7th Argo Science Workshop

ABSTRACT BOOK

This meeting is endorsed by CLIVAR and the UN Ocean Decade

CLIVAR

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DAY 1 – Tuesday 11 October 2022

Ocean Climate session (1)

Dr WIJFFELS Susan

Woods Hole Oceanographic Institution, USA

swijffels@whoi.edu

ORAL

Towards resolving the mean mesoscale upper ocean structure and circulation

Susan Wijffels and G. Gebbie
Woods Hole Oceanographic Institution

Using a parametric robust fitting technique, we extract the mean and seasonal variability of the global ocean from the surface to 2000dbar for the years 2000-2020, with fitted space scales of around 200km. Argo data, supplemented by ship and animal borne profiles for the shelves and polar regions, are fitted to map fields of salinity, temperature, geopotential anomalies and potential density. Velocity fields are also fit from both Argo trajectories at 1000dbar and surface drifters at 15dbar. For all parameters fitted, the data are regressed against an 'eddy' sea level and surface geostrophic vector velocity, to help reduce the noise that eddies present in resolving the long term mean and seasonal structures. For the case of surface drifters, in order to isolate the geostrophic velocity, a wind friction velocity is regressed to help remove the wind-driven Ekman and drifter windage, with drogued and un- drogued velocities allowed different windage terms. The full geostrophic velocity field is derived using the fitted geopotential gradients and reference velocity fields at 1000dbar.

The surface geostrophic and drifter velocities are in remarkable agreement outside the equatorial zone, independently confirming the fits. The flow field reveals that the ocean circulation is comprised of narrow semi-zonal filaments and braided jets at all depths, which are associated with mean density fronts. These flows are dominantly non-divergent. Isopycnal ventilation pathways are explored, in the context of salinity and potential vorticity distributions. A surface heat and freshwater budget is also attempted, and comparisons made with independent flux estimates. The dominating and competing role of mixed layer Ekman and geostrophic convergences in controlling the structure of the mesoscale lateral structure of the ocean surface fluxes is evident, with seasonal and eddy lateral flux divergences playing a significant but secondary role.

Dr GRAY Alison

University of Washington, United States

argray@uw.edu

ORAL

Three-dimensional observational estimates of mesoscale eddy kinetic energy in the global ocean

Alison Gray, University of Washington Ola Forma Kihle, University of Washington
Cimarron Wortham, Northwest Research Associates

The flow of energy through the global ocean plays a fundamental role in governing ocean circulation on a wide range of spatial and temporal scales and thus directly impacts the climate system. The energy associated with the mesoscale field is of particular importance, as this component of the flow field contains approximately 90% of the total kinetic energy in the ocean and drives significant isopycnal mixing but is not resolved in coupled climate models.
Furthermore, global observations of mesoscale energy have been mostly limited to the sea surface, where satellite altimeters can easily detect spatial variability in geostrophic currents and associated eddy kinetic energy (EKE). A persistent mystery in physical oceanography is how mesoscale energy is dissipated, a process which likely occurs near the ocean bottom. Yet to date, subsurface estimates of EKE have only been derived from the sparse set of moored current meters in the open ocean and are accordingly limited to relatively short records from only a few locations.

To address this significant gap in our knowledge, here we estimate the three-dimensional distribution of mesoscale eddy kinetic energy in the upper 2000 m of the global ocean directly from observations. Specifically, we integrate measurements from the satellite altimetric record (providing a reference velocity near the surface) with the subsurface observations from the Argo array of profiling floats (from which we estimate both geostrophic shear and velocity at depth). Using advanced multi-scale spatio-temporal mapping methods, we then construct gridded estimates of both the time-mean and mesoscale time-varying components of the global oceanic kinetic energy field over the period 2004-2020. These results are evaluated through direct comparison to the global database of moored current meter measurements as well as with simulation experiments using a high-resolution numerical model.

Dr PORTELA Esther

UTAS/LOPS - Australia/France

ORAL

Physical Mechanisms Driving Oxygen Subduction in the Global Ocean

Esther Portela, Nicolas Kolodziejczyk, Clément Vic, and Virginie Thierry

Future changes in subduction are suspected to be critical for the ocean deoxygenation predicted by climate models over the 21st century. However, the drivers of global oxygen subduction have not been fully described or quantified. Here, we address the physical mechanisms responsible for the oxygen transport across the late-winter mixed layer base and their relation with water mass formation.

Up to 70% of the global oxygen uptake takes place during Mode Water subduction mostly in the Southern Ocean and the North Atlantic. Te driving mechanisms are (i) the combination of strong currents with large mixed-layer-depth gradients at localized hot spots and (ii) the wind-driven vertical velocity within the subtropical gyres. Oxygen diffusion, despite being underestimated in this study, is likely to play an important role in the global ocean oxygenation. The physical mass flux dominates the total oxygen subduction while the oxygen solubility plays a minor role in its modulation. The original study was carried out by using the ocean state product ECCOv4, which combines state-of-the-art ocean circulation models with global ocean data sets. The oxygen data were taken from the World Ocean Atlas, based only on bottle oxygen data. Using the methodology developed in Portela et al. (2020), the global oxygen subduction patterns and rate are assessed using the most updated Argo oxygen climatology.

Dr DELPECH Audrey

UCLA, Department of Atmospheric and Oceanic Sciences - USA

adelpech@atmos.ucla.edu

ORAL

Deep Eddy Kinetic Energy in the Tropical Oceans Revealed From Argo Floats

Audrey Delpech[1,2], Sophie Cravatte[1,3], Frédéric Marin[1], Claire Ménesguen[4] and Yves

Morel[1 1] Laboratoire d'Etudes en Géophysique et Océanographie Spatiale, Toulouse, France

[2] UCLA, Department of Atmospheric and Oceanic Sciences, Los Angeles, USA
[3] IRD, Nouméa, New Caledonia
[4] Ifremer, Brest, France

At the ocean surface, satellite observations have shown evidence of a large spectrum of waves in the tropics. However, very little is known about the existence and properties of the deep variability in these regions. Most of the subsurface observations rely on localized measurements, which do not allow for a global description of the variability.
In this study, we use velocity estimates, provided by Argo float drifts at 1,000 m depth, to analyze the spatial and temporal distribution of the deep eddy kinetic energy (EKE) and its spectral signature with an unprecedented time and space coverage. In the tropical Pacific, high EKE is found along the equator, at the western boundary and poleward of 7°N. The EKE meridional distribution is also found to vary at the scale of the mean zonal jets: it is higher inside eastward currents. In addition, we develop an original statistical scale analysis to determine the temporal and spatial scale dependence of this deep EKE footprint. We show the presence of periodic features whose characteristics are compatible with theoretical equatorial waves dispersion relations. Annual and semiannual Rossby waves are observed at the equator, as well as

∼30-day Yanai waves, consistent with surface tropical instability waves inferred from satellite altimetry. The location and intensification of these waves match the downward energy propagation predicted by ray tracing linear theory. Short-scale variability (with

∼70-day periods
and 500-km wavelength) has also been detected poleward of 7°N. The generation mechanisms of this variability are discussed, as well as its importance for the mean circulation.

Dr LAMAS Luisa

Instituto Hidrigráfico, Portugal

luisa.lamas@hidrografico.pt

ORAL

Combined use of Argo and Glider data to characterize the ocean: observing Meddies in the Eastern North Atlantic

L Lamas(1), I Martins(1), J Vitorino(1), C Barrera(2)

(1) Instituto Hidrográfico, Portugal

(2) PLOCAN, Spain

(3)

The combined use of data from multiple platforms is explored in this study, where observations obtained by Argo floats and underwater Gliders are used to characterize the ocean in the Eastern North Atlantic (NE Atlantic).

The characterization of the physical parameters of the water column in the study domain is clearly relevant, particularly due to the uniqueness of the dynamics in the region, conferred by the presence of the Mediterranean Water (MW) and conditioned by topographic features present in the area, which can cause the formation, deflection and displacement of important subsurface structures, such as Mediterranean Water eddies, known as Meddies.

In recent years, Instituto Hidrográfico has been collaborating with PLOCAN to establish sustained glider observations across the NE Atlantic, providing a unique source of observations of the ocean interior in this region. In both missions, carried out in 2019 and 2020, meddies were identified in the water column thus providing the motivation of this study. Temperature and Salinity profiles obtained by 2 Argo floats that sampled the region concurrently with both missions, showed a clear signature of the warm and salty MW at intermediate waters, but it was not trivial, from Argo data alone, to identify a meddy. However, Argo data is significant in the area (>10000 cycles in 10 years), providing valuable information about the mean conditions in the region of study.

Here, we show an example of how to exploit the advantages of combining data from different platforms in sustained observational programs, maximizing the capacities by each individual technology-component, to characterize the ocean dynamics.

Dr DESBRUYERES Damien

Ifremer, France

damien.desbruyeres@ifremer.fr

ORAL

Warming-to-cooling reversal of overflow-derived water masses in the Irminger Sea during 2002-2021.

Damien G. Desbruyères, Eva Prieto Bravo, Virginie Thierry, Herlé Mercier, Pascale Lherminier, Cécile Cabanes, Tiago C. Biló, Nora Fried, M. Femke De Jong.

Shipboard hydrography along the A25-Ovide section (2002 – 2018) is combined with a high-resolution mooring array (2014 – 2020) and a regional fleet of Deep-Argo floats (2016 – 2021) to describe temperature changes of overflow-derived water masses in the Irminger Sea. Removing dynamical influences enables to identify a new statistically-significant trend reversal in Iceland Scotland Overflow Water (ISOW) and Denmark Strait Overflow Water (DSOW) core temperatures in the mid-2010s. A basin-wide cooling trend of -16 6 m°C yr^{-1} during 2016 – 2021 – but reaching as strong as -44 13 m°C yr^{-1} for DSOW in recent years – is found to interrupt a warming phase that was prevailing since the late 1990's. The absence of an apparent reversal in the Nordic Seas and the faster changes detected in DSOW compared to ISOW point out the entrainment of subpolar signals within the overflows near the Greenland-Iceland-Scotland sills as a most likely driver.

Dr JOHNSON Gregory

NOAA/Pacific Marine Environmental Laboratory, USA

gregory.c.johnson@noaa.gov

ORAL

Antarctic Bottom Water Warming and Circulation Slowdown in the Argentine Basin from Analysis of Deep Argo and Historical Shipboard Temperature Data

Gregory C. Johnson[1] and Brian A. King[2]

[1]NOAA/Pacific Marine Environmental Laboratory, Seattle, Washington 98115, USA

[2]National Oceanography Centre, Southampton, United Kingdom

A decadal warming trend of 2 (±0.2) m°C yr^{-1} in Antarctic Bottom Water within the western Argentine Basin is found by comparing Deep Argo temperature profiles from 2021–2022 to nearby historical shipboard data from 1972–1998. This trend is similar in magnitude, but with ~5 times more certainty, than a previously published trend detected in the eastern Argentine using repeat hydrographic section data (WOCE Section A16S) from 1989, 1995, and 2014. Furthermore, the present analysis detects a warming rate in the coldest water entering the basin almost twice that in the interior. This bottom-intensified westward flow of Antarctic Bottom Water from the south is banked against the southern boundary of the Argentine Basin. The observed reduction in deep meridional temperature gradient indicates a reduction in geostrophic shear, consistent with a reduced flow rate, and transport, of the coldest, deepest water entering the basin.

Dr SEVELLEC Florian

LOPS-CNRS - France

florian.sevellec@univ-brest.fr

ORAL

Estimation of Horizontal Turbulent Diffusivity from Deep Argo Float Displacements

F. Sevellec, A. Colin de Verdiere, and N. Kolodziejczyk

Laboratoire d'Oceanographie Physique et Spatiale, Univ-Brest CNRS IRD Ifremer, Brest, France

We use an analog method, based on displacements of Argo floats at their parking depth (nominally located around 1,000 dbar) from ANDRO dataset, to compute continuous, likely trajectories and estimate the Lagrangian dispersion. From this, we find that the horizontal diffusivity coefficient has a median value around 500 $m^2\ s^{-1}$ but is highly variable in space: reaching values from 100 $m^2\ s^{-1}$ in gyre interior to 40,000 $m^2\ s^{-1}$ in a few specific locations (in the Zapiola gyre and in the Agulhas Current retroflection). Our analysis suggests that the closure for diffusivity is proportional to Eddy Kinetic Energy (or square of turbulent velocity) rather than (absolute) turbulent velocity. It is associated to a typical turbulent time scale of 4 to 5.5 days, which is noticeably quite constant over the entire globe, especially away from coherent intense currents. The diffusion is anisotropic in coherent intense currents and around the equator, with a primary direction of diffusion consistent with the primary direction of horizontal velocity variance. These observationally based horizontal diffusivity estimations, and the suggested Eddy Kinetic Energy closure, can be used for constraining, testing, and validating eddy turbulence parameterization.

Dr MORRIS Tamaryn

South African Weather Service

tamaryn.morris@weathersa.co.za

ORAL

A study on cyclonic eddy-borne Argo floats in the Greater Agulhas Current System

Tamaryn Morris[1,2], Borja Aguiar-González[3,2], Francisco Machín[3], Ángel Rodríguez-Santana[3], Romain Cancouët[4]

[1]Marine Unit, South African Weather Service, Cape Town, South Africa

[2]South African Environmental Observation Network, Cape Town, South Africa

[3]Departamento de Física, Universidad de Las Palmas de Gran Canaria, Campus Universitario de Tafira, 35017 Las Palmas, Spain

[4]Euro-Argo ERIC, Plouzané, France

The Greater Agulhas Current System is a highly energetic and eddying system southeast of southern Africa. Under this scenario, eddies generated southwest of Madagascar are suitable candidates to assess the transfer of mesoscale eddy kinetic energy, and heat/salt contents, to the Agulhas Current (AC). Madagascar eddies are generated southwest of the island and travel westward covering a distance of approximately 130 km in roughly 4 months. Previous analyses have shown that, along this journey, Madagascar eddies experience profound changes in terms of horizontal and vertical scales, but also keep coherent water mass properties in their interior, suggesting robust solid rigid dynamics are governing. However, the fate of the eddies' kinetic energy, and the mixing processes occurring when they vanish at the AC, remain poorly known.

In this study, we present results from three *ad hoc* Argo float experiments where Madagascar cyclonic eddies were targeted. The experiments were deployed in April and July 2013, and May 2022. We focus on assessing the role of these eddies in mixing and energy exchange at the boundary. To this aim, the Argo floats were configured at high temporal resolutions, and parked at different depths. Results from the two experiments from 2013 show these eddies are transporters of cooler and fresher water into the AC. Among the floats deployed in 2013, one out of nine remained within the cyclonic eddy until it interacted with the AC, capturing the full dissipation of the eddy. The experience gained from 2013 is currently being applied to the ongoing Argo float experiment, deployed in May 2022.

Preliminary results will focus on the assessment of the heat/salt fluxes, mixing and kinetic energy exchange occurring between the eddy and the AC. We do this by combining the Argo float *in situ* observations with remotely sensed measurements and model data.

Dr SERAZIN Guillaume

LOPS-CNRS, France

guillaume.serazin@univ-brest.fr

ORAL

A seasonal climatology of the upper ocean pycnocline

Climatologies of the mixed layer depth have been provided using several definitions based on temperature/density thresholds or hybrid approaches. The upper ocean pycnocline (UOP) that sits below the mixed layer base, sometimes referred to as the transition layer or as the seasonal pycnocline, remains poorly characterised though it is an ubiquitous feature of the ocean surface layer. The UOP often consists in a rapid change in density with depth and enhanced vertical shear that connects the well-mixed surface layer to the stratified ocean interior. The UOP is important for the ventilation of the ocean as it represents a barrier to mixing between the upper ocean and the ocean interior.

Available hydrographic profiles (e.g., Argo, CTD on marine mammals) provide near-global coverage of the world's oceans and allow the characterisation of spatial and seasonal variations of the upper ocean vertical stratification, including the UOP. Based on these profiles, we estimate the depth, thickness and intensity of the UOP, and assess when and where the UOP can be considered as a layer with constant thickness. We provide monthly maps of the UOP complementing the available MLD climatologies and we compare the UOP characteristics with the depth and stratification of the mixed layer. We aim at assessing the UOP intensity in winter and spring when the stratification is usually weak and submesoscale vertical motions can penetrate below the mixed layer base. During these seasons, the UOP intermittency must be taken into account because restratification may occur with intermittent events.

Mr CHANDLER Mitchell

Scripps Institution of Oceanography, USA

mlchandl@ucsd.edu

ORAL

Variability in the Deep Western Boundary Current of the Southwest Pacific Basin identified using Deep Argo

Mitchell Chandler[1], Nathalie Zilberman[1], Janet Sprintall[1], Philip Sutton[2]
[1]*Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA*

[2]*National Institute of Water and Atmospheric Research, Wellington, NZ*

The Deep Western Boundary Current (DWBC) that flows along the Tonga-Kermadec Ridge in the Southwest Pacific is the main conduit for redistributing the dense water masses formed on the Antarctic continental shelf into the western subtropical Pacific. However, despite the instrumental role of this DWBC in the deep meridional overturning circulation, the spatial and temporal variability of the DWBC is poorly understood. Roughly 1000 full-depth temperature and salinity profiles have been collected by Deep Argo floats deployed in the DWBC between 2017 and 2021. This new dataset provides a unique opportunity to improve our understanding of along-flow variations and study changes in water mass characteristics of this DWBC at seasonal to interannual time scales. Preliminary results on the leading mechanisms of variability will be described and compared to studies at nearby locations in the DWBC based on ocean mooring and shipboard data including at 32°S and in the Samoan Passage, and compared to concurrent Deep Argo measurements in the southward recirculation of the DWBC offshore of the Tonga-Kermadec Ridge.

Dr WANG Tong

Tohoku University, Japan

wangtong.330@gmail.com

ORAL

Spiciness anomalies in the upper North Pacific based on Argo observations

TONG WANG1, TOSHIO SUGA1, 2 AND SHINYA KOUKETSU2

1 Department of Geophysics, Graduate School of Science, Tohoku University; 2JAMSTEC RCGC

The density-compensated salinity anomalies (spiciness anomalies) in the upper North Pacific were investigated using Argo float profiles during 2004–2018. The freshening of the subtropical thermocline were found within the Central Mode Water (CMW) and the North Pacific Intermediate Water (salinity minimum). Meanwhile, the salinity of the lighter layer within the North Pacific Tropical Water (salinity maximum) increased. The interannual and longer spiciness anomalies were interpreted with three-dimensional evolutions and links to the fate of three mode waters (i.e., Subtropical Mode Water (STMW), Eastern Subtropical Mode Water (ESTMW), and CMW). In the STMW, the salinity was dominated by a quasi-decadal variability, which was consistent with the KE variability with a 1-year lag, and did not show rapid freshening. In the CMW, the salinity decreased with a quasi-decadal variability, which was weaker and out of the phase compared with the STMW. In the ESTMW, the salinity was dominated by year-to-year variability. The spiciness anomalies originated mainly in the outcrop region of the isopycnals, where they were accompanied by the formation of water masses and the subduction of the mode waters. They were also propagated and decayed downstream the geostrophic currents. However, a few of the interannual anomalies found in the northern part of the CMW were almost dampened before their spread further south. In addition, some anomalies in the ESTMW appeared and intensified without a connection to the mixed layer. These anomalies occurred far from the outcrop line, suggesting the effects were caused likely by a salt-finger that is related to the modification of the mode waters. Furthermore, the propagation of the spiciness anomalies in the western to the central subtropics was significantly faster than the geostrophic current and inclined to the inner side of streamlines. These indicated the transport by eddies in addition to geostrophic current.

Dr ASSELOT Rémy

IFREMER – France

remy.asselot@ifremer.fr

ORAL

Argo floats reveal the mechanisms controlling the deepening of anthropogenic carbon towards the deeper layers of the North Atlantic

Main author: Rémy Asselot[1]

Co-Authors: Lidia I. Carracedo[1], Virginie Thierry[1], Herlé Mercier[1], Raphaël Bajon[1], and Fiz Pérez[2]

[1]Ifremer, University of Brest, CNRS, IRD, Laboratoire d'Océanographie Physique et Spatiale (LOPS), UMR6523, Centre de Bretagne, 29280 Plouzané, France
[2]Instituto Investigaciones Marinas (IIM, CSIC), calle Eduardo Cabello, 6, 36208, Vigo, Spain

Since the industrial revolution, human activities have emitted a large amount of anthropogenic carbon (C_{ant}) into the atmosphere through the burning of fossil fuel, the production of cement and land-use change. Via air-sea gas exchange, the ocean absorbs roughly a third of C_{ant}, meaning that C_{ant} is an additional source of carbon for the ocean. In particular, the North Atlantic (NA) is known to be a region with a high C_{ant} storage capacity. Whereas the distribution of C_{ant} in the upper NA layers is well documented, its transport to the deep ocean and the mechanisms controlling it remain scarcely described. To shed light on this research gap and explore the deep pathways of C_{ant}, we use a database provided by Argo floats equipped with oxygen sensors and located in the NA sub polar region. Our study shows that the deepening of C_{ant} in the water column happens mainly via deep winter convection in the Labrador and Irminger Seas and diapycnal mixing above the Reykjanes Ridge. Additionally, we illustrate that this deep penetration of C_{ant} in the subpolar North Atlantic is actually driven by a compound of mechanisms happening at different spatio-temporal scales.

Dr GIGLIO Donata

University of Colorado Boulder, USA

donata.giglio@colorado.edu

ORAL

Atmospheric river impacts on the upper ocean: a study using Argo floats

Authors: Donata Giglio, Lauren Hoffman, Bill Mills, Sarah Purkey, John Gilson, Aneesh C. Subramanian, Brian Kawzenuk, Anna Wilson, Marty Ralph

Atmospheric Rivers (ARs) are elongated structures in the atmosphere that transport water vapor from the tropics to mid-latitudes over the oceans in highly episodic events. They are shown to be a major source of rainfall in the western United States, they impact Greenland and Antarctic ice melt events, and they play a role in exchanges of heat and freshwater at the air- sea interface. Our understanding of air-sea exchanges during ARs is limited, especially in the open ocean, as they occur at relatively short time scales and on small spatial scales, and they depend on the preconditioning of the system, hence they are challenging to observe and model.

