IWMO 2026

16th International Workshop on Modeling the Ocean

2-5 June 2026
Palma, Balearic Islands

ABSTRACT BOOK

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CSIC
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EXCELENCIA MARÍA DE MAEZTU 2023-2027

CONTENT

ABOUT THE WORKSHOP

The 16th International Workshop on Modeling the Ocean (IWMO 2026), held in Palma (Balearic Islands), stands as a leading international forum for integrating advanced numerical modeling with multi-platform ocean observations. By promoting high-level dialogue between theoretical modelers and observational scientists, the workshop addresses the pressing need for physically consistent representations of the Earth system across a wide range of spatial and temporal scales. Its strategic relevance is further reinforced by the Outstanding Young Scientist Awards (OYSA) and a dedicated special issue in Ocean Dynamics, ensuring that the most innovative contributions reach the global scientific community.

The technical program places particular emphasis on the mesoscale and submesoscale transition, examining how ocean mixing, frontal instabilities, and filamentation processes regulate vertical heat fluxes and tracer subduction. A central objective is the advancement of next generation forecasting systems that incorporate fully integrated Earth system coupling, linking atmosphere, waves, ocean, and sea ice to improve the simulation of extreme events. This includes the deployment of cutting edge numerical approaches such as Vortex Force discretizations in Z grid models and unstructured grid frameworks capable of resolving complex land ocean interactions and storm surge dynamics.

Beyond these physical processes, the workshop explores nonlinear ocean dynamics through the study of coherent structures, Lagrangian betweenness, and finite scale escape times (FSET) to quantify transport barriers, retention zones, and connectivity pathways. These tools are applied to pressing ecological and environmental challenges, including microplastic dispersion and larval connectivity modeling for species of high socioeconomic value, such as the red shrimp. The program also highlights the transition toward Digital Twin of the Ocean (DTO) architectures, leveraging high resolution data assimilation, variational methods, and physics informed machine learning to reduce uncertainties in coastal hazards and reconstruct subsurface features.

The workshop further underscores the convergence of observational and modeling advances by integrating data from high frequency radar, autonomous gliders, and wide swath satellite altimetry (SWOT) into standardized, model ready data streams. This synergy is essential for resolving ocean interfaces in estuaries and semi enclosed basins, where sediment transport, nonlinear tidal interactions, and geomorphological feedbacks shape coastal evolution. By incorporating biogeochemical modules and bioenergetic models, the research presented also extends to habitat suitability assessments for species restoration and the tracking of anthropogenic pollutants.

COMMITTEES

ORGANISING COMMITTEE

- Taken together, these contributions reaffirm IWMO's role as a catalyst for translating state of the art Earth system science into operational tools that support marine conservation,

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AT-A-GLANCE SCHEDULE

Day	Date	Theme
Day 1	Tuesday, 2 June 2026	Eddies to Fronts: Mesoscale-Submesoscale Dynamics and Ocean Mixing
Day 2	Wednesday, 3 June 2026	Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events
Day 3	Thursday, 4 June 2026	Nonlinear Oceans: Instabilities, Coherent Structures, and Biological Applications
Day 4	Friday, 5 June 2026	High-Resolution Modeling for Coastal and Operational Oceanography: Hazards, Transport, and Management

PROGRAMME / DAY 1

Tuesday, 2 June 2026

Eddies to Fronts: Mesoscale-Submesoscale Dynamics and Ocean Mixing

08:30-09:00	Registration
09:00-09:30	Welcome
09:30-10:00	Plenary 1: **Baylor Fox-Kemper -** Emulators and parameterizations: Indirect tools for climate science
10:00-10:40	**Oral Subsession 1 | Eddies to Fronts: Mesoscale-Submesoscale Dynamics and Ocean Mixing**
Speaker	**Talk title**
Vincent Combes	On the Variability of the Agulhas Bank Circulation
Maximo Garcia Jove-Navarro	Enhancing Mesoscale Understanding and Predictability through High-Resolution Data Assimilation and Nested Modelling in the Western Mediterranean
10:40-11:10	Coffee break (Poster)
11:10-12:30	**Oral Subsession 2 | Eddies to Fronts: Mesoscale-Submesoscale Dynamics and Ocean Mixing**
Speaker	**Talk title**
Federico Angel Velazquez-Munoz	Gradual decoupling and physical evolution of Tehuantepec eddies driven by pulsed wind forcing and their offshore displacement.
Florian Le Guillou	VarDyn: Consistent High-Resolution Surface Ocean Fields from a Data-Driven Variational Approach
Jiachen Zhang	Investigation of Realistic Typhoon Forcing on Near-Inertial Waves Generation and Evolution in the South China Sea
Peng Zhan	Submesoscale Vertical Heat Flux Amplifies a Cross-Scale Positive Feedback in the Arabian Sea
12:45-14:30	Lunch break
14:30-15:30	**Oral Subsession 3 | Eddies to Fronts: Mesoscale-Submesoscale Dynamics and Ocean Mixing**
Speaker	**Talk title**
Hiroki Tsuribe	Transition between Inter-Basin Asymmetric Meridional Overturning Circulations Induced by Wind and Southern Gateway Depth Change
Takumi Nishikawa	Wave-resolving Simulation of Nonlinear Interactions between Surface and Internal Gravity Waves and Entrainment at the mixed layer base
Yutaka Yoshikawa	Evaluation of Two Surface Wave Mixing Schemes; Case Study in the Spring-Summer Northwestern Pacific

PROGRAMME / DAY 1

16:00-17:00	Oral Subsession 4 | **Eddies to Fronts: Mesoscale-Sub-mesoscale Dynamics and Ocean Mixing**
Speaker	**Talk title**
Guan-Yu Chen	Numerical Simulation and Rapid Forecast of Internal Solitary Waves in Northern South China Sea
Jen-Ping Peng	Integration of SWOT and In-Situ Observations into a High-Resolution Data-Assimilative Ocean Model for 3D Representation of a Small-Scale Intrathermocline Eddy
Diego Vega-Giménez	Modeling the Amplification of Cyclone Mocha's Intensity and Storm Surge Dynamics Driven by Anthropogenic Ocean Warming

PROGRAMME / DAY 2

Wednesday, 3 June 2026

Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events

08:45-09:00	**Registration**
09:00-09:30	**Plenary 2: Joanna Staneva -** Coastal and Regional Ocean Prediction Across Scales, Processes and Applications

09:30-10:30	**Oral Subsession 1 | Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events**
Speaker	**Talk title**
Tal Ezer	On Gulf Stream exploration: from Spanish sailors in the 1500s to today's coastal impact and future climate change
Jinyu Sheng	Abnormal Subsurface Cooling on the Slope Water off the Scotian Shelf Connected to Hydrodynamic Variability over the Tail of Grand Banks
Ruizi Shi	Global Attribution of Rising Coastal Wave Hazards to Climate-Driven Wind Intensification and Tropical Cyclone Amplification

10:30-11:10	**Coffee break (Poster)**

11:10-12:30	**Oral Subsession 2 | Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events**
Speaker	**Talk title**
Jianping Gan	Climate shiftings of spinning, warming, productivity and deoxygenation in the future western Pacific marginal sea
Tsubasa Kodaira	Toward Modeling Extreme Landfast Sea-Ice Melt in Lutzow-Holm Bay, East Antarctica
Yuki Koshida	Mechanism of the Atlantic Meridional Overturning Circulation (AMOC) response to Arctic runoff perturbation
Zhongya Cai	Effects of Current Curvature on Topography-Modulated Cross-Shelf Motions

12:45-14:30	**Lunch break**

14:30-15:30	**Oral Subsession 3 | Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events**
Speaker	**Talk title**
Chenyang Yao	Implementation and Numerical Verification of the Vortex Force Formalism in a Regional Z-grid Ocean Model (ORCTM-SWAN v1.0)
Thao Thi Nguyen	Future changes of coastal extremes from the regional wave-ocean coupled model system for the Northern European continental shelf
Gabriel Jorda	Modelling the impacts of the 2025 flash flood in Mar Menor with the BELICH forecasting system

