contrasting cyclonic eddies of the Tasman Sea. Our results show that not all cyclonic eddies are created equal, ie the smaller frontal eddy is significantly more a-geostrophic, more energetic and more productive than the mesoscale cyclone, despite its small size (35km diameter) and short life (4 weeks).

Intense ocean frontogenesis inducing submesoscale processes and impacting biochemistry

SIMÓN RUIZ[1], ANANDA PASCUAL[1], AMALA MAHADEVAN[2], MARIONA CLARET[3], ANTONIO OLITA[4], CHARLES TROUPIN[5], JOAQUÍN TINTORÉ[5], PIERRE POULAIN[6], ANTONIO TOVAR-SÁNCHEZ[1], BAPTISTE MOURRE[5], ARTHUR CAPET[6]

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

We present the results of ALBOREX, a multi-platform and multi-disciplinary experiment completed in May 2014. This unique process-oriented experiment in the eastern Alboran Sea (Western Mediterranean) examined mesoscale and submesoscale dynamics at an intense front. High-resolution (0.4 - 1 km) observations from autonomous underwater gliders revealed lateral density gradients of the order of 1 kg/m3 in 10 km and significant vertical excursions of chlorophyll and oxygen at both sides of the front. Vertical velocities of about 20 m/day have been diagnosed using the Quasi-Geostrophic Omega equation applied to hydrographic data. This vertical velocity is likely underestimated due to unresolved submesoscale processes. We quantify frontogenetic terms to assess the intensification/relaxation of buoyancy forcing which can be responsible of large vertical displacements in a scenario of strong confluence of (fresh) Atlantic Water and the resident (more saline) Mediterranean Water. Our results suggest that frontogenesis mechanism induces vertical velocities higher than 100 m/day in the eastern Alboran front, driving the tongues of chlorophyll and oxygen captured by ocean gliders, as well as local increases of nutrients and primary production (Olita et al., this conference). These findings, based on observations, are consistent with numerical simulations from a Process Ocean Model Study (Claret et al., this conference).

Investigating the eddy diffusivity concept in the coastal ocean

IRINA I. RYPINA[1], ANTHONY KIRINCICH[1], STEVEN J. LENTZ[1], MILES A. SUNDERMEYER[2]

[1] *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts*

[2] *University of Massachusetts Dartmouth, New Bedford, Massachusetts*

This work aims to test the validity, utility, and limitations of the lateral eddy diffusivity concept in a coastal environment through analyzing data from focused field experiments involving drifters and dye releases within the footprint of a high-resolution (800 m) high-frequency radar south of Martha's Vineyard MA. Specifically, we investigate how well a combination of radar-based velocities and drifter-derived diffusivities can reproduce observed dye spreading over an 8-hour time interval. A drifter-based radar-specific estimate of an anisotropic diffusivity tensor is used to parameterize small-scale motions that are un- and under-resolved by the radar system. This leads to a significant improvement in the ability of the radar to reproduce the observed dye spreading.

Hydrodynamic Model for the Arauco Gulf and Chiloé Inland Sea (Chile)

Cristian Salas[1,2], Sebastián Vasquez[1], Aquiles Sepúlveda[1], Sergio Núñez[1], Sebastián Inzunza[2], Belen de la Torre[2], Sebastián Cornejo[2]

[1] *Instituto de Investigación Pesquera, Chile*

[2] *Departamento de Geofísica, Universidad de Concepción, Chile*

Two hydrodynamic models have been generated for the central-southern Chile, one encompassed the Arauco Gulf (AG) and other cover the Chiloé Inland Sea (CIS). The model used was the Regional Ocean Modeling System version AGRIF (ROMS_AGRIF) (Shchepetkin; McWilliam 2005) and the study period was from 1993 to 2013. In order to improve the spatial resolution in specific time frame in both model we used roms2roms method (Mason et al., 2010), in which "child" model increase 1/3 in resolution. The horizontal resolution for the "parent" AG-ROMS model was 1.5 km and for the "parent" CIS-ROMS model 4 km. Both models used atmospheric forcing NCEP-DOE reanalysis 2 provided by PSD (Physical Sciences Division, NOAA/OAR/ESRL) and initial and boundary conditions from the Estimating the Circulation and Climate of the Ocean (ECCO) global data assimilation product (Wunsch & Heimbach, 2007). The models incorporated the most important freshwater discharge for each domain, these are the Bío Bío river and Puelo river for AG and CIS respectively. A validation was carried out by comparing simulated Sea Surface Temperature (SST) and sea level anomaly (SLA) with satellite observed data. Satellite products used for this purpose were MODIS-Aqua (SST) and AVISO (SLA). This validation method was based on Empirical Orthogonal Functions (EOF) in time and space. In addition, we used in situ temperature and salinity data recorded by a CTD profiler deployed from research cruises (CIMAR Fiordos) for comparative analysis of the vertical structure of the water column. In the case of AG-ROMS we also used sea surface current data from High Frequency (HF) radars for comparative purposes. The AG model performed well in representing an intense upwelling process in Punta Lavapié during summer, currents in two layers, the fresh water plume from the Bío Bío river and a surface current modulated by north wind during winter. On the other hand, the CIS-ROMS model showed good subsurface performance (10-50 m deep) outside the Reloncaví Estuary, the temperature differed between 0.1 and 1°C, while the salinity between 0.25 and 2 psu. The bathymetric data assimilation achieved improvements of 40% in depth using observed data provided by the National Hydrographic and Oceanographic Service (SHOA). The validation of the regional field of SST showed that CIS model reproduced the spatial and temporal variability (89% of the inter annual variability). The "child" CIS-ROMS model showed an improvement in the description of sea level anomaly in selected stations compared with the "parent" model. Finally, an exploratory analysis was carried out to analyze the effect of using high versus low resolution wind forcing in CIS-ROMS model for a specific period by using the Weather Research and Forecasting model (WRF).

The Prospects for Future Satellite Estimation of Mesoscale and Submesoscale Vorticity

R. M. Samelson[1], D. B. Chelton[1], M. G. Schlax[1], J. T. Farrar[2], M. J. Molemaker[3]
[1] *CEOAS, Oregon State University, USA*
[2] *Woods Hole Oceanographic Institution, USA*
[3] *IGPP, University of California, Los Angeles, USA*

Presently available satellite data are limited to investigation of mesoscale variability with wavelength scales larger than about 200 km. Two future satellite missions offer promising prospects for observations of smaller-scale variability. One of these is the Surface Water/Ocean Topography (SWOT) altimetric mission with a planned launch in 2020. The other, which is in the early planning stages, is a radar scatterometer mission to measure surface winds and surface ocean currents, tentatively called the Winds and Currents Mission (WaCM). WaCM determines vector surface currents from the Doppler shift of the radar returns from multiple look angles.

The onboard-processed estimates of SSH from SWOT will have a footprint size of 1 km with an expected standard deviation of 2.74 cm in the white-noise component of measurement errors. The swath width for SWOT is 120 km with a nadir gap of 20 km. The baseline design for the onboard processed estimates of surface current velocity from WaCM is for a footprint size of 5 km with a standard deviation of 0.5 m/s in the white-noise component of measurement errors that is assumed to be equally partitioned between the two vector components. The swath width for WaCM is expected to be 1300 km with a nadir gap of 100 km.

While the small footprint sizes of the SWOT and WaCM measurments have the potential to significantly improve the understanding of small-scale variability, the ability to do so depends both on measurement errors and on sampling errors that arise from the limited swath width and discrete sampling at the irregular times of satellite overflights. The effects of measurement and sampling errors are investigated separately and in combination from simulated SWOT and WaCM sampling of the SSH and surface velocity fields in a high-resolution (0.5 km grid spacing) numerical model of the California Current System (CCS). The resolution capability is defined here to be the half-power filter cutoff wavelength of the spatial smoothing that is required to achieve a signal-to-noise variance ratio (SNR) of 10. The focus of this investigation is on surface vorticity, which is estimated directly from WaCM data and geostrophically from SWOT data.

From consideration of measurement errors alone (i.e., based on the unrealistic assumption that SWOT and WaCM sample the entire CCS model domain on each overflight), the resolution capability of SWOT is significantly better than that of WaCM with the baseline measurement noise standard deviation of 0.5 m/s. Comparable resolution can be achieved from WaCM if the standard deviation of the measurement noise can be reduced to 0.15 m/s.

The resolution capabilities of SWOT and WaCM change dramatically when sampling errors are considered. Because of its much narrower swath width, the SNR in SWOT estimates of vorticity is completely dominated by sampling errors. A time period of 14 days is required for SWOT to sample the full CCS domain. In comparison, WaCM samples the full CCS domain every 24 hours. As a consequence, the resolution capability of WaCM is significantly better than that of SWOT, even with the baseline measurement noise standard deviation of 0.5 m/s. Preliminary analysis for the case of 14-day averages indicates that the resolution capability for WaCM is about 50 km, whereas the measurement capability for SWOT is about 150 km.

The role of mesoscale eddies along the ice edgefor primary production in the Fram Strait

ANNETTE SAMUELSEN[1]
[1] *Nansen Environmental and Remote Sensing Center, Bergen, Norway*

The ice-edge is a favorable area for the generation of mesoscale eddies. At high latitudes, these eddies are often order of 10 km, but have been observed up to 50 km. These eddies can be remotely observed by SAR, but close to the ice edge ocean color is often unavailable because of the presence of ice and clouds. Because these eddies will transport fresh-water it is likely that they influence the stratification and mixing and thus the local blooming conditions. A regional model for the Fram Strait with resolution 3.5 km has been set up as a coupled physical-biogeochemical model, HYCOM-NORWECOM, nested into a 15-km basin-scale model for the North Atlantic and Arctic. The biogeochemical model represents nutrients, phytoplankton, zooplankton and detritus. The 3.5 km resolution model is adequate to resolve the largest eddies in the region, while smaller eddies and submesoscale processes are not properly resolved. Small patches of higher primary production are present close to the ice edge, despite nutrient availability being comparable to adjacent regions. During late summer both biomass and primary production close to the ice edge are dominated by diatoms and closely follows the mesoscale structures. Here we investigate whether theses eddies play a role primarily in redistributing the water with high production and if the eddies themselves contribute to enhancement or reduction in the production.

Submesoscale features at the Gulf Stream North Wall and their impact on the heat and salt transport during the LatMix survey winter 2012

ALEJANDRA SANCHEZ-RIOS[1], KIPP SHEARMAN[1], JODY KLYMAK[2], CRAIG LEE[3], ERIC D'ASARO[3], MILES SUDERMEYER[4], JONATHAN GULA[5], STEPHEN PIERCE[1]

[1] *CEOAS, Oregon State University, USA*
[2] *SEOS, University of Victoria, Canada*
[3] *APL, University of Washington, USA*
[4] *SMAST, University of Massachusetts Dartmouth, USA*
[5] *Laboratoire de Physique des Océans, Université de Bretagne Occidentale, France*

As part of the ONR-sponsored LatMix Experiment, ship-based and glider-based observations following a Lagrangian float are used to examine the evolution of temperature, salinity and density along the Gulf Stream north wall in wintertime. Satellite observations during the survey showed the presence of submesoscale ($<$10 km) features along the front. These features were in the form of filaments of warm and salty water detached from the Gulf Stream core, visible from satellite data and with corresponding features in the vertical observed in the profiles, we refer to this features as streamers. The large Rossby number (Ro$>$1) calculated for this area suggests the presence of submesoscale dynamics associated with the streamers. Calculating the trend in time at each depth and cross-front location we found increase of heat and salinity in regions where the strongest cross-front gradients of velocity were observed at the mixed layer and around 150m depth, these changes are density compensated and suggest isopycnal mixing and a connection between the mixed layer and subsurface layers. Mixing time scales and vertical velocities can be estimated with the data from the dye injected in the mixed layer at the beginning of the drift. Using the residual velocity from the non-divergent stream-function, calculated from the total velocity field, we can obtain the correlation between the streamers and the divergent flow, which will give us an insight into the effects of these streamers to the transport of heat and salt at the Gulf Stream North Wall. Although confidence estimates prevent an accurate flux divergence calculation, we show, using a heat and salt budget analysis, that Reynold flux estimates are consisted with a cross-frontal exchange that can reproduce the observed temporal trends.

Impact of Severe Cyclonic Storm on Zooplankton Diversity in a tropical vulnerable mangrove wetland

Santosh Kumar Sarkar[1], BhaskarDeb Bhattacharya[1]
[1] *Department of Marine Science, University of Calcutta*

Climate-related changes in the physical and chemical oceanic environment have been considered as major drivers of significant fluctuations in zooplankton production, community structure, and phenology. The present study attempts to assess the dimension of ecological changes in coastal regions of Indian Sundarban mangrove wetland due to occurrence of the severe cyclonic storm 'Aila' on 25th May, 2009. Sundarban is a low lying, vulnerable, tide-dominated delta formed at the estuarine phase of Ganges (Hooghly) River and Bay of Bengal. During 'Aila', the total surge height of 10-13 m with wind speed of 90-110 kmph lashed the Sundarban and brought about stupendous change in the ecology of coastal waters. The variations in community structure of mesozooplankton (0.2 – 20 mm body size) in the context of water quality parameters were recorded during pre- and postAila event. Mesozooplankton samples were collected using a Ring Trawl Net (Hydro-Bios No. 438 700, Germany) of mouth area 0.78 m2, mesh size 200 µm. The net was towed on water surface for 10 minutes and the volume of water filtered was measured by a calibrated flowmeter (Hydro-Bios No. 438 110, Germany) mounted in the mouth of the net. The zooplanktons were fixed with 4% buffered formalin solution and taken to the laboratory for further analyses. A sharp increment in water turbidity, chemical oxygen demand (COD), phytopigment chlorophyll b and micronutrients (nitrate, phosphate and silicate) was noticed during post-Aila period. A three-fold increase of phosphate concentration was recorded with mean concentration of 1.18 μgm-atom l-1 of the pre-Aila period reached as high as 3.51 μgm-atom l-1 during post-Aila period. An enrichment of silicate concentration was also noticed during post-Aila period from 84.58 μgm-atom l-1 to 93.22 μgm-atom l-1. The average numerical density of total zooplankton was 1344 ind. m-3 and 889 ind. m-3 during pre- and post-Aila period respectively. An absolute dominance of two copepod species of diverse feeding guilds, namely, Bestiolina similis (herbivore) and Oithona brevicornis (carnivore) was observed during post-Aila period. Meroplanktons such as nauplius, zoea and ichthyoplanktons which constituted a substantial part of the total mesozooplankton (31 %) during pre-Aila period, were completely absent in post-Aila stage. The results of the index of dominance (Yi), revealed that before cyclone the copepod community was dominated by six copepod species while, the maximum index of dominance was of B. similis (Yi = 0.68) and minimum one of Acartia spinicauda (Yi = 0.04). The natural disaster has influenced the wetland ecosystem most convincingly as majority of the mesozooplankton species of diverse feeding guilds were removed, resulting imbalance for trophic interactions, altering food-web structures and consequent changes in ecosystem functions. These are directly related to the fishery potentialities and crucial to the socioeconomic status for a large section of the coastal people inhabiting in this vulnerable environment. Hence natural disaster management should be given high priority with the policy makers, planners and administrators

in formulating strategies for disaster risk reduction from a socio-ecological viewpoint.