For the first time, an experiment was designed to observe AR-related changes in the upper ocean using Argo floats. Argo profile measurements show upper ocean freshening and (in some cases) cooling at the passage of the AR, if wind stress at the ocean surface is low. The observed freshening is consistent with AR-related precipitation.

DAY2 – Wednesday 12 October 2022

Model & Satellite session

Pr SPEICH Sabrina

LMD-IPSL, ENS-PSL, France

sabrina.speich@lmd.ens.fr

ORAL

Unveiling the ocean dynamics at the mesoscale from Argo and satellite observations

Sabrina Speich[1], Rémi Laxenaire[1,2] , Artemis Ioannou[1], Yanxu Chen[1], Gaston Manta[1], Corentin Subirade[1], Yan Barabinot[1], Marin Cornec[3,4], Hervé Claustre[3]
[1]Laboratoire de Météorologie Dynamique, IPSL, ENS-PSL, Paris, France [2]Laboratoire de l'Atmosphère et des Cyclones, Saint-Denis de La Réunion, France [3]Laboratoire d'oceanographie de Villefranche, Villefranche s/mer, France [4]Laboratoire NOAA-PMEL, Seattle, WA, ENS-PSL, Paris, France

Ocean dynamics and its interaction with the atmosphere are key in regulating the state and evolution of our climate. They also strongly shape marine ecosystems. Recent studies suggest that the most energetic and impactful process are governed by the ocean small-scale (1 km to 100 km) and varies in time periods of a few hours to weeks.

Within these scales, the advent of the Argo (core, BGC and deep) programs allows to uncover the ocean dynamics at the mesoscale (50-100 km). Here we focus on ocean mesoscale eddies. They are ubiquitous in the ocean, and typically exhibit different characteristics to their surroundings, allowing them to efficiently transport across long distances properties such as heat, salt and biogeochemical tracers, including oxygen and carbon, around the ocean.

In this presentation we will describe the new global atlas of mesoscale eddies, TOEddies that provides all eddies detected by altimetry to which we have associated the entire base of Argo profiles. Our studies suggest that most of the detected structures are not surface but subsurface intensified eddies. Many of them subduct relatively quickly after being spawn by unstable currents. Because most of subsurface eddies are invisible from altimetry we have developed also a method to define if an Argo profile lies within a subsurface eddies and what is its vertical extent and properties.

Example of applications of our methods is relatively diverse, and span the definition of ocean eddies as coherent structures, the interpretation of GO-SHIP cruises estimates of transport, Mode Water formation and propagation, cross-shelf water exchanges as well as how ocean eddies affect marine ecosystems.

Dr REMY Elisabeth

Mercator Ocean International, France

eremy@mercator-ocean.fr

ORAL

Impact of Argo observations in OceanPredict Operational Ocean Systems

Elisabeth Remy (Moi), Florent Gasparin (IRD), Yosuke Fujii (JMA/MRI) and the OceanPredict OSEval task team

Global Ocean real time forecasts and reanalysis highly rely on in situ observation of the ocean interior to deliver accurate estimate of the physical state of the ocean. Argo floats are the major source of information at global scale allowing to constrain the water mass properties in real time analysis and reanalysis. We will review the impact of the present and future Argo observations in operational systems, based on assimilation experiments conducted with different OceanPredict operational systems, including the Mercator Ocean global system. The decrease of the analysis error estimated from assimilation experiments with the planned extensions of the Argo array in the deep ocean and in Western Boundary current will also be presented.

The complementarity of the in-situ temperature and salinity Argo profiles with satellite observations, especially sea surface height data will be addressed. Dedicated data assimilation experiments are showing that the Argo temperature and salinity observations are constraining the large space and time scales compared to altimetry observations that constrain the meso-scale but give only an integrated view of the water column.

The limitation and best practices associated with observation impact assimilation experiments and diagnostics will also be discussed.

Ms SILVA Susana

Dom Luiz Institute (IDL) - Faculty of Sciences of the University of Lisbon (FCUL) - Portugal

smsilva@fc.ul.pt

ORAL

Vertical Structure of Mesoscale Turbulence in the Azores Current System combining ARGO profiles, climatology, and altimetry

Silva S.M.*, Peliz Á.J.
Instituto Dom Luiz – Faculdade de Ciências, Lisboa, Portugal.

The world's ocean eddy field has been vastly studied using, not only altimetric data (e.g., Chelton et al, 2011), but also composites, where the Sea Level Anomaly (SLA) is combined with ARGO floats' data (e.g., Amores et al, 2017) to describe its vertical structure. Previous works regarding the Azores Current (AzC) turbulent vertical structure are scarce, comprising mainly in situ studies of individual eddies (e.g., Pingree and Sinha, 1998; Pingree et al., 1996).
In this work, we use more than 12000 ARGO profiles, spanning 20 years of data, that are converted into temperature and salinity anomalies by subtracting the WOA2018 climatology (interpolated to the ARGO profile location and year-day). These anomalies are then decomposed into an isopycnal change relative to the climatology - sometimes referred as Spice, and a change associated with the vertical movement of isopycnals - Heave, following Bindoff and McDougall (1994). These two components co-exist in the ocean interior, but our expectation is that wave-dominated processes will have a stronger Heave, while coherent eddies, particularly close to frontal zones, will display a larger Spice signal. We try to study the relationship between these diagnostics, by isolating different populations of eddies using temperature and salinity anomaly criteria as well as SLA signals.

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Ms BHATTACHARYA Trishneeta

Indian National Centre for Ocean Information Services, India

trishneeta@gmail.com

ORAL

Observed seasonal variability of thermohaline structure and associated biological response in the Eastern Equatorial Indian Ocean using Argo profiling floats

Authors: Trishneeta Bhattacharya, Kunal Chakraborty

Due to privacy concerns, please contact trishneeta@gmail.com for further information.

Dr QUARTLY Graham

Plymouth Marine Laboratory, UK

gqu@pml.ac.uk

ORAL

The Different Chlorophyll Structures in North Atlantic Cyclonic and Anticyclonic Eddies

Guiyan Han[1,2], Graham Quartly[2], Ge Chen[1,3], and Jie Yang[1,3]

1 College of Marine Technology, Institute for Advanced Ocean Study, Ocean University of China, Qingdao, 266200, China
2 Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth, PL1 3DH, Devon, United Kingdom
3 Laboratory for Regional Oceanography and Numerical Modeling, Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266237, China.

Radar altimetry provides an effective means to detect and follow the motion of eddies, as it provides a near- global view every 10 days unencumbered by the presence of clouds. We fit a simple elliptical model to the contours of sea level anomaly and consider the chlorophyll observations within each feature. Ocean colour satellites provide a record of the chlorophyll in the near-surface layer, whilst BGC-Argo profiles give the depth information. Although cyclonic eddies are associated with upwelling (and anticyclones with downwelling), the satellite data show their effect can be more complex than uniform enhancement, with dipole patterns quite common for weak features. The Argo profiles do show that anticyclones typically increase the depth of the subsurface chlorophyll maximum in the subtropical North Atlantic, but the contrasting effects of eddy pumping and Ekman pumping show two distinct classes of response in the mid- latitude ocean at the same time.

Dr COSSARINI GIanpiero

National Institute of Oceanography and Applied Geophysics, Italy

gcossarini@ogs.it

ORAL

Experience, lessons learnt and challenges of biogeochemical model validation with BGC- Argo in the EU Marine Copernicus Service

Gianpiero Cossarini[1], Anna Teruzzi[1], Luc Vandenbulcke[2], Veli Çağlar Yumruktepe[3], Susan Kay[4], Alexander Mignot[5], Elodie Gutknecht[5], Virginie Racapé[6], Thierry Carval[7], Lena Spruch[8], Isabel Garcia Hermosa[5], Marcos Sotillo[9], Marie Drevillon[5]

[1]OGS (IT), [2]UNI LIEGE (BE), [3]NERSC (NO),[4]MET OFFICE (UK), [5]MOI (FR), [6]POKAPOK (FR), [7]IFREMER (FR),
[8]BSH (DE), [9]PUERTOS (ES)

Within the EU Marine Copernicus Service, biogeochemical short-term forecasts and outlooks for marine conditions are provided by state-of-the-art data processing and advanced biogeochemical models at the global and regional scales.
Validation of biogeochemical models and uncertainty assessment of predictions are key elements of the Marine Copernicus Service philosophy. However, availability of independent data can represent a limitation, and uncertainty estimation often relies principally on comparison with surface chlorophyll- a from satellite and insitu climatologies or historical datasets.
Besides satellite surface observations, the increased availability of near-real time data from BGC-Argo floats represents a complementary source of high level observations which are regularly used for both delay mode model qualification and near-real time forecast skill assessment. Bias and RMSD based on model-observation matchups and graphical representations (e.g., Hovmoller diagram, scatterplots, Taylor diagrams) are the most common metrics implemented in the global and regional biogeochemical Copernicus modeling centers. Additionally, beside depth-averaged quantities, metrics related to the depth of key ecosystem features (e.g., deep chlorophyll maximum, nitracline, minimum oxygen zone) are informative of model capabilities to reproduce coupled physical-biogeochemical vertical dynamics.
Maturity and cost-effectivness of the biogeochemical validation depend on several factors: representativeness of the BGC-Argo float fleets within a given region, spatial and temporal coverage of the different sensors and quality control at the level of both DAC and Copernicus In-Situ distributions and as pre-processing in the modelling centers.
Results, best practices, lessons learnt from the Copernicus Product Quality working group and the biogeochemical modeling centers are provided to show the benefit, potential needs and perspectives of the BGC-Argo use in operational oceanography.

Ms ROCHNER Andrea

University of Exeter, UK

ar654@exeter.ac.uk

ORAL

Can assimilating Biogeochemical-Argo data improve carbon flux estimates?

Andrea Rochner David Ford Katy Sheen
Andrew Watson

Analysing the observations from a growing number of biogeochemical (BGC) Argo floats has greatly improved our understanding of BGC processes. But these observations can yield additional value when combined with model simulations. For example, Ford (2021) showed improvements in the BGC simulation when assimilating synthetic BGC profiles, i.e. profiles mimicking BGC-Argo floats in a model simulation. Here, we test the impact of assimilating actual BGC-Argo float observations into a physical-biogeochemical model using the same 3D-Variational data assimilation method as Ford (2021). The analysis focusses on the Southern Ocean, where most BGC-Argo floats have been deployed due to the dedicated effort by the SOCCOM programme. We evaluate the influence of the assimilation on the air- sea flux of carbon dioxide. Assimilating BGC profiles adds valuable information about the vertical distribution of BGC properties, especially in combination with satellite observations with global surface coverage. The model-based results of the data assimilation can be used to investigate drivers of carbon fluxes, globally and on a regular grid, and therefore help to better understand the underlying processes. The results also highlight biases in the biogeochemical model which can inform model development, e.g., for the ocean components of Earth System Models used for future projections.

References:

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Dr TERUZZI Anna

OGS - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Italy

ateruzzi@ogs.it

ORAL

Maximizing the integration of BGC Argo data and predicting systems

Anna Teruzzi [1], Carolina Amadio [1], Laura Feudale[1], Gloria Pietropolli [1], Gianpiero Cossarini[1] [1] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS

The availability of near real time (NRT) data from BGC-Argo floats provides the opportunity to improve the skill of marine biogeochemical forecasts through data assimilation. In the framework of the EU Marine Copernicus Service, the operational system for the short-term forecast of Mediterranean Sea biogeochemistry already includes the assimilation of ocean colour satellite observations and BGC-Argo nitrate and chlorophyll profiles. Although results are very encouraging there are still a number of challenges to be addressed such as the inclusion of new variables and the improvement of the effectiveness of the BGC-Argo impact on the modelled ecosystem dynamics. Being oxygen the most common sensor in BGC-Argo, its observations are prone to be included in the actual assimilation system and to derive nutrient pseudo-observations through Neural Network (NN) applications. In this framework, the development of quality control (QC) for oxygen (e.g., sensor drift and comparison with climatology) represents a good practice to be included in NRT systems. This work is devoted to presenting a novel QC approach on BGC-Argo oxygen, an upgrade of NN- derived pseudo-observations dataset, and assimilated simulations with different setups of assimilated variables. Moreover, novel skill performance metrics have been developed to evaluate the impact of the different sets of assimilated observations.
Three different setups of the Mediterranean Sea biogeochemical model have been tested: a control run without assimilation; a multivariate run with assimilation of BGC-Argo chlorophyll, nitrate and oxygen; and a multivariate run that assimilates pseudo-observations of NN-derived nutrients and chlorophyll. Results show the feasibility of oxygen assimilation in biogeochemical forecast models. Moreover, skill performance metrics have revealed the significantly higher impact of oxygen BGC- Argo data with respect to the other biogeochemical variables, while enhanced impact on nutrient and phytoplankton dynamics at the regional and sub-regional levels is shown when profiles of pseudo- observations are assimilated.

Ms MEHLMANN Melina

Dalhousie University Canada

melina-mehlmann@dal.ca

ORAL

Evaluation of Biogeochemical ocean models from CMIP6 in the North Atlantic Ocean

Melina Mehlmann, Prof. Dr. Katja Fennel, Dr. Arnaud Laurent

Testing, evaluating, and improving biogeochemical ocean models is of great importance in climate and oceanographic research, particularly for projecting climate change. While the evaluation of physical model components has become increasingly comprehensive and sophisticated, an evaluation of the biogeochemical (BGC) components has so far been difficult to accomplish because of a lack of comprehensive global-scale BGC observations. Here, BGC-Argo profile data from the surface to 2000 m depth from the North Atlantic are compared to chlorophyll-a, nitrate, and oxygen simulated by state-of-the-art ocean models of the CMIP6 ensemble. Physical variables salinity and temperature are included to investigate modeled relationships between model physics and BGC. For calculation of differences between individual model outputs and observational data, the North Atlantic is divided into BGC provinces defined by physical oceanographic features. Initial results indicate large misfits between modeled BGC and BGC-Argo observations.

DAY2 – Wednesday 12 October 2022

Ocean Climate session (2): focus on the Mediterranean Sea

Dr KUBIN Elisabeth

OGS, Italy

ekubin@ogs.it

ORAL

Heat content and temperature trends in the Mediterranean Sea as derived by Argo float data (2005 – 2020)

Elisabeth Kubin*, Milena Menna*, Elena Mauri*, Giulio Notarstefano*,* Sebastian Mieruch°, Pierre-Marie Poulain*
**OGS - Institute of Oceanography and Applied Geophysics, Sgonico, Trieste, Italy*
°AWI - Alfred Wegener Institute, Bremerhaven, Germany
Keywords: Heat content trends; temperature trends; Argo floats; Mediterranean Sea; Mediterranean sub-basins; climate change;

The Mediterranean Sea is very sensitive to climatic changes due to its semi-enclosed nature and is defined as one of the hotspots in future climate change projections. In this study we use Argo float data to describe spatial variabilities and trends in Ocean Heat Content (OHC) within the entire Mediterranean Sea and for specified sub-basins (e.g. Western and Eastern Mediterranean, Gulf of Lion, South Adriatic). The amount of the OHC, spatially averaged in bins of 1 °x1 ° over the period 2001-2020, increases from west to east in the Mediterranean Sea.
Time series of temperature and OHC from 2005 to 2020, estimated in the upper and intermediate layers (5-700 m) and deeper layer (700-2000 m), reveal significant warming trends and an increase of OHC: the upper 700 m of the Mediterranean Sea show a warming trend of 0.041±0.012 °Cyr^{-1}, corresponding to a yearly increase in OHC of 3.59±1.02 Wm^{-2}. The upper 700 m of the Western Mediterranean Sea are warming fastest with an increase in temperature at a rate of 0.070±0.015 °Cyr^{-1}, corresponding to a yearly increase in OHC of 5.72±1.28 Wm^{-2}.

Mixing and convection events transport and disperse the temperature and OHC changes: significant warming trends are evident in the deeper layers (700-2000 m) of the two deep convection sites in the Mediterranean Sea (Gulf of Lion, South Adriatic), with an exceptionally strong warming trend in the South Adriatic from 2013 to 2020 of 0.058±0.005 °Cyr^{-1}, corresponding to a yearly increase in OHC of 9.43±0.85 Wm^{-2}.

The warming of different water masses will show its feedback on ocean dynamics and the atmosphere (air-sea fluxes) in the next years, decades or even centuries when these warming waters spread or re-emerge. This will stress ecosystems and accelerate the extinction of several marine species. This study contributes to a better understanding of climate change in the Mediterranean region and should be another wake-up call for policy makers and society.

Mr BARBONI Alexandre

Ecole Polytechnique, France

alexandre.barboni@lmd.ipsl.fr

ORAL

Anticyclones in the Mediterranean sea have significantly deeper winter MLD and delayed maximum.

Barboni Alexandre, Coadou-Chaventon Solange, Stegner Alexandre

The mixed layer is the uppermost layer of the ocean, driven by atmospheric fluxes. It follows a strong seasonal cycle, deepening in winter due to buoyancy loss, shallowing very close to the surface in summer with restratification. Recently several global and regional studies show a MLD modulation by mesoscale eddies with the seasonal cycle. In winter, MLD tends to be deeper inside anticyclonic eddies and shallower inside cyclonic ones. Gaube et al. (2019) shows globally an eddy-induced MLD anomaly up to about ±50m. However such studies were done globally with eddy composites and using an averaged climatology as MLD reference.

The Mediterranean sea contains a wide variety of mesoscale eddies, with the specific presence of several large anticyclones living up to 4 years, in particular in the Eastern basin. These anticyclones were extensively surveyed over the past decade with Argo deployments. Several floats were trapped inside anticyclones for months and recorded 18 winter MLD deepening events inside 14 long-lived well-sampled anticyclones, with a temporal resolution on the order of a week.

The comparison between these timeseries at the eddy core and outside-eddy measurements reveals that winter MLD deepening inside anticyclones is stronger but also lasts longer. The MLD reaches a maximum on average 100m deeper and one month later than the neighbouring outside-eddy ocean. In addition the linear trend proposed by Gaube et al (2019) of the MLD anomaly as a function of the sea surface deviation was not retrieved. Extreme MLD anomalies up to +350m and marked differences between sub-basins were also measured, showing the limit of a smoothed composite approach of eddy- induced MLD.

Dr JUZA Mélanie

SOCIB, Spain

mjuza@socib.es

ORAL

Propagation in depth of marine heatwaves in the Mediterranean Sea as observed by the Argo network

Mélanie Juza (1), Lara Díaz-Barroso (1), Joaquín Tintoré (1,2)

(1) Balearic Islands Coastal Observing and Forecasting System (SOCIB), Palma, Spain
(2) Mediterranean Institute for Advanced Studies (IMEDEA) (CSIC-UIB), Esporles, Spain

In a warming world, society is facing major climate-related challenges, risks and disasters. Among them, marine heat wave (MHW) events have devastating impacts on ecosystems, threaten economies, and strengthen severe storms and flooding by warming the ocean. MHWs are increasing substantially in intensity, duration and frequency worldwide, particularly in the Mediterranean Sea which responds rapidly to climate change. Although MHWs have a strong signature at surface, they are not restricted to the surface and can propagate deeper in the water column. The depth penetration of such extreme warm events may impact the vertical ocean properties and ocean circulation, and have negative ecological consequences.

In this study, MHW events in the Mediterranean Sea are first identified at surface using sea surface temperature from satellite observations. Then, the propagation of surface MHWs into the ocean interior is addressed through the analysis of vertical hydrographic profiles from profiling floats in the Mediterranean Sea over the period 2012–2021. This study shows the depth penetration of such events into the sub-surface as well as its sub-regional and seasonal variability. Such four- dimensional observations also allow highlighting the resulting enhanced upper-ocean density stratification in all sub-regions of the Mediterranean which would increase the degree of decoupling between surface and deep oceans causing changes in water masses and marine life.

The continuous ocean monitoring with sustainable multi-platform observational networks is essential to better understand the ocean behavior in response to extreme events and improve their prediction from local to sub-regional scales. This will help to establish mitigation and adaptation strategies for the marine conservation and sustainable management of the oceans in a warming world.

Dr HRVOJE Mihanović

Institute of Oceanography and Fisheries Croatia

hrvoje.mihanovic@izor.hr

ORAL

Exceptionally high salinities in the Adriatic Sea since 2017 – multiplatform approach to monitoring and research

Hrvoje Mihanović[1], Ivica Vilibić[1,2], Jadranka Šepić[3], Frano Matić[1], Zrinka Ljubešić[4], Elena Mauri[5], Riccardo Gerin[5], Giulio Notarstefano[5] and Pierre-Marie Poulain[5]

[1] Institute of Oceanography and Fisheries, Split, Croatia

[2] Division for Marine and Environmental Research, Ruđer Bošković Institute, Zagreb, Croatia

[3] Faculty of Science, University of Split, Split, Croatia

[4] Faculty of Science, Department of Biology, University of Zagreb, Zagreb, Croatia

[5] National Institute of Oceanography and Applied Geophysics - OGS, Sgonico, Italy

Exceptionally high salinity values were observed in summer and autumn of 2017 in the Adriatic (S > 39.0). The analysed data encompassed Argo profiling floats observations, CTD measurements carried out along the well-surveyed climatological transect in the Middle Adriatic (the Palagruža Sill, 1961–2022) and several glider missions, accompanied with satellite altimetry and operational ocean numerical model (Mediterranean Forecasting System) products. Unlike typical ingressions of saltier and warmer waters originating in the eastern Mediterranean (Levantine Intermediate Water—LIW) that usually occur between 200 and 400 m, seasonally strong inflow of warm and high salinity waters (S > 38.8) has been observed much closer to the surface since spring 2015, as the main LIW core deepened to 400-700 m. Such double-maxima vertical pattern was eventually disturbed by winter convection at the beginning of 2017, increasing salinities throughout the water column. A new episode of very strong inflow of high salinity waters from the Northern Ionian was observed in late winter and spring of 2017, this time restricted almost to the surface. As most of 2017 was characterized by extremely dry conditions, low riverine inputs and warmer than usual summer over the Adriatic and Northern Ionian, salinity values above the sharp and shallow (15–40 m) thermocline significantly increased. The maximum recorded salinity was 39.26, as measured by the Argo float in the Southern Adriatic. Surface salinity maximum events, but with much lower intensity, have been documented in the past. However, since 2017 such events became almost regular, and exceptionally high salinites are now commonly observed in the Adriatic, with seasonal interplay of mixing, inflow from the Ionian and stratification/evaporation contributing to the overall increase in salinity. The most recent Argo observations in the southern Adriatic show that salinities are higher than 38.8 throughout the water column.