15:30-16:00	**Coffee break (Poster)**

16:00-17:00	**Oral Subsession 4 | Earth-System Modeling: Ocean-Atmosphere-Waves-Sea Ice and Extreme Events**
Speaker	**Talk title**

PROGRAMME / DAY 2

Yusuke Ushijima	Sea Surface Temperature Biases in CMIP6 Coupled Models Modulating the Latitude of the North Pacific Westerly Jet
Diego Pereiro	Marine Heatwaves in Irish Waters
Fei Chai	Marine Heatwaves in the Coral Triangle: Spatiotemporal Variability and ENSO Modulation

17:15	**Photo Session**
18:00	**Guided city tour**

PROGRAMME / DAY 3

Thursday, 4 June 2026

Nonlinear Oceans: Instabilities, Coherent Structures, and Applications

08:45-09:00	Registration
09:00-09:30	Plenary 3: **Emilio Hernandez Garcia** - Horizontal and vertical Lagrangian hotspots: bottlenecks and caustics in the ocean
09:30-10:30	Oral Subsession 1 | **Nonlinear Oceans: Instabilities, Coherent Structures, and Biological Applications**
Speaker	**Talk title**
Gabor Drotos	Microplastic particles sinking in the water column of the Mediterranean Sea: simulation and theory
Tim Toomey	Three-dimensional Lagrangian dispersion properties in the Atlantic Ocean from a global reanalysis
Mingyu Li	Decadal changes in three-dimensional connectivity and accumulation cores in the Western North Pacific
10:30-11:10	Coffee break (Poster)
11:10-12:10	Oral Subsession 2 | **Nonlinear Oceans: Instabilities, Coherent Structures, and Biological Applications**
Speaker	**Talk title**
Li Li	Mechanism in turbulence and high-frequency oscillation due to wave-current interactions in Qiantang River Estuary, Hangzhou Bay, China
Wenzheng Man	Long-Range Propagation of Mode-1 M2 Internal Tides from Luzon Strait to Xisha Islands
Zhiqiang Liu	A Tidally and Subtidally Forced Open Boundary Condition for Unstructured-Grid Coastal Modeling
12:10-12:30	Special Issue – Ocean Dynamics
12:45-14:30	Lunch break
14:30-15:30	Oral Subsession 3 | **Nonlinear Oceans: Instabilities, Coherent Structures, and Biological Applications**
Speaker	**Talk title**
Huijie Xue	Physical and Biogeochemical Controls of Hypoxia Durations in the East China Sea
Ignacio Saint-Malo Zamacola	At the convergence: the role of mesoscale dynamics in the habitat selection and bycatch risk of sea turtles in the Eastern Central Atlantic.
Ignacio Martinez-Caballero	Modeling larval connectivity of Aristeus Antennatus (red shrimp) through Lagrangian dynamics and network analysis

PROGRAMME / DAY 3

16:00-17:00	Dedicated Poster Session
Speaker	**Title**
Vincent Combes	On the Variability of the Agulhas Bank Circulation
Lara Diaz Barroso	Assessing coastal profiling floats drift and high resolution shelf modelling in the Balearic Sea
Fabio Giordano	On the effect of different grid resolutions and mixing schemes on mesoscale dynamics in coastal ocean models: a case-study in a shallow, semi-enclosed basin (northern Adriatic Sea)
Ismael Hernandez-Carrasco	Diagnosing Fluid Parcel Retention in Oceanic Flows through Local Absolute Dispersion: Application to the Mediterranean Sea
Sara Cloux (Presenting Cristóbal López)	Linking Surface Filaments to Vertical Transport in the Ibiza Channel
Yiguo Li	Continuous Data Assimilation in Quasi-Geostrophic Turbulence
Yu-Chun Lin	Data-assimilated upper ocean temperature with machine learning
Ying Ma	Physics-Driven Sea Surface Temperature and Ocean Front Forecasting Network
Miyano Nishida	Impact of Ocean Physical Conditions on Oceanic Carbon Pumps and Atmospheric Carbon Dioxide during the Last Glacial Maximum
Elisabet Rodriguez Cruz	Back to basics: A multi-model framework to support native oyster (Ostrea edulis) restoration (ECOCREDIT project)
Victor Rodriguez-Mendez	A Comparative Analysis of Clustering Algorithms for Characterizing Surface Ocean Variability in the Western Mediterranean
Juan-Manuel Sayol	Pathways of Wastewater Dispersal in the Southern Ocean: From Coastal Outfalls to Large-Scale Circulation
Francesco Michele	Estimation of Vertical Velocities in the Mediterranean Sea Using a Machine Learning Approach
Yu-Lin Eda Chang (Presenting Tsubasa Kodaira)	Wave-induced drift of pumice: transitions from forward to backward transport
Giulia Cerny Oliveira (Presenting Jinyu Sheng)	Numerical Study of Circulation and Sea Ice over the Labrador Sea and Adjacent Waters
Kelli Johnson (Presenting Joanna Staneva)	Enhancing Coastal Monitoring and Forecasting With Focus
Douglas Vieira da Silva (Presenting Joanna Staneva)	Drivers for the vertical structure of Suspended Particulate Matter along the Inner Continental Shelf of the Western Black Sea
Daniel García-Veira	**Future coastal flooding associated with Posidonia oceanica decline under climate change**

17:00	International Scientific Committee meeting

PROGRAMME / DAY 4

Day 4 | Friday, 5 June 2026

High-Resolution Modeling for Coastal and Operational Oceanography: Hazards, Transport, and Management

09:30-10:30	**Oral Subsession 1 | High-Resolution Modeling for Coastal and Operational Oceanography: Hazards, Transport, and Management**
Speaker	**Talk title**
Xiao Hua Wang	Study on sediment dynamics in Batemans Bay, NSW, Australia
Yuezhang Xia	Deep-sea mining vehicle, Mining vehicle plume, Sediment transport, Numerical simulation
Ricardo de Camargo	The Brazilian contribution to SurgeMIP initiative

10:30-11:10	Coffee Break (Poster)

11:10-12:30	**Oral Subsession 2 | High-Resolution Modeling for Coastal Operational Oceanography: Hazards, Transport, and Management**
Speaker	**Talk title**
Luca Arpaia	Exploiting high resolution bathymetric datasets in high-order finite element coastal models
Eider Loyola Azanza	A relocatable HRES wave forecast system for coastal wave energy infrastructures management.
Rebeca Álvarez	From multi-platform observations to model-ready data services: SOCIB's data lifecycle supporting ocean forecasting systems
Camilo Andres Melo Aguilar	WMOP, a decade of operational forecasting supporting ocean science and marine applications: challenges and opportunities for integration into digital twin architecture

12:30-12:45	OYSA awards
12:45-13:00	Concluding remarks

DAY 1 / EDDIES TO FRONTS: MESOSCALE–SUBMESOSCALE DYNAMICS AND OCEAN MIXING

** Abstracts are listed in order of appearance in the programme.*

BAYLOR FOX-KEMPER
Brown University, USA

Baylor studies the physics of the ocean and how the ocean fits into the Earth's climate system, using climate models, satellites, and autonomous observations. In 2013, Baylor joined the Department of Earth, Environmental, and Planetary Sciences at Brown University, after working in other roles at the University of Colorado, Princeton, NOAA, the Woods Hole Oceanographic Institution, and MIT. He co-led the Ocean, Cryosphere, and Sea Level Change chapter of the IPCC Sixth Assessment Physical Science Basis (WGI) Report, and he is presently co-chair of a World Climate Research Program Core Project on Earth System Modelling and Observations.

At Brown, Baylor works mainly within the Oceans, Ice, and Atmospheres Research Group. He is the STEM faculty director of the Equitable Climate Futures initiative, an elected fellow of the Institute at Brown for Environment and Society (IBES), an affiliated faculty member of the Brown Theoretical Physics Center, the Brown Center for Fluid Mechanics, and the Initiative for Sustainable Energy, and he supports the SciToons and Vis-A-Thon programs. He is also an associate editor of Science Advances and a JASON.