Seasonal variations of submesoscale dynamics in high-resolution simulations of the North Pacific

HIDEHARU SASAKI[1], PATRICE KLEIN[2], YOSHIKAZU SASAI[1]
[1] *JAMSTEC*
[2] *IFREMER*

Several high-resolution simulations have recently highlighted the seasonality of oceanic submesoscales - highly (poorly) energetic in winter (summer) – but only in two regions: in the NorthWestern Atlantic Ocean including the Gulf Stream (Menza et al. JPO, 2013) and in the NorthWestern Pacific Ocean including the Kuroshio Extension (Sasaki et al. NC, 2014). Energetic submesoscales in winter in these regions are explained by the mixed-layer instability (MLI). High-resolution in-situ observations within the Gulf Stream region have confirmed this seasonality (Callies et al. NC, 2015).

The future altimetry missions (COMPIRA and SWOT) are expected to capture oceanic features over a wide scale range, including submesoscales, in all parts of the World Ocean and not only in energetic areas. In advance, the present study extends previous results on the impact of submesoscales to the whole North Pacific Ocean. Quantification of submesoscale impacts is allowed by the comparison of two simulations of the North Pacific Ocean, at 1/30th and 1/10th degree resolutions.

In the regions of the Kuroshio Extension, Subtropical Countercurrent, Mid-latitude Eastern Pacific and Subtropical Eastern Pacific, submesoscales are much more energetic in winter than in summer in the 1/30th degree simulation. Emergence of these submesoscales is again explained by MLIs. In addition, the spectral kinetic energy (KE) fluxes indicate an inverse KE cascade, i.e. a significant transfer of KE from submesoscales to larger ones. In the 1/10th degree simulation, these MLIs are not resolved and as a consequence (1) total KE is significantly weaker and (2) no seasonality is observed. In the Subarctic regions, the impact of submesoscales revealed by the 1/30th degree simulation is not so significant. A seasonality of submesoscales is still observed in the Subarctic Western Pacific but not in the Subarctic Eastern Pacific. The scale of MLIs in these regions, certainly too small to be resolved in the 1/30th degree simulation, requires to perform simulations at higher resolution. This is our future work.

Submesoscale frontal vortices and eddies along the East Australian Current observed by HF Radars

AMANDINE SCHAEFFER[1], MONINYA ROUGHAN [2], ALESSANDRA MANTOVANELLI[3], ANTHONY GRAMOULLE[4]
[1] *University of New South Wales, Sydney Australia*

The East Australian Current (EAC) is the major feature of the ocean circulation along south-eastern Australia, influencing the shelf circulation, water temperature, phytoplankton to fish distribution and abundance and the regional climate. While the shedding of mesoscale warm core eddies where the EAC separates from the coast is relatively well understood, little is known about its sub-mesoscale frontal instabilities. More than 1 year of surface currents from HF Radars, in conjunction with mooring measurements, satellite sea surface temperature and ocean color, highlight for the first time the occurrence and propagation of small scale meanders along the inshore edge of the EAC. These instabilities are mostly barotropic and migrate poleward as far as 500 km south, with advection speeds of 0.3 m/s. Investigation into the flow field kinematics shows high Rossby numbers and a strong impact on horizontal divergence and particle dispersion. Wind stress appears to influence the fate of these ageostrophic meanders, their growth and potential evolution into cyclonic cold core eddies. Such coherent structures are a major mechanism for the transport and entrainment of nutrient rich coastal waters, impacting physical and biological connectivity over large distances.

Analysis of the salinity intrusion in the river Elbe estuary using FerryBox measurements and a 1d advection/diffusion model

J. Schulz-Stellenfleth[1], E.V. Stanev[1], A. Valle-Levinson[2]

[1] *Helmholtz Zentrum Geesthacht, Institute of Coastal Research, Germany*

[2] *University of Florida, USA*

The salinity intrusion in the Elbe estuary is analysed using surface salinity measurements acquired by a FerryBox system mounted on a cargo ship operating between Cuxhaven and Immingham. The observations provide information on the along river salinity gradient with a temporal resolution sufficient to study mechanisms taking place on different time scales. Both a spectral analysis and an EOF decomposition is performed showing that the dynamics is dominated by only a few characteristic modes. The measurements are decomposed into a slow mode, which is associated with variations in river runoff and a fast mode, which is associated with the semi-diurnal tide. It is shown that the slow variations in the salinity gradient are well correlated with E-Hype river discharge data. The faster dynamics is highly correlated with water levels measured by a tide gauge in the estuary. It is shown that the amplitude of the tidal salinity variations is strongly dependent on the slow mode. In situations with large river discharge the salinity variations within one tidal cycle are significantly stronger.

A 1d advection/diffusion model is used for a further analysis of the observations. The model consists one part for the slow dynamics which basically describes a balance between fresh water discharge and diffusion. Analytical expressions for along river salinity profiles at ebb conditions can be derived for different profiles assumed for the Diffusion coefficient. The analytical expressions were fitted to the observations using a polynomial ansatz for the Diffusion profiles. The fit procedure provides estimates for the ratio of the fresh water inflow velocity and the diffusion along the river. The second part of the model is concerned with tidal dynamics, which mainly leads to advection of the salinity profiles. The periodic advection velocities were estimated using several tide gauge measurements along the river in combination with a 1d barotropic model. Using a first order approximation an analytical expression can be derived for the salinity variation within one tidal cycle. The results are compared with the observations showing overall reasonable agreement. In situations with strong fresh water runoff it is however evident that additional effects have to be taken into account. In particular further offshore two dimensional effects become significant and the salinity dynamics is strongly influenced by across river advection and diffusion processes. In addition we will discuss the potential impact of tidal variations of the vertical diffusion, which is not contained in the model.

Connectivity pathways to Marine Protected Areas in the Western Mediterranean Sea

ROBERTA SCIASCIA[1], MARCELLO G MAGALDI[1]

[1] *Institute of Marine Sciences, National Research Council (CNR-ISMAR), La Spezia, Italy*

The spatial structure of marine populations strongly depends on the physical dispersion of propagules (e.g. larvae) and their interaction with the environment. Marine protected areas (MPAs) are one of the most used tools to preserve marine populations. Most of them have been established to protect beautiful areas while minimizing their socio-economical impact. However, the knowledge of connectivity pathways to MPAs is fundamental to redefine or create new areas that can actually protect the environment and enhance biodiversity.

Here, we examine the connectivity among marine protected areas and the dispersal of propagules in the Western Mediterranean sea namely in the Tyrrhenian Sea. We use a numerical high-resolution, eddy permitting, ocean model (ROMS) together with a Lagrangian transport model (LTRANS) to simulate the fate of a large number of particles (10000) released in the ROMS 3D hydrodynamic field. Each particle represents a passive larva with a life span of one month. The transport and connectivity have been estimated for different periods throughout the year. In particular, we focus on the role of the vertical component of the velocity field and of the biological settling velocity.

Our results suggest that connectivity is strongly influenced by vertical velocities and the MPAs are likelier to be connected to the surrounding areas when trajectories are computed including the vertical velocities contribution. This is largely due to the interaction of particles with the intermediate waters present in the Tyrrhenian Sea and to their strong seasonal variability driven by density differences in water masses. Finally, we find that recirculation processes due to the presence of eddies influence the connectivity and particles can re-enter the MPAs multiple times during their life span.

Interpretation of the surface boundary layer dynamics using simultaneous HF radar and ADCP measurements, drifting buoys, and modeling

ALEXEI SENTCHEV[1], PHILIPPE FORGET[2], PHILIPPE FRAUNIE[2], KONSTANTIN KOROTENKO[3]

[1] *Lab. Oceanography and Geosciences UMR 8187, Université du Littoral - Côte d'Opale, Wimereux, France*

[2] *Mediterranean Institute of Oceanography UM 110 UTLN - AMU - CNRS/INSU 7294 - IRD 235, La Garde, France*

[3] *Lab. Marine Turbulence, Shirshov Institute of Oceanology Russ. Acad. Sci., Moscow, Russia*

Ocean surface boundary layer dynamics is investigated by using velocity observations and modelling approach. Three observation techniques were simultaneously used to monitor surface currents in the NW Mediterranean: High Frequency (HF) radars, surface drifting buoys, and high resolution velocity profiling by towed and freely drifting ADCP. The comparison of velocity measurements revealed a high degree of consistency in the acquired data. Current dynamics in the uppermost surface layer (1 m thick) is correctly shaped by each observing system. However the surface boundary layer dynamics can not be reconstructed successfully without taking into the account velocity variation with depth. Current velocity surveys were realized under sea breeze conditions with developed stratification at the end of a summer period. It is shown that even low wind forcing creates velocity shear and induces a noticeable difference in current direction between the surface and sub-surface layers. Evolving wind causes continuous evolution of surface currents, occurring in the upper layer of several meters thick, but does not affect the background circulation. One-dimensional turbulent model is used to reproduce the temporal evolution of current velocity in the surface boundary layer under real forcing. The sensitivity of the model to variation of forcing terms is investigated. The results are compared with velocity profiles repeatedly acquired by drifting ADCP.

Co-existence of multi-directional waves in the Red Sea

SHANAS P.R[1], ABOOBACKER V.M[1], ALAA M. A. ALBARAKATI [1]

[1] *Department of Marine Physics, Faculty of Marine Science, King Abdul-Aziz University , Saudi Arabia.*

The waves in the Red sea have unique characteristics unlike the other Seas in the world. The narrow strait along with its topographic features at the south restricts the propagation of distant swells from the Indian Ocean to the Red Sea, hence the waves in this region are generally associated with the prevailing wind systems, more frequently in combination of both regional and local wind conditions that leads to complex sea states. It is evident from the measured wave data at a buoy location, north of Jeddah in the Red Sea. The correlation analysis between wind speed and significant wave height indicates that distinct amount of waves observed at this location are generated by the local wind systems in addition to the waves propagated from distant areas in the Red Sea. To extend the analysis over the entire domain of the Red Sea, numerical modelling has been carried out using a third generation wave model (namely WAVEWATCH III), and validated against the measurements. The results reveal the seasonal and diurnal variabilities in the wave parameters. The model spectra show the presence of multi-directional energies in a daily cycle, which is due to the co-existence of the multi-directional waves having different frequencies.

Observing submesoscale interleaving and vertical exchange

ANDREY SHCHERBINA[1]
[1] *Applied Physics Laboratory, University of Washington, USA*

Submesoscale dynamics tend to create fine-scale vertical interleaving, rivaling in complexity the lateral streakiness of submesoscale "soup". Interleaving features with vertical scales of 10s of meters are commonly observed at the base of restratifying mixed layers, but may also extend into the upper pycnocline. These features are created by 3D overturning associated with submesoscale instabilities, and therefore can be linked directly with subduction and the vertical exchange of tracers and nutrients driven by submesoscale turbulence. The three-dimensional structure of submesoscale interleaving was observed in a number of recent field experiments (LatMix 2011-2012, LASER 2016), allowing direct comparison with realistic high-resolution numerical simulations.

Since vertical interleaving is readily observable with autonomous and towed profiling instruments, it can be used for proxy characterization of submesoscale turbulence even when the relevant horizontal scales of 1-10 km are not resolved. A pilot analysis of profiling float observations in the North Atlantic Salinity Maximum region revealed seasonal and spatial variability of interleaving features, possibly linked to the corresponding variability of submesoscale dynamics. The next step is extending the analysis to other regions across the globe.

Seamless modelling of European Seas with a two-way nested model

JUN SHE[1], JENS MURAWSKI[1], KASPER STENER HINTZ [1]

[1] *Research and Development Department, Danish MEteorological Institute*

HBM (HIROMB-BOOS Model) was originally developed as a coupled ocean-ice model for both operational forecasting and climate modelling in the Baltic-North Sea region. The model has been recently developed for seamless modelling of the entire European Seas. A free test run was made for the period 2007-2014 with 10 two-way nested domains and correspondent horizontal resolutions between 0.1-3 nautical miles, to demonstrate the feasibility of seamless modelling of the Pan-European Seas (Baltic Sea, North Sea, North Atlantic Shelf Sea, Mediterranean Sea and Black Sea) with one executable. The model has been optimized to reach a fair computational performance. As a preliminary indication of scientific quality of the model, the modelled sea level is validated against observations for all regional seas. This presentation will introduce the model configuration, the computational performance and preliminary verification results of the model run.

Properties of symmetric instability

SHENGLICHEN[1], JIUXING XING[1]
[1] *Graduate School at Shenzhen, Tsinghua University, China*

MITgcm is used to simulate the symmetric instability. The genesis conditions are reexamined. We show the developing steps of this process by investigating variations of stratification, velocities and energy flux. The sensitivity of model parameters is also tested. The research is being carried on currently, hopefully more results will come out in following months.

Reconstructing ocean interior motions from surface observations: a systematic comparison of existing and new methods

SHAFER SMITH[1]

[1] *Courant Institute of Mathematical Sciences, New York University, New York, NY 10012, USA*

Satellites can measure ocean surface height and temperature with sufficient spatial and temporal resolution to capture mesoscale features across the globe. Measurements of the ocean's interior, however, remain sparse and irregular, thus the dynamical inference of subsurface flows is necessary to interpret surface measurements. The most accurate approach is to incorporate surface measurements into a data-assimilating forward ocean model, but this approach is expensive and slow, and thus impractical for time-critical needs, such as offering guidance to ship-based observational campaigns. Two recently-developed approaches in the literature have made use of the apparent partial consistency of upper ocean dynamics with quasigeostrophic (QG) flows that take into account surface buoyancy gradients to "reconstruct" the interior flow from knowledge of surface height and buoyancy. One approach assumes a correlation between the potential vorticity (PV) at the surface and at depth, with a proportionality determined by mean gradients; the second assumes the flow can be represented by a linear combination of the barotropic and baroclinic modes, appended by a 'surface' mode, and uses boundary values to determine the coefficients. These two methods have each been demonstrated in limited applications, but neither has been systematically tested in a range of flows, nor have the two methods been compared to one another.

Here we set out (1) to develop explore the accuracy of these methods as a function of depth, scale and flow type, and (2) to develop variants of these methods that use a recently-developed modal decomposition that represents the surface and interior dynamics in an efficient way, allowing the separation of surface energy from total energy. The existing and new reconstruction methods are systematically tested and compared using output from a suite of high horizontal and vertical resolution quasigeostrophic simulations that are driven by baroclinically unstable mean flows with a range of surface buoyancy and interior potential vorticity gradient combinations. In addition, we apply the methods to output from a high resolution primitive equation simulation of a forced and dissipated baroclinic front in a channel. The systematic approach allows us to quantify the relative skill of each method in terms of the structure of the observed flow, providing guidance for the advantages and limitations of each approach.

Submesoscale Tracer Evolution in the Oceanic Mixed Layer

KATHERINE M. SMITH[1], PETER E. HAMLINGTON[1], BAYLOR FOX-KEMPER[2]
[1] *Department of Mechanical Engineering, University of Colorado, Boulder, USA*
[2] *Department of Earth, Environmental, and Planetary Sciences, Brown University, USA*

The ocean is estimated to store over 20% of all anthropogenic CO_2 and is the largest reservoir of carbon in the Earth system that is active on short timescales. The evolution and properties of biogeochemical tracers in the upper ocean, such as phytoplankton, nutrients, and CO_2, are critical for understanding the role of the ocean in the global carbon cycle. For example, phytoplankton consume inorganic carbon as well as nutrients that diffuse across the air-sea interface or that are entrained from depth. Similarly, CO_2 diffuses across the air-sea interface and is transformed into carbonate and bicarbonate by chemical reactions.