Dr MENNA Milena

National Institute of Oceanography and Applied Geophysics, Italy

mmenna@ogs.it

ORAL

Impact of the Medicane Apollo on a cyclonic vortex of the Ionian Sea

Milena Menna[1], Riccardo Martellucci[1], Marco Reale[1], Gianpiero Cossarini[1], Stefano Salon[1], Giulio Notarstefano[1], Elena Mauri[1], Pierre-Marie Poulain[1] and Cosimo Solidoro[1]

[1] National Institute of Oceanography and Applied Geophysics, Oceanographic Section, Sgonico (TS), 34010, Italy

In October 2021, the Sicily Channel and the central-western Ionian Sea were affected by the passage of the tropical-like cyclone, or MEDICANE, Apollo. The system reached its maximum intensity between 29 and 30 October 2021 producing several damages, intense precipitations and huge coastal floodings in Sicily and Calabria regions. The surface circulation in the MEDICANE impacted area was characterized by permanent cyclonic vortices, offering the chance to describe the impact of a tropical-like cyclone on a pre-existing cold circulation structure.

Atmospheric and ocean reanalyses (ERA5 and Marine Copernicus Service), as well as in-situ data from Argo floats, were used to describe the temporal evolution of Apollo, the resulting air-sea interaction, the thermohaline and biological response to its passage in the upper layer (0-150 m) of the western Ionian Sea.

During the event, the core of the marine cyclone was characterized by a dramatic drop in temperature, corresponding to a local maximum in the wind-stress curl, Ekman pumping and current field relative vorticity. The strengthening of the cyclonic circulation led by the wind stress curl produced a strong vertical mixing in the surface layer (from 0 m to the Mixed Layer Depth - MLD) and an upwelling in the subsurface layer below the thermocline (MLD-150 m). The combined effect of vertical mixing and upwelling resulted in a shoaling of MLD, deep chlorophyll-a maximum, nutricline, and halocline. Oxygen and chlorophyll-a concentrations increased at surface, due to the enhanced oxygen solubility in the cooler water and higher productivity due to the increase of nutrients upwelled to the surface layer.

These results show that the pre-existing cyclonic vortex along Apollo's trajectory leads to a different physical response compared to the one observed during previous MEDICANEs, confirming the influence of the conditions in place in driving the ocean's reply to the extreme weather systems.

Dr KASSIS Dimitris

Hellenic Centre for Marine Research, Greece

dkassis@hcmr.gr

ORAL

An update of North Aegean hydrography derived from autonomous profiling floats

The recent expansion of Argo floats in regional seas and coastal waters has provided new datasets on the hydrography of areas that were previously under-sampled. Such a case is the North Aegean, a sub- basin of important oceanographic processes that affects the hydrography of the wider Eastern Mediterranean basin. In this study, an analysis of a large number of Argo profiles in the North Aegean , acquired since 2014, is presented. The results highlight a large level of spatial variability, and both seasonal and inter-annual trends of the physical parameters in the water column. In the upper layers, both temperature and salinity are mostly determined by the two dominant water masses of different origin, the Black Sea Water (BSW) and the Levantine Surface Water (LSW). The presence of these water masses in combination with the air-sea interaction seem to affect the status of the underlying layers. The temperature and salinity fields of the underlying layers become increasingly more heterogenic with depth and spatial gradients. This fact, is also related to the presence, or absence, of Dense Water Formation (DWF) events that are reflected in the bottom layers of different plateaus and trenches in the area. These results have also shown that enhanced Argo coverage has allowed the update of the area's complex hydrographic picture and revealed its important variability. Although in a still preliminary phase, the potential of Argo to perform successful missions in sub-basins of such complex bathymetry and coastlines, underlines the utility of Argo expansion in the coastal areas of the European marginal seas.

Dr FEDELE Giusy

CMCC Foundation, Italy

giusy.fedele@cmcc.it

ORAL

Characterization of the Atlantic Water and Levantine Intermediate Water in the Mediterranean Sea using 20 years of Argo data

Giusy Fedele[1], Elena Mauri[2], Giulio Notarstefano[2], and Pierre Marie Poulain[2]

[1]Regional Models and Geo-Hydrological Impacts Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, 81100 Caserta, Italy

[2]National Institute of Oceanography and Applied Geophysics, OGS, 34010 Sgonico (TS), Italy

Atlantic Water (AW) and Levantine Intermediate Water (LIW) are important water masses that play a crucial role in the internal variability of the Mediterranean thermohaline circulation. To be more specific, their variability and interaction, along with other water masses that characterize the Mediterranean basin, such as the Western Mediterranean Deep Water (WMDW), contribute to modify the Mediterranean Outflow through the Strait of Gibraltar, and hence they may influence the stability of the global thermohaline circulation.

This work aims to characterize AW and LIW in the Mediterranean Sea, taking advantage of the large observational dataset (freely available on https://argo.ucsd.edu, https://www.ocean-ops.org, last access: 17 January 2022; Wong et al., 2020) provided by Argo floats from 2001 to 2019. AW and LIW were identified using different diagnostic methods, highlighting the inter-basin variability and the strong zonal gradient that both denote the two water masses in this marginal sea. Their temporal variability was also investigated over the last 2 decades, providing a more robust view of AW and LIW characteristics, which have only been investigated using very short periods in previous studies due to a lack of data.

A clear salinification and warming trend characterize AW and LIW over the last 2 decades ($\sim 0.007 \pm 0.140$ and 0.006 ± 0.038 yr−1; 0.026 ± 0.715 and 0.022 ± 0.232 ◦C yr−1, respectively). The salinity and temperature trends found at sub-basin scale are in good agreement with previous results. The strongest trends are found in the Adriatic basin in the properties of both AW and LIW.

DAY 3 – Thursday 13 October 2022

BGC session

Dr FUJIKI Tetsuichi

Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan

tfujiki@jamstec.go.jp

ORAL

Phytoplankton dynamics in the high nutrient – low chlorophyll regions: the northwestern subarctic Pacific

Tetsuichi Fujiki · Shigeki Hosoda · Naomi Harada

Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka 237-0061, Japan
E-mail: tfujiki@jamstec.go.jp

Understanding of phytoplankton dynamics and its control factors provides a basic knowledge of the structure and functioning of ocean biogeochemical (BGC) cycle. The northwestern subarctic Pacific (NWSP) is a large counter-clockwise gyre that extends from the northeast of Japan to near the international dateline and is generally considered to be a region of high-nutrient and low-chlorophyll waters. Ship-based observations showed that the seasonal variability of the phytoplankton community in the NWSP is controlled mainly by iron (Fe), with light and temperature limitation occurring in winter and spring, and Fe availability plays an important role in regulating the magnitude and duration of the summer blooms.

Although other season blooms could not be detected by the ship-based observations, a time-series of Chl *a* maps based on satellite remote sensing of ocean color observed relative high concentrations of surface Chl *a* in autumn as well as in the summer in the NWSP. However, it remains unclear how the autumn blooms are caused, because of lack of *in situ* data on the phytoplankton community and environmental parameters of the upper ocean in autumn. In this study, we use autonomous observation platforms, a BGC-Argo float and a profiling buoy system, to explore the seasonal variability of phytoplankton biomass in the NWSP in greater detail, including blooms of both summer and autumn, and to identify and characterize the key mechanisms causing the bloom phenomenon.

Dr STRUTTON Peter

University of Tasmania, Australia

Peter.Strutton@utas.edu.au

ORAL

Biogeochemical Argo floats reveal the evolution of subsurface biomass in South Indian Ocean eddies

Peter G. Strutton, Helen E. Phillips, Earl R. Duran, Sylvia Pump and Thomas W. Trull

There is increasing recognition that eddies modulate open ocean productivity, and that this influence depends on both eddy source and evolution. Southeast Indian Ocean eddies are important pathways for the westward transport of biomass anomalies from the Leeuwin eastern boundary current into the oligotrophic South Indian Ocean. Eddy processes at the base of the mixed layer may stimulate productivity and sustain phytoplankton biomass, allowing the impact of eddies to extend thousands of kilometres into the ocean interior.

Here we present 4 months of high-frequency profiles from autonomous floats in anti- cyclonic and cyclonic eddies in the South Indian Ocean. From September to October, chlorophyll was evenly distributed throughout the mixed layer. With the onset of spring warming and stratification, chlorophyll became slightly more concentrated at the base of the mixed layer, invisible to satellites, where it persisted into summer and into the central South Indian Ocean. The increased chlorophyll at depth was likely due to increased phytoplankton chlorophyll content relative to biomass, but the magnitude of the chlorophyll to carbon signal was muted by increases in heterotrophic carbon. In these subsurface biomass maxima, isolated from the atmosphere, there was no significant change in oxygen saturation state over several months suggesting these communities are sustained by low ongoing productivity in balance with community respiration.

Mr PETIT Flavien

LOV, Sorbonne Université, France

flavien.petit@imev-mer.fr

ORAL

Variability in the fluorescence signal in relation to phytoplankton community composition and implications for the retrieval of the chlorophyll a concentration from BGC-Argo floats

Fluorescence is a practical method implemented in the BioGeoChemical-Argo (BGC-Argo) network for estimating the chlorophyll a concentration (Chla), a widely used proxy of phytoplankton biomass. Despite a strong correlation between the Chla and fluorescence signal on restricted spatial and temporal scales, large regional variations with a clear latitudinal gradient in the Chla-to-fluorescence ratio, referred to as "slope factor", have been observed in the global ocean. This indicates the potential influence of phytoplankton community composition, resulting from the combined effects of phytoplankton absorption and quantum yield of fluorescence. As phytoplankton communities play a key role in global biogeochemical cycles, it is critical to understand their variability to accurately determine Chla. In order to examine the role of phytoplankton community composition on the fluorescence signal, we used a global concurrent dataset of Chla estimated from BGC-Argo float fluorescence measurements and High-Performance Liquid Chromatography determinations, as well as phytoplankton absorption measurements. The community composition of phytoplankton shows a strong influence on absorption, with smaller cells characterized by reduced package effect and high absorption by accessory pigments in the blue spectral region. The quantum yield of fluorescence presents a clear trend with lower values in oligotrophic areas than in high latitude regions. In oligotrophic regions, picophytoplankton exhibit low values of the fluorescence quantum yield, which we attribute to the non-photosynthetic pigment zeaxanthin. The present work, showing that the slope factor is significantly correlated to the size structure of phytoplankton communities, is a first step towards a better estimation of Chla from BGC-Argo floats. Different methods have been proposed for assessing community size structure from BGC-Argo floats and thus could be used to better constrain the calibration of fluorescence in Chla.

Mr STOER Adam

Dalhousie University, Canada

adam.stoer@dal.ca

ORAL

Retrieval of ocean net primary productivity from daily cycles of carbon biomass measured by profiling floats

Adam C. Stoer and Katja Fennel

Current techniques for measuring ocean net primary productivity (NPP), a central metric in ecology and biogeochemistry, from water samples are time-consuming, expensive, and cannot be practically scaled up to continuously observe ocean basins. While satellite remote sensing addresses these limitations, satellite-derived NPP involves idealized models of the water column that do not include direct observation of all phytoplankton in the euphotic zone. However, with direct observations, we can use the daily cycle of photosynthetically-produced biomass to infer NPP throughout the euphotic zone. In this study, we estimate NPP in the upper 200 m from these daily cycles of carbon biomass using particle backscattering, a bio-optical proxy for particulate organic carbon, collected by BGC Argo floats and compare them to similarly derived estimates from dissolved oxygen. With this approach, we extract euphotic-zone-integrated NPP that is representative of conditions in the temperate and polar regions of the southern hemisphere over the past decade. We estimate NPP in the region south of 30°S as ~10.7 Pg C y^{-1}, and south of 50°S (the Southern Ocean) as ~4.8 Pg C y^{-1}.
This technique will be valuable for providing the basin-scale, ground-truthed information necessary to validate NPP models and assess changes in subsurface primary productivity related to climate.

Dr SHARP Jonathan

University of Washington, CICOES / NOAA PMEL, USA

jonathan.sharp@noaa.gov

ORAL

Variability in Ocean Oxygen from GOBAI-O2: A Machine-Learning-Based Data Product

Jonathan D. Sharp, Andrea J. Fassbender, Brendan R. Carter, Gregory C. Johnson

Over the past 50 years, the upper ocean has lost about 2% of its dissolved oxygen inventory, with important implications for biogeochemical cycling and the metabolism of aerobic marine organisms. Historical analyses of ocean deoxygenation have relied on either model output or the interpolation of sparse observations from ship-based surveys. By leveraging the vast quantity of in situ observations collected by the global Argo array, we have created a new gridded dissolved oxygen product based on a combined dataset of observations from Argo floats and ship surveys, and taking advantage of machine learning techniques for spatiotemporal interpolation. We rigorously evaluate the implementation of two machine learning techniques, using real observations and Earth system model output, to demonstrate validity in the trends and spatial patterns they produce. With the new gridded oxygen product (GOBAI-O_2: Gridded Ocean Biogeochemistry from Artificial Intelligence – Oxygen), we examine the distribution of dissolved oxygen in the global ocean, as well as trends and interannual variability over the past two decades. We find global deoxygenation over the early 21st century associated with ocean warming, with particularly strong trends in the Southern Ocean. We note that changes in the volumes of oxygen minimum zones don't exactly correlate to changes in the global oxygen inventory, likely due to regional differences in oxygen production and consumption processes. Finally, we compare our global and regional trends to previous estimates of ocean deoxygenation from both models and observations. GOBAI-O_2 carries the benefits of being straightforward to analyze as it is continuously resolved over space and time, easy to update as new observations are made available, and possible to adapt for the mapping of other chemical properties that are observed by both floats and ship surveys.

Dr MORK Kjell Arne

Institute of Marine Research, Norway

kjell.arne.mork@hi.no

ORAL

Net community production in the Norwegian Sea estimated from nitrate fluxes using profiling floats

Kjell Arne Mork1*, Yngve Børsheim1, Giorgio Dall´Olmo2, Kjell Gundersen1, Øystein Skagseth1, Henrik Søiland1

1 Institute of Marine Research, Norway
2 Plymouth Marine Laboratory, UK

Two profiling floats equipped with nitrate and other biogeochemical sensors were deployed in the Norwegian Sea. Nitrate data combined with a mixed layer model to remove the physical signal in nitrate were used to determine the annual average and monthly net community production (NCP) for the years 2020 and 2021. The NCP became positive in April when the vertical mixing weakened. Chlorophyll-a and particulate organ carbon (POC) data from the floats indicated however that the phytoplankton production already started in February when the mixed layer was still 200 m deep. The average annual NCP was positive in the upper 42 m for both years. Integrated over this depth, the average annual NCP was calculated to 66 g Cm-2 yr-1 and 48 g Cm-2 yr-1 for 2020 and 2021, respectively. The difference between the two years is explained by changes in atmospheric forcing during spring that affected the vertical mixing differently.

Mr TRUCCO-PIGNATA Pablo Nicolás

University of Southampton - National Oceanography Centre, UK

pntp1n18@soton.ac.uk

ORAL

Interannual variability of net community production in the Subantarctic Mode Water formation region estimated with autonomous platforms

Pablo Trucco-Pignata[1], Peter Brown[2], Dorothee Bakker[3], Hugh Venables[4], Alberto Naveira-Garabato[1], Filipa Carvalho[2], Katsia Pabortsava[2], Maribel García-Ibáñez[3], Sheri White[5], Stephanie Henson[2], Adrian Martin[1].

[1]National Oceanography Centre, University of Southampton, Southampton, UK, [2]National Oceanography Centre, Southampton, UK, [3]Centre for Ocean and Atmospheric Sciences, School of Environmental Sciences, University of East Anglia, Norwich, UK, [4]British Antarctic Survey, Natural Environment Research Council, Cambridge, United Kingdom, [5]Woods Hole Oceanographic Institution, Woods Hole, MA, United States

In the Subantarctic Zone (SAZ) of the southeast Pacific, the densest, coolest, and freshest Subantarctic Mode Water (SAMW) is formed. There, advected water masses reset their physicochemical characteristics by interchanging properties with the atmosphere. The formation of SAMW plays a critical role in global climate through its impact on the overturning circulation and oceanic heat and carbon uptake.

We evaluate the efficiency of this carbon uptake, and how it relates to the biological carbon pump. To do so, we estimate the interannual variability of net community production from 2008 to 2020 in the mixed layer in the eastern Pacific sector of the Southern Ocean. We use oxygen observations from biogeochemical Argo floats, gliders and moorings to resolve an upper ocean mass balance model. This model estimates the physical processes that modulate the observed evolution of oxygen in the mixed layer, and attributes the residual to biological processes. We calculate a mean annual net community production (ANCP) of 3.3 ± 4.5 mol C m-2 yr -1 for the SAZ, with an observed decreasing trend of -0.7 mol C m-2 yr -1 for the 12 year period studied.

Dr CORNEC Marin

NOAA-PMEL/University of Washington, USA

marin.cornec@noaa.gov

ORAL

Quantifying the Biological Carbon Pump in the North Atlantic with BioGeoChemical Argo floats

M. Cornec[1,2], Y. Huang[2,3], N. Buzby[1,2], & A. J. Fassbender[2]

[1]University of Washington; [2]National Oceanic and Atmospheric Administration- Pacific Marine Environmental Laboratory; [3] University of California Santa Cruz

Understanding and quantifying the mechanisms driving the biological carbon pump is required to better constrain the global cycling of this fundamental element. The North Atlantic Ocean is home to two regions with distinct trophic conditions and hydrographic regimes, representative of typical global ocean systems: the subpolar gyre with seasonal dynamics between spring phytoplankton blooms and winter convective mixing, and the subtropical gyre characterized by oligotrophic conditions and quasi-permanent stratification that limits vertical exchanges. This study compares various aspects of the biological carbon pump in these two regions based on multiparameter Biogeochemiocal (BGC) Argo float measurements. The large spatial coverage and high spatiotemporal resolutions of the float measurements allow seasonal and annual quantification of the Net Community Production (NCP) and associated fluxes in the twilight zone by combining multiple bio-optical and chemical tracers measured or derived from BGC float measurements (e.g., dissolved oxygen, dissolved inorganic carbon, total alkalinity). Combined with in situ observations from regional time series sites (e.g., BATS and the Irminger Sea Array) and a depth- resolved net primary production model, our float NCP estimates provide new insight into (1) the subpolar spring bloom contribution to annual carbon export and (2) nutrient supply and carbon production in the subtropical gyre. This study exhibits how a multi-sensor and multi-platform approach can be used to refine our understanding of the biological carbon pump at a global scale.

Dr McWHORTER Jennifer

National Oceanic and Atmospheric Administration, USA

jennifer.mcwhorter@noaa.gov

ORAL

Mesoscale eddies: Potential coral bleaching drivers and relief in the Gulf of Mexico

Jennifer K McWhorter[a], Emily Osborne[a], Matthieu Le Henaff[a], Claudia Schmid[a]

[a]Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL, USA

Cyclonic eddies shed by the Gulf of Mexico Loop Current may provide cool relief to the Flower Garden Banks National Marine Sanctuary (FGBNMS) and anticyclonic eddies may drive additional warming. The FGBNMS corals are located in a section of the water column (20- 100m depth) where the differences in properties between eddies are expected to be significant. Given that the most common time of year for eddy shedding from the Loop Current is July to September when most warming events are likely to occur, the oceanographic properties of these mesoscale eddies could be important for coral reefs, especially as warming increases into the future. Temperature and salinity from core Argo floats (2010-Present) as well as ship-based observations (2005-2020) show vertical water column properties correlated with these mesoscale eddies as they approach the FGBNMS. A recently deployed biogeochemical-Argo (BGC-Argo) float array in the Gulf of Mexico (2021-Present) is used to examine eddy influence on water column oxygen, pH, nitrate, and bio-optical properties to deduce the biogeochemical impact of propagated eddies on the neighboring FGBNMS region.

Dr FASSBENDER Andrea

NOAA Pacific Marine Environmental Laboratory, USA

andrea.j.fassbender@noaa.gov

ORAL

Inequity in the deep: The amplified mesopelagic response to carbon accumulation

Andrea J. Fassbender (PMEL), Brendan R. Carter (CICOES/PMEL), Mar C. Arroyo (UCSC/PMEL), Jonathan D. Sharp (CICOES/PMEL), Hartmut Frenzel (CICOES/PMEL), Yibin Huang (UCSC/PMEL)

Commonly used metrics, such as pH and the saturation state of calcium carbonate minerals, for describing the impact of ocean acidification on marine chemistry generally exhibit the largest changes at the sea surface where anthropogenic carbon (C_{ant}) invades. However, other equally important metrics related to organismal metabolism and proton pump regulation, such as the

partial pressure of carbon dioxide gas (pCO_2) and the hydrogen ion concentration ($[H^+]$), exhibit the largest changes below the surface where C_{ant} concentrations are lower. The larger subsurface changes for these parameters are caused by nonlinearities in the carbonate system and differences in how carbon accumulates throughout the water column over time due to the aggregate impacts of respiration, calcium carbonate dissolution, and C_{ant} penetration. These

factors vary regionally, causing regional differences in how subsurface pCO_2 and $[H^+]$ respond to total carbon variations, which may be important to consider when assessing carbon dioxide removal strategies. Proposed alteration of subsurface total carbon and total alkalinity fields would cause regionally varying impacts on many carbonate chemistry parameters, with potential implications for chemical thresholds (e.g., hypercapnia; pCO_2 > 1,000 µatm) that may influence habitat suitability or co-stressor overlap (e.g., with hypoxia) for marine organisms. In this study

we use observations from ships and floats to (1) characterize subsurface pCO_2 and $[H^+]$ sensitivities to persistent C_{ant} addition as well as variations in the vertical profiles of accumulated respiration and calcium carbonate dissolution, and (2) consider how the seasonal imprint of metabolic processes (e.g., the ratio of pCO_2 production to oxygen consumption) may be influenced by C_{ant} accumulation.

Mr TERRATS Louis

Laboratoire d'Océanographie de Villefranche (LOV), France

louis.terrats@obs-vlfr.fr

ORAL

Latitudinal gradient in the flux of sinking particles driven by the phytoplankton community: a BioGeoChemical-Argo float investigation in the Southern Ocean

Louis Terrats, Hervé Claustre, Nathan Briggs, Antoine Poteau, Benjamin Briat, Léo Lacour, Antoine Mangin, and Griet Neukermans.