His Ph.D. is from the MIT/WHOI Joint Program in Oceanography working with Joe Pedlosky (at WHOI) and Paola Rizzoli (at MIT). In his pre-oceanographic career, He trained in physics at Reed with Nick Wheeler and at Brandeis with Stanley Deser and X.-J. Wang.

Emulators and parameterizations: Indirect tools for climate science

As Earth system models grow in complexity and computational cost, two approaches offer opportunities to accelerate progress and deepen understanding: parameterizations and emulators. I will distinguish these two strategies in a practical way. Focusing on the ocean, I'll first discuss some recent work led by student Anna Lo Piccolo on incorporating submesoscale entrainment into an updated mixed layer eddy parameterization. Then, I'll discuss an emulator that is a key path to quantifying regional mixed layer depth (MLD) affects climate sensitivity, connecting surface mixing processes to the spread in model projections of climate change. By combining observations with this emulator, we attribute about 40% of uncertainty in projected climate sensitivity to processes leading to MLD biases. I'll also show how an emulator (the energy balance model–Kalman filter: EBM–KF) can do many things we struggle to do with climate models. It assimilates global surface temperature and ocean heat content to generate rapid, probabilistic projections and allows efficient exploration of policy thresholds, internal variability, and the impact of external forcings like volcanic eruptions.

Together, these new emulator tools—optimized for interpretability, accuracy, and speed—provide new ways to study the climate.

Modeling the Amplification of Cyclone Mocha's Intensity and Storm Surge Dynamics Driven by Anthropogenic Ocean Warming

Diego Vega-Gimenez[1,*] , Angel Amores[1,2], Daniel Argüeso[2] , Marta Marcos[1,2] & Ananda Pascual[1]

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Anthropogenic climate change continues to intensify sea surface temperatures (SSTs), amplifying extreme events such as marine heatwaves. Warmer oceans provide additional energy to tropical cyclones, enabling stronger winds and lower central pressures. Consequently, the most intense storms (Categories 4 and 5) are becoming more probable (Kossin et al. 2020). This thermodynamic intensification directly threatens coastal regions, as stronger winds and extreme pressure drops significantly amplify storm surges.
To investigate this link, we focus on Tropical Cyclone Mocha, which struck the Bay of Bengal in May 2023. We employ a high-resolution atmosphere-ocean modeling framework to quantify the role of anthropogenic SST warming in shaping Mocha's intensity and subsequent storm surge. An ensemble of simulations is conducted with the Model for Prediction Across Scales-Atmosphere (MPAS-A) under two scenarios: a *factual* world using observed SSTs, and a *counterfactual* world where the anthropogenic warming signal is removed while preserving internal variability (Marcos et al 2025).

These atmospheric ensembles are then used to force the unstructured-grid SCHISM-WWM model. This hydrodynamic-wave framework explicitly resolves storm surge, tides, and nearshore wave dynamics over a flexible mesh capable of handling steep bathymetric gradients. Simulations with and without explicit wave-current coupling are performed to assess wave contributions to extreme water levels. Model performance is validated against in-situ tide gauges and satellite altimetry to ensure model fidelity (Vega-Gimenez et al. 2025).

Preliminary results suggest that warmer SSTs significantly enhanced Mocha's intensity, driving higher storm surges and extreme sea levels at landfall. By contrasting factual and counterfactual ensembles, we isolate the human fingerprint on both cyclone severity and extreme ocean responses, providing critical insights into the evolving dynamics of storm surges in a warming climate.

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Enhancing Mesoscale Understanding and Predictability through High-Resolution Data Assimilation and Nested Modelling in the Western Mediterranean

Maximo Garcia-Jove[1]; Baptiste Mourre[2]; Nikolaos D. Zarokanellos[1]; Guiomar López[1]; Emma Reyes[1]; Pierre F. J. Lermusiaux[3]; Daniel L. Rudnick[4]; Joaquín Tintoré[2]

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High-resolution real-time forecasting systems are essential for capturing mesoscale and submesoscale variability in the Western Mediterranean Sea, with direct implications for transport, vertical exchange, and ocean prediction. Here, we present recent advances in the Western Mediterranean Operational forecasting system (WMOP), focusing on improvements in data assimilation (DA) and their impact on forecast skill. WMOP integrates an Ensemble Optimal Interpolation-based DA framework that combines multi-platform observations, including satellite sea surface temperature (SST), high-frequency radar surface currents, and temperature–salinity (T/S) profiles from Argo floats and moorings, to improve the representation of ocean variability across scales. This work focuses on two complementary case studies. First, within the CALYPSO (ONR) project, a dedicated field experiment conducted in the Balearic Sea in 2022 investigated three-dimensional transport pathways from the surface to the ocean interior. A multiplatform observational strategy, including autonomous platforms (gliders and floats) and ship-based measurements (CTD surveys and drifters), was combined with high-resolution numerical simulations (2 km to 650 m). The joint analysis captures the temporal evolution of a mesoscale front and the merging and splitting of associated submesoscale eddies, allowing us to quantify their role in vertical exchanges and subduction processes. These results provide a framework to assess how DA constrains the evolving potential vorticity structure and associated ageostrophic motions that regulate vertical exchanges. Second, within the FOCCUS (EU) project, we assess the impact of enhanced DA capabilities through the assimilation of high-resolution Sentinel-6A Level-3 Sea Level Anomaly (SLA) data. Assimilation of 5 Hz and 20 Hz along-track observations improves the reconstruction of mesoscale variability, increasing correlation and variance relative to independent SWOT observations, particularly at smaller spatial scales. The improved reconstruction of sea level gradients enhances the representation of geostrophic shear and mesoscale strain, with implications for the generation of submesoscale variability. This work contributes to the development of next-generation coastal forecasting systems and Digital Twin applications for the Mediterranean Sea.

Acknowledgments:

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Gradual decoupling and physical evolution of Tehuantepec eddies driven by pulsed wind forcing and their offshore displacement.

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The present study investigates the physical evolution and temporal variability of anticyclonic eddies generated in the Gulf of Tehuantepec, a region driven by intense and intermittent wind-jet events (Tehuanos). By employing a three-dimensional numerical approach with the Princeton Ocean Model (POM), we isolate the response of the ocean to wind stress by initializing the domain from a state of rest and applying a time-modulated wind jet. Our results, supported by Sea Level Anomaly (SLA) and geostrophic velocity observations, describe the transition of these mesoscale structures from their near coastal generation to their westward propagation away from the coast. A key finding is that the consolidation of a coherent eddy requires the cumulative energy of multiple wind pulses, rather than a single event. Furthermore, we identify a spatial threshold where the wind-jet's influence on eddy intensification diminishes as the structure moves offshore, leading to a gradual decoupling from the atmospheric forcing and allowing for the subsequent initiation of a new eddy. As these eddies propagate into the Tropical Pacific, we quantify the evolution of their physical variables—such as vorticity, velocity and radius—under the influence of the planetary vorticity gradient. This process-oriented study contributes to a better understanding of the mechanisms behind eddy shedding, providing a useful framework for exploring how the ocean's response to pulsed wind stress and the planetary vorticity gradient modulate the mesoscale dynamics of the Eastern Tropical Pacific.

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VarDyn: Physically Consistent High-Resolution Sea Surface Heigh, Temperature and Salinity from a Data-Driven Variational Approach

Florian Le Guillou[1, *], Sammy Metref[1], Clément Ubelmann[1], Bertrand Chapron[2], Marie-Helene Rio[3]

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Sea surface height (SSH, often referred to as sea level), sea surface temperature (SST), and sea surface salinity (SSS) are three key variables for monitoring the ocean state. SSH provides critical information on ocean circulation, sea level variability, and heat storage, while SST captures surface warming and air–sea exchanges. SSS complements these variables by constraining the freshwater cycle, ocean stratification, and water mass formation. Together, they offer a more comprehensive and dynamically consistent view of ocean surface dynamics.