Due to both vertical and horizontal turbulent mixing, oceanic tracers are not spatially uniform throughout the mixed layer and exhibit patchy distributions over a wide range of scales [Martin et al. (2002)]. Since concentrations of tracer species at mixed layer boundaries can greatly affect ex- change rates, it is crucial to include the effects of turbulent mixing in tracer transport models. Recent studies have shown that physical transport by submesoscale (1∼10km) circulations can give rise to substantial tracer heterogeneity [Mahadevan and Campbell (2002); Levy et al. (2001)]. However, the effects of small scale motions (1km∼1m), as well as the coupling between large and small scale processes, have yet to be examined in detail. Small scale turbulence can affect reactive tracer evolution since the associated short mixing time scales are similar to reaction (or chemical) time scales. Additionally, small scale motions have been shown to compete with submesoscale upwelling and also contribute to a deepening of the oceanic mixed layer [Hamlington et al. (2014)]. A comprehensive look at the coupling and competition between large and small scale motions is required in order to gain a more complete understanding of their impacts on tracer evolution in the upper ocean.

In this talk, a large eddy simulation spanning a spatial scale range from 20km down to 5m is used to examine the role of multiscale turbulent mixing on ocean tracers [Smith et al. (2015)]. The simulations include the effects of both wave-driven Langmuir turbulence and submesoscale eddies, and tracers with different initial and boundary conditions are examined. Tracer properties are characterized using spatial fields, statistics, multiscale fluxes, and spectra, and the results show that tracer mixing depends on air-sea tracer flux rate, tracer release depth, and flow regime. These results and their implications for the development of reduced order tracer transport models are discussed.

REFERENCES

Hamlington, P. E., L. P. Van Roekel, B. Fox-Kemper, K. Julien, and G. Chini, 2014: *J. Phys. Oceanogr.*, **44**, 2249–2272.

Levy, M., P. Klein, and A. M. Treguier, 2001: *J. Mar. Res.*, **59**, 535–565.

Mahadevan, A. and J. W. Campbell, 2002: *Geophys. Res. Lett.*, **29 (19)**, 32.
Martin, A. P., K. J. Richards, A. Bracco, and A. Provenzale, 2002: *Global Biogeochem. Cycles*, **16 (2)**, 1025.
Smith, K. M., P. E. Hamlington, and B. Fox-Kemper, 2015: *J. Geophys. Res.: Oceans*, http://dx.doi.org/10.1002/2015JC011089.

Tidal effects on the Yellow Sea circulation and ecosystem

Jae-Kwi So[1], Hyoun-Woo Kang[1], Ok-Hee Seo[1], Chan Joo Jang[1]
[1] *Korea Institute of Ocean Science and Technology*

Tidal effects on the Yellow Sea circulation and ecosystem variables have been investigated using a physics-ecosystem coupled model. The physical module of the model uses a finite difference grid in the horizontal coordinates (C-grid) and a hybrid σ-z grid in the vertical coordinate to describe realistically the shallow and mild slope topography along with the deep and steep slope topography. The ecosystem module of the coupled model, which is based on *Neumann* (2000), is composed of eleven variables, that is, four nutrient types (nitrates, ammonia, phosphates and silicates), three phytoplankton functional groups (diatoms, flagellates and blue-green algae), two zooplankton group (micro- and meso-zooplankton), detritus and dissolved oxygen, and it also comprises bottom detrital sediment. Chlorophyll-a is computed prognostically on the basis of the model of *Fennel et al.*(2006) and *Geider et al.*(1997). The results of model experiment for two cases of including and excluding tide, were compared. In the sectional view along the 36°N, cold water appears in the eastern side of the Yellow Sea in winter for both cases. In case of including tide, cold water moves gradually toward the central bottom of the Yellow Sea and get settled there in summer, which is similar to observations. In the case of excluding tide, however, YSBCW appears and disappears in the eastern side of the Yellow Sea, and the stratification is weaker than that in the case with tide. The responses of ecosystem variables along the 36°N section were also discussed for the two cases. In the experiment including tide, high concentration of phyto- and zooplankton appears in the eastern part and less high one in the western bottom of the Yellow Sea and low values in the upper layer of the western part in summer. In case excluding tide, however, phyto- and zooplankton distribution shows low values in upper layer and some high values in the bottom layer in summer. But, in both cases, sectional distribution of phyto- and zooplankton shows no marked correlation with the YSBCW.

Spatially coherent organized motion in the upper ocean turbulent boundary layer: Langmuir cells and ramp-like structures

ALEXANDER V. SOLOVIEV[1], CAYLA W. DEAN[1]
[1] *Nova Southeastern University's Halmos College of Natural Sciences and Oceanography*

Langmuir cells have been recognized as an important part of the upper ocean turbulent boundary layer (McWilliams et al. 1997). Models of Langmuir circulation are now very sophisticated but still pose some questions (Soloviev and Lukas 2014). In particular, the traditional models of Langmuir circulation do not account for ramp-like structures, which are widespread features in the upper ocean turbulent boundary layer, with axes perpendicular to the axes of Langmuir circulation (Wijesekera et al. 1999). Vortices associated with ramp-like structures have transverse axes, while Langmuir circulations have a longitudinal axis, relative to the wind. How can ramp-like structures coexist with Langmuir cells? We have developed a new concept, which links the Langmuir circulation and ramp-like structures to wave stirring and Tollmien-Schlichting instability. Using computational fluid dynamics tools, we have been able to reproduce both Langmuir cells and ramp-like structures coexisting in space though intermittent in time. The mechanism resembles convective initiation of longitudinal rolls in the atmospheric boundary layer (Brown, 1991). However, in the upper ocean turbulent boundary layer, the vorticity transport in the vertical direction occurs by breaking waves stirring the near-surface layer of the ocean; while, in the atmospheric boundary layer, by penetrative convection. The proposed mechanism for generation of Langmuir circulation may complement that of Craik and Leibovich (1976) within a certain range of wind/wave conditions (in particular, under high wind speed conditions when the vortex force term including Stokes drift can be suppressed due to strong near-surface turbulence). We also discuss the available observational data that can help with verification of models of spatially coherent structures in the upper ocean turbulent boundary layer.

References

Brown, R.A. , 1991: Fluid Mechanics of the Atmosphere. International Geophysics Series 47, Academic Press, San Diego.

Craik, A.D.D., and S. Leibovich, 1976: A rational model for Langmuir circulations. J. Fluid Mech. 73, 401–426.

McWilliams, J.C., P.P. Sullivan, and C-H. Moeng, 1997: Langmuir turbulence in the ocean. J. Fluid Mech. 334, 1-30.

Soloviev, A.V. and R. Lukas, 2014: The Near-Surface Layer of the Ocean: Structure, Dynamics, and Applications (Second edition), Springer, NY, 552 pp.

Wijesekera, H. W., Paulson, C. A., Huyer, A., 1999: The effect of rainfall on the surface layer during a westerly wind burst in the western equatorial Pacific. J. Phys. Oceanography 29, 612–632.

Mediation of air-sea CO_2 fluxes by mesoscale eddies in the Southern Ocean

HAJOON SONG[1], JOHN MARSHALL[1], UTE HAUSMANN[1]
[1] *Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology*

The eddy-rich Southern Ocean (SO) has a huge seasonal variability in mixed layer depth (MLD) ranging from $O(10\text{ m})$ in summer to a few hundred meters in winter. The modulation of MLD by mesoscale eddies and implications for biogeochemistry are expected to be substantial, yet not fully understood partially due to the challenge of separating mesoscale effects from those of the larger-scale circulation. In this study, we report the significant impact of mesoscale eddies on air-sea CO_2 fluxes using offline simulations of a biogeochemical model, which provides a clear and definitive way to separate out the effect of mesoscale processes. Two simulations of carbon cycle are compared. The first one is forced by an eddy-rich circulation, the second by a smoothed circulation in which mesoscale kinetic energy is suppressed by half but the mean circulation is kept the same. Strikingly, smoothing out the mesoscale leads to significantly less outgassing of CO_2: by 0.3 Pg C yr^{-1} which is roughly 1/3 of the seasonal variability in SO CO_2 flux. Reduction in outgassing rates is a consequence of reduced vertical mixing and associated MLD shallowing, by $O(100\text{ m})$, in the smoothed solution, lowering the supply of carbon-rich deep water into the surface layer. Our results clearly demonstrate the importance of parameterizing the interaction between vertical mixing and mesoscale circulations in order to realistically represent ocean biogeochemical processes in climate models.

Sub-mesoscale freshwater stratification influencing air-sea heat fluxes

GUALTIERO SPIRO JAEGER[1], AMALA MAHADEVAN[2]
[1] *MIT / WHOI Joint Program, USA*
[2] *Woods Hole Oceanographic Institution, USA*

Cruise observations in the Bay of Bengal show a strong spatial coherence between SST and SSS anomalies. Mesoscale stirring of freshwater forms filaments with sharp fronts, lateral gradients are slumped into shallow stratification beneath the fresh side, which shoals the ML depth. Uniform surface heat loss then cools the lighter fresh side more than the denser salty side. Partially compensated features of O(1-10km) are actively created by surface forcing in combination with sub-mesoscale restratification dynamics. Similarly, sheared Ekman surface flow thinning out freshwater patches enhances shallow stratification beneath fresh layers, and insulates the saltier water below. Air-sea heat fluxes modulated by SST may thus be correlated with SSS, and the net fluxes changed by small-scale freshwater layer dynamics.

Performance analysis of WRF-ARW model for simulation of seasonal atmospheric flow-field Parameters over tropical coastal region

SRIKANTH MADALA[1]

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

The Land-Sea breezes (LSBs) are a thermally generated mesoscale circulation due to land-sea differential heating and associated low-level pressure gradient in the atmosphere. Surface heating, land-sea temperature gradient, strength and direction of synoptic flow, latitude and coast line orientation are influenced by the thermally driven LSBs. In this study, the Advanced Research WRF (ARW) mesoscale model is used to predict boundary layer features in different seasons over the coastal region of Chennai in Southern India. Sensitivity experiments are conducted with two non-local [Yonsei University (YSU), Asymmetric Convective Model version 2 (ACM2)] and three turbulence kinetic energy (TKE) closure [Mellor- Yamada Nakanishi and Niino Level 2.5 (MYNN2), Mellor-Yamada-Janjic (MYJ) and quasi-normal scale elimination (QNSE)], Planetary Boundary Layer (PBL) parameterizations for simulating the low-level atmospheric flow in different seasons. Simulations are validated with the available meteorological observations at one meteorological tower, twelve automated weather stations and one Doppler Weather Radar (DWR) derived wind data over Chennai region. Simulations reveal that the characteristics of LSBs vary widely in different seasons and are more prominent during the pre-monsoon and monsoon seasons (March-September) with large horizontal and vertical extents compared to the post-monsoon season and winter. Qualitative and quantitative results indicate that, the simulations with ACM2 followed by MYNN2 and YSU produced various features of the LSBs and boundary layer parameters, those are in better agreement with observations. The study shows that, the seasonal variation of onset time, vertical extent of LSBs and mixed layer depth, which would influence the air pollution dispersion in different seasons over the study region.

The Evolution of a California Undercurrent Submesoscale Eddy (Cuddy)

Jacob M. Steinberg[1], Charles C. Eriksen[1], Noel A. Pelland[1]
[1] *School of Oceanography, University of Washington, USA*

Long-lived subthermocline eddies generated by the California Undercurrent, termed ”Cuddies”, have long been recognized as elements of the California Current System that carry warm, saline, low oxygen Undercurrent waters offshore. Multiple autonomous underwater vehicles (Seagliders) were used to identify and continuously survey a Cuddy offshore of Washington State and Vancouver Island, British Columbia, Canada, for four months during the winter of 2013-2014. Repeat sections across the eddy enabled characterization of its water properties and current structure. The Cuddy surveyed consisted of an isolated mass of high spice/low oxygen water with its core at 200m depth and its radius of maximum velocity at roughly 11km. It had little discernible surface expression, while beneath its core, isopycnal deflection extended to at least 500m depth. Rotating anti-cyclonically, a core region in solid body rotation was observed out to, at most, 1/2 of the radius of maximum velocity where speeds reached over 0.2 m/s. At radii greater than the radius of maximum velocity, a transition region existed where exterior waters were stirred by the Cuddy. In this region layered lateral intrusions were observed, presumed sites for enhanced lateral and vertical mixing. This mixing was subsequently characterized using scalar field variance and variations in spice curvature. At radii greater than twice the radius of maximum velocity, currents returned to background flow values. During its survey the Cuddy traveled northwest in the along-slope direction (between the 1000m and 2000m isobath) over 400km at speeds ranging up to 0.08 m/s. After an initial period of near stationarity, it translated poleward rapidly until reaching a second period of slow movement by which time its rotary strength was markedly weakened. Its Rossby Number, weakened by nearly half while the core scalar field values (spice and oxygen) remain fairly constant. This highlights the difference between the spin down time-scale and lateral diffusion time-scale, and also offers insight into submesoscale horizontal mixing regimes. Due to the large across-shore gradient in water mass properties, the Cuddy anomaly magnitude and shape varied as it moved on and offshore. A second, much larger Cuddy was likely observed further offshore at the very end of the glider missions.

Biogeochemistry of Southeastern Arabian Sea

SUDHEESH V[1,2], SUDHARMA K V[1], GVM GUPTA[1]
[1] *Centre for Marine Living Resources and Ecology, Kakkanad, Cochin-37, India*
[2] *Department of Chemical Oceanography, Cochin University of Science and Technology, Cochin 682016, India*

The biogeochemistry of the South Eastern Arabian Sea (SEAS) is closely linked to the seasonally changing coastal currents by northward and southward flowing West India Coastal Current (WICC) during WM and SM, respectively. The transition seasons viz. spring inter-monsoon (SIM) and fall inter-monsoon (FIM) exhibit mixed signals between SM and WM. SEAS is largely controlled by monsoonal forcing on the mixed layer variations and nutrient cycling. The seasonal reversal of surface circulation enables the transport of high saline waters from the northern Arabian Sea during SM, whereas low saline waters from the Bay of Bengal into the SEAS during WW. It is a dynamic region, as it initiates both upwelling during summer and down-welling during winter monsoon. The south eastern Arabian Sea is the only region where the upwelling occurs in conjunction with intense rainfall and fresh water influx. The upwelling induced high productivity is found to attract a substantial fishery yield in the SEAS during the SM and FIM. Another important fact is that since the western coastal areas of SEAS are in general, thickly populated, the coastal waters become vulnerable to human-induced perturbations such as eutrophication and acidification. Although several studies have been undertaken in the recent past in the SEAS, none of them have made systematically to address complete evolutionary and decaying patterns of all these coastal processes and their cascading effects on the system biogeochemistry. The present studies covering entire continental shelf region would therefore be a first attempt to address these coastal processes in the SEAS on long-term basis. The present study provides the first detailed information concerning biogeochemical changes associated with the evolution, propagation and withdrawal of upwelling along the SEAS. The time series study along the Cochin shelf waters resulted that the inner shelf system was net autotrophic, on an annual basis, as the organic matter produced exceeded its consumption. This gives us little hope as many of the coastal systems are under serious threat because of anthropogenic perturbations. In addition to this, our data do not show any indication of an intensification of hypoxic conditions due to human activities unlike many other coastal areas. It may be also noted that, eventhough the north of our study region along the west coast of India, the inner shelf has been experiencing sulphidic conditions, such conditions do not seem to occur off Kochi presumably due to the difference in the initial oxygen content of upwelling source water. However, the low oxygen sub-pycnocline waters over the shelf maintains the oxygen levels critically poised and just short of anoxia, underlining the vulnerability of the region to potential global change. In view of model results predicting the expansion of OMZs in future, hypoxia in coastal waters of SEAS is expected to add further stress on coastal biogeochemistry and fishery resources.