The so-called gravitational pump, i.e. the sinking of particles into the mesopelagic zone (~100-1000m), is the main contributor to the biological carbon pump. Here, we examined the spatiotemporal variability in the gravitational pump with BioGeoChemical-Argo floats in the Southern Ocean, a critically under- sampled area. Using time-series of vertical profiles of bio-optical measurements, we characterized the particle stock in the euphotic zone, examined the particle export to the underlying mesopelagic zone, the transfer efficiency of sinking particles to depth, and the particle flux at 1000 m. We separated float observations into five latitudinal bands delineated by Southern Ocean fronts. We observed a significant increase in the particle flux at 1000 m with increasing latitude, despite comparable particle stocks in the euphotic zone. This latitudinal gradient in the deep particle flux concurred with a rise in the concentration and transfer efficiency of sinking particles in the mesopelagic zone. We showed that this latitudinal gradient can be explained by the composition of the phytoplanktonic community and the size of particles, derived from bio-optical float measurements at the surface. The predominance of micro-phytoplankton, large particles, and non-limiting silicate concentrations observed in the southernmost latitudes lead to an intense and efficient transport of sinking particles to depth.

Dr BERNARDI BIF Mariana

Monterey Bay Aquarium Research Institute, USA

mariana@mbari.org

ORAL

Using BGC-floats to observe particulate organic carbon dynamics in the southeast Pacific and southwest Atlantic Oceans

Mariana Bernardi Bif, Jacki Long, Kenneth Johnson

The production of particulate organic carbon (POC) in the upper ocean and subsequent export to the deep via sinking is a fundamental process that sequesters carbon out of contact with the atmosphere, known as the biological carbon pump. The magnitude of POC production and strength of the carbon pump varies spatially and with seasons but observing and quantifying such processes in the open ocean and at high-resolution is challenging. Here we use BGC-float optical data to observe seasonal production and export of POC in the South Pacific and South Atlantic Oceans at a similar latitudinal band (28-42˚S and 26-38˚S, respectively). The regions are located in the Subtropical Zone of the Southern Ocean but are periodically influenced by Subtropical Front entrainments. Backscattering (bbp) measurements, a proxy for POC, are shown in combination with chlorophyll-a (chla) data from fluorometers. Data quality control involved careful multi-step processes, including a gain factor correction for float chla measurements using satellite data. We were able to partition bbp and chla data into fractions belonging to big (>100µm) and small (<100µm) particles through the water column. Our results show strong seasonality in both regions, with maximum POC production and export in the warmer months and deeper export of small particles below the euphotic zone versus large particles. The magnitude of POC production and export, partition between size-fractions and export efficiency were remarkably different between the two regions. To better understand environmental factors associated with POC production and export dynamics we further hypothesize on the causes of these regional contrasts by leveraging oceanographic data and additional float sensor data.

Dr JOHNSON Kenneth

Monterey Bay Aquarium Research Institute, USA

Johnson@mbari.org

ORAL

Carbon to nitrogen uptake ratios observed across the Southern Ocean by the SOCCOM profiling float array

Authors: Kenneth S. Johnson, Matthew R. Mazloff, Mariana B. Bif, Yuichiro Takeshita, Hans W. Jannasch, Tanya L. Maurer, Joshua N. Plant, Ariane Verdy, Peter M. Walz, Stephen C. Riser, Lynne D. Talley

Measurements of pH and nitrate from the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) array of profiling floats were used to assess the ratios of dissolved inorganic carbon (DIC) and nitrate (N) uptake during the spring to summer bloom period throughout the Southern Ocean. Data were available for 243 bloom periods observed by 115 floats from 30°S to 70°S. Similar calculations were made using the Takahashi surface DIC and nitrate climatology. To separate the effects of atmospheric CO2 exchange and mixing from phytoplankton uptake, the ratios of changes in DIC to nitrate of surface waters (ΔDIC/ΔN) were computed in the Biogeochemical Southern Ocean State Estimate (B-SOSE) model. Phytoplankton uptake of DIC and nitrate are fixed in B-SOSE at the Redfield Ratio (6.6 mol C/mol N). Deviations in the B-SOSE ΔDIC/ΔN must be due to non-biological effects of CO2 gas exchange and mixing. ΔDIC/ΔN values observed by floats and in the Takahashi climatology were corrected for the non-biological effects using B-SOSE. The corrected, in situ biological uptake ratio occurs at values similar to the Redfield Ratio, with two major exceptions. North of 40°S biological DIC uptake is observed with little or no change in nitrate giving high C:N. In the latitude band at 55°S, the Takahashi data give a low C:N value, while floats are high. This may be due to a change in CO2 air-sea exchange in this region from uptake during the Takahashi reference year of 2005 to outgassing of CO2 during the years sampled by floats.

Dr HUANG Yibin

NOAA Pacific Marine Environmental Laboratory, USA

yibin.huang@noaa.gov

ORAL

Role of Biology in Sustaining the Southern Ocean Carbon Sink

Yibin Huang[1,2] and Andrea Fassbender[1,2]
[1]Department of Ocean Sciences, University of California, Santa Cruz, CA, USA,
[2]NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, WA, USA

The Southern Ocean (SO) plays a critical role in regulating Earth's climate through the carbon cycle, acting as a major sink for anthropogenic carbon dioxide (CO_2) released to the atmosphere. While atmospheric CO_2 forcing plays a fundamental role in determining the modern air-sea disequilibrium that allows the SO to function as a net carbon sink, biological (and physical) processes are also important. The biological carbon pump facilitates the consumption and export of inorganic carbon from the surface ocean to depth, maintaining the vertical carbon gradient and lowering near-surface pCO_2 levels seasonally. More specifically, biological activity transforms inorganic carbon into multiple types of carbon that no longer exchange with the atmosphere, including particulate organic carbon (POC), dissolved organic carbon (DOC), and particulate inorganic carbon (PIC or calcium carbonate). The production of each carbon pool has a distinct impact on the efficiency of the biological pump and on surface ocean pCO_2. Yet, little is known about how these biogenic carbon pools co-vary and mediate air-sea CO_2 exchange in the SO. Here, we use observations from 151 biogeochemical profiling floats to disentangle the role of each carbon pool in SO air-sea exchange. We find strong meridional variability in the magnitude and types of carbon produced, with elevated relative DOC contributions in the subtropics and sea-ice-dominated zones. PIC production peaks around the polar Antarctic zone and adjacent frontal regions (47-67 °S), an area known as the "great calcite belt". Cumulatively, we find that during the productive season (from September to March of the subsequent year), PIC production diminishes SO CO_2 uptake by 0.15 ± 0.11 Pg C yr^{-1}, whereas organic carbon production (POC+DOC) enhances CO_2 absorption by 1.6 ± 0.3 Pg C yr^{-1}. Without biological activity, the SO would outgas 1.1 ± 0.3 Pg C yr^{-1} to the atmosphere during the productive season.

POSTERS Sessions & Flash talks

DAY 1			
ID	**Speaker**	**Poster title**	
A01	**JHA**	Generation and Assessment of ARGO Sea Surface Temperature Climatology for the Indian Ocean Region	Virtual
A02	**RYKOVA**	Feature Mapping: a method to refine ocean features in gridded products	Virtual
A03	**PAUTHENET**	Four-dimensional temperature, salinity and mixed layer depth of the Gulf Stream, reconstructed from remote sensing and in situ observations with neural networks	Virtual
A04	**JONNAKUTI**	Machine Learning-based approach for Delayed Mode quality control of salinity data from Argo floats.	Virtual
A05	**CHAMBERLAIN**	The Performance of Present, Future, and Optimal Argo Infrastructure	In Person
A06	**LIU**	Increasing Discrepancies in Salinity between Multiple Objective Analyses Since 2015	Virtual
A07	**TVS**	Can grounded Argo float data be used for validating bathymetry	Virtual
A08	**SIIRIÄ**	Argo under-ice in the northern latitudes	In Person
A09	**BALEM**	Argo floats deployed at the North Pole, will we see them again?	Virtual
A10	**WOOD/WILLIS**	Ocean warming and Greenland ice loss: the case for expanding Argo to Greenland's continental shelf	In Person
A11	**CABANES**	A improved Near Real Time Quality Control Tool for Argo trajectory files	Virtual
A12	**GAO**	Internal Wave Imprints on Temperature Fluctuations as Revealed by Rapid-Sampling Deep Profiling Floats	Virtual
A13	**HIRANO**	SBE41CTD sensor pre-deployment screening in JAMSTEC	Virtual
A14	**HOSODA**	Argo real-time QC procedure using signature-based neural network	In Person
A15	**KOBAYASHI**	Salinity bias with negative pressure dependency caused by anisotropic deformation of CTD measuring cell under pressure examined with a dual-cylinder cell model	Virtual
A16	**PETIT**	Deep through-flow in the Bight Fracture Zone and its role in the hydrological evolution of the Irminger Current	Virtual
A17	**ROGACHEV**	Large Oyashio eddy drives interbasin exchange between the Sea of Okhotsk and the subpolar Pacific	Virtual
A18	**SAMBE**	Classification of Argo Profiles in the Mid-latitude Northwest Pacific Ocean by Unsupervised Clustering and Their Potential Use	In Person
A19	**SATO**	Performance evaluation of the optical dissolved oxygen sensor, ARO-FT, on Argo floats	Virtual
A20	**THIERRY**	Assessing the extension of the argo array towards the deep ocean: an analysis of the long-term stability and accuracy of the SBE61, SBE41 and RBR CTD sensors	In Person

DAY 2			
B01	**FERNANDEZ CASTRO**	Lagrangian pathways for heat, carbon and nutrients subduction with sub-antarctic mode waters	In Person
B02	**OKE**	A demonstration of why only delayed-mode Argo data should be used for ocean reanalysis	Virtual
B03	**YUMRUKTEPE**	BGC-Argo driven generic modeling framework for the Nordic Seas biogeochemistry	In Person
B04	**FUJII**	Evaluation of Argo in the UN Ocean Decade Project SynObs	In Person
B05	**KIDO**	An introduction of newly developed eddy-resolving quasi-global ocean reanalysis product -JCOPE-FGO-	Virtual
B06	**MAURI**	Extremely high salinity in the water column of the South Adriatic Pit	In Person
B07	**TUOMI**	Enhancing the monitoring of the Baltic Sea environmental state using Argo floats	In Person
B08	**LI**	Improvements on the drift of dissolved oxygen sensor (ARO-FT)	In Person
B09	**ROCHA DE SOUZA**	Equity, Diversity, and Inclusion: A case study using the Argo International Program	In Person
B10	**BENAVIDES**	Argo in boundary currents: study cases using the VirtualFleet software	In Person
B11	**DOI**	Impact of BGC Argo data on state estimation by using the Estimated Ocean State for Climate Research (ESTOC)	Virtual
B12	**FROUIN**	Additive varying coefficient model for estimating diffuse attenuation coefficient from satellite-derived water reflectance	Virtual
B13	**MACÉ**	Calibration of an optical model using BGC-ARGO profiles	In Person
B14	**MERCHEL**	Argo floats in the South Baltic Sea - five years of use	In Person
B15	**OULHEN**	Reconstructing the ocean using Argo data and a data-driven method	In Person
B16	**ROUTABOUL**	New satellite telemetry solutions to meet the new needs of ARGO profiling floats	In Person
B17	**SHULGA**	Salinity recovery using regional bio optical products	Virtual
B18	**TRAYLOR**	Assessing Integrated Satellite-Float Productivity Estimates in the NASA EXPORTS Campaigns	In Person
DAY 3			
C01	**IZETT**	Expanding the global coverage of gross primary production and net community production using biogeochemical profiling floats	In Person
C02	**KOESTNER**	A multivariable empirical algorithm for estimating particulate organic carbon concentration in marine environments from optical backscattering and chlorophyll-a measurements	In Person

C03	**GIDUGU**	Estimation of Seasonal changes in Vertical distribution of phytoplankton biomass in Tropical Indian Ocean from Bio-Argo and remote sensing observations	Virtual
C04	**AHMED**	Oxygen saturations of the Northwest Pacific subsurface waters using an array of Argo floats	Virtual
C05	**HONDA**	Estimation of Particulate Organic Carbon Flux with BGC-Argo Backscatter data from the Western North Pacific	Virtual
C06	**JOY-WARREN**	Connecting phytoplankton taxa distributions to air-sea CO2 fluxes in the Southern Ocean	In Person
C07	**MUNZIL**	Application of Bio-Argo float in understanding denitrification in the northern Indian ocean.	Virtual
C08	**SCHMECHTIG**	New method for Chlorophyll-A calibration	In Person
C09	**XU**	Constraining the twilight zone remineralization rate in the South China Sea basin: insights from a multi-method intercomparison	Virtual
C10	**CORREDOR ACOSTA**	Argo Float Reveals Biogeochemical Characteristics Along the Freshwater Gradient Off Western Patagonia	Virtual
C11	**EVRARD**	Towards a new phase for Euro-Argo programme: the contribution of Euro-Argo RISE project	In Person
C12	**FEUCHER**	Subpolar gyre decadal variability explains the recent oxygenation in the Irminger Sea	In Person
C13	**FRENZEL**	OneArgo toolboxes for accessing and visualizing Argo data	In Person
C14	**KOLODZIEJCZYK**	Decadal patterns of dissolved oxygen in the global ocean (2009-2018)	In Person
C15	**MAZE**	"argopy": a python library to focus on Argo science	Virtual
C16	**MORRIS**	Best practices for Core Argo floats: Physical handling, metadata and data considerations	Virtual
C17	**ORGANELLI**	Developing synergies between BGC-Argo and Earth Observation to assess the impact of ocean extremes on marine ecosystems	In Person
C18	**OSBORNE**	Preliminary results from a new marginal sea biogeochemical-Argo array in the Gulf of Mexico	In Person
C19	**PARK**	An Oxygen Mass Balance of the Labrador Sea from Biogeochemical Argo Float and Hydrographic Data	In Person
C20	**RENOSH**	Vertically resolved light models for the global ocean based on machine learning techniques	In Person
C21	**ZHANG**	Unveiling the fate of organic particles in the oligotrophic ocean	In Person

Mr JHA RAVI KUMAR

Indian National Center for Ocean Information Services India

ravijha070@mail.com

Generation and Assessment of ARGO Sea Surface Temperature Climatology for the Indian Ocean Region

Ravi Kumar Jha; Udaya Bhaskar TVS

ARGO program development can be overseen as a sustainable paradigm for real-time ocean obser- vations amongst many major in-situ sources. ARGO program has emerged significantly throughout the global ocean, and it seemed imperative to recognize its importance. In this study, we have se- lected one of the vital parameters, namely sea surface temperature (SST). Two decades-long ARGO in-situ observations are used as a primary source, and monthly SST gridded products on a climato- logical scale using data interpolation variational analysis (DIVA) with a resolution of 0.25° has been derived and investigated for the Indian Ocean region. GUI-based visual quality control has been performed to eliminate visible outliers before the product generation. The monthly ARGO SST (ASST) product is evaluated using five different SST products derived from in-situ, satellite, and ship data sets. ASST products are evaluated with other reliable climatologies using various statis- tics such as Bias, RMSE, Correlation, and Skill Score. Further, ASST monthly products are evalu- ated from the high-quality real-time buoys network of RAMA and OMNI. Finally, ASST products appeared to correlate highly with the other reliable SST products. Overall, it is noted that the near- surface temperature measurements from ARGO floats could be used in generating gridded SST products as they form valuable data sets in space and time.

Dr RYKOVA Tatiana

CSIRO – Australia

tatiana.rykova@csiro.au

Feature Mapping: a method to refine ocean features in gridded products

Gridded products of ocean properties underpin a lot of research. But most of these products under-utilise the observations. Gridded fields don't fit the observations as closely as they should. Often this is intentional, to avoid over-fitting. But it limits the usefulness of gridded products. Here, we borrow the idea of post-processing, from weather forecasting, and employ traditional analysis techniques, from physical oceanography, to re-map gridded properties of the ocean to better align with Argo observations. We call this method - Feature Mapping. Specifically, feature mapping adjusts water-mass properties (TS-properties) and isopycnal depths of a gridded field, to align with observations. The resulting feature-mapped gridded fields better-align with observations at observation locations, delivering gridded fields with stronger, more realistic, vertical and horizontal gradients that may be better suited to many applications.

Dr PAUTHENET Etienne

LOPS/IFREMER, France

etienne.pauthenet@ifremer.fr

Four-dimensional temperature, salinity and mixed layer depth of the Gulf Stream, reconstructed from remote sensing and in situ observations with neural networks

Etienne Pauthenet, Loïc Bachelot, Kevin Balem, Guillaume Maze, Anne-Marie Tréguier, Fabien Roquet, Ronan Fablet, and Pierre Tandeo

Despite the ever-growing amount of ocean's data, the interior of the ocean remains under sampled in regions of high variability such as the Gulf Stream. In this context, neural networks have been shown to be effective for interpolating properties and understanding ocean processes. We introduce OSnet (Ocean Stratification network), a new ocean reconstruction system aimed at providing a physically consistent analysis of the upper ocean stratification. The proposed scheme is a bootstrapped multilayer perceptron trained to predict simultaneously temperature and salinity (T-S) profiles down to 1000 m and the Mixed Layer Depth (MLD) from surface data covering 1993 to 2019. OSnet is trained in the Gulf Stream region, to fit sea surface temperature and sea level anomalies onto all historical in-situ profiles. To achieve vertical coherence of the profiles, the MLD prediction is used to adjust a posteriori the vertical gradients of predicted T-S profiles, thus increasing the accuracy of the solution and removing vertical density inversions. The prediction is generalized on a 1/4◦ daily grid, producing four-dimensional fields of temperature and salinity, with their associated confidence interval issued from the bootstrap. The OSnet reconstructed field is coherent even in the pre-ARGO years, demonstrating the good generalization properties of the network. It reproduces the warming trend of surface temperature, the seasonal cycle of surface salinity and mesoscale structures of temperature, salinity and MLD. Our results are promising and demonstrate the power of machine learning methods to improve the prediction of ocean interior properties from observations of the ocean surface.

Mr JONNAKUTI Pavan Kumar

Indian National Centre for Information Services

jpawan33@gmail.com

Machine Learning-based approach for Delayed Mode quality control of salinity data fro Argo floats.

Pavan Kumar Jonnakuti, TVS Udaya Bhaskar
Indian National Centre for Ocean Information Services (INCOIS), MoES, Govt of India, "Ocean Valley", Pragathinagar (BO), Nizampet (SO), Hyderabad - 500090

Argo floats are autonomous floats designed to measure the temperature and salinity of the world's oceans. Once deployed, these floats go as deep as 2000 meters and, while coming up, automatically measure the temperature and salinity of the underlying ocean. These floats are a substitute for ship-based data sets; currently, as many as ~3800 are active in the global oceans. These autonomous instruments measure and transmit data seamlessly, regardless of weather, season, or region. However, the salinity sensors on these floats are sensitive to bio-fouling and can cause degradation to the data. As these are once deployed, and data is continuously obtained, they are not available for calibration, unlike the instruments on the ship. In view, the Machine Learning based approach is employed in this work to check and correct the degradation of the salinity sensor on floats. All available date, time, positions, pressure, salinity, and temperature profiles in the global ocean are trained using Artificial Neural Networks. This trained model is then used to correct the degraded salinity based on the pressure, temperature, and metadata information. The method is very effective, and salinity correction was observed on par with the OWC method. Hence this method can substitute for manual inspection by an expert about the region. Also, the developed model can be used for all the floats within the area, enabling DMQC of orphan floats and enhancing the number of DMQC profiles in GDAC.

Dr CHAMBERLAIN Paul

Scripps Institution of Oceanography, USA

pchamber@ucsd.edu

The Performance of Present, Future, and Optimal Argo Infrastructure

Paul Chamberlain Lynne Talley Bruce Cornuelle Matt Mazloff Sarah Gille

The core Argo array has operated for over 20 years with the design goal of uniform spatial distribution. Recent studies have acknowledged increased variability in some parts of the ocean and recommend increased core Argo density in the equatorial waters, boundary currents, and marginal seas. Biogeochemical (BGC) floats currently observe the ocean from a collection of pilot arrays, but recently funded proposals will transition these pilot arrays to a global array. The current BGC Argo implementation plan recommends uniform spatial distribution of BGC Argo floats. Using modeled, full depth, BGC fields we estimate, for the first time, the effectiveness of current Argo infrastructure. We also study the effectiveness of uniformly distributed BGC Argo arrays at observing the ocean at various float densities. Then, using previous Argo trajectories, we estimate the future distribution of the Argo array and quantify how how well it observes the ocean. Finally, using a novel technique for sequentially identifying the best deployment locations, we suggest the optimal array distribution for BGC Argo floats.

Mr LIU Chao

University of Delaware, USA

chaoliu@udel.edu

Increasing Discrepancies in Salinity between Multiple Objective Analyses Since 2015

Chao Liu[1], Xinfeng Liang[1*], Rui M. Ponte[2], and Don P. Chambers[3] [1]School of Marine Science and Policy, University of Delaware, Lewes, DE, USA

[2]Atmospheric and Environmental Research (AER), Lexington, MA, USA

[3]College of Marine Science, University of South Florida, St. Petersburg, FL, USA

Comprehensive in-situ observations of ocean salinity have greatly benefited from the Argo Program. However, discrepancies in salinity between a number of observation-based objective ocean analyses (OA) were reported, particularly since 2015 when a large portion of the salinity data developed a drift toward higher salinity. Here we investigate the salinity variability over 2005-2019 and provide an assessment of the discrepancies in the gridded salinity fields. We found that most widely-used OAs show an unusual salinity increase after 2015 which is too large to be real. Growing inconsistency on monthly salinity anomaly is also evident over 2015-2019 when compared with prior time periods. The inconsistency is very apparent in the 700-2000 m and between 25-60°S, where a common geographical pattern is found on the residuals over the trends. These issues are at least partially attributed to the recognized data drift, and should be concerned by ocean and climate research communities.

Dr TVS Udaya Bhaskar

Indian National Centre for Ocean Information Services (INCOIS)

uday@incois.gov.in

Can grounded Argo float data be used for validating bathymetry

TVS Udaya Bhaskar[1], RUVN Satish[1]

[1]Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences (MoES), Govt. of India, "Ocean Valley", Pragati Nagar (BO), Nizampet (SO), Hyderabad - 500090, India.