Gridded maps of SSH, SST, and SSS are widely used across a range of applications, many of which require high fidelity in both the spatial localization of structures and the accuracy of the fields. These maps are typically derived by interpolating multi-sensor satellite observations. In current operational frameworks, the different variables are processed through largely independent chains: SSH relies on multi-altimeter optimal interpolation, while SST and SSS are derived from separate combinations of infrared, microwave, and radiometric measurements. As a result, consistency between surface variables is not explicitly enforced. In contrast, data assimilation approaches based on primitive equation models aim to ensure dynamical consistency, but often struggle to reproduce accurate, high-resolution surface fields due to model errors, limited resolution, and imbalances in the representation of surface processes.

Here, we present VarDyn, a hybrid methodology that combines minimal physical constraints with a variational scheme to enhance the joint mapping of SSH, SST, and SSS. Its core strategy is to use reduced surface-focused models matched to observation density, enabling a controllable and fully data-driven reconstruction. SSH is constrained by quasi-geostrophic (QG) dynamics, while SST and SSS follow advection–transport models. The control acts on model forcings in a data-driven latent space, yielding a weak-constraint 4D-Var formulation. By synthesizing historical multi-sensor observations and leveraging recent high-resolution measurements from missions such as SWOT, VarDyn reconstructs consistent, high-resolution surface ocean fields (SSH, SST, SSS) with enhanced accuracy and effective resolution relative to current operational satellite-based merged products, reducing root mean square error while preserving fine-scale variability, and providing a strong foundation for next-generation ocean reanalyses.

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Investigation of Realistic Typhoon Forcing on Near-Inertial Waves Generation and Evolution in the South China Sea

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Near-inertial waves (NIWs) generated by tropical cyclones are essential components of the ocean's energy budget and mixing processes. However, standard atmospheric reanalysis products often inadequately resolve the fine-scale structure of the cyclone core. This persistent limitation results in a significant underestimation of near-inertial kinetic energy (NIKE) and a misrepresentation of oceanic responses. This study examines how the specific spatial structure of wind forcing (beyond mere wind intensity) modulates internal wave dynamics and deep-ocean mixing in the South China Sea.

Utilizing high-resolution numerical simulations, we systematically compared ocean responses driven by a realistic wind field against those driven by standard and linearly enhanced JRA-3Q reanalysis data. Our results indicate that the realistic forcing corrects existing energy biases, yielding an approximate 30% increase in total NIKE compared to traditional reanalysis forcing. Notably, we demonstrate that the intense wind stress curl (WSC) near the typhoon eyewall significantly influences NIW propagation. This highly localized forcing excites low-mode NIWs, facilitating enhanced outward energy radiation.

Additionally, we show that the refined spatial wind structure plays a critical role in deep-ocean turbulent mixing via a threshold effect. The intense vertical shear generated by the eyewall WSC overcomes stratification suppression. Importantly, linearly enhancing reanalysis wind data is insufficient to replicate this deep mixing process, as it fundamentally lacks the necessary fine-scale spatial structure. These findings emphasize the importance of accurately resolving the fine structures of typhoons to effectively model deep-ocean dynamical processes and energy pathways.

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Submesoscale Vertical Heat Flux Amplifies a Cross-Scale Positive Feedback in the Arabian Sea

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Submesoscale processes are critical for vertical heat transport. While the global open ocean typically follows a winter-intensified paradigm driven by surface cooling, high-resolution simulations reveal that the Arabian Sea exhibits a unique seasonal cycle. In the western basin, submesoscale activity and vertical heat flux (VHF) peak during the summer southwest monsoon, triggered by intense coastal upwelling and the Somali Current. This study demonstrates that monsoon-amplified frontal gradients and mixed-layer instabilities drive a cross-scale positive feedback loop, where upward SVHF reinforces isopycnal tilting and baroclinic eddy growth. These findings challenge the conventional winter-peak paradigm and underscore the importance of region-specific submesoscale dynamics in regulating regional climate and heat distribution. Meanwhile, a cross-scale positive feedback loop is sustained during the summer monsoon as monsoon-driven upwelling and isopycnal tilting trigger both mesoscale and submesoscale baroclinic growth, which generate upward heat fluxes that maintain horizontal buoyancy gradients while the mesoscale energy forward cascades into submesoscale motions to further reinforce this cycle.

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Transition between Inter-Basin Asymmetric Meridional Overturning Circulations Induced by Wind and Southern Gateway Depth Change

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While the Atlantic Meridional Overturning Circulation (AMOC) dominates the global thermohaline circulation in the present climate, proxy records indicate that a Pacific equivalent (PMOC) may have existed in past warm periods [1]. Understanding the mechanisms driving this inter-basin asymmetry and its transition is essential for interpreting the paleo-ocean state and its change.

Jones and Cessi (2017) showed that wind-driven dynamics alter inter-basin salinity transport and density structures, ultimately inducing asymmetric MOCs in asymmetric basins [2]. Here, considering the tectonic change and possible shift in westerly wind latitude in the past climate, we investigate the combined effects of the meridional position of zonal wind stress and inter-basin gateway depth on the transition between asymmetric MOC states. Using an ocean general circulation model (MITgcm), we simulated circulations forced by inter-hemispherically symmetric wind and thermohaline forcing in two idealized basins of different widths—representing the Pacific and Atlantic—connected by a southern gateway located at 50-60°S [3, 4]. Simulations were run with several westerly wind latitudes (40 ° – 70°N/S) and gateway depths (500 – 4000 m).

Results indicate that a vigorous AMOC dominates under conditions of a deep sill (≧1000 m) combined with a low-latitude westerly wind (≦ 45°N/S). Conversely, PMOC dominates if westerlies blows at high latitudes (>= 50°N/S) regardless of the gateway depth. These findings suggest a plausible paleoclimate scenario: in a warm paleoclimate with a shallow (< 500m) gateway, PMOC was strong and westerlies were positioned poleward (south of 50°S). As tectonic shifts deepened the gateway, subsequent Antarctic cooling due to the emergence of ACC drove an equatorward shift of the westerlies, triggering the global transition from PMOC to AMOC [5, 6]. Consequently, shifts in historical wind patterns must be explicitly considered when interpreting past ocean circulation.

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Wave-resolving Simulation of Nonlinear Interactions between Surface and Internal Gravity Waves and Entrainment at the Mixed Layer Base

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Surface gravity waves (SWs) are known to generate Internal gravity waves (IWs) through nonlinear interactions. These IWs are expected to cause the turbulent mixing in the stratified layer, since they generally have high frequencies close to the local buoyancy frequency and hence likely dissipate. Indeed, Olbers and Eden (2016) focused on triad interactions between SWs and IWs and analytically quantified the contribution of IW dissipation to mixing based on weakly nonlinear theory. This analytical evaluation, however, has not yet been examined experimentally.

In this study, we use a numerical model that explicitly resolves SWs (Imamura et al., 2025). This model allows us to reproduce the triad nonlinear interactions and evaluate the resultant mixing without approximations or assumptions. More details are given in Imamura et al. (2025).

Here we consider a pair of SWs propagating freely on the surface of water with the mixed layer above the uniformly stratified layer. No external forcing, such as wind stress, was imposed at the free surface.

The simulation shows that SWs soon generate IW in the stratified layer via the triad coupling. Amplitudes of the excited IWs. In addition, agree fairly well with amplitudes of the analytical solution of Olbers and Eden (2016), showing the validity of their theory. It should be noted that at later times, the mixed layer base starts to fluctuate with larger amplitude than the analytical amplitude, resulting in larger temperature perturbations(entrainment), at the mixed layer base. These temperature perturbations suggest that SWs are able to contribute the mixing more vigorously than the previous analytical study. Kinetic energy analysis over the wave-number space indicates that higher order nonlinear interactions between SWs are responsible for the temperature perturbations at the mixed layer base. We will show these results in the meeting.