How to obtain ocean turbulent dynamics at super resolution from optimal multiresolution analysis and multiplicative cascade?

JOËL SUDRE[1], HUSSEIN YAHIA[2], ORIOL PONT[2], VERONIQUE GARCON[1]

[1] *LEGOS/CNRS, UMR 5566, 18 Avenue E. Belin, F-31401 Toulouse Cedex 4, France*
[2] *GeoStat team, INRIA Bordeaux Sud-Ouest, 351 Cours de La Libération, 33405 Talence Cedex, France*

A fundamental challenge in oceanography is the synoptic determination of ocean circulation using the data acquired from space, with a coherent depiction of its turbulent characteristics. This determination has the potential of revealing all aspects of the ocean dynamic variability on a wide range of spatio-temporal scales and will enhance our understanding of ocean–atmosphere exchanges at super resolution, as required in the present context of climate change. A method to obtain ocean dynamics products at different super resolutions is presented here, using an approximation of the energy cascade, expressed in a microcanonical formulation, and associated to turbulent signals provided by different products of Sea Surface Temperature (SST). The basics idea is to propagate across the scales motion information at lower resolution coming from GEKCO product [Sudre et al., 2013] in a multiresolution analysis computed on adimensional critical transition informations [Sudre et al., 2015].

REFERENCES

Sudre J., Maes C., and Garçon V., 2013, On the global estimates of geostrophic and Ekman surface currents, Limnology and Oceanography: Fluids and Environments, vol. 3, pp. 1–20, DOI 10.1215/21573689-2071927.

Sudre J., Yahia H., Pont O. and Garçon V., 2015, Ocean turbulent dynamics at Superresolution from optimal multiresolution analysis and multiplicative cascade, IEEE transaction on geoscience and remote sensing, vol. 53, NO. 11, DOI 10.1109/TGRS.2015.2436431.

Characterising the meridional gradient in surface forcing on upper ocean submesoscales and its impacts on phytoplankton biomass in the Southern Ocean

SEB SWART[1], MARCEL D. DU PLESSIS[1], SANDY J. THOMALLA[1], PEDRO M.S. MONTEIRO[1]

[1] *Southern Ocean Carbon & Climate Observatory, Council for Scientific & Industrial Research, South Africa*

The vast expanse of the Southern Ocean can be seperated meridionally into various frontal regimes with an extreme north-south gradient in physical oceanographic properties and atmospheric conditions. These frontal zones exhibit distinctive seasonal cycles of phytoplankton biomass that may be dependent on the underlying physical drivers. These unique responses have direct implications for biogeochemical processes that are related to carbon uptake in the Southern Ocean. The region provides a prime test-bed to better understand the sensitivity of upper ocean dynamics to varying space and time scales of forcing. We therefore look to identify the role of submesoscale processes on mixed layer dynamics and how they are impacted by different surface forcing mechanisms. We characterise the stratification and dynamics of the mixed layer through the presence and interaction of fine scale features such as submesoscale eddies, fronts and meanders, as well as identifying the role that atmospheric forcing, such as storms that exert turbulent effects and heat flux variations, on the surface ocean. An unprecedented dataset obtained from a series of multi-month glider deployments, at different latitudinal extents of the Southern Ocean, provides high-resolution measurements of upper ocean physical and biogeochemical fields. Ancillary satellite reanalysis wind and net heat flux products provide the basis by which to test the relationship between the submesoscale field and surface forcing and their impacts on upper ocean stratification. The glider bio-opticsobservations allows us to assess the impact of mixed-layer processes on phytoplankton biomass in the upper ocean. Furthermore, the use of the Argo float array provides information of the influence of these observed fine-scale processes and ocean-atmosphere interactions at the basin scale.

Interaction between winds and fronts in shallow mixed layers in the Bay of Bengal during the summer monsoon

AMIT TANDON[1], SANJIV RAMACHANDRAN[1], AMALA MAHADEVAN[2]
[1] *Department of Mechanical Engineering, University of Massachusetts, Dartmouth, USA*
[2] *Woods Hole Oceanographic Institution, Woods Hole, USA*

The northern Indian Ocean plays a central role in the life cycle of the Indian monsoon. This region, however, is the source of large model biases in sea-surface temperature, mixed-layer depth, sea-surface salinity and barrier-layer thickness. Large scale models consistently yield mixed layers in this region that are deeper, saltier and colder than observed. Such biases limit the ability of numerical models to accurately represent the upper-ocean structure in the Bay, an understanding of which is essential to decipher the complex air-sea interactions during the monsoon. Motivated by these concerns, we perform idealized simulations of upper ocean fronts for conditions representative of the Bay during the summer monsoon months. The fronts lie within shallow, stratified layers in the upper tens of metres with horizontal density gradients significantly stronger than those typically considered in earlier investigations of upper ocean fronts. The simulated domain is a zonally periodic channel and the grid resolution is fine enough to permit submesocale eddies, thus enabling us to explore the dynamical consequences of submesoscale lateral variability on the vertical structure of the upper Bay. The simulations are forced with hourly winds and air-sea fluxes from mooring observations in the northern Indian Ocean. Simulations are conducted both with and without idealized precipitation within a localized region to simulate the effects of river water or precipitation, the key source of near-surface lateral density variability in the Bay. Using this idealized configuration, we examine the interaction between surface forcing and fronts, and their implications for submesoscale instabilities in the Bay during monsoon-like conditions. Our results show the presence of filaments with relative vorticity comparable to planetary vorticity and the formation of multiple stratification peaks at various depths, in agreement with recent shipboard observations. The stratification varies on the upfront and downfront sides of the salinity fronts. We compare and contrast these simulations for different mixing schemes.

Simulation of Submesoscale Coastal Procesesses by Coupling of Fully 3D Fluid Dynamics and Geophysical Fluid Dynamics Models

H. S. TANG[1], K. QU[1], A. AGRAWAL[1]

[1] *Department of Civil Engineering, City College of New York, City University of New York*

Coastal ocean flows involve various physical processes spanning at distinct scales and intertwining with each other, and now it is becoming necessary to develop capabilities to model such processes, especially those at submesoscales. In order to simulate these processes, we proposed a hybrid modeling system that is an integration of the Solver for Incompressible Flow on Overset Meshes (SIFOM), which is a fully 3D fluid dynamics model, and the Finite Volume Coastal Ocean Model (FVCOM), which is a geophysical fluid dynamics model [*Tang and Wu*, 2010; *Tang and Wu*, 2010; *Tang et al.*, 2014]. In the hybrid modeling system, SIFOM is employed to capture submesoscale, local processes, and FVCOM is used to simulate large-scale background flows. The integration deals with distinct governing equations, different numerical algorithms, and dissimilar computational grids, and it is two-way and realized using an overset-grid method and the Schwartz alternative iteration. As the first of its kind, the SIFOM-FVCOM system is able to simulate many multiscale and multiphysics phenomena that are beyond the reach of other exisiting models.

In this presentation, further numerical experiments will be given to validate the SIFOMFVCOM system and demonstrate its performance. Formulation for inclusion of buoyancy force is investigated, and two methods to treat such force are discussed, together with recommedation for one of them on the basis of their solution accuracy and computational efficiency. As an illustration of the system's capacity to deal with local processes, Largrangian particle tracking is presented to elucidate sensitivity of particle trajectory to such processes in flow within the Jamaica Bay. In addition, simulation of storm surge during the Hurricane Sandy is also shown to demonstrate the unparallel capability of the SIFOM-FVCOM system to simultaneously resolve large-scale surge currents as well as small-scale flow structure in high-fidelity and the resulting hydrodynamic load at bridge piers in the Hudson River.

REFERENCES

Tang H. S. and Wu X. G., 2010. CFD and GFD hybrid approach for simulation of multi-scale coastal ocean flow. *iEMSs 2010. Int. Congress on Environmental Modelling and Software. Fifth Biennial Meeting*, Ottawa, Canada, July 5-8, 2010. *Modelling for Environments Sake*, David A. Swayne,Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.).

Wu X. G. and Tang H. S., Coupling of CFD model and FVCOM to predict small-scale coastal flows, *J. Hydrodynamics*, ser. B, 22, 284-289.

Tang H.S., Qu K., and Wu X.G., 2014. An overset grid method for integration of fully 3D fluid dynamics and geophysics fluid dynamics models to simulate multiphysics coastal ocean flows. *J. Comput. Phys.*, 273, 548-571.

Submesoscale wrinkles on the ACC

John R. Taylor[1], Phil Hosegood[2], Jean-Baptiste Sallee[3], Kate Adams[2], Scott Bachman[1], Megan Stamper[1]

[1] *Department of Applied Mathematics and Theoretical Physics, University of Cambridge, UK*
[2] *School of Marine Science and Engineering, Plymouth University, UK*
[3] *University Pierre and Marie Curie, Paris VI, Paris, France*

We will present new observations, theory, and high-resolution numerical simulations of submesoscale features within the Antarctic Circumpolar Current (ACC). Observations were made as part of the SMILES project from April-May 2015 east of Drake Passage in the Scotia Sea. During the cruise, a large northward meander of the ACC was sampled at high resolution using towed bodies, surface drifters, microstructure, and dye release. Satellite imagery indicated the presence of submesoscale 'wrinkles' along the sharp temperature gradient associated with the ACC. Observations using a moving vessel profiler (MVP) will be shown which reveal rich three-dimensional structure associated with these features. A linear stability analysis and nonlinear numerical simulations, initialized with an idealized version of the observed front and ACC jet qualitatively reproduce the observed features. The numerical simulations allow us to quantify the vertical velocity associated with the submesoscale features, and their interaction with the strong barotropic jet associated with the ACC.

Meso and submesoscales in the tropics: observability from altimetric and modelled SSH

MICHEL TCHILIBOU[1], LIONEL GOURDEAU[1], FREDERIC MARIN[1], ROSEMARY MORROW[1]
[1] *LEGOS, Toulouse, France*

Meso and submesoscale dynamics are particularly studied in the mid latitudes where QG and SQG theories are well suited, and fewer studies exist in the tropics where such theories fail at the equator. The tropics are distinguishable from mid latitudes with a small Coriolis parameter vanishing at the equator, and large Rossby radius. These peculiarities are at the origin of a dynamic that strongly responds to the wind forcing through tropical waves propagating zonally, and of a large range of wavenumbers for meso and submesoscales interactions. The main tropical meso and submesoscales features are associated with Tropical Instability Waves (Marchesiello et al., 2011), but coherent vorticity structures also span the tropical band, as described by Ubelmann and Fu (2011). Such studies are based on modeled velocity analysis, and questions remain on the SSH signature of these tropical structures, and their observability with satellite altimetry. There is also a discrepancy in the spectral slope for wavenumber spectrum of SSH between altimetry and models in the tropics (Richman et al., 2012), and understanding this discrepancy, and the surface signature of these structures is of interest in the context of the next SWOT mission. In this poster, we revisit the meso and sub mesoscale dynamics in the tropics using 1/36° regional and 1/12° global resolution models of the tropical Pacific, and compare the modelled surface characteristics with an analysis of along track altimetric data. We focus on EKE and SSH signatures in different range of wavelengths. Their wavenumber spectra are computed in different dynamic boxes and the corresponding spectral slopes representative of the tropical meso-submesocales are evaluated. We attempt to discriminate between the geostrophic and ageostrophic components.

On the role of small-scale instabilities in the development of elliptic vortices

DANIEL THEWES[1], GUALTIERO BADIN[2], FRANCESCO RAGONE[3]
[1] *Institute of Oceanography, University of Hamburg, Germany*
[2] *Institute of Oceanography, University of Hamburg, Germany*
[3] *Laboratoire de Physique, ENS de Lyon, France*

In this study we analyse the stability and evolution of elliptical vortices making use of the surface semi-geostrophic approximation (SSG). Similar to the surface quasi-geostrophic (SQG) approximation, SSG assumes nonlinear advection of potential temperature at (one of) the boundaries (i.e. the sea surface) and constant potential vorticity in the interior. Differently from SQG, however, SSG assumes advection by the total (geostrophic plus ageostrophic) flow. The resulting equations differ from SQG for the presence of a transformation to geostrophic coordinates and for a nonlinear term that corresponds to the Okubo-Weiss parameter and that is responsible for enhancing strain and vorticity. The combined effect of the nonlinear term and the coordinate transformation are known to give rise to a cyclone/anticyclone asymmetry and to frontal structures. The relative importance of these two elements on the evolution of the vortices is investigated. As the small-scale instabilities are trapped to the sea surface, the evolution of the solutions is also explored as a function of depth. Solutions are compared with the solutions from SQG.

Observations of the evolving structure of an upwelling filament off Java during the 2006 Indian Ocean Dipole.

VISHNU THILAKAN[1], SAJI N HAMEED[1], DEBASIS SENGUPTA[2], HIDENORI AIKI[3]

[1] *Environmental Informatics, University of Aizu, Japan.*

[2] *Center for Atmospheric and Oceanic Sciences, Indian Institute of Science, India.*

[3] *Institute for Space-Earth Environmental Research, Nagoya University, Japan.*

Coastal upwelling off Java is a seasonal phenomenon with large impacts on regional biochemistry, ecology and climate. Although the strongest upwelling is narrowly confined to the coast, associated SST cooling occurs over a much broader spatial extent. This disparity of scales is often attributed to the effect of large scale oceanic processes such as horizontal advection or to modifications by air-sea heat fluxes. A preliminary examination of several ocean model simulations show that these simulations are unable to account for the disparity in scale between coastal upwelling and its SST signature, despite the aforementioned processes being present or included in the simulations.

Due to scarcity of insitu observations our understanding of the characteristics and mechanisms associated with this upwelling system is very limited. In addition persistent cloud cover is present in the vicinity of the upwelling region due to its location in the midst of the Indo-Pacific warm pool. This further limits estimates of SST from satellites to relatively cloud free periods. Cloudiness is signficantly reduced or absent during positive Indian Ocean Dipole (IOD) events and therefore IOD events present a rare window of opportunity for observing the fine scale SST structure from satellites.

Here we show for the first time the existence of upwelling filaments associated with the Java coastal upwelling zone and document their role in advecting upwelled waters several hundreds of kilometers offshore. Radiometer imagery of SST, satellite estimated absolute dynamic topography (ADT) and vertical ocean temperature profiles from ARGO buoys are used in concert with other anciliary data to describe the influence of upwelling filaments in the meridional transport of upwelled waters off Java during the initial phase of the 2006 Indian Ocean Dipole (IOD) event. During June and July of 2006, three upwelling filaments are clearly seen in SST and are associated with mesoscale warm ADT eddies to their immediate south. The strongest growth rate occurs for the filament in the middle and is associated with strong mesoscale deformation of negative ADT along the Java coast. The SST filaments have much smaller scale meso-scale features, with the upwelling signature have a width scale of 20-40 km. Examination of ARGO profiles suggest that the maximum isopycnal displacement associated with the upwelling front is about 60-80 m. Geostrophic currents estimated from ADT reveal the evolution of a sharp and intense frontal jet that advects upwelled waters about 1000 kms south of the coastal upwelling region. These new observations points to the importance of mesoscale-modulated transports in the upper-ocean heat budget of the equatorial eastern Indian Ocean.