Application of Argo floats profiling depth data to improve the bathymetry maps in poorly sampled regions of the continental shelf has been demonstrated in this study. As a part of the international Argo program 3000 floats have been deployed in the global ocean. The deepest profiling depth was 2000 m for majority of the Argo floats. As these floats are freely drifting objects, they tend to move to shallow regions owing to the currents and get grounded. All the profiling depths data from a sample float near the continental shelf were compared with the ship track data obtained from bathymetry surveys which are used for generating the bathymetry of the oceanic basin. The profiling depth data from these grounded floats (depth where profiling depth is deeper than the bathymetry) was used to validate the bathymetry of the location. Significant improvement of the bathymetry for a region can be done where the trackline data are sparse and routine bathymetric surveys are not possible. This work shows an additional application of Argo data apart from the routine generation of climatology of temperature and salinity and generation of sub-surface velocities.

Dr SIIRIA Simo-Matti

Finnish Meteorological Institute, Finland

simo.siiria@fmi.fi

Argo under-ice in the northern latitudes

Simo-Matti Siiriä[1)], Ingrid M. Angel-Benavides[2)],Birgit Klein[2)], Laura Tuomi[1)]
1) Finnish Meteorological Institution, Finland
2) Bundesamtes für Seeschifffahrt und Hydrographie, Germany

For understanding the status and changes of the global oceans, it is vital to have representative data from the high-latitude areas. In the Arctic, the steady growth of the seasonal ice zone opens the possibility for the operation of Argo floats, which could well complement existing measurements due to their relatively low cost, year-round measurements and under-ice sampling capabilities. This includes sampling during the ice formation, a period very difficult to sample where data is rarely available and collected almost exclusively by marine mammals.
As part of the Euro-Argo RISE project (Euro-Argo Research Infrastructure Sustainability and Enhancement), two reports were written to further aid on the expansion of the Argo array towards the northern high latitudes. One with recommendations on how to operate the floats in these regions, including local configurations of the ice avoiding software, to assist institutions and national programs interested in deploying floats there. The other report concerns the Delayed-Mode Quality Control in marginal Seas, including the Arctic and Baltic, where current challenges were identified (ex. reference data availability and quality), and recommendations were provided (ex. method adaptations).
Currently, more than 2500 Argo profiles have been collected in the seasonal ice zones of the Nansen Basin, East Greenland current and in the shallow waters of the Barents Sea and the Gulf of Bothnia (Baltic Sea). We present an analysis of the performance of the European fleet under-the-ice and evaluate the importance of these observations (seasonal distribution vs. other platforms, cost per profile, etc.).

Mr BALEM Kevin

IFREMER, France

kevin.balem@ifremer.fr

Argo floats deployed at the North Pole, will we see them again ?

Balem Kevin[1], Martinez Almoyna Carlhand Maud[1], Kolodziejczyk Nicolas[1], Lique Camille[1], Talandier Claude[1]
1 : Univ. Brest, CNRS, IRD, Ifremer, Laboratoire d'Océanographie Physique et Spatiale (LOPS), IUEM, Brest 29280, France

The Arctic ocean is changing at an alarming and unprecedented rate, in response to the on-going climate change. Yet, the hydrological properties and their changes remain poorly observed in this basin. One reason is that the winter harsh conditions and permanent sea ice cover make cruise and autonomous platform operations difficult. As a result, the Arctic is one of the last basins over the global ocean not covered by the Argo network. Argo floats are designed to transmit their data and positions when reaching the surface at the end of each profile, which is not possible in sea ice covered regions. In September 2021, two Argo floats were deployed under sea ice at the North Pole (90°N) in the western Eurasian Arctic Basin, as part of the french project ARticGO. They are equipped with an Ice-Sensing-Algorithm (ISA), making them able to detect the presence of sea ice, and continue profiling without reaching the surface until they enter an ice-free region.
In order to better assess the under ice behavior of the floats in Eurasian Basin and the probability for these floats to reach an free ice region, where they can transmit their data, we used the Virtual Fleet python software to perform a Lagrangian tracking, using 10-year [2006-2015] model outputs of a pan-Arctic ocean-sea ice model at high resolution (~4km). A dedicated module has been developed in Virtual Fleet to mimic the ISA-like behavior of polar floats, and we performed multiple trajectory simulations to analyze the impact of the deployment strategy and the environmental conditions (sea ice).

Dr WOOD Michael

Jet Propulsion Laboratory, USA

mike.wood@jpl.nasa.gov

Ocean warming and Greenland ice loss: the case for expanding Argo to Greenland's continental shelf

Michael Wood, Josh Willis

Over the last several decades, the Greenland ice sheet has been a major contributor to global sea level rise. About half of Greenland's ice loss has been attributed to the widespread acceleration of its outlet glaciers which discharge icebergs into the Arctic Ocean and sub- Arctic Seas. This glacier speed-up is linked with ocean temperature variability in Greenland's coastal waters: as subsurface water temperature increased in the 1990's, submarine melt rates increased, glaciers destabilized, and the ice sheet was thrown into a state of mass loss that continues to this day. These developments indicate that ocean observations on the Greenland shelf are critical for predicting sea level rise. Yet, prior to 2015 most observations were limited to sporadic oceanographic cruises along the continental shelf in southwest Greenland. This changed dramatically in 2015 with the onset of NASA's Oceans Melting Greenland (OMG) mission. OMG was a 7-year (2015-2021) airborne mission that conducted annual surveys of shelf waters during summer. In its final few years, OMG tested deployment of Argo-like floats on the continental shelf. Incredibly, these deployments proved highly successful. Several floats remained on the shelf through the winter providing the first ever year-round time series of subsurface temperature in several critical locations on the shelf. Based on the lessons learned during the OMG mission, we outline a strategy to expand the Argo array to sample these critically important shelf waters that drive Greenland's ice loss, and hence global sea level rise. We describe our experience using Alamo and APEX profiling floats, alongside ship-based and air-deployed CTDs, and recommend key sites where these floats should be deployed to have impact on predictions of glacier retreat, and global sea level rise. We envision an array of roughly ten floats on the shelves maintained via international collaboration and local Greenlandic support.

Dr CABANES Cécile

CNRS, France

cecile.cabanes@ifremer.fr

A improved Near Real Time Quality Control Tool for Argo trajectory files

Cécile Cabanes[1,2], Nicolas Kolodziejczyk[2], Gaelle Herbert[2], Solène Dealbera[2] [1] University of Brest, CNRS, IRD, UAR3113, Plouzané, France

[2] University of Brest, CNRS, Ifremer, IRD, LOPS Laboratory, Plouzané, France

In 2000, the international Argo observational program was launched to observe the global *in situ* ocean temperature and salinity, in order to monitor the ocean's variability and understand its role in climate. Twenty years later, more than 2.5 millions quality controlled profiles have been provided over the global ocean, overwhelming the amount of profiles ever carried out in the history of oceanography.

In addition to the major increase in temperature and salinity profile of high quality, Argo autonomous floats are cycling between surface and their nominal parking depth at 1000 dbar, where they drift during 10 days. Thus, through the positioning and/or timing of the float over their cycle life, they provide an unprecedented integrated huge dataset of trajectories (Argo 'Traj' files), i.e. horizontal trajectories and velocity at 1000 dbar and at the surface. These deep velocities provide unprecedented absolute references used to reconstruct ocean currents and turbulence, to constrain and validate model reanalyses and climate models, as well as to constrain the earth geoid reference for satellite altimeter measurements. In contrast to the sparse sampling of currentimeters provided by scientific cruises and few equipped moorings at few locations, the Argo float trajectories are unique sources of deep velocity data since the coverage is global and more than 20 years of data are available.

However, contrary to the P/T/S profiles, Argo trajectory files are not systematically qualified in delayed mode. Although Argo deep displacement product including DMQC exists (e.g. ANDRO https://doi.org/10.17882/47077), it is sparsely updated. On the other hand, the Argo trajectories undergo very few automatic QC in real time at DAC level, leaving a lot of suspicious data. Here, we present a simple tool including extra-automatic controls and logs on trajectory files such as grounding, time and position control, pressure parking depth and climatology checks… . This tool significantly improves the quality of the Argo trajectories database. This tool could also be an help for the future delayed mode operator involved in the validation of Argo trajectory to screen and prioritize delayed mode operations.

Dr GAO Zhiyuan

Key Laboratory of Physical Oceanography/Institute for Advanced Ocean Science/Frontiers Science Center for Deep Ocean Multispheres and Earth System, Ocean University of China

gaozhiyuan@stu.ouc.edu.cn

Internal Wave Imprints on Temperature Fluctuations as Revealed by Rapid- Sampling Deep Profiling Floats

Zhiyuan Gao[1,2], Zhaohui Chen*[1,2], Xiaodong Huang[1,2], Zhenhua Xu[2,3], Haiyuan Yang[1,2], Zhongsheng Zhao[1,2], Chong Ren[2], Lixin Wu[1,2]

[1]Key Laboratory of Physical Oceanography/Institute for Advanced Ocean Science/Frontiers Science Center for Deep Ocean Multispheres and Earth System, Ocean University of China, Qingdao, China

[2] Pilot National Laboratory for Marine Science and Technology (Qingdao), Qingdao, China

[3] Key Laboratory of Ocean Circulation and Waves, Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China

Key Points:

- Internal waves are found to have considerable imprints on temperature fluctuations using rapid-sampling deep profiling floats.
- The temperature fluctuations can reach 7 m°C at 4000 m, posing challenges to assess the real deep ocean warming rate.
- The internal waves induced temperature fluctuations in the deep ocean are generally larger in the Philippine Basin and Mariana Arc.

Internal waves play important roles in modulating the temperature variations and heat transfers in stratified oceans. However, due the deep ocean measuring approach limitations, it is still challengeable to characterize the temperature fluctuations induced by internal waves in the deep oceans below 2000 m. In this study, a fleet of rapid-sampling deep profiling floats with an approximately daily sampling rate were deployed in the northeastern South China Sea (SCS), Philippine Basin (PB), Mariana Arc (MA), and Kuroshio Extension (KE). Results show that the internal waves, internal tides or near-inertial waves, have considerable imprints on local temperature fluctuations. Geographically, the internal wave induced temperature fluctuations are generally larger in the PB and MA, indicative of a strong deep signature of internal tides generated by local energetic tide-topography interactions or radiation from remote sources. The temperature fluctuations at 4000 m can reach up to 7 m°C in most regions, which may cover up real signals of temperature change, posing challenges to assess the deep ocean warming rate through currently insufficient deep profiling floats. Besides, the amplitude of isopycnal displacement in the PB and MA are evidently larger than in KE at 4000 m, which implies enhanced diapycnal diffusivity and mixing in the deep layers of open oceans with rough topography.

Ms HIRANO Mizue

JAMSTEC, Japan

hiranom@jamstec.go.jp

SBE41CTD sensor pre-deployment screening in JAMSTEC

Since the Argo programme was started in 1999, JAMSTEC has deployed 1338 Argo floats in May 2022. From the beginning of the Argo programme, SBE is producing over 10000 CTD sensors (SBE41) for Argo floats, keeping the high quality to satisfy the Argo criteria. Although the accuracy and stability of SBE41 is largely improved, troubles of hardware and sensor accuracies are still occasionally occurred partly due to updates. Sometimes such troubles are detected before deployment. Therefore, pre-deployment calibration is one of the important procedures to keep the Argo observation network to be a healthy situation.

Until now, the number of screenings for SBE41 is 676, which is over half of the Argo floats obtained by JAMSTEC. Previously the calibration system for screening in JAMSTEC was similar in SBE, however, JAMSTEC developed a simpler calibration system for SBE41 to improve cost- effectiveness and operation time. The ability of the system can conduct screening of three floats at once. To calibrate SBE41 in the simpler calibration system, we use SBE3 for the temperature sensor and SBE4 for the conductivity sensor as the reference sensor. The SBE3, SBE4, and three SBE41s are connected via a tube flowing with artificial seawater, and conductivity and temperature (CT) are measured for 11minutes. We can verify the SBE41 CT values by comparing them with the reference sensor SBE3 and 4. We also made efforts to control the room temperature and the used seawater to be stable to obtain better performance. Through this effort, we succeed that the calibration accuracies in the simpler system are mostly as the same as in the Argo project (water temperature ± 0.002˚C, pressure
± 2.4 dbar, and salinity ±0.01 psu). Using the simpler calibration system, we could detect 8 conductivity sensors that were suspected to be unhealthy.

Dr HOSODA Shigeki

JAMSTEC RIGC, Japan

hosodas@jamstec.go.jp

Argo real-time QC procedure using signature-based neural network

Shigeki Hosoda, Nozomi Sugiura, Shinya Kouketsu, Kanako Sato, Tadashi Henmi

Argo profile data undergone the real-time quality control (rQC), which are currently automatically processed by DACs, could contain some error data, and could sometimes be difficult to use directly for analytical researches. In this study, we propose a signature-based neural network (NN) for automated QC of Argo profiles, improving the procedure proposed by Sugiura and Hosoda (2020). The weights of the NN were determined by learning the existing pairs of the signature of raw profile and its delayed-mode QC (dQC) flag across global Argo observation. In this method, the discriminant function with the path signature as input is made nonlinear by applying a NN, and the imbalance between the numbers of normal and abnormal data is resolved by adjusting the importances in the cost function. We applied the method to the global Argo profile data, and examine the advantages for the current procedures. One of the main results is that the score of precision/recall is approaching to an acceptable level of practical use, clearly improved from the previous version of the signature method. The other implication is that the precision/recall score seems to be dependent on observed area of ocean. The signature-based NN has large advantages to end- users to help providing better rQCed data by just applying a simple processing, and also opening up a possibility in offering a quick and automated QC processing of Argo profiles prior to providing dQC data.
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Dr KOBAYASHI Taiyo

JAMSTEC, Japan

taiyok@jamstec.go.jp

Salinity bias with negative pressure dependency caused by anisotropic deformation of CTD measuring cell under pressure examined with a dual-cylinder cell model

Measurements made by deep floats had a salinity bias with a negative pressure dependency. Salinity is affected by conductivity measurements via changes in the CTD measuring cell geometry under pressure. To remove the effect, a canceling factor for pressure *CPcor* is prepared theoretically by the manufacturer considering the isotropic deformation of a single- cylinder measuring cell under pressure; the observed negative pressure dependency, however, requires an even smaller *CPcor* . This study examined the causes of the inconsistency for salinity measurements with a dual-cylinder cell model, considering that the actual CTD measuring cell is a glass cell covered by a polyurethane jacket. The dual-cylinder cell model clarifies that the CTD measuring cell deforms anisotropically to yield a smaller *CPcor*; mainly because the inner glass cell deforms radially to a greater extent than the single-cylinder model due to the radial stress from the outer cylinder (jacket) being stronger than the hydrographic pressure. The observed fresh bias at the sea surface is attributed to a slight shrinkage of the outer jacket because of compression set of polyurethane in deep ocean. The shrunken polyurethane jacket is elongated over time due to a creep phenomenon, which causes less-freshening of the fresh bias found at the sea surface. The observed linear relationship between the smaller *CPcor* and the fresher bias at the sea surface is attributed to the variation of the wall thickness of the polyurethane jacket when it shrinks similarly. The study suggests another idea to improve the salinity accuracy of CTD sensors greatly: a change of the jacket material into an elastomer. The improvement makes the present setting of *CPcor* be more valid and reliable, because the elastomer jacket hardly affects the change of the measuring cell geometry under pressure, which in turn removes the pressure effects on salinity measurements.

Dr PETIT Tillys

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

tillys.petit@gmail.com

Deep through-flow in the Bight Fracture Zone and its role in the hydrological evolution of the Irminger Current

Iceland-Scotland Overflow Water (ISOW) is exported from the Nordic Seas into the Iceland Basin to feed the lower limb of the Meridional Overturning Circulation. The Bight Fracture Zone (BFZ) is known to be a major route for ISOW toward the Irminger Sea, but the role of this gateway in the evolution of ISOW properties over the subpolar gyre is unclear. A combination of ship-based and Deep-Argo data gathered between 2015 and 2018 allow us to investigate the pathways and hydrological evolution of ISOW as it flows through the BFZ, as well as its influence on the North-East Atlantic Deep Water (NEADW) properties in the Irminger Sea. The ISOW flow through the BFZ amounts to 0.76 ± 0.2 Sv and is mainly fed by the lighter part of the ISOW layer flowing west of 29-30°W as part of the East Reykjanes Ridge Current in the Iceland Basin. In the rift valley of the BFZ, between an eastern and a western sill, the bathymetry of the BFZ shapes a cyclonic circulation along which the ISOW layer is homogenized. The largest changes in ISOW properties are however observed downstream of the western sill, at the exit of the BFZ. There, ISOW is mixed isopycnally with comparatively fresher NEADW circulating in the Irminger Sea and lies over a layer of denser NEADW that possibly entered the Irminger Sea south of the BFZ. The fresher NEADW results from the erosion of the ISOW core by mixing with inflows from the interior of the Irminger Sea as it flows northward from the Charlie-Gibbs Fracture Zone. Hence, our analysis reveals the key role of the BFZ through-flow in compensating these inputs of fresh inflows along the northward Irminger Current.

Dr ROGACHEV Konstantin

V.I. Ilichev Pacific Oceanological Institute – Russia

rogachev@poi.dvo.ru

Large Oyashio eddy drives interbasin exchange between the Sea of Okhotsk and the subpolar Pacific

Konstantin Rogachev and Natalia Shlyk Pacific Oceanological Institute

The water exchange between the Sea of Okhotsk and subpolar Pacific governs the intermediate water ventilation. The mechanism of this exchange have not yet revealed. What determines the variations of this exchange flow to the subpolar Pacific have not yet shown. Most of the previous works suggested that the interbasin exchange occurs through the two deepest straits along the Kuril Islands which are the Kruzenshtern Strait to the north of the Middle Island Chain and the Boussole Strait to the south. Here we show the evidence that large anticyclonic eddy drives the interbasin exchange via the mid depth straits in the Middle Island Chain. Based on hydrographic, Argo and Argos data we estimate the flow from the Sea of Okhotsk to the subpolar Pacific through this Middle Island Chain. This mechanism explains significant differences between the structure of the Oyashio in extremely cold year in the subpolar Pacific.

Ms SAMBE Fumika

Tohoku University – Japan

fumika.sambe.r6@dc.tohoku.ac.jp

Classification of Argo Profiles in the Mid-latitude Northwest Pacific Ocean by Usupervised Clustering and Their Potential Use

FUMIKA SAMBE[1], TOSHIO SUGA[1,2]

1 Department of Geophysics, Graduate School of Science, Tohoku University 2 JAMSTEC

The mid-latitude northwest Pacific Ocean is a region where transport, stirring, and mixin of subtropical and subarctic waters occurs strongly. These physical processes form oceanographic vertical structures with different characteristics in each region. Many studies have been conducted on the characteristics and distribution of the vertical structure by using existing definitions of structure based on spatially and temporally limited data, such as shipboard observations. The basic research framework has not changed significantly, although a large amount of vertical profile data is now available spatially and temporally comprehensively with the expansion of the global ocean observation network represented by Argo. We thought that the accumulation of Argo vertical profile data would allow us to recapture the characteristics of ocean structure using data-driven science objectively and applied unsupervised clustering to Argo data on temperature and salinity in the mid-latitude northwest Pacific Ocean. The dataset was classified into five clusters, each distributed to form its own regions. The vertical structure of each class showed characteristics that corresponded largely to the distribution areas elaborated by previous studies. The results were also used to suggest changes in the vertical structure associated with changes in the dynamic state of the Kuroshio Extension and seasonal changes in vertical structure in the mixed-water region.

Dr SATO Kanako

JAMSTEC - Japan

k_sato@jamstec.go.jp

Performance evaluation of the optical dissolved oxygen sensor, ARO-FT, on Argo floats

Authors: Kanako Sato, Hiroshi Uchida, and Shigeki Hosoda
Institute: JAMSTEC

To investigate how climate change signals subducted with STMW affect subsurface ocean structure, how they re-appear on the sea surface further downstream, and how they affect air- sea interactions and surface biogeochemical processes, 11 APEX floats equipped with ARO- FT in the northwestern Pacific subtropical region in 2021. All of ARO-FTs were performed aging by manufacturer (JFE Advantech Co., Ltd.) and JAMSTEC's laboratory, by putting the sensor membranes under high pressure using JAMSTEC's high pressure tank. After that, they were calibrated in JAMSTEC's laboratory before their deployment. The difference between dissolved oxygen profile of float's Prof_no.1 and in-situ dissolved oxygen profile at its deployment is have a clear linear relationship with the in-situ dissolved oxygen profile. Therefore, we correct dissolved oxygen profile of float's Prof_no.1 with the linear regression. The values of slope and offset fell within the range of 1.024~1.061 and 3.44~7.69, respectively, and the individual differences in correction coefficients slope and offset are not large. With this correction, we were able to obtain a correction value that was almost within the initial accuracy of the ARO-FT. Since all these floats can measure dissolved oxygen during drifting at the sea surface, we examined the temporal drift of ARO-FTs by using them. Linear changes in the difference of oxygen partial pressure measured by ARO-FTs from one calculated by using surface pressure of ERA5 in operation for about one year range from ⍰0.01 mbar. Therefore, ARO-FTs are stable about one year.
This work was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, Grant-in-Aid for Scientific Research on Innovative Areas (19H05700).

Dr THIERRY Virginie

Ifremer, France

vthierry@ifremer.fr

Assessing the extension of the argo array towards the deep ocean: an analysis of the long-term stability and accuracy of the sbe61, sbe41 and rbr ctd sensors.

AUTHORS: V. Thierry[1], M. Amice[3], X. André[3], D. Desbruyeres[1], C. Cabanes[1], A. González[2], G. Le Provost[3], A. Mosquera[2], P. Vélez[2]

[1] LOPS, Univ Brest CNRS, Ifremer, IRD, UBO, Plouzané, France.
[2] Instituto Español de Oceanografía (IEO) – Consejo Superior de Investigaciones Científicas (CSIC), Tenerife, Spain.
alberto.gonzalez@ieo.es, pedro.velez@ieo.es, angela.mosquera@ieo.es
[3] IFREMER, Plouzané, France.