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Evaluation of Two Surface Wave Mixing Schemes; Case Study in the Spring-Summer Northwestern Pacific

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Two generation mechanisms have been proposed for nonbreaking surface wave-induced turbulence. One is for the Langmuir turbulence[1], characterized by nonlocal nature of the turbulence from the surface[2]. The other is the turbulence generated locally by wave orbital motion[3]. Here, the former is referred to as LC mechanism while the latter is OM mechanism. Wave resolving DNSs of the wave-induced turbulence show that the OM mechanism did not work (but the LC works) even under windless conditions (where the OM mechanism was suggested to occur)[4]. Yet the OM-based mixing schemes are used in some OGCMs, because the OM mixing schemes improve simulated SSTs and MLDs[5].

Here we run OGCM[6,7] to evaluate performance of the OM scheme[8] and the LC scheme[9] on SSTs and MLDs. We focus on spring-summer Northwestern Pacific, where the ML is shallow while surface waves have long wavelength. This condition highlights the differences between OM and LC schemes; wave orbital motion likely penetrates to greater depths to locally generate turbulence below the ML in the OM scheme, while the nonlocal turbulence assumed in the LC scheme is likely limited near the surface by strong stratification at and below the MLD.

The simulation results showed that both wave-induced mixing schemes enhanced vertical mixing in the upper 100 m. Further evaluation revealed that the LC mixing scheme generally improved SSTs and MLDs, whereas the OM mixing scheme significantly overestimated vertical mixing, leading to pronounced cold bias in SSTs especially in the northern part of the model domain where the ML is particularly shallow. These results indicate that the LC mixing scheme is better in realistically simulating the upper ocean especially in heating seasons.

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Numerical Simulation and Rapid Forecast of Internal Solitary Waves in Northern South China Sea

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In this study, Internal Solitary Waves (ISWs) in the Northern South China Sea (NSCS) are simulated using the Coastal and Regional Ocean COmmunity model (CROCO), a non-hydrostatic hydrodynamic model. The model utilizes a bathymetric grid of 961 by 601 points with a high horizontal resolution of 15 arc-seconds and 40 vertical sigma layers. Initial and boundary conditions are derived from HYCOM, with tidal forcing provided by the Tidal Model Driver. Simulated ISW arrival times were validated against in-situ measurements collected by a research vessel during a cruise northeast of Dongsha Island in the western NSCS.

Using Hovmöller diagrams to trace wave evolution, the study identifies that waves are generated at the eastern ridge during peaks in eastward tidal currents. As these waves propagate westward, a portion of the energy is reflected upon encountering the western ridge. The observed extraordinary heights of these ISWs are attributed to resonance within the source zone. Given the physical complexity of ISW generation and the high computational cost of 3D simulations, this study demonstrates the efficacy of AI for efficient ISW forecasting.

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Integration of SWOT and In-Situ Observations into a High-Resolution Data-Assimilative Ocean Model for 3D Representation of a Small-Scale Intrathermocline Eddy

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Small-scale intrathermocline eddies (ITEs), with horizontal scales of only tens of kilometers, remain difficult to represent in data-assimilative ocean models because their surface signals are weak while their strongest hydrographic and momentum signatures are largely subsurface. Here, we use observations from the Surface Water and Ocean Topography (SWOT) mission and the FaSt-SWOT field campaign to reconstruct a small-scale ITE in the western Mediterranean (April - May 2023). Daily SWOT wide-swath altimetry, together with glider and CTD profiles, are assimilated into the Western Mediterranean OPerational (WMOP) forecasting system at 2 km and hourly resolution, we evaluate the respective contributions of SWOT and in-situ observations to model reconstruction.

Three assimilation strategies are compared: (1) SWOT SSH only, (2) in-situ observations only, and (3) both combined, all built on a generic baseline assimilation of conventional along-track altimetry, SST, HF-radar, moorings. Our results show that SWOT provides the key horizontal constraint for regional circulation and spatial structure of the ITE, reducing SSH RMSE by 38% compared to no-SWOT simulation. Nevertheless, when SWOT is used without vertical profile information, the reconstructed eddy is biased toward a surface-intensified structure.

By contrast, glider and CTD measurements provide the subsurface salinity constraints that satellite altimetry cannot observe directly. These profiles serve as the primary constraint governing the interior density structure and are crucial for recovering the ITE's subsurface dynamics. Joint assimilation recovers both the surface and subsurface representation of the eddy. This synergistic approach yields the best overall performance, including RMSE for temperature and salinity by 23% and velocity by 24% compared to SWOT-only assimilation. These results highlight the feasibility and value of integrating spatially extensive satellite data with vertically resolved in-situ measurements into a regional ocean model and establishes a robust framework for improving finescale ocean analysis and forecasting in the SWOT era.

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On the Variability of the Agulhas Bank Circulation

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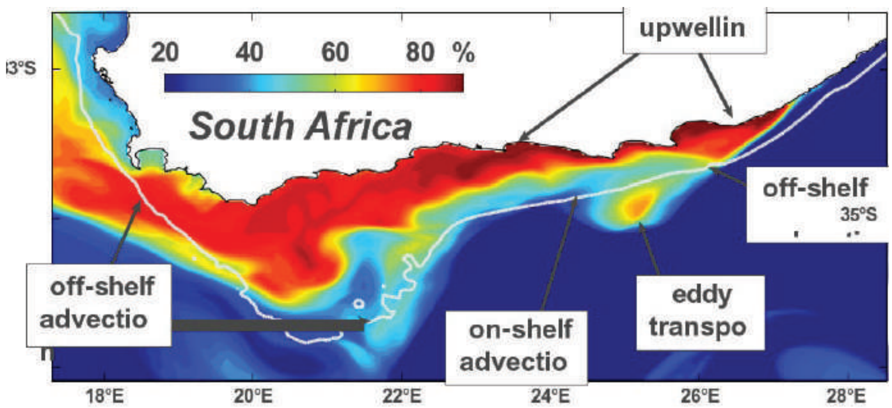
This modeling study investigates the variability of the Agulhas Bank (AB) circulation, focusing on its connections to the local wind forcing and the Agulhas Current (AC) as well as to teleconnections to the tropical South Atlantic. The mean AB circulation is dominated by a westward flow composed of a coastal jet, an outer-shelf flow influenced by AC intrusions, and a strong mid-shelf jet shaped by both wind and AC dynamics. Empirical Orthogonal Function analyses of sea surface height (SSH) and temperature reveal patterns strongly linked to AC position and wind variability, with significant correlations between SSH anomalies and AC displacements. Passive tracer experiments show that while AC-driven vertical transport can uplift deeper waters onto the shelf, wind-driven upwelling and mixing are critical for surface expression. This study also identifies a teleconnection with the tropical South Atlantic, as coastal trapped waves propagate interannual SSH variability southward, though their influence on AB circulation appears limited in dynamical significance. Overall, AB circulation emerges as a complex interplay of local and remote forcings, with variability largely governed by the AC and wind, and modulated by occasional tropical signals.



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DAY 2 / EARTH-SYSTEM MODELING: OCEAN-ATMOSPHERE-WAVES-SEA ICE AND EXTREME EVENTS

** Abstracts are listed in order of appearance in the programme*

EMILIO HERNÁNDEZ-GARCÍA

IFISC (UIB-CSIC)

Emilio Hernández-García is a physicist whose research explores the interplay between physical processes and biological dynamics in the ocean. His work integrates nonlinear dynamics, statistical physics, and numerical modelling to investigate transport, mixing, and the emergence of spatial structures in marine environments. He has made significant contributions to the development and application of Lagrangian methods in oceanography —particularly Lyapunov-exponent techniques and flow-network approaches — to characterize coherent structures and assess their influence on plankton dynamics and the shaping of marine ecosystems.