High-resolution view of the spring bloom initiation and net community production in the Subantarctic Southern Ocean using glider data

SANDY THOMALLA[1,2], MARIE-FANNY RACAULT[3], SEBASTIAAN SWART[1,2], PEDRO MONTEIRO[1]

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

[2] *Department of Oceanography, Marine Research Institute, University of Cape Town, Rondebosch 7701, South Africa*

[3] *Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth, PL1 3DH, UK*

In the Southern Ocean there is increasing evidence that seasonal to sub-seasonal temporal scales, and meso- to submesoscales play an important role in understanding the sensitivity of ocean primary productivity to climate change. This drives the need for a high-resolution approach to resolving biogeochemical processes. In this study, 5.5 months of continuous, high-resolution (3 hourly, 2km horizontal resolution) glider data from spring to summer in the Atlantic Subantarctic Zone is used to investigate; 1) the mechanisms that drive bloom initiation and high growth rates in the region and 2) the seasonal evolution of water column production and respiration. Bloom initiation dates were analysed in the context of upper ocean boundary layer physics highlighting sensitivities of different bloom detection methods to different environmental processes. Model results show that in early spring (September to mid-November) increased rates of Net Community Production (NCP) are strongly affected by meso- to submesoscale features. In late spring / early summer (late-November to mid-December) seasonal shoaling of the mixed layer drives a more spatially homogenous bloom with maximum rates of NCP and chlorophyll biomass. Highly variable NCP in summer is driven by subseasonal storms that alter the depth of the mixed layer thus regulating iron and light requirements at appropriate time scales for sustained net autotrophy well into late summer (mid-February and beyond). This study highlights the need for future research and climate models to resolve both meso- to submesoscale and subseasonal processes in order to accurately reflect the phenology of the phytoplankton community and understand the sensitivity of ocean productivity to climate change.

Interactions between inertial oscillations and geostrophic flows in the upper ocean

Jim Thomas[1], Shafer Smith[1], Oliver Buhler[1]

[1] *Courant Institute of Mathematical Sciences, New York University, New York, USA*

We investigate theoretically and numerically different regimes for the interactions between storm-generated inertial oscillations and pre-existing geostrophic balanced flows. The regimes are characterized by the relative strength of the waves' dispersion, which can be strong, intermediate, weak, or very weak, depending on the relative magnitude of the Rossby number of the balanced flow and the Burger number of the inertial oscillations. A hierarchy of amplitude equations are derived for these different asymptotic regimes and these asymptotic predictions are then illustrated by numerical integration of the rotating shallow water system. Although this interaction problem has been considered by several others before, weak dispersion regime is the only asymptotic regime that has been previously explored. A major goal of this work is therefore to emphasis that the other regimes, not considered before, can contribute significantly to the overall picture of inertial oscillations being modulated by a mean flow in the upper ocean. This point is ascertained by considering a test problem — vertical propagation of inertial oscillations from the upper ocean after their generation. We show that if weak dispersion regime dominates over other regimes, vertical propagation of the waves can be faster and vice versa.

Estimates of submesoscale turbulence: Structure functions from ocean gliders

Andrew Thompson[1], Jörn Callies[2], Patrice Klein[3], Adrian Martin[4]
[1] *California Institute of Technology*
[2] *Massachusetts Institute of Technology*
[3] *IFREMER*
[4] *National Oceanography Centre, Southampton*

The characterization of turbulent processes in the ocean and atmosphere has benefited from the use of spectral or structure function methods. Recently, McCaffrey et al (2015) used the Argo profiling float network to calculate the turbulent properties of the ocean down to 2000 m depth at scales greater than 25 km using a structure function approach to account for the non-uniformity of the measurements in space and time. Here we present a similar analysis that probes ocean characteristics at spatial and temporal lags at submesoscales.

During the OSMOSIS field program, two ocean gliders continuously sampled a 15 km by 15 km domain from the surface to a depth of 1000 m in the northeast Atlantic for a full year. We use data collected by the OSMOSIS gliders to calculate second-order structure functions for a range of different properties, including density, potential vorticity and tracers, such as temperature and salinity on both pressure and density surfaces. Using both the gliders, a robust data set of observations exists that samples spatial separations between 1 and 20 km and temporal lags from 0.5 to 50 days. The structure functions show a distinct seasonal cycle in the upper ocean with variance enhanced at scales 5 km in the winter. There is a depth dependence in the slope of the structure functions. For instance, the buoyancy structure function has a slope of roughly 1 at a depth of 100 m in the winter, with the slope shoaling to a value closer to 2/3 below 500 m. Two dimensional structure functions for spatial separation and temporal lag will also be discussed. Preliminary results show a peak in the variance within the OSMOSIS domain at 25 days. These results will be compared with linear instability predictions calculated from the glider data as documented in Thompson (et al. 2016).

McCaffrey, K., B. Fox-Kemper and G. Forget, 2015. Estimates of ocean macro turbulence: Structure function and spectral slope from Argo profiling floats. J. Phys. Oceanogr., 45, 1773-1793.

Thompson, A.F., A. Lazar, C. Buckingham, A.C. Naveira Garabato, G.M. Damerell and K.J. Heywood, 2016. Open-ocean submesoscale motions: A full seasonal cycle of mixed layer instabilities from gliders. J. Phys. Oceanogr., in press.

Do submesoscale frontal processes ventilate the oxygen minimum zone off Peru?

Sören Thomsen[1], Torsten Kanzow[2], Francois Colas[3], Vincent Echevin[3], Gerd Krahmann[1], Anja Engel[1]

[1] *Physical Oceanography Dep., GEOMAR, Germany Kiel*
[2] *Physical Oceanography Dep., AWI, Germany Bremerhaven*
[3] *L'Ocean / RDI, France Paris*

The Peruvian upwelling system shows pronounced submesoscale variability and encompasses the most intense and shallowest oxygen minimum zone (OMZ) in the ocean. Making use of high-resolution glider-based observations carried out off Peru during austral summer 2013 we investigate whether submesoscale frontal processes do ventilate the near-surface Peruvian OMZ. We present observational evidence for the subduction of highly oxygenated surface water in a submesoscale cold filament. The observed subduction event in summer ventilates the upper oxycline but does not reach into OMZ core waters. Lagrangian diagnostics are used to study the pathways of newly upwelled water in a regional submesoscale permitting model. The model analysis suggests that the newly upwelled waters gain buoyancy due to surface heating in summer. Thus the subduction along isopycnals cannot reach into the density range of OMZ core. Contrary, in winter the absense of strong warming after the upwelling event allows ventilation along isopycnal to deeper depth compared to summer. Therefore submesoscale processes may ventilate the upper part of the OMZ core during winter. In the model about 50 % of the newly upwelled floats leave the mixed layer within 5 days emphasizing a hitherto unrecognized importance of subduction for the ventilation of the upper boundary of the Peruvian OMZ.

The impact of submesoscale eddies on particle transport and dispersion over the Texas-Louisiana shelf

KRISTEN M. THYNG[1], ROBERT D. HETLAND[1]

[1] *Department of Oceanography, Texas A&M University, USA*

Submesoscale eddies are present in the northwest Gulf of Mexico on the continental shelf during the low-wind summer months. These eddies develop within and along the edge of the Mississippi-Atchafalaya river plume; evidence from hydrography, numerical models, and satellite images shows that they dramatically alter the surrounding flow field. We investigate the impacts of the submesoscale shelf eddies on transport with a numerical circulation model of the region combined with a drifter model. The circulation model, run in ROMS, has high horizontal resolution and is set up to capture river plume dynamics on the continental shelf of Texas and Louisiana in particular. The drifter model calculates particle movement using saved model output. With this combined system, we run daily simulations of densely-packed surface drifters to investigate their trajectories and statistics over seasonal and interannual changes. The submesoscale eddies impact the flow by increasing dispersion. Additionally, these eddies increase cross-shelf transport of particles; an implication of this increase in transport include faster flushing of pollutants from the coastal region. We additionally compare the behavior seen in these realistic eddies with those of an idealized experiment meant to capture the fundamental eddy behavior. This allows us to characterize dispersion caused by eddies as a function of the relevant parameter space of the system.

Vertical mixing in a deep ocean channel in the central valley of the Mid-Atlantic Ridge

SANDRA TIPPENHAUER[1], TORSTEN KANZOW [1]

[1] *Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany*

Diapycnal mixing in the deep ocean is known to be much stronger in the vicinity of rough topography of mid-ocean ridges than over abyssal plains. In this study a microstructure probe attached to an autonomous underwater vehicle (AUV) was used to infer the spatial distribution of the dissipation rate of turbulent kinetic energy (ϵ) in the central valley of the Mid-Atlantic Ridge. This represents the first successful realization of a horizontal, AUV-based, deep-ocean microstructure survey. The study focused on a channel with unidirectional, partially supercritical sill overflow. The density was found to decrease along the channel following the mean flow of 3 to 8 cm/s. The magnitude of the dissipation rate was distributed asymmetrically relative to the position of the sill. Elevated dissipation rates were present in a segment 1 to 4 km downstream of the sill, reaching $1 \cdot 10^{-7}$ W/kg. Flow speeds of more than 20 cm/s and elevated density finestructure were observed within this segment. The average along-channel flow was found to be strongly modulated by the semi-diurnal M_2 tidal flow. Supercritical flow down the lee slope of the sill was observed during strong flow velocity conditions, and a hydraulic jump is expected to occur downstream of the sill during these phases. Consistently, upward displacement of isopycnals was observed in the area where the velocity distribution suggested the presence of a hydraulic jump. Indications for upstream propagating hydraulic jumps were found during phases of decreasing flow velocities. Upstream propagating hydraulic jumps offer a possibility of inducing turbulent mixing closer to the sill or even upstream of it. The distributions of the flow, density and mixing rate provide a consistent picture of the fundamental physical mechanisms controlling the mixing in this deep ocean channel, i.e. tidally modulated, jet unidirectional sill overflow with a hydraulic jump inducing turbulent mixing downstream. These results indicate deep-ocean mixing to depend heavily on the local bottom topography and flow conditions. Although one particular channel was studied, the fundamental physical mechanisms identified in this study are expected to be applicable to other, similar channels. Furthermore, the results nicely illustrate that horizontally-profiling AUV-based observations may be an efficient tool to study deep-ocean turbulence over complex terrain where free-falling and lowered turbulence measurements are inefficient and time-consuming.

The Region of Freshwater Influence (ROFI) in Mekong River

TU TRAN ANH[1], UU DINH VAN[2]
[1] *Institute of Marine Environment and Resources, VAST, Vietnam*
[2] *Hanoi University of Science, VNU, Vietnam*

The aim of the Vietnam - France cooperation project "Physical functioning of estuaries and coastal zone, marine optical properties and remote sensing applications" is to investigate the governing processes and the variability of the coastal processes off the big rivers in Vietnam. This region can be seen as a an excellent example for a region of freshwater influence (ROFI). Within the scope of this project ship experiments as well as model studies will be conducted in the ROFI. The results of first ship experiments, accomplished during a cruise in June 2014. The shallow region of the ROFI is characterized by a strong horizontal density gradient, which defines the frontal zone in the ROFI. This zone also represents the region of strongest vertical mixing. The results from model show that, in flood season, salinity profile is nearly linear and identically. In the river mouth, gradient of salinity and temperature is 1.937‰/m and 0.048oC/m, respectively. In dry season, in the outside, salinity is less affacted by the disorder process and it is nearly identically with value higher than 33.6‰. The different of salinity between surface and bottom layers is unremarkable while temperature showed the decreasing to depth with gradient is 0.016oC/m

The Region of Freshwater Influence (ROFI) in Mekong River

Tu Tran Anh[1], Uu Dinh Van[2]
[1] *Institute of Marine Environment and Resources, VAST, Vietnam*
[2] *Hanoi University of Science, VNU, Vietnam*

The aim of the Vietnam - France cooperation project "Physical functioning of estuaries and coastal zone, marine optical properties and remote sensing applications" is to investigate the governing processes and the variability of the coastal processes off the big rivers in Vietnam. This region can be seen as a an excellent example for a region of freshwater influence (ROFI). Within the scope of this project ship experiments as well as model studies will be conducted in the ROFI. The results of first ship experiments, accomplished during a cruise in June 2014. The shallow region of the ROFI is characterized by a strong horizontal density gradient, which defines the frontal zone in the ROFI. This zone also represents the region of strongest vertical mixing. The results from model show that, in flood season, salinity profile is nearly linear and identically. In the river mouth, gradient of salinity and temperature is 1.937‰/m and 0.048oC/m, respectively. In dry season, in the outside, salinity is less affacted by the disorder process and it is nearly identically with value higher than 33.6‰. The different of salinity between surface and bottom layers is unremarkable while temperature showed the decreasing to depth with gradient is 0.016oC/m

Submesoscale structures related to the series of upwelling events in the Gulf of Finland, numerical experiments

GERMO VÄLI[1], VICTOR ZHURBAS[1,2], URMAS LIPS[1], JAAN LAANEMETS[1]

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

[2] *Shirshov Institute of Oceanology, Russia*

The role of submesoscale processes in the Gulf of Finland was investigated using model simulations for series of upwelling events along the northern and southern coasts of the gulf in July–September 2006. The model applied is the Princeton Ocean Model. The horizontal step of the model grid is 0.5, 0.25 and 0.125 nautical miles in the gulf and reaches 2.0 nautical miles in the rest of the Baltic Sea; there are 60 $sigma$-levels in the vertical direction. The role of upwelled water salinity contribution to the strength of baroclinic upwelling front along the northern and southern coast and thereby to the dynamics of the Gulf surface layer was analyzed. Model results with refinement of the grid size to 0.125 nautical miles revealed two forms of submesoscale structures in the gulf's surface layer – high Rossby number threads (elongated spots where Ro>1 with typical width and length of 2–3 km and 10–50 km, respectively) and cyclonic eddies with Ro>1 core of diameter of 4–6 km. The high potential vorticity threads presumably formed during the development phase, while the cyclonic eddies during the relaxation phase of upwelling. One of the simulated submesoscale cyclonic eddies with the Ro>1 core extension as deep as 30 m and was traced for the period of 33 days.

Finite-element baroclinic multiscale model of the Columbia River plume

VALENTIN VALLAEYS[1], TUOMAS KÄRNÄ[2], ANTÓNIO M. BAPTISTA[2], ERIC DELEERSNIJDER[3,4], EMMANUEL HANERT[5]

[1] *Institute of Mechanics, Materials and Civil Engineering (IMMC), University of Louvain, Belgium*

[2] *Institute of Environmental Health (IEH), Oregon Health & Science University, OR, USA*

[3] *Institute of Mechanics, Materials and Civil Engineering (IMMC) & Earth and Life Institute (ELI), University of Louvain, Belgium*

[4] *Delft Institute of Applied Mathematics (DIAM), Delft University of Technology, The Netherlands*

[5] *Earth & Life Institute (ELI), University of Louvain, Belgium*

Unstructured grid models allow highly flexible spatial discretization and therefore accurate representation of complex phenomena, such as the hydrodynamics in Regions Of Freshwater Influence (ROFI) of large rivers, characterized by large density variations, rapid flow dynamics and complex topography. The whole river-sea continuum can therefore be simulated seamlessly.

The complex interactions between tides, river inflow and ocean dense waters in shallow areas lead to strong density gradients and rapid currents, often difficult to handle in a numerical model. Many models tend to stabilize the computations by adding diffusion, leading to overly-smoothed fronts.

The aim of this study is to analyze the baroclinicity of the SLIM model. SLIM 3D is a baroclinic discontinuous Galerkin finite element model. It has so far only been used to model very shallow areas, such as an idealised Rhine ROFI or subregions of the Great Barrier Reef. The ability of stabilizing the density field by adding as less diffusion as possible is assessed through two different test cases.