Due to the role played by the deep ocean in the climate system and the Earth's energy and sea-level budgets, OneArgo aims to extend the coverage of the network to full ocean depth. Ensuring long-term stability and sensor accuracy to achieve reliable pressure, temperature and salinity measurements is a challenge that the Argo community is facing today. Within the framework of the NAOS and EuroArgo-RISE projects, an experiment was carried out to assess the performance of the new generation of Argo sensors: SBE61 and SBE41CP from Sea-Bird Scientific and the Concerto-3 CTD from RBR. All sensors were integrated simultaneously on Deep-Argo floats, allowing synchronization and comparison of their *in situ* measurements. Two 3-headed floats (SBE4CP, SBE61 and RBR Concerto-3) and two 2-headed floats (SBE61 and RBR Concerto-3) were deployed in 2020 or 2022 in the Canary basin, where the deep waters have been monitored since 1997. The pressure difference between the sensors varies as a function of pressure and generally increases from 0 at the sea surface to +/-5 dbar, which is within sensor accuracy. In the deep layers, the temperature differences between the sensors lie within sensor accuracy (+/-0.002°C) and are stable over time. Salinity data from the sensors are compared to ship-based calibrated casts acquired at float deployment. Salinity data of the three sensors need to be corrected of pressure dependent bias (the so-called CPcor correction term) and a conductivity gain (M). Once corrected, excellent agreement with the ship-based reference profiles are achieved.

Dr FERNANDEZ CASTRO

Bieito - University of Southampton, UK

b.fernandez-castro@soton.ac.uk

Lagrangian pathways for heat, carbon and nutrients subduction with sub-antarctic mode waters

Bieito Fernández Castro*[1], Matthew Mazloff[2], Richard G. Williams[3] and Alberto C. Naveira Garabato[1]

[1]Ocean and Earth Science, National Oceanography Centre, University of Southampton, Southampton, UK

b.fernandez-castro@soton.ac.uk, acng@soton.ac.uk

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

mmazloff@ucsd.edu

[3] Department of Earth, Ocean, and Ecological Sciences, School of Environmental Sciences, University of Liverpool, UK

ric@liverpool.ac.uk

Sub-Antarctic Mode Waters (SAMW), forming in the deep winter mixed layers in the Sub-Antarctic Zone (SAZ) to the north of the Antarctic Circumpolar Current (ACC), connect the ocean thermocline with the atmosphere, contributing to ocean carbon and heat uptake and transporting high-latitude nutrients northward, to fuel primary production at low latitudes. The important climatic role of SAMW is controlled by the rate of fluid subduction from the deep winter mixed layers and the concentration of heat, carbon and nutrients at the end of winter. These concentrations depend on a range of processes, both physical (air-sea exchange, transport of Antarctic waters across the ACC, along ACC advection, eddy fluxes, diapycnal mixing, etc.) and biogeochemical (biological uptake, export and remineralisation), whose relative contributions are very poorly understood. With a Lagrangian particle-tracking experiment in a data-assimilative coupled physico- biogeochemical model of the Southern Ocean (B-SOSE), we assess the origin of the water masses reaching SAMW formation regions and the physico- and biogeochemical transformations occurring along their transport pathways. Our results underline the importance of the advection of subtropical waters along the ACC for the sequestration of heat and anthropogenic carbon and in modulating the fertilization of the low-latitude thermocline.

Key words: Southern Ocean, Sub-Antarctic Mode Waters, Lagrangian, B-SOSE, carbon uptake, heat uptake, nutrients

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Dr OKE Peter

CSIRO, Australia

peter.oke@csiro.au

A demonstration of why only delayed-mode Argo data should be used for ocean reanalysis

Argo data is important for constraining ocean reanalyses. Argo data includes real-time data and delayed-mode data. Real-time data has been processed using automatic quality-control, to identify and flag obviously bad data. But delayed-mode data has been manually inspected, with point-wise corrections, and subtle drifts identified and either corrected or flagged. Delayed-mode data is most suitable for underpinning ocean reanalyses. Using a global, eddy- resolving ocean reanalysis system, we show that the assimilation of real-time data for salinity can significantly degraded reanalysed sub-surface salinity. For context, we compare the quality of the reanalysed salinity for the pre-Argo period, for a period using delayed-mode Argo data, and for a period using real-time data. Compared to the pre-Argo period, salinity errors are reduced by 30% when delayed-mode data are assimilated, but only by 20% when real- time data are assimilated. This indicated that one-third of the improvement realised by assimilating Argo data, is lost if real-time data are used instead of delayed-mode data. An action for the ocean reanalysis community is to only use delayed-mode Argo data for reanalyses.

Dr YUMRUKTEPE Veli Çağlar

The Nansen Center, Norway

caglar.yumruktepe@nersc.no

BGC-Argo driven generic modeling framework for the Nordic Seas biogeochemistry

Yumruktepe, V. Ç., Mousing, E. A., Tjiputra, J., Samuelsen, A.

The marine ecosystem is a key component of the climate system and consequently its representation in models is vital for better understanding and predicting climate dynamics. Biogeochemical model estimations, however, have high uncertainties. Some of this uncertainty stems from uncertainties in model representations of physical processes such as mixing and vertical velocity to which the timing and magnitude of production is highly sensitive. Biogeochemical parameters are adjusted to overcome the shortfalls of the physical model often resulting in the use of unrealistic parameter values. The BGC-Argo array offers a unique data set that can be used to constrain model physics in order to reduce the biogeochemistry errors stemming from uncertainties in modelled physical processes. BGC-Argo array also provides high resolution data to validate the biological variables, making it possible to develop improved regional parameterisations of biochemical variables. In this study, we develop an along BGC-Argo track 1D modelling framework where the model physics is constrained by the BGC-Argo temperature and salinity profiles to reduce the uncertainties related to mixed layer dynamics allowing the evaluation of errors stemming from biogeochemical formulation and parameterization. We objectively analyse the model results using combined BGC-Argo and satellite data and improve the model biogeochemical dynamics. The framework uses GOTM as the physics model and FABM as the coupler. We use ECOSMO II(CHL) as the biogeochemical model. The generic framework allows for easy implementation of any BGC-Argo profiler. With the FABM coupler, the framework can be used with many other biogeochemical models allowing an inter-model comparison study. As a 1D framework, the experiments are cost effective and allow a parameter analysis prior to 3D simulations. We present the framework, example cases for the Nordic Seas, the applied routines for model improvement and future implementations integrating the system with 3D regional and climate studies.

Dr FUJII Yosuke

JMA/MRI, Japan

yfujii@mri-jma.go.jp

Evaluation of Argo in the UN Ocean Decade Project SynObs Authors

Yosuke Fujii (JMA/MRI), Elisabeth Remy (MOI), Hao Zuo (ECMWF), Peter Oke (CSIRO), Lijing Cheng (IAP-CAS), and Yiguo Wang (NERSC)

“Synergistic Observing Network for Ocean Prediction” (SynObs) is the UN Decade Project led by OceanPredict Observing System Evaluation Task Team, and seeks the way to extract maximum benefits from the combination of various observation platforms, typically the combination of satellite and in situ observation data such as Argo, or the combination of coastal and open ocean observation platforms, to ocean/coastal predictions. It aims to identify the optimal combination of different ocean observation platforms through observing system design/evaluation, and to develop advanced assimilation methods with which we can draw synergistic effects from various combinations.
One activity currently being carried out under the SynObs project is to evaluate the impacts of abrupt salinity drift in Argo floats reports since 2015 using observing system experiments (OSEs). In this activity, we evaluate the impacts of applying the latest gray list or using delayed-mode Argo data instead of the real-time ones using different ocean reanalysis systems as well as objective analysis systems. A continuously positive trend in the global ocean salt content is visible since 2015 in almost all analysis products, including ones with delayed-mode Argo data. Possible causes of this global ocean salt content signals estimated with various analysis products are under investigation.

Dr KIDO Shoichiro

Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Application Lab, Japan

skido@jamstec.go.jp

An introduction of newly developed eddy-resolving quasi-global ocean reanalysis product -JCOPE-FGO-

Shoichiro Kido[1], Masami Nonaka[1], and Yasumasa Miyazawa[1]
1: Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Application Lab

Ocean reanalysis and forecasting systems, which combine information derived from observations and numerical ocean models through data assimilation scheme, serve as a powerful tool for monitoring and predicting the behavior of ocean. Recent progress in observational and modelling technique as well as increase in computational power have enabled us to routinely monitor the state of world oceans, and various ocean reanalysis products have been released so far. In this presentation, we will present an overview of our newly- developed eddy-resolving quasi-global ocean reanalysis product, named the Japan Coastal Ocean Predictability Experiments-Forecasting Global Ocean (JCOPE-FGO).

The JCOPE-FGO is a global extension of the regional JCOPE system originally configured for the western North Pacific, and it covers the global ocean from 75°S to 75°N with a horizontal resolution of 0.1°x0.1°. In this system, information obtained from in-situ temperature and salinity profiles (including those from Argo profiles) and satellite observations of SST and SSHA are dynamically incorporated into an eddy-resolving ocean general circulation model with the 3DVAR scheme. The JCOPE-FGO provides estimates of three- dimensional oceanic states from January 1993 to present. Comprehensive validations of analyzed oceanic fields of the JCOPE-FGO against various types of available observations revealed that the product can realistically represent spatial distributions of water mass structures and dynamical fields in most part of the global ocean, although some quantitative discrepancies are also identified over several specific regions. The temporal variations in these fields are also correctly captured both in the tropical and extratropical oceans. This suggests that this product serves as a useful tool for monitoring changes in oceanic state and understanding their physical origins. We hope to discuss some possible applications of this product for ocean observations (e.g., the design of observational platforms, tracking of Argo floats…etc) as well as its potential improvement.

Ms MAURI Elena

National Institute of Oceanography and Applied Geophysics, Italy

emauri@ogs.it

Extremely high salinity in the water column of the South Adriatic Pit

Elena Mauri, Riccardo Martellucci, Milena Menna, Giulio Notarstefano, Antonella Gallo, Annunziata Pirro, Massimo Pacciaroni and Pierre-Marie Poulain.
National Institute of Oceanography and Applied Geophysics – OGS, Borgo Grotta Gigante 42/C 34010 - Sgonico (TS) – Italy

Since the Mediterranean is a particularly sensitive and responsive to ongoing climate change, its northern basin, the Adriatic Sea, a site of deep-water formation processes, constitutes an important laboratory for evaluating the effects of such changes on the water column physical parameters, and consequently, on convective processes.
The 2013-2021 time series of the Argo float data in the Southern Adriatic Pit displays a drastic salinification in the subsurface layer extending into deeper layers. This phenomenon is especially evident after 2017. The Levantine Intermediate Water (LIW) usually enters the south Adriatic Pit at 100-400 m depth, highlighted by a salinity maximum. In the studied period, the LIW is no longer characterized by the highest salinity. The inflow of subsurface high salinity water, sporadically visible throughout the years between summer and early winter, from 2019 becomes progressively saltier and temporally more persistent all year long, reaching record-breaking values in 2020-2021. The concomitance of several factors, some related to the Adriatic-Ionian Bimodal oscillating System (BiOS) circulation, others more closely related to the general warming and salinification of the entire Mediterranean Sea, support this extremely high salinification event.

This work will investigate the causes of this extraordinary increase of salinity in the Southern Adriatic as it affects the thermohaline characteristics of the area with consequences on ocean dynamics and potential effects on climate.

Dr TUOMI Laura

Finnish Meteorological Institute, Finland

laura.tuomi@fmi.fi

Enhancing the monitoring of the Baltic Sea environmental state using Argo floats

Laura Tuomi and Simo-Matti Siiriä

Finnish Meteorological Institute (FMI). Erik Palménin aukio 1, FI-00560 Helsinki, Finland

The Baltic Sea is a semi-enclosed, heavily eutrophied shallow marginal sea. Monitoring the physical, chemical and biological conditions of the Baltic Sea, coordinated by the Baltic Marine Environment Protection Commission (HELCOM), allows us to follow the development of its state. Alongside the traditional monitoring performed with research vessels, the role of the new automated measurement techniques, such as Argo floats and gliders, in the monitoring of the state of the Baltic Sea is being discussed. Argo floats, for example, complement the traditional monitoring by providing higher temporal coverage for the measurements, thus enabling monitoring of the seasonal variations in temperature, salinity, and oxygen conditions. Argo floats also operate independently of the weather conditions and measure also during the ice season in the ice-covered areas.

Argo floats have been used in the Baltic Sea since 2012 and our experience in operating the floats in this shallow and seasonally ice-covered sea has considerably increased. Presently measurements with Argo floats are made in six of the Baltic Sea sub-basins by Finland, Poland, and Germany. Argo floats have become a viable addition to the Baltic Sea measurement and monitoring activities. The experiences and best practices to operate Argo floats in marginal seas and seasonally ice-covered areas compiled by the Euro-Argo RISE project, will further enhance the use of Argo floats in the Baltic Sea. Furthermore, the Baltic Sea Use Case demonstrates the possibilities of Argo floats in monitoring the changes in the Baltic Sea surface and deeper layer temperatures.

We will present the advances made in the use of Argo floats in the Baltic Sea. Use cases of the Argo float data will also be given and the status and future possibilities for utilizing Argo floats in the Baltic Sea for monitoring will be discussed.

Dr LI HUA

JFE Advantech CO., Ltd, Japan

lihua@jfe-advantech.co.jp

Improvements on the drift of dissolved oxygen sensor (ARO-FT)

Shinichi Takai, Technology Department, Ocean and River Instruments Division, JFE Advantech Co., Ltd, Japan
Hua Li, Oceanographic Research Lab, Ocean and River Instruments Division, JFE Advantech Co., Ltd, Japan
Hiroshi Uchida, Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, Japan

It has been documented (Bittig et. al. 2018) that optical DO sensors experience approximately -5 % per year drift during their storage and transportation in air. In order to suit the requirements of Argo float application, we developed DO sensor, “ARO-FT”, which has well-known features of fast-response (<1 s) and long-term stability. To evaluate the storage drift, we stored the ARO-FTs in room temperature without providing power for 6 months and measured the drift every two months by our standard calibration procedure with 20 measurement points (4 temperatures × 5 DO concentrations). From this, we learned that the drift was
-1.36 % (average of 4 temperature points at 100 % saturation) in 6 months and we could estimate the drift to become about -2.72% per year. Aging of sensor films, in general, result in overestimating on DO measurements. On the contrary, the drift during storage had a tendency to underestimate the DO values. To reduce the drift during storage, we have been studying the sensing foil materials that probably cause these unusual changes and searching for methods to minimize the influence.

Dr ROCHA DE SOUZA Mariana

NOAA, USA

mariana.rochadesouza@noaa.gov

Equity, Diversity, and Inclusion: A case study using the Argo International Program

Mariana Rocha de Souza, Stephen C Diggs

The IPCC summary for policymakers explicitly requests that climate researchers and policymakers actively increase the participation of “traditionally marginalized groups including women, young people, indigenous peoples, local communities, and ethnic minorities” to address the challenges ahead. It is possible to implement budget-neutral but impactful changes in how we approach workforce development, and we can increase collaboration in a way that will proactively welcome scientists and engineers from different backgrounds and countries.
Ultimately, we believe such efforts can increase both the efficacy and visibility of the research that will come from the resulting diverse global community. In this presentation, we will look at some of the Argo data from deployments to publications and propose a suite of practical initiatives that can be authentically integrated into the international Argo program.

Dr PIECHO-SANTOS A. Miguel
I.M. ANGEL-BENAVIDES (Presenter)

IPMA-Portuguese Institute for the Sea and the Atmosphere / CCMAR-Centre of Marine Sciences U. Algarve, Portugal

BSH- Federal Maritime and Hydrographic Agency, Hamburg, Germany

amsantos@ipma.pt

Argo in boundary currents: study cases using the VirtualFleet software

I.M. Angel-Benavides[1], K. Balem[2], L. Díaz-Barroso[3], B. Klein[1], M. Le Jeune[2], G. Maze[2], C. van Migerode[1,4], A.M. Piecho-Santos[5,6]

1 BSH-Federal Maritime and Hydrographic Agency, Hamburg, Germany
2 Ifremer, University of Brest, CNRS, IRD, Laboratoire d'Océanographie Physique et Spatiale, IUEM, 29280, Plouzané, France
3 SOCIB- Balearic Islands Coastal Observing and Forecasting System, Palma de Mallorca, Spain
4 Ghent University, Ghent, Belgium
5 IPMA-Portuguese Institute for the Sea and the Atmosphere, Lisboa, Portugal
6 CCMAR-Centre of Marine Sciences Univ. Algarve, Faro, Portugal

The Argo Program is a key component of the Global Ocean Observing System. The core program consists of drifting floats that make a 2000m profile of temperature and salinity every 10 days. The global ocean has been sampled on target since 2007, with a spatially uniform array of floats providing, at least, one profile every 10 days on a 3x3-degree global grid. But this core mission has been recognised as sub-optimal for turbulent regions, including the equatorial band and Western Boundary Currents. Boundary current (BC) regions are hot spots of the ocean's variability, they host strong currents constantly instable, hence turbulent, which concentrate large signals (e.g. of mean/eddy meridional heat transport or surface heat transfer). The Argo Program thus need to improve its observation strategy for turbulent BC regions in order to better capture their complex ocean interior structure and variability. Historically, the Argo Program has recommended a doubling of the profile density in BC regions. In this study, we tested this recommendation and further follow on new approaches based on several simulations studies using the VirtualFleet software, a python tool that simulate the trajectories and sampling of virtual floats. Simulations were done for the Gulf Stream Extension, the East Greenland Current and the West Spitzbergen Current in the Nordic Seas, the Western Mediterranean Sea and the Gulf of Cadiz. Several optimization strategies were tested. Our results show how to improve the Argo mission in those areas and provide recommendations for the sampling strategies (deployment plans and configuration parameters) to be possibly adopted by the core Argo Program.

Mr DOI Toshimasa

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

doit@jamstec.go.jp

Impact of BGC Argo data on state estimation by using the Estimated Ocean State for Climate Research (ESTOC)

Toshimasa Doi, Satoshi Osafune, Shinya Kouketsu, Shigeki Hosoda and Shuhei Masuda

Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan.

BGC Argo float array is increasing the presence in monitoring spatio-temporal variations in ocean environment. We try to estimate both physical and biogeochemical ocean states with integrating various observations including BGC Argo float array through a 4-dimensional variational data synthesis system, which is constructed based on a pelagic lower trophic level ecosystem model and oceanic general circulation model. This data synthesize system can estimate dynamically self-consistent ocean state which integrates available ocean observations. By using the data synthesis system, we focused on the dissolved oxygen observation accumulated by BGC Argo, and examined the effectiveness of BGC Argo observations in ocean state estimation. We divided the global ocean into five basins (Atlantic, Pacific, Indian, Southern Ocean, and Arctic Ocean), and obtained optimal model parameters for the atmospheric exchange coefficient of oxygen at sea-surface and the rate of oxygen consumption by biogeochemical activity for each basin with Green's function approach. By comparing the results based on obtained optimized parameters between with and without BGC Argo observations, we evaluate the observation impacts on our ocean state estimation. The results can contribute to clarify the importance of the deployment of BGC Argo to the global ocean.

Dr FROUIN Robert

**Scripps Institution of Oceanography,
University of California San Diego, USA**

rfrouin@ucsd.edu

Additive varying coefficient model for estimating diffuse attenuation coefficient from satellite-derived water reflectance

[1]Tan, J., [2]Begouen Demeaux, C., [2]Boss, E, [1]Frouin, R.

[1]Scripps Institution of Oceanography, University of California San Diego, La Jolla, California
[2]School of Marine Sciences, University of Maine, Orono, Maine

Diffuse attenuation coefficient for downward irradiance in the 400-700 nm range, KdPAR, obtained from Biogeochemical-Argo (bio-Argo) vertical light profiles was matched with spectral remote sensing reflectance, Rrs, derived from MODIS data. The matchup data set was used to develop a semi-parametric additive varying coefficient model (AVCM) to estimate KdPAR from Rrs at 412 to 678 nm (10 wavelengths). The coefficients of the model are function of informative (modifying) variables such as Sun zenith angle, geographic location, sea surface temperature, biome, and the Julian day of the measurement. First, the Rrs multivariate ensemble is decomposed into principal components (PCs), and the PCs most correlated to KdPAR are selected. The AVCM relates linearly KdPAR to the selected PCs. The importance of the ancillary variables is examined, and those with little influence on the coefficients are discarded. Statistical performance is compared with that of other KdPAR models, parametric and non-parametric. The advantage of using satellite-derived Rrs in developing the AVCM, as opposed to using measured Rrs or synthetic data, is that the predictive variables contain the actual noise expected in application to satellite imagery. The ongoing bio-Argo program will increase the number of available matchups in diverse conditions and regions, allowing more accurate KdPAR estimates at the globalscale.

Mr MACE Loïc

University of Liège, Belgium

loic.mace@uliege.be

Calibration of an optical model using BGC-ARGO profiles

Loïc Macé[1,2], Luc Vandenbulcke[1], Jean-Michel Brankart[2], Pierre Brasseur[2], Marilaure Grégoire[1]

[1]: Modelling for Aquatic Systems (MAST), University of Liège, Belgium
[2]: Institut des Géosciences de l'Environnement, Grenoble Alpes University, France

Biogeochemical processes are largely described by empirical equations, with parameters that must be calibrated in each basin on the basis of locally collected observations. In modeling, these parameters are subject to uncertainties, the evaluation of which has been little documented so far. The main objective of my PhD work is to tackle this issue by developing an ensemble system for the coupled physical-biogeochemical model NEMO-BAMHBI. Applied to the Black Sea, it aims to evaluate the main sources of uncertainty in the model, both physical and biogeochemical, which have a significant influence on climate and health indicators of the basin. To do so, perturbations will be applied either to the external physical forcings or to the parameters to assess those that are the most uncertain. Using this system, the objective is to produce climate ensemble projections of the physical and biogeochemical state of the Black Sea on a decadal scale. These projections will focus on features such as the evolution of the Black Sea oxygenated layer.

In particular, the simulation of light propagation in seawater is expected to be a major source of uncertainty, which could be reduced by adding an complex optical model to the coupled system. To calibrate this model, ARGO irradiance, chlorophyll and CDOM profiles are used to assess the quality of the light propagation simulation through 1D model runs. With ARGO biogeochemical data as input, the model results are compared to the ARGO irradiance profiles, allowing the evaluation of the optical model. Its addition offers the opportunity to later test the influence of a reflectance assimilation scheme in the system, and to perturb the optical parameters themselves to evaluate uncertainties arising directly from the optical model.