After holding positions at the University of the Balearic Islands and at McGill University in Montreal, he is now a CSIC Research Professor at the Institute for Cross-Disciplinary Physics and Complex Systems (IFISC) in Mallorca. There, he leads and collaborates on projects addressing ocean transport, ecological modelling, and climate-related variability. His publications span theoretical advances, methodological innovations, and interdisciplinary applications, frequently bridging physics and marine science to tackle complex oceanographic questions.

Horizontal and vertical Lagrangian hotspots: bottlenecks and caustics in the ocean

In recent decades, major advances in Lagrangian techniques for ocean flows have enabled, among other achievements, the systematic characterization of both persistent and transient transport barriers, the quantification of the influence of coherent ocean structures on transport, and the assessment of physical and biological connectivity among marine regions.

In this talk, I will describe two developments that quantify how transported particles accumulate or pass preferentially through specific ‘corridors’. The first one [1] introduces ‘Lagrangian betweenness’ to identify flow bottlenecks, with implications for the location of biodiversity hotspots. The second one [2] uses geometric analysis of how trajectories of sinking particles are convoluted by complex flows to reveal mechanisms leading to their accumulation on the seafloor or their concentration at intermediate depths.

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On Gulf Stream exploration: from Spanish sailors in the 1500s to today's coastal impact and future climate change

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ABSTRACT

In the 1500s, the Gulf Stream (GS) was first encountered by Spanish sailors off the Florida coast. Charting of the GS in the 1700s to help sailors cross the Atlantic Ocean followed by ship observations in the 1800s and 1900s (see Ref.#1 for the history of GS exploration). Today, modern undersea gliders, high-frequency radars, satellite data, and computer models help scientists reveal the complex nature of this mighty current. The presentation will describe recent research that has been focused on the links between the GS, extreme weather events, climate change, and impacts on sea level and coastal currents (Ref.#2 and Ref.#3). Examples of those links include a potential slowdown of the Atlantic Meridional Overturning Circulation (AMOC) and the GS that could increase coastal flooding, and hurricanes that disrupt the flow of the GS and cause sea level rise days after the storm passed (Ref.#4). A better understanding of the role of the GS and remote influence from the open ocean on coastal dynamics will help in the prediction of future climate change impacts.

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Abnormal Subsurface Cooling on the Slope Water off the Scotian Shelf Connected to Hydrodynamic Variability over the Tail of Grand Banks

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Hydrodynamics over the Slope Water off the Scotian Shelf affect significantly marine ecosystems on the Scotian Shelf and Gulf of Maine, which are highly productive ecoregions. The abnormal changes in subsurface temperatures on the Slope Water are examined based on the daily global ocean analysis known as GLORYS12 for the 30-year period of 1995-2024. The 30-year averaged monthly mean temperatures and salinity over the Slope Water show very large cross-slope gradients in the top 200 m, which vary from relatively cold and low-saline shelf waters from the shelf-break to relatively warm and high-saline waters over the offshore deep ocean waters. Consistent with in-situ observations, the monthly mean temperatures in the upper ocean of this region have large seasonal variability, with relatively cold (~4 ^{o}C) and nearly uniform waters in the top 50 m in winter and spring, and relatively warm (~20 ^{o}C) and highly stratified surface waters in the thin surface layers of less than 20 m in summer. The subsurface (100 m) temperatures have warming trends of about 0.08-0.09 ^{o}C/year over the Slope Water region, ~0.010 ^{o}C/year over the southern Flemish Pass. Examination of daily anomalies of subsurface temperatures shows relatively large interannual variability over the Tail of the Grand Banks, Slope Water region, and the slope off the Gulf of Maine. The abnormal subsurface cooling over the Slope Water is caused by the stronger-than-normal equatorward advection of the cold and low-saline upper Labrador water mass carried by the offshore branch of the Labrador Current. The latter is prompted by retreats of warm and high-saline waters from the continental slope off the southern Grand Banks. An index is developed based on the northmost positions of warm waters branched off from the North Atlantic Current. This new index has certain skills in determining the onset of abnormal subsurface cooling over the Slope Water region.

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Climate shiftings of spinning, warming, productivity and deoxygenation in the future western Pacific marginal sea

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The western Pacific marginal sea (PMS), spanning from tropical to high latitude region, is the transition zone between the Southeast Asia continents and open Pacific Ocean. PMS is shifting physically and biogeochemically in responses to changing climate. These changes are socio-economically critical to more than 30% of the world's population and 29% GDP. The largely ambiguity in CMIP results have not well resolved these shiftings due to their regional deficiency. Unlike deep open ocean, the responses in the PMS are largely heterogeneous controlled by unique marginal sea dynamics characteristics internally and sea-ocean exchange externally. By using regionally calibrated physical-biogeochemical coupled modeling system, we find that current system in Pacific Ocean is slowing-down, sea-ocean exchange intensifying and consequently 3D spinning circulation weakening in the PMS. These lead to depriving nutrient and biological productivity as well as intensifying deoxygenation. Our findings fill the knowledge gaps in projecting climate trends in marginal seas.

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Toward Modeling Extreme Landfast Sea-Ice Melt in Lutzow-Holm Bay, East Antarctica

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An exceptional melt of coastal landfast sea ice occurred during the austral summer of 2025 in Lützow--Holm Bay, East Antarctica. Field observations revealed anomalously thin snow and ice cover, under-ice meltwater, and relatively warm near-surface seawater. Here we show that this extreme melt was preconditioned by a wintertime mechanical breakup associated with strong winds, which reduced ice thickness and suppressed subsequent ice growth. Surface heat budget analysis based on ERA5 indicates that moderate atmospheric heat input, when amplified by ice--albedo feedback, was sufficient to melt approximately 1.2~m of sea ice within two months.

Numerical modeling using MITgcm has been initiated to better understand and reproduce the event. The model domain covers 66.2–70.2°S and 33.5–45.5°E, with a horizontal resolution of approximately 2 km and 60 vertical layers (360 × 240 × 60). Ocean temperature and salinity are prescribed based on World Ocean Atlas 2013, varying in the vertical but horizontally uniform. The external forcing consists of the eight प्रमुख tidal constituents, and the barotropic tidal velocity normal to the lateral boundaries is imposed using TPXO8. Some preliminary results are introduced in the presentation.

Mechanism of the Atlantic Meridional Overturning Circulation (AMOC) response to Arctic runoff perturbation

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The Atlantic Meridional Overturning Circulation (AMOC) is driven by deep-water formation at the North Atlantic high latitude and influenced by the freshwater budget of the Arctic, upstream of these sites. The runoff in the Arctic, surpassing the net precipitation, significantly influences on the deep-water formation and the AMOC. However, the impact of the individual river runoff on the AMOC, as well as the mechanism and the time scale, remains to be clarified. In this study, we used the Sea ice – Ocean general circulation model and investigated the influence of perturbation of individual runoff into the Arctic.

The model used is CCSR Ocean Component Model (COCO). The model employs a global tripolar grid and the horizontal resolution is approximately 1°. JRA55-do was applied as the sea surface boundary condition and sea surface salinity restoring is not adopted. After a long-term spin-up, the AMOC maximum at the 26°N was approximately 15 Sv. Using this spin-up state as the initial condition, a 1000-year control experiment was conducted. To assess the influence of Arctic runoff on the AMOC, we performed experiments in which the runoff from four major Arctic rivers—Lena, Yenisey, Ob, and Mackenzie—was individually reduced by an equal amount as Mackenzie, the smallest of the four rivers.

In all perturbation cases, reducing river runoff led to a rapid strengthening of the AMOC, peaking approximately 80 years after the perturbation. Thereafter, the AMOC gradually weakened, approaching a quasi- equilibrium state. The Russian rivers (Lena, Yenisey, Ob) exerted a greater influence on AMOC than the Mackenzie. This difference was due to a more pronounced enhancement of deep convection in the Labrador Sea in Russian river cases. Furthermore, it was demonstrated that the timescales of the AMOC and deep convection responses were determined by the convergence of density fluxes into the Labrador Sea.