We first analyze the performance of the SLIM model on the lock-exchange test case. As coastal waters feature strong density gradients, the baroclinicity needs stabilization. Therefore, we study the use of different limiters.

We then analyze the plume of the Columbia River as simulated with SLIM in two different regimes of the Columbia River ROFI. The horizontal structure is discussed and compared to another model of the region based on SELFE. The key features of the simulated plume in different regimes are also discussed.

Direct simulation of mesoscale and submesoscale eddy influences in the Antarctic Circumpolar Current using MPAS-Ocean

LUKE VAN ROEKEL[1], TODD RINGLER[1], MILENA VILENZIANI[1], JUAN SAENZ[1], PHILLIP WOLFRAM[1]

[1] *Los Alamos National Laboratory*

The impacts of submesoscale and mesoscale eddies on ocean circulation has been extensively studied. However, these studies often consider the impact of these eddies on the large-scale ocean separately. Simulating the interaction of these eddies is fairly challenging, as it requires resolution of disparate scales (O(1km) and O(10km) respectively). Here we utilize the Model for Prediction Across Scales-Ocean (MPAS-Ocean) to address this issue. MPAS-Ocean utilizes a horizontally unstructured mesh based on spherical centroidal voronoi tessellations, which allows for variability of horizontal resolution within a domain. MPAS-Ocean is applied to a zonally symmetric domain that captures the climatology of the Antarctic Circumpolar Current (ACC). Two simulations are conducted, in both the model resolves the first Rossby radius of deformation everywhere in the domain and only one contains a region of high resolution in the ACC that resolves submesoscale eddies. The results are presented utilizing the Eliassen Palm Flux Tensor (EPFT) framework to elucidate the influence of each scale of eddy on the mean flow and possible interactions. Further, the EPFT framework allows for a diagnosis of the diffusivity of PV due to submesoscale and mesoscale eddies. Uncertainties in the results due to the choice of sub-grid parameterizations (in particular vertical mixing) are also discussed.

Subtidal variability of river plumes off central Portugal in winter 2013: event scale simulation

NUNO VAZ[1], JOÃO G. RODRIGUES[1], MARCOS MATEUS[2], GUILHERME FRANZ[2], FRANCISCO CAMPUZANO[2], RAMIRO NEVES[2], JOÃO M. DIAS[1]

[1] *CESAM, Physics Department, University of Aveiro, Portugal*

[2] *MARETEC, Instituto Superior Técnico, University of Lisbon, Portugal*

As the largest estuary on the Iberian coast, the Tagus Estuary (TE) has a significant impact on coastal hydrography, circulation and ecology off central coast of Portugal. The TE plume is thought to play an important role in the region, by altering stratification, nutrient and circulation patterns on the adjacent coast. Previous research of the TE plume mainly relied on in-situ observations or on satellite imagery data, both limited in space and time. As a result it is difficult to obtain a full description of the TE plume propagation on synoptic time scales, especially in the plume front.

In order to overcome this, a numerical model implementation is used to study the TE buoyant plume propagation and its impact in coastal circulation and hydrography in the region of influence of Tagus estuary. The numerical implementation is based on the model MOHID (www.mohid.com) and comprises the region of the Tagus estuary and the near coast. In this study, subtidal variability of the surface plume response to local wind and river runoff is studied. Also, predicted surface structure of velocity, salinity and water temperature is analyzed for a period from March 20 to April 11, 2013, when this region was under a storm influence, where intense southern winds and high river discharge induces an intense alongshore propagation of the TE plume. The main focus is given to the derivation of the TE plume main features on synoptic time scales and its impacts on near coastal circulation and hydrography. To compute the contribution of the main forcing in the TE plume propagation Self Organizing Maps (SOM) are used.

It was found that river runoff and wind induce strong variability in the coastal ocean, and that the TE plume has a rapid response to changes in the main forcing. Under high river discharge, there is an alongshore northward propagation of the TE plume, corresponding to a frequency of occurrence of about 50%. However it is also noticeable a southern propagation of the plume during short favorable upwelling and downwelling wind events, revealing a dominance of the river discharge over the wind in establishment the TE plume dispersion. The same is found during transitional periods, revealing a significant influence of the plume both north and south of the estuary mouth. The TE plume presents some bi-directional features even during extreme downwelling conditions, where the estuarine outflow tend to be advected both northward and southward as a consequence of the high estuarine discharge and also by the shelf waters advection effect that induces a southward prpagation of estuarine waters.

Mesoscale variability in the arid-steppe zone of Caspian Lowland: observation and modeling

NATALIA VAZAEVA[1,2], OTTO CHKHETIANI[1,3], LEONID MAKSIMENKOV[1]
[1] *A.M.Obukhov Institute of Atmospheric Physics, Russian Academy of Science, Russia*
[2] *Moscow State Technical University named after N.E. Bauman, Russia*
[3] *Space Research Institute, Russian Academy of Science, Russia*

The motions similar to Langmuir circulations are observed in the Atmospheric Boundary Layer (ABL). As a result of this motions the large-scale structures such as mesoscale cellurar convection and roll (also referred to as band, or cloud street) those are of great importance in the heat, water and other substance transfer process through ABL are generated. In this work the case study investigation of the arid-steppe zone of the south of Russia in the Chernozemelski district of Kalmykia (in Caspian Lowland) based on experiment data obtained by the sodar, temperature profiler, meteostation, and the comparison with the theoretic estimates, satellite and re-analysis (ECMWF) data, large-eddy simulation findings of the Weather Research and Forecasting model (WRF) were carried out. The particular part of the research is devoted to the helicity. It is the useful diagnostic characteristics of a number of geophysical and astrophysical flows. The role of helicity in atmospheric and ocean large-scale dynamics and its possible prognostics sense attracts permanent interest. There is a good correlation between the integral helicity obtained on ABL acoustic sounding experiment data (Kalmykia (2007) with the square of the wind velocity on the higher sounding levels (400-800 m) in slightly unstable or neutral stratification conditions. The generation, evolution and destruction of the roll circulation and the nocturnal low-level jet events were observed during field study. The mean value for the large-scale motions helicity density were obtained (0.3-0.4 m/sec2). The helicity is appreciably higher during the nocturnal low-level jet events - up to 0.8 m/sec2. The layer average helicity in the ABL is closed to estimates of turbulent helicity (0.02-0.12 m/sec2). The large-eddy simulation findings describe the meteorological situation in the exploration area with a reasonable degree of accuracy. The authors are grateful to M.V. Kurgansky for his constructive comments and interest in this work. This study was supported by the Russian Science Foundation (projects N°14-17-00124, N°14-17-00806).

SIZE FRACTIONATED PHYTOPLANKTON STRUCTURE ACROSS A COASTAL FRONT IN THE COASTAL UPWELLING ZONE OFF CENTRAL-SOUTHERN CHILE

ELIANA VELASCO VINASCO [1,2,3], CAMEN MORALES [2,4], SAMUEL HORMAZABAL [2,5], VALERIA ANABALÓN [2,6]

[1] *Postgrado en Oceanografía, Universidad de Concepción, Concepción, Chile.*
[2] *Instituto Milenio de Oceanografía (IMO), Concepción, Chile*
[3] *Grupo de Investigación en Ciencias Oceanográficas, Universidad del Valle, Cali, Colombia*
[4] *Departamento de Oceanografía, Universidad de Concepción, Concepción, Chile*
[5] *Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Chile*
[6] *Instituto de Oceanografía y Cambio Global, Universidad de las Palmas de Gran Canaria, España*

Submesoscale features such as fronts are found off central-southern Chile, a region characterized by seasonal wind-driven coastal upwelling, defined as areas of sharp gradients in physical properties (e.g. temperature, salinity and density) at the surface; usually limits the active upwelling region and may act as a boundary between coastal and adjacent oceanic region. These structures are known to promote alterations in the size structure of phytoplankton communities; however the results may be variables. Based on this, we examine the potential role of front located between in the upwelling zone off central-southern Chile (36°30'S, 36°45'S) in the size fractionated phytoplankton structure during February 2014. The front was well defined by clear gradients in surface temperature (2°C). Water masses in the upper 100 m to the east of the front were saline (>34.3) and cool (<13°C) as typical for coastal area where upwelling occurs. West of the front, low salinity (<34) and warmer waters (>17°C) were evident. Depth- averaged total chlorophyll-a (Chl-a T) varied by a factor of 5 (0.34-1.69 mg m-3) and size fraction biomass: Microplanktonic (Chl-a M) varied almost 15-fold (0.05-0.76 mg m-3), Nanoplanktonic (Chl-a N) by 3.3 (0.24-0.78 mg m-3) and Picoplanktonic (Chl-a P) by 11.3 (0.04-0.45 mg m-3) from the coast to the ocean across a coastal front. Previous studies of the frontal feature in other upwelling system, showing strong frontal enhancement of phytoplankton biomass with a dominance of large-sized cells or microphytoplankton; however in this study the microplanktonic fraction recording the lowest values both biomass (<0.3 mg m-3) and percentage contribution (<20%) in these zones, increased from the frontal to oceanic zone. An important aspect of upwelling fronts is their periodic relaxation or breaching, this can occur by the intermittent upwelling (active/relax events) and interaction with eddies and filaments. The interaction of the frontal zone with these features of submesoescala could be the cause of the subsequent release into offshore water of microphytoplankton fraction previously accumulated in the coastal water and so increasing this fraction on the ocean side. The total phytoplankton biomass was dominated by nanoplankton fraction (>40%) from the coast to the ocean, and was particularly prominent in the frontal zone (>70%). An increase of the picoplankton fraction (20 to 40%) was observed in the coastal zone of the front, probably by a predominance of phototrophic cyanobacterias, particularly Synechococcus which is small but grows efficiently in the cold (<15°C), high nutrient surface waters. These differences would lead

us to believe that frontal formation mechanisms or community responses to fronts are sufficiently varied to require substantial research to understand their differences, as well as the overall contributions to local ecology in this zone of study

Seasonal Variability of the Oxygen Minimum Zone off Peru in a high-resolution regional coupled model

OSCAR VERGARA[1], BORIS DEWITTE[1], IVONNE MONTES[2], VERONIQUE GARÇON[1], MARCEL RAMOS[3], AURÉLIEN PAULMIER[1], OSCAR PIZARRO[4]

[1] *Laboratoire d'Études en Géophysique et Océanographie Spatiales, CNRS/CNES/UPS, UMR5566, Toulouse, France*

[2] *Instituto Geofísico del Perú (IGP), Lima, Perú*

[3] *Centro de Estudios Avanzado en Zonas Áridas (CEAZA), Coquimbo, Chile*

[4] *Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Concepción, Chile*

In addition to hosting one of the most productive upwelling systems, the oceanic region off Peru is embedded in one of the most extensive Oxygen Minimum Zone (OMZ) of the planet. The dynamics of the OMZ off Peru remains uncertain in part due to the scarcity of data and the intricate diversity of processes involved. Here we use a high resolution coupled physical-biogeochemical model to investigate the seasonal variability of OMZ off Peru. The focus is on characterizing the climatological regimes in dissolved oxygen within the OMZ associated to the coastal zone and to the off-shore ocean, considering that the former undergoes the direct influence of the equatorial and local wind forcings, whereas the latter is inherently linked to the turbulent flow (mesoscale activity) and the mid-depth circulation. Along the coast, seasonal events of oxygenation (relative maximum of dissolved O2 concentration 18 μM at the OMZ core) are observed during Austral winter, and result from the competing effects of the seasonal wind induced upwelling, which would tend to decrease the O2 content, and the intraseasonal wind-activity induced mixing that favors an O2 increase. Off-shore, the OMZ can be divided in two regions: an upper zone above 400m where eddy O2 flux is dominant and varies seasonally, and a lower part where O2 flux results from the vertically propagating variability associated to the seasonal extra-tropical Rossby wave. At the northern and southern boundaries of the OMZ, the eddy O2 flux exhibits a marked seasonal variability, which can explains the seasonal expansion/contraction of the OMZ. Implications for understanding the long-term trend in OMZ variability are discussed.

Deep submesoscale dynamics near the Mid-Atlantic Ridge

CLÉMENT VIC[1], JONATHAN GULA[1], GUILLAUME ROULLET[1]

[1] *Laboratoire d'Océanographie Physique et Spatiale, UMR 6523 UBO-CNRS-Ifremer-IRD, Brest, France*

This work is a contribution toward a consistent dynamical view of the structure of deep currents near strong topographic features from the meso- to the submeso-scale. We focus the study on a region surrounding the Lucky Strike hydrothermal source, located on the Mid-Atlantic ridge (32.28°E, 37.30°N). Lucky Strike is a unique place for deep ecosystems to develop, well monitored by a European Observatory (EMSO). A key biological motivation is the connectivity, namely the determination of how the species can be spread over long distances by currents. We therefore focus our study on the dispersion with the goal of resolving as much turbulence as possible, and in particular the turbulence generated by interaction with the topography. We use ROMS with a technique of one-way nesting that allows to increase sharply the resolution from an Atlantic simulation ($\delta x \sim$6 km) to a near-site simulation ($\delta x \sim$250 m). The tide, quite important along the ridge, is included. Overall, the simulations are done in a state-of-the-art manner. They reveal a deep ocean filled with submesoscale eddies. We present the distinguished role of tide vs. submesoscale turbulence in the dispersion. We also report on the consequences of this submesoscale production in terms of bottom energy dissipation.

Classification of Submesoscale Instabilities in the Antarctic Circumpolar Current using Seagliders

GIULIANA A. VIGLIONE[1], ANDREW F. THOMPSON[1], JANET SPRINTALL[2], SEBASTIAAN SWART[3]

[1] *ESE/GPS, Caltech, USA*

[2] *CASPO, Scripps Institution of Oceanography, USA*

[3] *NRE, Council for Scientific and Industrial Research, South Africa*

Submesoscale motions influence vertical velocities in the upper ocean and are thought to generate flows that penetrate the strong, persistent buoyancy gradients found at the base of the mixed layer. These strong velocities are not currently captured by large-scale ocean models, but may influence fluxes of gases, nutrients, and heat between the mixed layer and the deeper ocean. Despite the importance in setting global transport, studies of submesoscale motions in the Antarctic Circumpolar Current (ACC), which is key in setting inter-ocean exchanges, have been limited due to a lack of observations.

During the ChinStrAP (Changes in Stratification at the Antarctic Peninsula) project, two Seagliders were deployed northwest of the Antarctic Peninsula over a period of four months, providing an unprecedented data set to investigate submesoscale phenomena in this region. Over 40 distinct hydrographic sections and 1400 profiles were collected across the continental shelf break and used to calculate the lateral buoyancy gradients and potential vorticity (PV) over an entire austral summer season and into the early fall. The balanced Richardson angle (the ratio of the vertical to lateral buoyancy gradients) is used to classify submesoscale instabilities (PV < 0), including instances of gravitational, symmetric, and centrifugal instability.

Significant differences in the PV, lateral buoyancy gradients, and relative contributions of temperature and salinity to the stratification occur downstream and upstream of Shackleton Fracture Zone (SFZ), a significant bathymetric feature off the Peninsula. This suggests a difference in both the dynamics and the water masses in these regions. Although the mean mixed layer depth both upstream and downstream is roughly 40m, a significantly higher fraction of the mixed layer is unstable upstream of SFZ than downstream of the ridge (negative PV in 33% vs. 25% of the mixed layer).