Dr MERCHEL Małgorzata

Institute of Oceanology PAN, Poland

merchel@iopan.pl

Argo floats in the South Baltic Sea - five years of use Merchel Małgorzata, Walczowski Waldemar, Wieczorek Piotr

Argo floats have been used for oceanographic surveying of the world's ocean for over 20 years. In 2009, the Institute of Oceanology of the Polish Academy of Sciences joined the global Argo program as a representative of Argo Poland. For many years, IOPAN deployed Argo floats exclusively in the Arctic region where the annual AREX measurement campaign takes place. Poland also started launching Argo floats in the Baltic Sea at the end of 2016.
Data from Argo floats is extremely valuable. In the period from 2016 to 2021, floats launched in the South Baltic area by IOPAN made over 5,000 CTD profiles. This allows for a much more accurate determination of the seasonal cycle of temperature and salinity at all levels in the waters we have studied: the Gdansk Deep and the Bornholm Basin. Longer time series will allow for precise determination of climate change. Some floats are additionally equipped with an oxygen sensor. This significantly increased the value of the collected data, especially in such an ecologically sensitive reservoir as the Baltic Sea.
The advantage of measurements made with Argo floats is their independence from weather conditions, thanks to which we obtain measurements from all seasons. Along with synoptic data from ships, data from mooring and surface buoys, measurements from Argo floats are becoming an important element of the southern Baltic monitoring system, improving numerical models and validating satellite observations.

Mr OULHEN Erwan

LOPS, France

erwan.oulhen@hotmail.com

Reconstructing the ocean using Argo data and a data-driven method

Erwan Oulhen, Nicolas Kolodziejcyk, Pierre Tandeo, Florian Sévellec, Bruno Blanke

The Argo observing system provides unprecedented insight into oceanic heat and freshwater content, and significantly enhances knowledge and reduces uncertainties about the changes of ocean state over the last 20 years. However, reconstructing regional variability during the pre-Argo period remains challenging due to sparse data coverage. By taking advantage of the better sampled Argo period, a set of dominant correlation patterns (calculated by an EOF analysis) – reduced for the sakes of dimensionality – can be estimated. From the associated principal components, temporal fluctuations and correlations are statistically learned. From the perspective of mapping pre-Argo observations using Data Assimilation (DA), this information can be used in a DA framework with the analog forecast to provide an adaptive reanalysis, reflecting the underlying physics as observed in the Argo database. This data- driven method is referred to as AnDA (Lguensat et al., 2017) and would provide a global temperature and salinity product covering a great part of the 20th century. The structure of the three-dimensional correlations is validated and the projection of randomly distributed observational profiles onto the reduced EOF space is applied in AnDA, according to Kaplan et al. (1997). The potential of the ISAS product (a reanalysis of Argo observations) for constituting a sufficiently informative database for AnDA is investigated and discussed.

Ms ROUTABOUL Solène

New satellite telemetry solutions to meet the new needs of ARGO profiling floats

CLS, world leader in satellite services and environmental in-situ data collection, has been working in cooperation with the **operational oceanography** community for more than 30 years.

CLS provides satellite services (Argos and Iridium) to a wide range of institutes, research centers, and has partnerships with most of the world's major oceanographic research programs such as ARGO (among others, we have specifically developed a RUDICS data hosting service for the community as a result of needs that have been brought to our attention).

The needs of ARGO profiling floats are changing and require the collection and transmission of increasingly large amounts of data, especially for BGC platforms.

New solutions allow to answer this need (IRIDIUM CERTUS) and CLS proposes to present these new solutions and to explain how it can answer the new challenges and needs of the ARGO community.

We also would like to present a new solution of independent back up system to ensure the recovery of the profiling floats (to avoid polluting the oceans, redeploying them, etc.) or simply to know where the platform is in case of non-functioning of the main communication link which is often IRIDIUM.

Dr SHULGA Tatyana

MHI, Russia

shulgaty@mail.ru

Salinity Recovery Using Regional Biooptical Products

Tatyana Shulga 1 Vyacheslav Suslin 2

1 Marine Hydrophysical Institute of RAS, Sevastopol 299011, Russia
2 State Oceanographic Institute N.N. Zubova, Roshydromet, Sevastopol 299011, Russia

The work proposes a salinity recovery method for the Sea of Azov based on implementation of a general regression compiling in situ archival data with regional biooptical parameters obtained from standard MODIS L2 products. The observations data were from the open internet services acquired directly from data providers and for these data the methodologies for quality control and merging were implemented. We are researched the following biooptical parameters: $a_{ph}(678)$ is the indicator of light absorption by phytoplankton pigments, *Tchl* is the sum of chlorophyll-a concentration and pheopigments, $a_{tot}(438)$ is the total absorption coefficient by all optically active components of the medium at 438 nm, $a_{CDM}(438)$ is the sum of the light absorption coefficient by colored dissolved organic matter and detrit at 438 nm, and $b_{bp}(438)$ is the particulate backscattering coefficient at 438 nm. The listed variables were chosen as they are the operational satellite ocean-colour products of the MODIS of NASA. The each set of satellite data with kilometer spatial resolution were converted into spatial maps of five biooptical parameters on a regular grid of the Sea of Azov. Based on the selected linear regressions satisfying the condition $R \geq 0.5$, general linear regression equations of the following form were compiled: $y = (a\text{aver} \pm \sigma 1)x + (b\text{aver} \pm \sigma 2)$, where $a$aver and $b$aver – averaged linear coefficients a и b, σ1 and σ2 – standard deviations, x – regional biooptical products, y – salinity (‰).The results of the study showed the possibility of using different approaches to build generalized empirical regressions for the spring and summer seasons. This is confirmed by the verification of the reconstructed salinity values from in situ data for the long-term average seasonal trends for recent periods 1986– 2018 and 2000–2018. The final result is a merged regressions for spring and summer designed for reconstruction salinity and making available the data for visualization seasurface salinity in maps synchronized in time with satellite images.

Keywords: Sea of Azov, Salinity, Ocean-colour Data, Biooptical Regional Products, Regression Analysis

Ms TRAYLOR Shawnee

MIT-WHOI Joint Program, USA

shawnee@mit.edu

Assessing Integrated Satellite-Float Productivity Estimates in the NASA EXPORTS Campaigns

Shawnee Traylor, Yibin Huang, Andrea J. Fassbender, David P. Nicholson

The NASA-led EXPORTS (EXport Processes in the Ocean from RemoTe Sensing) project seeks to quantify the fate and export of carbon from the euphotic zone via the biological carbon pump. The strength of the biological carbon pump can be assessed in part by the rate of net community production (NCP), the sum of all photosynthetic productivity minus respiratory losses of carbon. In a net autotrophic system, this excess fixed carbon is available for export to the deep ocean, where it can be sequestered from the atmosphere on decadal to millennial time scales. Two field campaigns were conducted to capture the end members of a range of ecosystem/carbon cycling states: the productive North Atlantic spring bloom in May 2021, and the iron-limited subarctic North Pacific in August 2018. Ship-based operations were bolstered by both satellite observations and numerous autonomous assets, including two BGC-Argo floats at each site, supported by NSF, NOAA, and NASA. The floats carry biogeochemical sensor suites (e.g. CTD, O2, NO3, pH, bio-optics) to enhance the spatiotemporal sampling range and produce budgets of oxygen, nitrate, and particulate organic carbon. Here we present a comparison of NCP measured in situ by BGC-Argo floats to satellite- and hybrid float-satellite- based estimates of NCP during the EXPORTS field campaigns. Float-derived NCP employs a mass balance approach using high-resolution oxygen and nitrate data collected by autonomous floats to determine NCP in the euphotic zone. Satellite-based estimates of NCP are made using algorithms trained on the oxygen-argon ratio anomaly that utilize observed sea surface temperature and modeled net primary productivity. Net primary productivity rates were determined via the Vertically Generalized Production Model (VGPM), the Carbon-based Production Model (CbPM), and the Carbon, Absorption, and Fluorescence Euphotic-resolving Model (CAFE) algorithms. These model algorithms are implemented with both satellite-only and integrated float-satellite inputs to explore the potential of a synergistic approach between BGC-Argo and remote sensing capabilities. We discuss how our results compare across estimation methods, link to the ship-based measurements made during the field campaigns, and how they reflect the distinct nature of the study sites' cycling regime.

Dr IZETT Robert

Dalhousie University, Canada

robert.izett@dal.ca

An evaluation of approaches to estimating gross primary production and net community production using biogeochemical profiling floats

Robert Izett; Adam Stoer; Arnaud Laurent; David Nicholson; Katja Fennel

We present an evaluation of emerging approaches to estimate primary production using biogeochemical Argo (BGC-Argo) floats. Our analyses assess the robustness of the "diurnal-cycle" and "budget-based" methods for deriving gross primary production (GPP) and net community production (NCP), respectively, over various time and space scales. Using field data, we first perform new GPP calculations using the global BGC-Argo float array and review published float-based NCP results from Ocean Station Papa in the Subarctic Northeast Pacific Ocean. We compare GPP and NCP rates derived from different tracers (e.g., oxygen, particulate organic carbon, nitrate) and variations of the diurnal- cycle and budget-based methods against datasets obtained from alternative methods. We also provide an estimate of the number of BGC-Argo floats required to obtain robust GPP estimates in an ocean region, leading us to advocate for the continued expansion of the BGC-Argo array. Based on these field evaluations, we perform numerical experiments to more closely evaluate the methodological uncertainties resulting from observational errors (e.g., sensor accuracy, lag) and parameterization assumptions of the respective GPP and NCP methods. By mimicking and manipulating the behaviour of BGC- Argo floats in a Regional Ocean Modeling System (ROMS) simulation of the Subarctic Northwest Atlantic Ocean, we ultimately assess the sensitivity of calculated GOP and NCP rates to a range of induced methodological variability and uncertainty. Across our analyses, preliminary results indicate important disparity between different GPP and NCP approaches, demonstrating the need for further methodological refinements. These analyses are timely, given the ongoing expansion of the BGC-Argo program, and provide an early evaluation of the tools available to the oceanographic community for assessing ocean productivity.

Dr KOESTNER Daniel

University of Bergen , Norway

daniel.koestner.optics@gmail.com

A multivariable empirical algorithm for estimating particulate organic carbon concentration in marine environments from optical backscattering and chlorophyll-a measurements

Daniel Koestner[1*], Dariusz Stramski[2], Rick A. Reynolds[2]

[1] University of Bergen, Bergen, Norway

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

* Correspondence: Daniel Koestner

Accurate estimates of the oceanic particulate organic carbon concentration (POC) from optical measurements have remained challenging because interactions between light and natural assemblages of marine particles are complex, depending on particle concentration, composition, and size distribution. In particular, the applicability of a single relationship between POC and the spectral particulate backscattering coefficient $b_{bp}(\lambda)$ across diverse oceanic environments is subject to high uncertainties because of the variable nature of particulate assemblages. These relationships have nevertheless been widely used to estimate oceanic POC using, for example, in situ measurements of b_{bp} from Biogeochemical (BGC)- Argo floats. Despite these challenges, such an in situ-based approach to estimate POC remains scientifically attractive in view of the expanding global-scale observations with the BGC-Argo array of profiling floats equipped with optical sensors. In the current study, we describe an improved empirical approach to estimate POC which takes advantage of simultaneous measurements of b_{bp} and chlorophyll-a fluorescence to better account for the effects of variable particle composition on the relationship between POC and b_{bp}. We formulated multivariable regression models using a dataset of field measurements of POC, b_{bp}, and chlorophyll-a concentration (Chla), including surface and subsurface water samples from the Atlantic, Pacific, Arctic, and Southern Oceans. The analysis of this dataset of diverse seawater samples demonstrates that the use of b_{bp} and an additional independent variable related to particle composition involving both b_{bp} and Chla leads to notable improvements in POC estimations compared with a univariate regression model based on b_{bp} alone. These multivariable algorithms are expected to be particularly useful for estimating POC with measurements from autonomous BGC-Argo floats operating in diverse oceanic environments. We demonstrate example results from the multivariable algorithm applied to depth-resolved vertical measurements from BGC-Argo floats surveying the Labrador Sea.

Ms GIDUGU Himakantha

Indian National Centre for Ocean Information Services(INCOIS)

himakanthag@gmail.com

Estimation of Seasonal changes in Vertical distribution of phytoplankton biomass in Tropical Indian Ocean from Bio-Argo and remote sensing observations

Himakantha Gidugu*, T.V.S Udaya Bhaskar, Chiranjivi Jayaram

*himakanthag@gmail.com

The present study describes seasonal changes in vertical distribution of Chlorophyll-a (Chla-a) in the North Indian Ocean (NIO). INCOIS has deployed 66 BGC Argo floats across NIO from 2013 to 2021 that provided nearly 10000 profiles. This data has good spatial coverage and is well sampled temporally across all months and seasons. The technical specifications and calibration coefficients of BGC Argo floats provided by the manufacturer are used to convert the raw data in counts into desired bio-optical quantities. Data were quality controlled as prescribed by ADMT. Chla-a depends on raw fluorescence data counts, scale factor and dark counts. Linear regression is used to compute the coefficient scale factor. The dark counts parameter represents the instrument response when there is no signal. However, post-processing evaluation is required to recompute the manufacturer- provided dark counts and scale factors to suit the regional waters. The chlorophyll observed by these floats is overestimated by a factor of 2 as noted by the previous studies. The chlorophyll data from the Argo floats across NIO considered in this study haven't been used in any of the previous analyses. Also, due to the non- availability of ship-based in-situ data, this study uses remote sensing chlorophyll data from MODIS to estimate the correction factors. The gain and offset values of all the floats are evaluated using floats in Arabian Sea(AS) and Bay of Bengal (BoB), and Equatorial Indian Ocean(EIO) and is applied to all the floats deployed in NIO by INCOIS. The scale factor values of chla- a for the regions, AS, BoB, and EIO are 0.7, 0.55, and 0.35. The average scale factor value for NIO is observed to be 0.48. This estimated value for NIO, is in range with the Global oceanic scale factor value of 0.5. The estimated values of alpha and beta will be applied to all the profiles and shall be submitted to GDAC.

Dr AHMED Mohamed

University of Victoria, Canada

mmmahmed@uvic.ca

Oxygen saturations of the Northwest Pacific subsurface waters using an array of Argo floats

Mohamed Ahmed[1] & Roberta Hamme[1]

[1]School of Earth & Ocean Sciences, University of Victoria, Victoria, BC, Canada

Ocean deoxygenation in our ocean are expected to increase in conjunction with the increase in ocean warming. One of these significant decreases in our ocean oxygen was observed in the North Pacific Intermediate Water (NPIW). NPIW is known to play a vital role in transporting low-salinity, and nutrient-rich water from the subarctic into the intermediate depths of the North Pacific subtropical gyre during the local winter-time convections. In this study, we study the O_2 content in the newly formed NPIW and quantify the extent of oxygen disequilibria over time and space. Our preliminary results showed that the NPIW is oxygen undersaturated by a bout 6% at the end of the convction. Our findings will provide a better understanding of oxygen consumption in the subsurface water and will allow an additional constraint for biogeochemical models and global carbon budgets in the North Pacific.

Dr HONDA Makio

Japan Agency for Marine-Earth Science and Technology

hondam@jamstec.go.jp

Estimation of Particulate Organic Carbon Flux with BGC-Argo Backscatter data from the Western North Pacific

Makio C. Honda, Tetsuichi Fujiki, Shigeki Hosoda, Yoshihisa Mino, Naomi Harada

For the sake of understanding the ocean's ability for uptake of atmospheric CO2 and predict its future change by the change of the global/ocean environment, the biological carbon pump (BCP) should be quantified precisely. The study of the BCP has been conducting by, mainly, time-series sediment trap observation. In the 21century, the global observation network of the Argo floats has been established. Recently, fluorometer, pH sensor, nitrate sensor and backscatter meter can be installed on the Argo float. The Argo float equipped with these sensors (BGC- Argo floats) have enabled us to study the various biogeochemical oceanography. Among these sensors, the backscatter meters can observe spatial- temporal variability of marine particles in the water column and, thus, these data possibly contribute to the BCP study. After 2018, the BGC- Argo floats have been deployed at time-series stations (K2 and KEO) in the western North Pacific. Backscatter data observed during years of 2017-2020 in the subarctic region and 2019-2021 in the subtropical region were converted to particulate organic carbon (POC) concentration data with the empirical equation and, sequentially, temporal variability in vertical profile of POC upper 1000 m were analyzed. As a result, it was revealed that the annual amplitude of POC concentration decrease with depth. Assuming the steady state and that lateral transport of POC are negligible, annual amplitude of POC concentration at respective depth can be regarded as POC flux at respective depth. The decrease of POC flux with depth is comparable to the general trend of POC flux observed by sediment trap observation.
However, POC flux at deep sea in both regions were comparable although POC flux observed by sediment trap is generally larger in the subarctic region, and estimated POC flux were about 1/2 – 1/10 of POC flux at respective depths estimated by previous sediment trap observation.

Dr JOY-WARREN Hannah

University of Washington and NOAA/PMEL, USA

hjoyw@uw.edu

Connecting phytoplankton taxa distributions to air-sea CO_2 fluxes in the Southern Ocean

Hannah Joy-Warrren,[1,2,3] Ayush Nag,[4] Andrea Fassbender,[3] Alison Gray[2]
1. Cooperative Institute of Climate, Ocean, and Ecosystem Studies, University of Washington (Seattle, Washington, USA)
2. School of Oceanography, University of Washington (Seattle, Washington, USA)
3. National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Lab (PMEL) (Seattle, Washington, USA)
4. Paul G. Allen School of Computer Science and Engineering, University of Washington (Seattle, Washington, USA)

The Southern Ocean has historically been considered a strong carbon dioxide (CO_2) sink— responsible for ~40% (~1 PgC) of anthropogenic CO_2 that enters the ocean annually— but its efficacy as a CO_2 sink has recently had a weaker period and may be more variable than previously thought. The Southern Ocean is also responsible for ~30% (~3.3 PgC) of the annual global organic carbon export, thereby exerting substantial influence on global climate. Prior research has identified connections between the ocean CO_2 sink strength and natural oscillations in ocean circulation, but less work has been done to evaluate the contribution of biological factors.

Phytoplankton are a key driver in global carbon cycling through photosynthesis and subsequent export of organic carbon to the deep ocean. Importantly, different phytoplankton taxa use differing amounts of carbon relative to other nutrients and are grazed by different zooplankton. Thus, different taxa contribute differently to carbon drawdown and export. This has implications for the amount of POC produced and exported to the deep ocean per unit nutrient availability, as well as the overall impact of phytoplankton on air-sea CO_2 flux.

Using a machine learning approach, we modeled phytoplankton taxa distributions along BGC-Argo float paths. We estimated air-sea CO_2 flux along the same float paths and connected variability in air- sea CO_2 flux to the taxa distributions. In estimating CO_2 flux, we also quantify the impacts of various pH sensor adjustments and a skin temperature correction.

This work aims to decipher the role of phytoplankton community composition in air-sea CO_2 flux variability and carbon export in the Southern Ocean. The assessment of phytoplankton species composition in relation to CO_2 flux variability represents a significant contribution towards quantifying the role of Southern Ocean phytoplankton in shaping carbon cycling.

Mr MUNZIL Mohammed

Indian National Centre for Ocean Information Services

munzil.pc@incois.gov.in

Application of Bio-Argo float in understanding denitrification in the northern Indian ocean

N* is a tracer introduced by Gruber and Sarmiento to studythe effect of denitrification and nitrogen fixation in the ocean in 1997. It uses phosphate to correct the nitrate portion of its distribution due to nitrification reaction. N* describes the combined effect of denitrification and nitrogen fixation or remineralization of the nitrogen-rich organic compound. This process is spatially well separated and can be understood whether the process from the signals is either coming from one or from different processes.

$$N^* = N - 16.P + 2.9 \quad \mu mol/kg$$

Here N* is the nitrate concentration in µmol/kg and P is the concentration of the phosphate in µmol/kg. The distribution of N* has been analyzed for the northern Indian ocean, both the Arabian Sea (AS) and Bay of Bengal (BoB), using data derived from two Bio-Argo floats. The average value of N* at denitrification depths are ~ -12 µmol/kg and ~-5 µmol/kg in AS and BoB, respectively. In concurrence with the previous studies, this study also confirms that AS is a strong denitrification basin, but BoB is not. It is mainly due to the slight difference in oxygen level between the Arabian Sea and Bay of Bengal: BoB being slightly more oxygenated than AS. Also, we found that N* decreases exponentially in the AS when the oxygen concentration is less than 2 µmol/kg; N* is as low as ~-20 µmol/kg in the core of the AS Oxygen Minimum Zone (OMZ). Along the Oman coast, which is outside the core of OMZ, N* shows large negative values (~-10 µmol/kg). This indicates that the Oman coast is also vulnerable to denitrification. In BoB, N* in the coastal Ocean is considerably low compared to the open ocean which implies coastal BoB is also vulnerable to denitrification in the near future.

Dr SCHMECHTIG Catherine

CNRS, France

catherine.schmechtig@imev-mer.fr

New method for Chlorophyll-A calibration

Schmechtig C., Sauzède R. , Renosh P.R., Poteau A., Jutard Q., Bretagnon M., D'Ortenzio F.and Claustre H.

The Chlorophyll-*a* (CHLA) concentration is one of the six core variables of the BGC-Argo program. It is considered as the proxy for phytoplankton biomass, which plays a key role in the global cycle of elements (primary production, community respiration and carbon export). Thus, qualifying this variable appears of primary importance.

The most used method to evaluate the CHLA parameter on floats is based on active fluorescence. The CHLA estimation from fluorescence is influenced by the physiological state of phytoplankton. It results in a variability of the fluorescence/CHLA ratio which can increase errors on the estimation from floats. Moreover, the initial calibration and the eventual long-term degradation of sensors may also impact the performance of the CHLA evaluation. Setting up a radiometer associated to a fluorometer on a float is an efficient way to assess the calibration of the CHLA (Xing et al., 2011, Xing et al., 2018), but presently, not all floats are equipped with such a sensor, preventing the whole fleet to be calibrated consistently.