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Effects of Current Curvature on Topography-Modulated Cross-Shelf Motions

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Over continental shelves, shelf currents typically follow isobaths under potential vorticity conservation, but when current curvature deviates from underlying isobath curvature, intensified cross-shelf motions occur, facilitating coastal–open ocean exchange. Using the process-oriented and realistic simulaiton, we examine the formation of the cross-isobath motions from the curvature perspective Over the Northern South China Sea (NSCS). Under geostrophic balance in the cross-stream direction, the along-stream dynamics of the shelf current are governed by the interplay of nonlinear advection, frictional stress, and pressure gradient forces, with their cross-stream variation shaped by topographic features. As a current flows across convex - concave topography, offshore and onshore cross-shelf motions are generated, accompanied by negative and positive curvature vorticity, respectively. A positive mismatch between current and topography curvature induces an offshore motion tendency, whereas a negative mismatch leads to onshore motion tendency. Analysis of the curvature vorticity budget indicates that the required curvature, and thus cross-shelf motion, is primarily controlled by topography-induced flow divergence/convergence, bottom frictional stress, and the conversion of current shear into curvature. These processes collectively shape the curvature structure of the shelf current and the associated cross-shelf motion. Together, these results highlight the critical role of curvature mismatch and topographic geometry in modulating cross-shelf transport, offering a complementary curvature-based perspective on current–topography interactions.

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Implementation and Numerical Verification of the Vortex Force Formalism in a Regional Z-grid Ocean Model (ORCTM-SWAN v1.0)

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Wave-current interaction (WCI) is a fundamental process in nearshore and shelf dynamics. While the Vortex Force (VF) formalism is well-established in terrain-following models, its consistent implementation in Z-grid ocean models remains a challenge for seamless ocean-to-coast modeling. This study presents the implementation of a VF-based coupled framework within the Z-grid Ocean Regional Circulation and Tide Model (ORCTM), coupled to the SWAN wave model using the OASIS3-MCT coupler.

The system systematically incorporates a VF formulation that includes both the Bernoulli head and non-conservative wave dissipation terms. To verify the numerical fidelity of the implementation, a sub-meter vertical resolution (0.1–0.3 m) is employed as a diagnostic benchmark to resolve the steep exponential shear of the Stokes drift. This strategy facilitates a rigorous verification of the VF discretization by effectively minimizing the vertical truncation errors inherent in standard, coarse Z-grid configurations.

The framework was evaluated against an idealized planar beach and the DUCK94 experiment. Numerical results for wave setup and alongshore currents are consistent with analytical and field data. The discretization resolves transient shear instabilities and surf zone eddies, capturing nonlinear wave-driven dynamics within a Z-grid environment. Momentum budget diagnostics confirm the dynamic consistency of the vortex force implementation over topographic steps. This work establishes a validated infrastructure for wave–current interaction in regional models, providing a baseline for future depth-integrated parameterizations in large-scale Z-grid applications.

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Future changes of coastal extremes from the regional wave-ocean coupled model system for the Northern European continental shelf

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Extreme storm surges are among the most severe coastal hazards threatening low-lying areas along the Northwest European shelf and the Baltic Sea, while marine heatwaves represent oceanic temperature extremes affecting both open-ocean and coastal environments. These events result from complex interactions between hydrological and meteorological processes and are projected to intensify in several regions under climate change. However, major challenges remain in developing a comprehensive understanding of future coastal extremes and their associated risks. To address this gap, we employed a regional wave-ocean coupled model to dynamically downscale a transient regionalized REMO–MPIOM coupled model under the Representative Concentration Pathway (RCP) 8.5 scenario. Three representative ensemble members from the REMO–MPIOM simulations were selected to investigate the role of internal variability in projected extreme events. Model performance was evaluated by comparing simulated historical storm surges and sea surface temperatures (SST) with tide-gauge records and satellite-derived products for the North Sea and Baltic Sea. We then assessed projected changes in extreme coastal events by the end of the twenty-first century, including the role of internal variability imposed by the parent model's boundary conditions. The Peaks-Over-Threshold (POT) method was applied to characterize both hazards. The results show that the coupled model reproduces key features of historical coastal extremes across both basins. Projected patterns indicate fewer but more intense storm surges along the North Sea coast, whereas marine heatwaves will occur more frequently but last for shorter periods throughout much of the North Sea. Our findings also emphasize the substantial role of internal variability in shaping future coastal extremes, underscoring the need to account for this uncertainty when interpreting regional climate projections. The insights gained from this study offer valuable guidance for enhancing coastal hazard preparedness, protecting infrastructure, and planning for long-term adaptation in vulnerable maritime regions.

MODELING THE IMPACTS OF THE OCTOBER 2025 FLASH FLOOD ON THE MAR MENOR LAGOON USING THE BELICH FORECASTING SYSTEM

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The Mar Menor, Europe's largest hypersaline lagoon, is highly vulnerable to continental and atmospheric forcings due to its shallow depth and limited water renewal. Recurrent ecological crises in 2016, 2019, and 2021—driven by agricultural runoff and urban pressure—have triggered severe eutrophication and anoxic episodes. To address these challenges, the BELICH project implemented an integrated monitoring and multi-model forecasting system.

The physical core of the system uses the SYMPHONIE hydrodynamic model, featuring a variable horizontal resolution (10–250 m) with a specific numerical treatment to accurately resolve the narrow channels (~30 m) connecting the lagoon to the Mediterranean. The model integrates high-resolution atmospheric and continental forcings, the latter simulated via the SWAT model and a semiempirical calibration method. Validation against interannual observations confirms the system's ability in reproducing sea level, temperature, and salinity across scales ranging from episodic events to seasonal and interannual variability.

The system was applied to the October 2025 extreme storm, which delivered torrential precipitation and peak river discharges that pushed the ecosystem towards hypoxia. Simulations characterized processes difficult to capture from observations alone, including the spatial extent of the freshwater plume and the identification of highly stratified zones acting as precursors to anoxia. Notably, the model successfully captured the breakdown of this stratification driven by shifts in wind forcing.

This event demonstrates the system's capability to resolve complex interactions between the lagoon and continental inputs and atmospheric forcing. Consequently, the model serves as the physical foundation for the BELICH forecasting system and a core component of the Mar Menor Decision Support System (DSS). By providing essential boundary conditions for biogeochemical modules, it constitutes a robust tool for mitigating ecological degradation through informed management strategies.

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Sea Surface Temperature Biases in CMIP6 Coupled Models Modulating the Latitude of the North Pacific Westerly Jet

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The climatological position of the North Pacific westerly jet is a key component of the atmospheric circulation, influencing seasonal climate variability over East Asia (e.g., Endo et al. 2021). Understanding the processes that control its latitude is therefore essential for improving climate simulations. Using multi-model analyses of Coupled Model Intercomparison Project Phase 6 (CMIP6) simulations and atmospheric general circulation model (AGCM) experiments, we show that coupled models exhibit a robust southward shift of the westerly jet relative to atmospheric-only simulations. This systematic difference indicates a substantial influence of sea surface temperature (SST) biases on the jet latitude, although atmospheric processes also contribute to intermodel variability. Sensitivity experiments with an AGCM further demonstrate that using CMIP6 multi-model mean SST biases reproduces a comparable southward jet shift, confirming that SST biases substantially influence the climatological jet position. In particular, the cold SST bias over the Western North Pacific subtropical gyre plays a dominant role in modulating the jet response. This cold bias weakens the meridional SST gradient in midlatitudes, leading to reduced lower-tropospheric baroclinicity and suppressed eddy activity. The associated decrease in northward momentum transport favors a southward shift of the jet. These results highlight the importance of reducing SST biases, especially in the Western North Pacific subtropical gyre, for improving the simulation of large-scale atmospheric circulation.