Submesoscale motions are also found to play a significant role in modulating the near surface stratification at this key location for the ventilation of deep density classes. Atmospheric reanalysis data are analyzed to examine changes in mixed layer depths in response to varying mechanical and buoyancy forcing. Down-front winds, which have been shown to destroy stratification, occur in this region the majority of the time. The results emphasize the significant role that submesoscale motions play in modulating the near-surface stratification at a key location for the ventilation of deep density classes.

Turbulence in the Strait of Sicily from microstructure measurements

ANDA VLADOIU[1], PASCALE BOURUET-AUBERTOT[1], YANNIS CUYPERS[1], BRUNO FERRON[2], KATRIN SCHROEDER[3], MIRENO BORGHINI[4], STEPHANE LEIZOUR[2], HARRY BRYDEN[5], SANA BEN ISMAIL[6]

[1] *LOCEAN, UPMC, Paris, France*

[2] *LPO, Ifremer , Plouzan, France*

[3] *ISMAR, Venice, Italy*

[4] *ISMAR, Lerici (SP), Italy*

[5] *Ocean and Earth Science, Southampton, United Kingdom*

[6] *Institut des Sciences et Technologies de la Mer, Tunis, Tunisia*

The Strait of Sicily is a relatively narrow and shallow sill that connects the Western and Eastern Mediterranean Basins. The mean circulation is characterised by a south-eastward surface flow (consisting of Mediterranean Atlantic Water) and a north-westward flow at depth (consisting of Western Intermediate Water, Levantine Intermediate Water and Cretan Intermediate Water). The dynamics also shows a strong variability at meso and submesoscale, with eddies as well as instabilities related to the cascading of eastern denser water through narrow canyons. It is also a unique region of the Mediterranean Sea, with strong internal tide generation. The consequence is a rich set of scale interactions, with strong currents, eddies and internal waves, resulting in strong turbulence.

The purpose of this study is to characterise turbulence and mixing in the Strait of Sicily, how they relate to dynamical processes at meso and submeso scales and the consequences on watermass transformations. Our analysis is based on microstructure measurements collected at two deep passages of about 500m depth during four cruises at different seasons (Ferron et al., 2016).

At the southern location turbulent kinetic energy dissipation rates (ε) are smaller than at the northern location, which is situated on a steeper slope donwstream of a very narrow sill. While ε tends to decrease with depth, from $\sim 10^{-8}$ to $10^{-12}Wkg^{-1}$ at the southern location, the range of ε values at the northern location does not vary significantly as a function of depth, with a mean of $\sim 10^{-7}Wkg^{-1}$. We show that these discrepancies between the two locations result from the influence of the complex bathymetry on the flow. Repeated measurements over half a tidal cycle reveal that the governing processes are both shear instability and internal wave breaking. Measurements in a canyon downstream of the northern steep topography towards the deeper Tyrrhenian Sea reveal turbulence enhancement as a result of dense water flow instabilities.

Turbulence in the Strait of Sicily leads to significant water mass transformations with diapycnal diffusivities of the order of $10^{-5} - 10^{-4}m^2s^{-1}$ for eastern intermediate waters.

A wave-wave parameterisation is proposed for ε. The best agreement with the observed dissipation rate is obtained at the southern location where turbulent mixing is mostly driven by internal tide and baroclinic near-inertial waves breaking. Instead, at the northern location, shear instabilty of the mean flow is a significant process for the onset of turbulence.

REFERENCES

Ferron, B. et al. Dissipation rates, mixing, geothermal heating and the overturning circulation of the Western Mediterranean Basin. In preparation

Observations of physical and ecological processes at the sea-ice edge and the meltwater front

WILKEN-JON VON APPEN[1], THORBEN WULFF[1], EDUARD BAUERFEIND[1]

[1] *Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany*

The marginal ice zone and the meltwater front of a moving ice edge in the Fram Strait were investigated with an Autonomous Underwater Vehicle (AUV) in 2013. The AUV was equipped with physical and biogeochemical sensors to study the complex interaction between physical processes and ecological responses along the ice edge. The AUV covered two cross-front sections of 9 km length each and recorded high resolution vertical profiles of the physical and biogeochemical properties between 0 and 50 m water depth and at a horizontal station spacing of 800–1000 m. In both physical and biogeochemical terms, the measurements revealed a complex structure of the water column. The distribution of phytoplankton and nutrients was highly inhomogeneous. Chlorophyll *a* concentrations of 5 μg l^{-1} were detected at the frontal interface in a small corridor just 2–4 km wide and only 5 m deep. Nutrients at the surface were depleted, but still present in the euphotic zone. Below the euphotic zone, nitrate concentrations of 8 μmol l^{-1} and oxygen saturation values of 100% resulted in a “dome-like” pattern—suggestive of vertical transport processes. Based on these measurements, four different zones featuring individual biogeochemical characteristics could be identified in the cross-front sections. The atmospheric forcing and the evolution of the ice cover contributed to the complexity of the water column. Submesoscale dynamics seem to have resulted in large scale upwelling as well as more localized upwelling and downwelling. Furthermore, frontogenesis likely contributed to vertical water movements at the meltwater front. The effect of these processes on the ecological conditions is explored.

We will also discuss the capabilities of a new towed undulating system which is equipped with sensors to measure most relevant physical and biogeochemical properties in the water column. The system is towed horizontally offset outside of the ship’s wake and can be used in open water as well as in light and medium sea-ice. We present plans for studies on physical-biological interactions in the marginal ice zone.

An asymptotic model for the coupled evolution of quasi-geostrophic flow and near-inertial waves

Gregory L. Wagner[1], William R. Young[2]
[1] *Department of Mechanical and Aerospace Engineering, University of California, San Diego, USA*
[2] *Scripps Institution of Oceanography, University of California, San Diego, USA*

We present an three-component asymptotic model that describes the nonlinear and coupled evolution of near-inertial waves, quasi-geostrophic flow, and near-inertial second harmonic waves with frequency near $2f_0$, where f_0 is the local inertial frequency. Two conservation laws of the three-component model imply that near-inertial waves forced by winds, tides, and flow-topography interaction can extract energy from mesoscale nearly-balanced fronts and currents. A second and separate implication of the three-component model is that quasi-gesotrophic flows can catalyze a loss of near-inertial energy to freely propagating waves with near-$2f_0$ frequency. These newly-produced near-$2f_0$ waves propagate rapidly in the vertical and transfer energy back to near-inertial waves with very small vertical scales. The upshot of this two-step process is a mechanism whereby quasi-geostrophic flow catalyzes a nonlinear cascade of near-inertial energy to the small scales of wave breaking and diapycnal mixing.

The submesoscale “wine-glass effect” concentrates particle export and biogeochemical fluxes

ANYA WAITE[1], LARS STEMMANN[2], ANDY HOGG[3], LIONEL GUIDI[4], PAULO CALIL[5]

[1] *Alfred Wegener Institute Helmholz Centre for Polar and Marine Research, D-27570 Bremerhaven, Germany*

[2] *Observatoire Océanographique de Villefranche , Villefranche-sur-Mer, BP 28 06234 France*

[3] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200 Australia*

[4] *Observatoire Océanographique de Villefranche , Villefranche-sur-Mer, BP 28 06234 France*

[5] *4Instituto de Oceanografia, Universidade Federal do Rio Grande (FURG), Brazil*

The vertical flux of organic particles from surface waters is a key factor determining the dynamics and export of CO2 in the ocean. We show that the sinking trajectory of organic particles within anticyclonic mesoscale eddies is deflected normal to the horizontal mean flow, at an angle set by ratio of particle sinking speed and the residual horizontal (ageostrophic) velocity. This results in a sub-mesoscale “wine-glass effect” where particles sink downwards in a curve towards the centre of the eddy. We show that the curve of the wine glass becomes less pronounced with increasing particle-sinking rate, thus the steepness of the wine glass increases with particle size. This is the first demonstration that the ratio between individual particle settling speed and ageostrophic forcing sculpts sub-surface particle concentrations within mesoscale features in the ocean. The wine glass effect is likely to concentrate biogeochemical processes within eddies, particularly particle degradation and remineralization. It will also mediate up to a 7 X local increase in vertical carbon fluxes via aggregation-mediated flux increases driven by local concentration peaks.

Carbon export at a shelf break front

Noah Walcutt[1], Meg Estapa[2], Colleen Durkin[3], David Nicholson[4], Roger Kelly[1], Melissa Omand[1]

[1] *Graduate School of Oceanography, University of Rhode Island*
[2] *Skidmore College*
[3] *Moss Landing Marine Laboratory, SJSU*
[4] *Woods Hole Oceanographic Institution*

The shelf break front in the Mid-Atlantic Bight is a region of enhanced mixing, productivity and variability over horizontal scales of 1 to 20 km. While submesoscale processes are likely to influence sinking carbon export at the front, observing and quantifying these impacts remain a tremendous challenge. A 5-day pilot cruise conducted in November 2015 and supported by the Rhode Island Endeavor Program, allowed us to test and compare multiple platforms that may be useful for measuring sinking export, particles and physical parameters over these small scales. A wire-walker, a neutrally buoyant sediment trap and a surface-tethered array (each equipped with carbon and particle-preserving traps), were co-deployed within 1 km, while a Slocum glider and the R/V Endeavor made nearby transects. Here we present preliminary data from this cruise.

The Influences of River, Wind, Wave, and Current on Sediment Transport Processes in coastal Louisiana, Fourleague Bay

JIAZE WANG[1], KEHUI XU[1,2], SAMUEL J. BENTLEY[2,3], GIANCARLO RESTREPPO[3]

[1] *Department of Oceanography and Coastal Sciences, Louisiana State University,Baton Rouge, Louisiana, 70803, USA*

[2] *Coastal Studies Institute, Louisiana State University,Baton Rouge, Louisiana, 70803, USA*

[3] *Department of Geology and Geophysics, Louisiana State University, Baton Rouge, Louisiana, 70803, USA*

Building land with a rising sea is a challenging problem in many major deltaic systems around the world. The Atchafalaya deltaic area is one of only a few growing sites in Louisiana coast. In order to better understand the far-field dispersal and deposition of fine sediments in the Atchafalaya system, two tripods were used to study the hydrodynamics and sediment dynamics at two stations in Fourleague Bay, which are 15 km southeast of Atchafalaya Delta. One tripod was located at the middle of the bay, and the other was near the marsh edge. Six sensors including OBS (Optical Backscatter Sensor) 3A, OBS 5+, ABS (Acoustic BackScatter sensor), ADV (Acoustic Doppler Velocimeter) Ocean, Argonaut ADV, and two wave gauges were deployed in the early summer and winter of 2015 for a month, respectively, with an extra one month flood season deployment in February, 2016. Our study was focused on the near-bed sediments transport to wetlands under fair weather, event condition, and also Mississippi river flood season. Based on the seasonal surface suspended sediments concentration (SSC), salinity, as well as turbidity, wave and current data, we have investigated the bottom boundary layer sediments dynamics, in order to illustrate sediments deposition and erosion processes under fair weather, energetic conditions and flood season in the bay. During an energetic event in the early summer 2015, strong southeasterly wind waves carried salty water from inner Louisiana shelf northwestward into the bay, and led to increasing water level, wave height, bottom shear stress, salinity, and near-bed turbidity. After the event, there was apparent decreasing of these parameters. During the abnormal river flood season deployment in winter 2015, a buoyant plume of sediments above the sea bed was observed in the bay. SSC data in the bay showed an increasing trend since April, which is probably related to the fine sediment dispersal from the deltaic area due to the river flow. Further simultaneous satellite data would be analyzed to help better understand the dynamic sediments dispersal process in the water surface. These onshore and alongshore transport events play a key role in trapping fine grained sediments not only near the sea bed, but also in the water surface, thus building land in coastal Louisiana. Besides, our observation results also provide valid information for the coastal dynamic modeling work.

Implications of spatially varying boundary layer turbulence at a frontal system

JACOB O. WENEGRAT[1], MICHAEL J. MCPHADEN[2]

[1] *Earth System Science, Stanford University, USA*

[2] *PMEL, National Oceanic and Atmospheric Administration, USA*

Turbulent momentum mixing is a central component of the dynamics of the ocean surface boundary layer. At submesoscale fronts, the presence of baroclinic shear and boundary layer turbulence drives secondary circulations that have implications for both near-surface physics and biology. However, despite the known spatial inhomogeneity of boundary layer turbulence, mathematical considerations generally require that theoretical treatments assume uniform viscosity, limiting their completeness. This work presents an approximate analytic solution to the turbulent thermal wind model that admits more physically realistic fields than previously possible, and illustrates how horizontal and vertical variations in boundary layer turbulence will modify currents in the near-surface layer. The solution shows how vertical structure in turbulent viscosity modifies horizontal flows, both within the surface Ekman layer as well as in the deep limb of the ageostrophic secondary circulation, with concomitant modifications of fluxes in the near-surface layer. Horizontal structure in vertical turbulent viscosity drives near-surface vertical velocities, active even in the presence of a spatially uniform forcing. These theoretical results will be discussed in the context of observations and numerical models of submesoscale fronts, as well as in relation to other frictional processes occurring in the boundary layer, such as those arising in response to wind stress and surface gravity waves.

HOW UNSTEADY WINDS CAN FUEL PHYTOPLANKTON BLOOMS AT SUBMESOSCALE FRONTS

D B WHITT[1], J R TAYLOR[1], M LEVY[2]
[1] *DAMTP, University of Cambridge, UK*
[2] *LOCEAN, Université Pierre et Marie Curie, FR*

Observations and models suggest that upper-ocean fronts sometimes exhibit higher chlorophyll, more biomass and/or different plankton community composition at and/or below the surface in a narrow region localized to the front. However, the dynamics that lead to biogeochemical anomalies at fronts are not fully understood.

I will present some results from an ongoing numerical process study of how the unsteady part of the wind stress frequency spectrum sustains anomalous nutrient fluxes and plankton biomass at fronts. A series of experiments with a primitive-equation model of a wind-forced submesoscale front coupled to a four-component ecosystem model illustrate a synergistic interaction between stronger low frequency (sub-inertial) and weaker high frequency (near-inertial) parts of the wind stress at the front. In this scenario, the addition of a weak high-frequency stress to a strong low-frequency stress leads to a qualitative change from deep biomass maximum to surface bloom isolated to the front, when neither frequency component of the stress would induce a bloom without the other. Moreover, the sensitivity of the biogeochemistry to the high-frequency part of the stress increases super-linearly in both the amplitude of the high frequency and low frequency parts of the stress. Special attention will be paid to the latter result, which implies that the percentage increase in biomass due to the high-frequency part of the stress can increase as the percentage of the total wind stress variance in the high frequencies decreases.

Seasonal and interannual variability of the Chesapeake Bay bio-physical plume and its response of to potential climate change

MENG XIA[1], LONG JIANG[1]
[1] *University of Maryland Eastern Shore*

Chesapeake Bay, a drowned river valley on the east coast of Unites States, is one of the largest and most productive estuaries on the North American Continent. Towards establishing a mechanistic approach to study the biophysical controls on phytoplankton outflow plume in Chesapeake Bay, we implemented a tridimensional hydrodynamic-biogeochemical model, the offline linked Finite Volume Coastal Ocean Model-Integrated Compartment Model (FVCOM-ICM), for the estuary, which showed acceptable model skill in simulating salinity, suspended solids, nutrients, dissolved oxygen and chlorophyll-a. In a 10-year simulation period (2003-2012), the modeled surface structure of the Chesapeake Bay phytoplankton plume was compared with the Moderate Resolution Imaging Spectroradiometer (MODIS) data for chlorophyll-a on-board the NASA Earth Observing System (EOS) Aqua satellite. Then we analyzed the seasonal and interannual variability of the phytoplankton outflow plume and investigated the relative roles of wind forcing, river discharge, nutrient loading and total suspended solids in driving the plume direction, size and structure. Sensitivity experiments of various climate forcing were conducted in a 15-day spring-neap tidal cycle to investigate the plume response. The precipitation pattern, although usually difficult to project, could exert strong influence on the watershed runoff streamflow, and the plume; we increased and decreased the discharge and nutrient loading based on the latest climate models, and simulated its regulation on the phytoplankton plume signature. The plume structure was also examined under various wind magnitudes and directions. Moreover, we increased the longwave radiation and the sea level according to the latest carbon dioxide concentration scenarios projected by the International Panel on Climate Change (IPCC). In addition, the tidal regime is subject to changes under climate change; the amplitude of all tidal components was adjusted to delineate the tidal impacts on the Chesapeake Bay salinity/phytoplankton plume.