We will present how existing methods are applied to BGC-Argo floats equipped with fluorometers and radiometers to calibrate CHLA and our adaptation with an innovative machine learning-based method to assess the CHLA correction for floats not equipped with a radiometer, making it applicable to the whole fleet and then at the global scale.

Mr XU Chao

Xiamen University, China

xuchao3091@live.com

Constraining the twilight zone remineralization rate in the South China Sea basin: insights from a multi-method intercomparison

Chao Xu [a], Mingwang Xiang [a], Bingzhang Chen [b], Yibin Huang [c, *] Bangqin Huang [a, *]

a. *State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen, China*
b. *Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK*
c. *NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, WA, USA*

The remineralization rate in the twilight zone (typically defined as the depth between the bottom of the euphotic zone and 1000 meters) determines the efficiency of carbon sequestration by biological carbon pump (BCP) and thus significantly affects the atmospheric CO_2 concentration. The accurately quantifying of the remineralization rate in the twilight zone, however, remains largely uncertain. We quantified the remineralization rate in the South China Sea (SCS) basin by multi-method for the first time, such as *in situ* observation and incubation. Based on BGC-Argo floats, electron transport system (ETS), and incorporation of both bacteria respiration and zooplankton respiration (BR + ZR), the remineralization rates were 5.1 ± 0.5 mol C m^{-2} yr^{-1}, 44.8 ± 19.6 mol C m^{-2} yr^{-1} and 6.4 ± 3.0 mol C m^{-2} yr^{-1}, respectively. Comparing the remineralization rate with export flux from the upper ocean, we suggest the BGC-Argo floats and BR + ZR methods were relatively reasonable and the ETS methods may overestimate the remineralization rate. We also estimated the potential total organic carbon sources in the twilight zone of the SCS basin, which was 6.0 ± 2.0 mol C m^{-2} yr^{-1}, which allows us to balance the carbon sources and sinks at the basin scale. In addition, we calculated the "Martin curve" based on the remineralization profiles, with b = 1.08 ± 0.11. The b value of the SCS conforms to the global "temperature-b" law, indicating that temperature is an important factor regulating the b value and may be used as a proxy to predict the effects of climate change on POC attenuation. Our results highlight the critical of multi-disciplinary and integrated process studies for constraining the biogeochemical processes. To better understand the BCP and carbon cycle, it is crucial to constrain the key processes in the twilight zone.

Keywords: biological carbon pump; carbon budget; community respiration; the twilight zone; BGC-Argo floats

Dr CORREDOR ACOSTA Andrea

Centro FONDAP-IDEAL de Investigación en Dinámica de Ecosistemas Marinos de Altas Latitudes, Chile

july.corredor@uach.cl

Argo Float Reveals Biogeochemical Characteristics Along the Freshwater Gradient Off Western Patagonia

Alexander Galán, Gonzalo S. Saldías, **Andrea Corredor-Acosta***, Richard Muñoz, Carlos Lara and José Luis Iriarte

The coastal region off Chilean Patagonia has been poorly studied due to the lack of available observations. Here we analyzed, by the very first time, biogeochemical (BGC) data to elucidate the role that biological and physical processes play on nitrate, oxygen, pH and hydrographic variables, along a salinity gradient off central Patagonia. Argo float profiles covering the upper ocean from December 2015 to July 2019 reveal that offshore waters are characterized by low temperatures and high salinities related to high oxygen and medium-high values of pH and nitrate. As the Argo float drifted onshore, freshwater influences the upper 50–100 m with low salinity and high temperature. Waters under the influence of the continental runoff were characterized by medium-to-high oxygen and pH levels, and the lowest nitrate concentrations. Interestingly, oxygen-deficient waters located beneath the freshwater-modified layer showed the lowest pH and highest nitrate. A comprehensive analysis of the temporal and vertical variability of the oxygen:nitrate ratio, in conjunction with biological-related and physical parameters, indicates that the BGC variability seems to be the result of a synergistic interaction between physical and biological processes, where the stratification sets up the environment and promotes the biological response that, in turn, is auto-regulated by modifying the chemical composition in the freshwater-influenced zone. The arrival of future floats with additional sensors (e.g. Chlorophyll/Fluorescence, Photosynthetically Active Radiation, Backscatter) will add new BGC properties that improve our understanding of the coastal marine response to the increasing freshwater input off western Patagonia in the context of climate change.

Dr EVRARD Estérine

Euro-Argo ERIC, France

esterine.evrard@euro-argo.eu

Towards a new phase for Euro-Argo programme: the contribution of Euro-Argo RISE project

E. EVRARD (1), I. ANGEL BENAVIDES (2), P. VELEZ (3), F. D'ORTENZIO (4), L. TUOMI (5), G. NOTARSTEFANO (6), C. GOURCUFF (1), A. BERRY (7), S. POULIQUEN (1) et al.

(1) Euro-Argo ERIC
(2) BSH
(3) CSIC/IEO
(4) Sorbonne University
(5) Finnish Marine Institute
(6) Instituto Nazionale di Oceanografia e di Geofisica sperimentale
(7) Marine Institute

Euro-Argo RISE (Euro-Argo Research Infrastructure Sustainability and Enhancement) is an EU Horizon 2020 research and innovation project aiming to bring to maturity the different components of the Argo network in Europe. The project pools together the effort of 19 European partners to optimise and enhance the European contribution to the Argo programme. The rationale behind this plan is the need to address the two prerequisites, identified during the OceanObs19 conference, to a better understanding of the global warming consequences on the ocean and the related societal challenges, namely, (a) improved biogeochemical and ecosystem observations and (b) the monitoring of abyssal layers.
The overall goal of Euro-Argo RISE is to sustain the European contribution to the core Argo and also consolidate the Deep-Argo and BGC-Argo missions. In addition, it tests pilot arrays in partially ice- covered regions and shallower water regions. This latter goal enhances the coverage within European Marginal Seas and thus brings Argo closer to the coast. Through improvements of the technology and the data system, a widening of the Euro-Argo ERIC membership and the further development of products that better fit its users' requirements, Euro-Argo RISE enables Europe to fulfil its international commitments to the revamped Argo programme and preserve its key international position. Furthermore, in line with the philosophy of the Argo programme, Euro-Argo RISE data are freely shared on public databases and integrated in the Argo Data System.

Dr FEUCHER Charlène

Laboratoire d'Océanographie Physique et Spatiale, France

charlene.feucher@univ-brest.fr

Subpolar gyre decadal variability explains the recent oxygenation in the Irminger Sea

Charlene Feucher1, Esther Portela1,2, Nicolas Kolodziejczyk1, and Virginie Thierry1
1Univ Brest, CNRS, Ifremer, IRD, LOPS, F-29280 Plouzané, France (charlene.feucher@univ-brest.fr)
2Institute for Marine and Antarctic Studies, University of Tasmania, Hobart 7001, Australia

The North Atlantic is one of the hot-spots for ocean oxygen ventilation due to cold surface water and strong winter convection. This region is subjected to large interannual to multidecadal variability, which is suspected to strongly impact the regional and temporal oxygen ventilation and inventory.
Here, we combined the most recent Argo dataset and repeated ship-based sections to investigate the oxygen variability of the Labrador Sea Water (LSW) in the Irminger Sea over the period 1991-2018 and its driving mechanisms. The oxygen concentration of LSW oscillated between 300 μmol/kg in the 90's and between 2015-2018, and 280 μmol/ kg in the period 2002-2014. Over the 28-year record the variance of the oxygen concentration within the LSW was 41.8 $(\mu mol/kg)^2$, while that of the oxygen solubility and Apparent Oxygen Utilization (AOU) were 7.0 $(\mu mol/kg)^2$ and 38.6 $(\mu mol/kg)^2$ respectively.

This reveals the processes associated with AOU (mixing and consumption) as the main control on the observed oxygen variability. In the 90's and between 2015 and 2018, positive North Atlantic Oscillation (NAO) index implied relatively cold waters and an intense subpolar gyre that enhanced winter convection in the Irminger Sea. LSW oxygen concentration was high and close to saturation (about 93% as referenced in the literature in this region). In contrast, during the period 2002-2014 of low oxygen concentration, negative NAO anomaly led to warmer waters, weaker convection, and generally higher AOU. The latter was likely associated with less intense local oxygen ventilation that increased the water age.
Between 1991 and 2018, the observed LSW oxygen concentration in the Irminger Sea is subjected to strong interannual to decadal variability that masks any significant linear trend.

Mr FRENZEL Hartmut

University of Washington/NOAA-PMEL, USA

hartmut.frenzel@noaa.gov

OneArgo toolboxes for accessing and visualizing Argo data

We have developed toolboxes for MATLAB and R that facilitate the downloading of Argo profiles and the visualization of these data. It is a core goal of the Argo program to make all data quickly available to the public, yet the storage of profile data at the Global Data Assembly Centers, where the files are sorted by their WMO IDs, makes it hard, especially for beginner users, to find data for a particular region, time, or type of Argo float (Core, Deep or Biogeochemical). Our toolboxes allow the user to specify either the WMO IDs of floats (e.g., those deployed by the user's institution) or a selected geographical region and/or time range as well as the physical and/or biogeochemical sensors of interest. Data can also be selected by their data mode (raw, adjusted or delayed) and quality control flags.

The toolboxes allow the user to easily create trajectory, profile, section, and time series plots, all without having to know the format of the data files. They are designed to maximize efficiency - profile index files are only downloaded at regular intervals, and updated profile files are only downloaded when new data are available. The toolboxes are available at https://github.com/NOAA-PMEL/OneArgo-Mat and https://github.com/NOAA-PMEL/OneArgo-R, where updated versions with new features will continue to be posted.

A website with video tutorials has been set up to introduce new users to these toolboxes.

Dr KOLODZIEJCZYK Nicolas

University of Brest, LOPS Laboratory, Argo-France, France
nicolas.kolodziejczyk@univ-brest.fr

Decadal patterns of dissolved oxygen in the global ocean (2009-2018)

Nicolas Kolodziejczyk[1], Esther Portela[1,2], Virginie Thierry[1], Annaïg Prigent[1 1]
University of Brest, CNRS, Ifremer, IRD, LOPS Laboratory, France

[2] University of Tasmania, IMAS, Hobart, Australia

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Recent studies suggest a ocean global long term deoxygenation (-2%) likely explained by anthropogenic warming. This tendency is also observed in the climate projection, however with a large uncertainties. Ocean deoxygenation is a major concern for marine life and human resources since it manifests notoriously by expansion of hypoxic zones and displacement of habitat for major pelagic species. Yet, lack of sustained and consistently sampled dissolved oxygen measurements put a large uncertainties on global and regional ocean oxygen change, and knowledge gap are still pending on physical and biogeochemical regional oxygen variability processes.

Since 2009 increasing Argo floats equipped with dissolved oxygen sensor have been deployed over the global ocean progressively populating regional basins over the last decades mainly in ocean ventilation zones of North Atlantic and Southern Ocean. This new Argo dissolved oxygen network, as part of the BGC Argo mission, provides us for the first time a regional and decadal insight over (quasi) global ocean within the first 2000 m depth.

Using ISAS optimal interpolation tools, we provide new Argo oxygen global annual and seasonal climatology over the last decade. In addition, regional patterns of oxygen change are revealed and investigated over the last decade. During this period, Southern Ocean region appears to have loss oxygen, while North Atlantic subpolar region has gain oxygen. Insight in regional variability and associated physical and biogeochemical processes will be discussed.

Dr MAZE Guillaume

Ifremer/LOPS, France

gmaze@ifremer.fr

"argopy": a python library to focus on Argo science

Guillaume Maze and Kevin Balem

The Argo expert community focused on - and successfully - delivering a curated dataset of the best scientificquality, has never provided its regular user base with a Python library to easily access and manipulate Argo measurements: the "argopy" software aims to fill this gap. "argopy" is dedicated to scientists without knowledge of the Argo data management system and file format. We will show how these scientists can easily fetch, manipulate and visualize Argo data and hence only focus on their analysis.
The overarching goal of "argopy" is to foster Argo data usage and to broaden the Argo user base. The "argopy" software is open source and compatible with all platforms. More at: https://github.com/euroargodev/argopy

Dr MORRIS Tamaryn

South African Weather Service

tamaryn.morris@weathersa.co.za

Best practices for Core Argo floats: Physical handling, metadata and data considerations

Tamaryn Morris, Megan Scanderbeg, Deborah West-Mack, Claire Gourcuff, Noe Poffa, Uday Bhaskar, Craig Hanstein, Liu Zenghong, Breck Owens, Kyle Grindley, Jeff Sherman…others?

Core Argo floats have been deployed in the global ocean for over 20 years. The program has contributed well over 2 million profiles of the upper 2000 m for a variety of operational and scientific applications. Core Argo floats have developed such that the program currently consists of more than eight Argo float types, some of which are second or third generation developments, three unique satellite communication systems and now two types of Conductivity, Temperature and Depth (CTD) sensor systems. Coupled with a well-established data management system, with delayed mode quality control, makes for a very successful, albeit intimidating, ocean observing network.

Here we present the Best Practices for Core Argo Floats in terms of float types, physical handling and deployments, recommended metadata parameters and the data management system. The objective is to engage young and developing scientists, research teams and institutions to the OneArgo Program, specifically that of Core Argo. By leveraging sustained contributions of current Core Argo float groups with new and emerging Argo teams and users, can the OneArgo initiative be realised. This paper makes involvement with Core Argo smoother by providing a framework for these observations.

Dr ORGANELLI Emanuele

CNR ISMAR, Italy

emanuele.organelli@cnr.it

Developing synergies between BGC-Argo and Earth Observation to assess the impact of ocean extremes on marine ecosystems

Emanuele Organelli[1], Marco Bellacicco[1], Angela Landolfi[1], Salvatore Marullo[1,2], Alexandre Mignot[3], Andrea Pisano[1], Simon Van Gennip[3], Chunxue Yang[1], Rosalia Santoleri[1]

[1] National Research Council of Italy (CNR), Institute of Marine Sciences (ISMAR), Rome, Italy

[2] Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA), Frascati, Italy

[3] Mercator Ocean International, Ramonville-Saint-Agne, France

Due to the ongoing ocean warming, ocean extremes become more frequent than before and provoke a dramatic impact on marine ecosystem life and productivity. In March 2022, under the ESA's Ocean Health initiative, the "deteCtion and threAts of maRinE Heat waves – CAREHeat" started. This project aims to evaluate changes and resilience of marine biodiversity and biogeochemistry of pelagic ecosystems around the globe after a Marine Heat Wave (MHW) event, from lower to higher trophic levels. To achieve this, CAREHeat will capitalize on BGC-Argo observations, Ocean Colour satellite measurements and biogeochemical models. Specifically, CAREHeat will develop synergies between these multiple observational platforms to address the following scientific questions:

- What is the effect of MHWs on phytoplankton chlorophyll concentration at the ocean surface and along the water column?
- Are phytoplankton chlorophyll changes related to modifications in biomass or physiology?
- How is the phytoplankton community structure affected by MHWs?
- How do community structure changes impact on ocean biogeochemistry and propagate over the water column affecting nutrient profiles and oxygen levels?
- How do changes at lowest trophic levels impact on carbon fluxes in support of higher trophic levels (micro-nekton, apex predators)?
- Is there a biogeochemical signature in the pH and air-sea CO_2 fluxes during MHW events, and to what degree of MHW severity is such signature becoming significant?

We will present preliminary results on space detected MHW events at the global scale, and the multiplatform observational strategy and datasets we will use to assess, characterize and describe their impacts on the marine ecosystems.

Dr OSBORNE Emily

NOAA/AOML, USA

emily.osborne@noaa.gov

Preliminary results from a new marginal sea biogeochemical-Argo array in the Gulf of Mexico

Emily Osborne[1], Yuanyuan Xu1[1,2], Jennifer McWhorter[1], Claudia Schmid[1], Molly Baringer[1]

[1]Atlantic Oceanographic and Meteorological Laboratory, National Oceanographic and Atmospheric Administration, Miami, FL, US

[2]Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School for Marine and Atmospheric Science, University of Miami, Miami, FL, US

Historically, the open Gulf region has been chronically under-observed with respect to water column ocean biogeochemistry. In September of 2021, NOAA deployed a small Gulf of Mexico biogeochemical Argo (BGC-Argo) array that begins to address the observational gap for this large marginal sea. We present one year of preliminary data from the Apex BGC- Argo floats launched during the Gulf of Mexico Ecosystems and Carbon Cruise (GOMECC- 4), which collected complimentary high quality coastal to deep basin observations across the Gulf. These floats have simultaneously measured five biogeochemical variables (oxygen, nitrate, pH, chlorophyll-a, and ocean particulates, in addition to temperature and salinity) over the upper 2000 m of the water column. Data from this array have applications to monitoring ocean health in the Gulf, including supporting ocean predictions; fisheries management; informing ocean acidification adaptation and mitigation.

Ms PARK Ellen

Woods Hole Oceanographic Institution, USA

erpark@mit.edu

An Oxygen Mass Balance of the Labrador Sea from Biogeochemical Argo Float and Hydrographic Data

Ellen Park, David Nicholson

The Labrador Sea is an important region of the ocean due to local deep water formation processes that play an important role in circulation, deep-water ventilation, and carbon and oxygen uptake. Quantifying the magnitude of these formation processes and their temporal variability is important for better constraining ocean carbon uptake and oxygenation of deep-water masses. To address this problem, we take a mass balance approach to the Labrador Sea, using a combination of ship-based, moored array, and float-based measurements. Water flows into and out of the Labrador Sea through the Davis Strait to the northwest and across the OSNAP mooring line to the southeast. Flow through the Davis Strait is predominantly net southward, characterized by northward flow of the West Greenland Current (WGC) on the eastern side of the strait and southward flow of the Baffin Island Current on the western side. Flow across the OSNAP line is characterized by northward flow into the Labrador Sea by the WGC and southward flow out of the Labrador Sea by the Labrador Current. Here, we use Biogeochemical Argo surface oxygen measurements to quantify monthly air-sea gas flux in this region. These results can be combined with hydrographic and moored array measurements of oxygen and velocity across the Davis Strait and OSNAP West line to close the oxygen mass balance. The residual of this mass balance provides another means for calculating respiration within the Labrador Sea. Here we will present preliminary results of oxygen flux into and out of the Labrador Sea across the air-sea interface and the Davis Strait. These results will be combined in future work with oxygen flux measurements across the OSNAP line to further constrain the oxygen mass balance in the region.

Dr RENOSH P.R.

**Sorbonne Université, CNRS INSU,
Institut de la Mer de Villefranche, France**

renosh.pr@imev-mer.fr

Vertically resolved light models for the global ocean based on machine learning techniques

P.R. Renosh[1], J. Zhang[1], R. Sauzède[1], and H. Claustre[1]

[1] Sorbonne Université, CNRS INSU, Institut de la Mer de Villefranche, Laboratoire d'Océanographie de Villefranche, Villefranche-sur-Mer, France

The profiles of light and its spectral distribution link to most of the physical, chemical and biological processes prevailing in the water column. Here, we present vertically resolved light models of downwelling irradiance (ED) and photosynthetically available radiation (PAR) for the global ocean by merging light profiles with satellite ocean color radiometry products and physical (temperature and salinity) properties prevailing at the location of light profiles. The present work is inspired from the SOCA (Satellite Ocean-Color merged with Argo data to infer bio-optical properties to depth) methodology originally proposed by Sauzède et al. (2016). SOCA is based on an artificial neural network methodology, and more especially on a Multi-Layer Perceptron (MLP). The present light models rely on SOCA type MLP and are trained with light profiles (ED/PAR) acquired from the Biogeochemical (BGC) Argo floats as outputs. The inputs of the MLP consist of surface derived from satellite ocean color radiometry products extracted from GlobColour (Rrs, PAR and kd490), temperature and salinity profiles from BGC-Argo as well as temporal components (day of the year and local time in cyclic transformation). The output for each model corresponds to ED profiles at the three wavelengths of BGC-Argo measurements (380, 412, and 490 nm) and PAR profiles.

The quality of the light profile retrieval by these models is assessed using two different and independent datasets: one is based on independent BGC-Argo profiles that are not used for the training; the other originates from SeaBASS. These light models show satisfactory predictions when compared with real measurements. The estimated accuracy metrics for these two validation datasets are consistent and demonstrate the robustness of these light models for global ocean applications.

Keywords: Global Ocean light models, ED380, ED412, ED490, PAR

Ms ZHANG Jie

Plymouth Marine Laboratory – UK

jie.zhang@imev-mer.fr

Unveiling the fate of organic particles in the oligotrophic ocean

Jie Zhang [1, 2*], Giorgio Dall'Olmo [2]

Phytoplankton fix atmospheric CO_2 into particulate organic carbon (POC) through photosynthesis in the sunlit zone and POC is transported by the biological carbon pump (BCP) into the deep ocean. The sinking organic particles exported by the BCP through the mesopelagic zone (~100-1000m) can either become food for deep-water and benthic organisms or be remineralized into CO_2 and stored in the deep ocean for decades to centuries.

Here, we investigate the fate of POC in the mesopelagic zone of the oligotrophic ocean using autonomously robotic observations – the Biogeochemical-Argo floats.

Oligotrophic regions, characterized as highly-stratified low-nutrient waters, occupy about one third of Earth's surface and are expected to expand due to global warming.

The oligotrophic ocean, especially subtropical gyres, is too vast to be thoroughly explored by traditionally ship-based observations. With Biogeochemical-Argo floats springing up, we are able to analyze global data from seasonal to interannual time scales. Therefore, it is the right time to investigate the carbon-export processes in the twilight zone of oligotrophic waters in the global ocean.

We focus on two scientific questions: 1. What is the particulate organic carbon budget in oligotrophic waters? 2. What processes influence the BCP efficiency in oligotrophic waters?

To answer the two questions above, we are researching the fate of organic particles accounting for the processes of aggregation, fragmentation and remineralization and delineating seasonal POC patterns in the mesopelagic zone. Ultimately, we aim to provide a baseline for biogeochemical modelers and to quantify more precisely the role of the oligotrophic ocean in sequestering carbon.

1 Laboratoire d'Océanographie de Villefranche, CNRS & Sorbonne Université, LOV, Villefranche-sur-Mer, France

2 Plymouth Marine Laboratory, Plymouth, UK.

* Email: haijijie@stu.xmu.edu.cn

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