Characteristics, vertical structures and heat/salt transports of mesoscale eddies in the southeastern tropical Indian Ocean

GUANG YANG[1,2], WEIDONG YU[1,2]

[1] *Center for Ocean and Climate Research, First Institute of Oceanography, State Oceanic Administration, China*

[2] *Laboratory for Regional Oceanography and Numerical Modeling, Qingdao National Laboratory for Marine Science and Technology, China*

Satellite altimetry sea surface height measurements reveal high mesoscale eddy activity in the southeastern tropical Indian Ocean (SETIO). In this study, the characteristics of mesoscale eddies in the SETIO are investigated by analyzing 564 cyclonic eddy (CE) tracks and 695 anticyclonic eddy (AE) tracks identified from a new version of satellite altimetry data with a daily temporal resolution. The mean radius, lifespan, propagation speed and distance of CEs (AEs) are 149 (153) km, 50 (46) days, 15.3 (16.6) cm s-1, and 651 (648) km, respectively. Some significant differences exist in the eddy statistical characteristics between the new-version daily altimeter data and the former weekly data. Mean vertical structures of anomalous potential temperature, salinity, geostrophic current, as well as heat and salt transports of the composite eddies, are estimated by analyzing Argo profile data matched to altimeter-detected eddies. The composite analysis shows that eddy-induced ocean anomalies are mainly confined in the upper 300 dbar. In the eddy core, CE (AE) could induce a cooling (warming) of 2ºC between 60 and 180 dbar and maximum positive (negative) salinity anomalies of 0.1 (-0.3) psu in the upper 50 (110) dbar. The meridional heat transport induced by the composite CE (AE) is southward (northward), whereas the salt transport of CE (AE) is northward (southward). Most of the meridional heat and salt transports are carried in the upper 300 dbar.

Summer Surface Chlorophyll Blooms in the Gulf of Aden Induced by Thermocline Shoaling and Eddies

FENGCHAO YAO[1], IBRAHIM HOTETI[2]

[1] *Red Sea Research Center, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia*

[2] *Physical Sciences and Engineering, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia*

The Gulf of Aden, although subject to seasonally reversing monsoonal winds, has been previously reported as an oligotrophic basin during summer, with elevated chlorophyll concentrations only occurring during winter due to convective mixing. However, the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) ocean color data reveal that the Gulf of Aden also exhibits a prominent summer chlorophyll bloom and sustains elevated chlorophyll concentrations throughout the fall, and is a biophysical province distinct from the adjacent Arabian Sea. Climatological hydrographic data suggest that the thermocline, hence the nutricline, in the entire gulf is markedly shoaled by the southwest monsoon during summer and fall. Under this condition, cyclonic eddies in the gulf can effectively pump deep nutrients to the surface layer and lead to the chlorophyll bloom in late summer, and, after the transition to the northeast monsoon in fall, coastal upwelling driven by the northeasterly winds produces a pronounced increase in surface chlorophyll concentrations along the Somali coast.

Dissolved Methane in Al Shabab and Al Arbaeen, lagoon System

YASAR N K[1], MOHAMMED IBRAHIM ORIF[2], RASIQ K T[3], RADWAN KHALID AL FARAWATI[4], MOUSA ZOBIDI[5]

[1] *Marine Chemistry, King Abdulaziz University, Saudi Arabia*
[2] *Marine Chemistry, King Abdulaziz University, Saudi Arabia*
[3] *Marine Chemistry, King Abdulaziz University, Saudi Arabia*
[4] *Marine Chemistry, King Abdulaziz University, Saudi Arabia*
[5] *Marine Chemistry, King Abdulaziz University, Saudi Arabia*

Both Al Shabab and Al Arbaeen lagoon system are located in the Jeddah coast, KSA. Due to the uncontrolled discharge of wastes, both the lagoons are polluted to maximum extent. Both systems are reflecting the oxygen depletion and it is more adverse in the Arbaeen systems. While observing the Dissolved oxygen data we could experience the anoxic conditions and the production of Hydrogen Sulfide around 50 micro M in the bottom level and even in the 0.1m depth the concentration is pretty high.The vertical distribution of temperature and salinity is not varying much, while spatial variation is interesting.The observed nutrient concentration is also quite interest and the level of Ammonia in both lagoons are high and more in arbaeen.The observed data is light on the denitrification and DNRA processes. From the reverse pattern of methane with DO values depicts the enhance production and the activity of methanogens in the oxygen depleted zone. The observed methane concentration is rather high in the arbaeen lagoons compared to shabab and its flux towards the surface is also quite large.

Wintertime Submesoscale River Plumes in the Bay of Biscay

Özge Yelekçi[1], Guillaume Charria[1], Xavier Capet[2], Gilles Reverdin[2], Sébastien Theetten[1], Frédéric Vandermeirsch[1], Joël Sudre[3], Hussein Yahia[4]

[1] *IFREMER, LOPS, France*
[2] *LOCEAN/IPSL, CNRS/UPMC/IRD/MNHN, France*
[3] *LEGOS/CNRS, UMR5566, France*
[4] *GeoStat team, INRIA Bordeaux Sud-Ouest, France*

Recent observations over the continental shelf in the Bay of Biscay (in the Eastern Atlantic along French and Spanish coasts) has revealed a complex small scale (O(1km)) activity with high frequency variations. A dataset of 11 years' (2003 to 2013) Sea Surface Temperature (SST) remotely sensed by MODIS sensor onboard Aqua and Terra satellites is studied to detail the spatial and seasonal distributions of fronts in this region. Spatial and temporal patterns revealed by this analysis are used to identify the driving mechanisms of these fronts and they are found to be in agreement with the previously well-known tidal or shelf break fronts in the region.

Furthermore, these observations have brought to attention one particular group of fronts that occur in mid-shelf during winter, similar examples of which have previously been studied in other regions (e.g. Mid-Atlantic Bight). These observed SST fronts in our region are shown to be the temperature signature of density fronts occurring along the river plume edges, where the main driver of the density difference is actually the increased freshwater input to the shelf.

A realistic high-resolution (1 km) hydrodynamic model is applied to the region to investigate the dynamics of such fronts. A scale decomposition that distinguishes the large, meso-, and submesoscale components of model results is carried out. Results show that, along the river plume front, submesoscale patterns prevail. They also possess a certain spatial variability such as filamentation in certain parts of the front, which can be indicative of baroclinic instability. Temporal evolution of this submesoscale variability and some of the forcings that can be responsible for it (e.g. surface cooling, wind stress, topography, or background circulation), together with the role of baroclinic instability are explored.

Vertical Flow and Restratification in the Upper Ocean by Meso- and Submesoscale Processes

Xiaolong Yu[1], Alberto Naveira Garabato[1], Adrian Martin[2], Christian Buckingham[1], Liam Brannigan[3]

[1] *School of Ocean and Earth Science, University of Southampton, Southampton, U.K.*
[2] *National Oceanography Centre, Southampton, U.K.*
[3] *Atmospheric, Oceanic & Planetary Physics, University of Oxford, Oxford, U.K.*

Vertical flows associated with meso- and submesoscale processes play a significant role in the dynamics of the ocean surface boundary layer, and in the oceanic exchanges of mass and tracers within and across the mixed layer. Here, we present an annual cycle of the vertical circulation and associated restratification estimated from two nested clusters of meso- and submesoscale resolving moorings, deployed in a mid-gyre area of the Northeast Atlantic in Septermber 2012 – September 2013 under the auspices of the OSMOSIS project.

Results show that vertical flows are substantially stronger at submesoscales than at mesoscales. Differences between submesoscale and mesoscale vertical velocities are modest at times of weak mesoscale eddy activity, but are often large (on the order of 100 m/day) when energetic mesoscale features propagate through the mooring array. Vertical buoyancy fluxes associated with strong submesoscale ageostrophic motions are found to be larger and more surface intensified, and to dominate restratification in the ocean surface boundary layer. Several strong events, occurring mainly during winter, are found to shape the annual-mean vertical buoyancy flux. The instability processes taking place during these events are identified.

The Energetic cascade in a model overturning circulation: from mesoscale eddies to the dissipation range

Varvara Zemskova[1], Brian White[1], Alberto Scotti[1]
[1] *Dept. of Marine Sciences, University of North Carolina at Chapel Hill, USA*

The driving forces of the Meridional Overturning Circulation (MOC) are one of the central questions in oceanography and climate, and it is important to understand its mechanism and sensitivity to changes in ambient conditions. The key to the energetics of the MOC is in the relative importance of mechanical forcing due to surface winds and surface buoyancy forcing. In previous work [Zemskova et al, 2015], model output from MITgcm ECCO2 ocean-state estimate was used to study dominant energy pathways and the rate of turbulent mixing in a framework of Available Potential Energy. In order to look at the submesoscale processes that cannot be directly assessed from the ocean-state estimate data, we now investigate the energetics of a 3D Direct Numerical Simulation (DNS) runs of a simplified model of the Southern Ocean, where contributions from both surface buoyancy (due to differential heating and freshwater input) and wind forcing are particularly important. The DNS allows resolution spanning from mesoscale to dissipative scales, which is necessary to study the energy cascade. The domain of the simulation is a rectangular basin with buoyancy forcing applied at the surface such that dense fluid is at the southern end (to simulate cooling near the pole) and lighter fluid at the northern end (heating at mid-latitudes). To model the Antarctic Circumpolar Circulation, the domain is periodic in zonal direction. Wind stresses of variable magnitudes are applied at the surface as well. The problem is solved numerically using a finite-volume Adaptive Mesh Refinement solver for the Boussinesq Navier-Stokes equations with a rotation rate that allows the simulations to be within the dynamic regime of the ocean. For each simulation, generation and conversion terms in the energy budget are calculated using the local APE framework [Scotti and White, 2014] to investigate the effects of surface forcing on the large-scale overturning, baroclinic eddy generation in the ACC, deep convective plumes, and diapycnal mixing.

The Seasonally Varying Eddy Energy Sources and Sinks in the Red Sea

PENG ZHAN[1], ANEESH C. SUBRAMANIAN[2], FENGCHAO YAO[1], IBRAHIM HOTEIT[1]
[1] *Division of Physical Sciences and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia*
[2] *Clarendon Laboratory, University of Oxford, Oxford, UK*

The budget of eddy energy sources and sinks in the Red Sea is examined using a high-resolution eddy-resolving ocean circulation model. Eddies are most intense in winter, and their strongest activity is captured mainly over the central and northern basins within the upper 200 m. Eddies acquire their energy from baroclinic instability, barotropic instability and turbulent wind stress, the first of which contributes to the majority of the total energy. The baroclinic process occurs in almost the entire basin, converting the mean available potential energy into eddy potential energy, while the barotropic process appears mainly along the boundary of the basin where the kinetic energy from the mean flow converts to eddy kinetic energy through interaction between the boundary current and topography. The energy resulting from turbulent wind is relatively small and limited to the southern basin. These processes intensify both during winter, when the rate of energy conversion is about one order of magnitude larger than that in summer, and near the surface. Eddy energy is balanced by the vertical and horizontal divergence of energy and more ubiquitously by turbulent dissipation processes. The overall vertical eddy energy flux is downward, and dissipation processes act as the main energy sinks in the basin. The seasonal variability of these energy conversion terms can explain the significant seasonality of eddy activities in the Red Sea.

Characterizing the subsurface chlorophyll a maximum in the German Bight

CHANGJIN ZHAO[1], KAI WIRTZ[1]

[1] *Institute of Coastal Research, Helmholtz-Zentrum Geesthacht (HZG), Geesthacht, Germany*

Stratification in the water column plays an important role in shaping the vertical distribution of phytoplankton. To what extent stratification and other processes such as settling determine the vertical profile of phytoplankton and thus influence the auto- vs. heterotrophic status of marine ecosystems is poorly understood. High-resolution, vertically resolved transect data for biogeochemical and physical properties were previously collected in the German Bight (GB) from 2009 to 2011 at a seasonal basis. We identified auto- and heterotrophic regimes by statistical analysis of the temperature-oxygen relation. Most profiles reveal a positive correlation between temperature and oxygen, indicating autotrophic features during spring and summer. However, in early spring, a significant negative correlation reflecting a heterotrophic regime can be found in water masses where temperature is relatively low and pigment concentration high. In late spring, at the onset of stratification, highest oxygen concentration often occur in the upper water column, while in summer this maximum is located around the pycnocline. The vertical relocation may indicate a shift in main limiting factors, from light in spring to nutrients in summer. In autumn, heterotrophic regimes can be observed more often, especially in temperature inversion layers. We suggest that our correlation method is a suitable tool to distinguish auto-heterotrophic regimes especially regarding the presence of stratification. Our outlook will then point to ongoing studies using a coupled model system, which integrates physical processes such as mixing and intrusion of offshore waters with biogeochemical processes.

Submesoscale eddies in the Barents and the Kara seas using satellite data: comparative analysis of spatial-temporal variability

ALEXEY ZIMIN[1,2], OKSANA ATADZHANOVA[1,2], DMITRIY ROMANENKOV[1], IGOR KOZLOV[2]
[1] *St. Petersburg Department of the P.P.Shirshov Institute of Oceanology RAS, St. Petersburg, Russia*
[2] *Russian State Hydrometeorological University, St. Petersburg, Russia*

The paper presents the comparative analysis of the spatio-temporal variability of submesoscale eddies in the Barents and the Kara seas conducted using satellite data. The areas of high eddy occurrence and eddies characteristic sizes were detected. To investigate the features of the surface manifestation of eddies, 1203 SAR-images (synthetic aperture radar images) of the Barents Sea for the time period between June – October 2007 and 900 SAR-images (ENVISAT ASAR (WSM/IMP) operating at C-band) of the Kara Sea for the time period between July – October 2007 were processed. Eddies diameters, their center coordinates and rotation types were defined. There were registered 2184 eddy manifestations in the Barents Sea, 505 out of them are anticyclonic and 1679 are cyclonic. The eddy sizes vary from 0.2 to 25 km in diameter and the average size is 3.3 km. Detected cyclonic eddies generally were smaller in diameter. Eddy structures more often were registered in June and July in the areas of frontal zones where cold and salt waters of the Central Trench merge with the central branch of the Nordkapp current, the waters of the Novaya Zemlya current and relatively freshened waters of the Murmansk current. One can assume that the genesis of eddies is associated mainly with disturbances in the salinity front under the influence of the wind and tidal processes. There were detected 1242 eddy structures in the Kara Sea with average size of 2.4 km. More than 90% of eddies had a diameter of up to 4 km. The average size of anticyclone eddies reached 2.8 km and is bigger, than the average size of cyclone eddies (2.3 km). The highest number of eddy structures was observed in July and August in the central part of the Kara Sea in the area of runoff frontal zones.