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Marine Heatwaves in Irish Waters

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Marine heatwaves (MHWs)—prolonged periods of anomalously high ocean temperatures[1]—are increasing in frequency and intensity due to anthropogenic climate change, with growing evidence of their occurrence in the Northeast Atlantic and Irish waters. These events arise from interacting atmospheric and oceanic processes, including local heat fluxes, circulation patterns, and large-scale climate modes such as the North Atlantic Oscillation and El Niño–Southern Oscillation[2]. MHWs can occur year-round and drive a wide range of ecological impacts[3], from shifts in species distributions to mass mortality events and habitat degradation[4], with consequences varying by season and ecosystem sensitivity. Despite recent extreme events, understanding of their impacts in Irish waters remains limited[5]. This study addresses that gap by analysing trends in the occurrence and intensity of MHWs in the region.

Here, a long-term (1982-2025) analysis of marine heatwave number, duration and intensity for the Irish Exclusive Economic Zone (EEZ) is presented, based on the Operational Sea Surface Temperature and Ice Analysis (OSTIA[6]) system run by the UK's Met Office. Yearly duration and cumulative intensity (ºC day) linear trend analysis are shown for the whole Irish EEZ and, in more detail, at the locations of the M2-M6 weather buoys from the Irish Marine Data Buoy Observing Network, where *in-situ* seawater temperature measurements exist. The analysis shows an increasing trend in the duration and intensity of MHWs everywhere throughout the Irish Shelf, but more noticeable in the Irish Sea, where MHWs have become increasingly persistent, at a rate of 24 days per decade. In addition, CTD observations are presented to characterise the vertical structure of the 2025 MHW along 53°N in Irish waters, showing a highly stratified water column with a shallow thermocline at 10-20 meters depth. Finally, impacts on fisheries and ecosystems are discussed.

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Marine Heatwaves in the Coral Triangle: Spatiotemporal Variability and ENSO Modulation

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The Coral Triangle encompasses some of the most biodiverse coral reef ecosystems on Earth and represents a critical focus of marine conservation efforts. Under sustained ocean warming, marine heatwaves (MHWs) have grown more frequent and intense, imposing increasing thermal stress on these reef systems. Using daily Optimum Interpolation Sea Surface Temperature version 2.1 (OISST v2.1) data spanning 1982–2023, alongside ERA5 reanalysis fields of wind speed, mixed layer depth, and air–sea heat fluxes, this study examines the spatiotemporal variability, ENSO-related asymmetry, and thermodynamic drivers of MHWs across the Coral Triangle.

Regional MHW characteristics exhibit pronounced spatial heterogeneity. The southern portion of the study domain generally shows higher MHW frequency, total MHW days, and cumulative intensity. Over the 1982–2023 period, background sea surface temperatures rose steadily, accompanied by statistically significant increases in MHW frequency and total days, as well as broad increases in event duration and cumulative intensity. ENSO modulates MHW activity in an asymmetric manner: during La Niña, monthly MHW spatial coverage is significantly elevated relative to neutral conditions, whereas no significant departure is detected during El Niño events.

Phase composite and event-scale analyses reveal that La Niña conditions tend to coincide with reduced surface wind speeds, suppressed latent heat loss, and positive net surface heat flux anomalies, collectively establishing thermodynamic conditions conducive to surface warming and MHW development. Long-term background warming has progressively narrowed the gap between mean SST and the MHW detection threshold, amplifying the sensitivity of the region to these anomalies. Taken together, this study documents the principal features of long-term MHW intensification in the Coral Triangle and proposes a mechanism linking asymmetric ENSO modulation to local air–sea heat exchange and threshold proximity. The findings offer insight into MHW dynamics in tropical marginal seas and contribute to the assessment of coral reef thermal stress risk under continued warming.

DAY 3 / NONLINEAR OCEANS: INSTABILITIES, COHERENT STRUCTURES, AND APPLICATIONS

** Abstracts are listed in order of appearance in the programme*

JOANA STANEVA

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Joanna Staneva is a physical oceanographer whose research focuses on coastal and regional ocean modelling, wave–current–atmosphere interactions, and data assimilation. Her work integrates numerical modelling, observational data, and machine learning to advance the understanding of coastal hydrodynamics, extreme sea states, and the predictability of the ocean system. She has made significant contributions to the development of coupled wave-ocean-atmosphere frameworks and to the improvement of operational forecasting systems, with applications spanning the North Sea, the Baltic Sea, and the Black Sea.

Joanna is a Senior Scientist and Head of the Department of Hydrodynamics and Data Assimilation at the Institute of Coastal Systems, Helmholtz-Zentrum Hereon, in Geesthacht, Germany. She holds a Diploma in Physics and a PhD in Physical Oceanography from the University of Sofia, Bulgaria. At Hereon, she leads research on multi-scale ocean modelling, coastal hazards, and the development of Digital Twins of the Ocean (DTOs) — a framework she actively promotes as co-chair of the international DITTO programme and through coordination of the Horizon Europe project FOCCUS.

Her scientific output spans theoretical and applied contributions to wave modelling, data assimilation schemes — including variational and neural-network-based approaches — and coupled Earth system modelling. She is a regular contributor to the Copernicus Marine Service Ocean State Reports and participates in a broad network of international collaborations bridging operational oceanography, climate science, and coastal management.

Coastal and Regional Ocean Prediction Across Scales, Processes and Applications

Coastal oceans are among the most dynamic and vulnerable regions of the global ocean, where physical, biogeochemical and anthropogenic processes interact across a wide range of spatial and temporal scales. Increasing pressures associated with climate change, marine heatwaves, coastal flooding, ecosystem degradation and expanding offshore activities require forecasting systems capable of resolving complex cross-scale interactions and delivering reliable, fit-for-purpose coastal information.

Recent advances in regional and coastal ocean prediction increasingly rely on the integration of high-resolution observations, numerical modelling, data assimilation and artificial intelligence within seamless forecasting frameworks extending from the open ocean to estuaries and nearshore environments. Particular challenges arise from the representation of land–ocean interactions, atmosphere–wave–ocean coupling, estuarine dynamics, riverine inputs and fine-scale coastal processes, which remain insufficiently resolved in many existing operational systems. This contribution highlights developments in integrated coastal forecasting systems using nested and unstructured-grid approaches, ensemble methodologies and AI-assisted downscaling and prediction. Examples from the North Sea, Baltic Sea, Mediterranean and estuarine environments demonstrate the importance of high-resolution modelling for resolving salinity fronts, coastal circulation, sediment transport, ecosystem variability and extreme events. The role of emerging observational capabilities, including multi-platform remote sensing, coastal data fusion and machine learning applications, is discussed in the context of improving predictability and reducing uncertainties in coastal forecasts.

The contribution also highlights developments within the FOCCUS project (Forecasting and Observing the Open-to-Coastal Ocean for Copernicus Users), focusing on seamless coastal monitoring and forecasting, improved observational products and enhanced hydrological–ocean interfaces. Integrated coastal prediction systems are increasingly evolving towards end-to-end environmental forecasting frameworks supporting coastal resilience, marine operations, ecosystem protection and climate adaptation. Achieving this transition requires stronger integration of observations and models across scales, improved representation of coastal processes and closer interaction between scientific developments and societal applications.

POSTERS

Microplastic particles sinking in the water column of the Mediterranean Sea: simulation and theory

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We aim to learn about the vertical distribution of microplastic particles sinking in the water column after release at the ocean surface. We focus on the Mediterranean Sea and also ask how statistics in subregions thereof differ from those in the entire sea. We numerically simulate trajectories of individual particles in the velocity field of the Mediterranean Sea Physics Analysis and Forecast data product of the Copernicus Marine Service[1]. Identical particles released at a single time instant sink, on average, with a velocity very close to their terminal sinking velocity in still fluid (nominal sinking velocity in what follows). Notwithstanding, an ensemble of identical particles also undergoes considerable dispersion close to ballistic type with a Laplace-like distribution along the vertical coordinate. If release is continual, the volumetric concentration of particles reaches a saturating value, which is independent of depth if the entire sea is considered and is in accordance with a simple analytic description of dispersion after flash releases. In subregions, the saturating volumetric concentration value decreases when the seafloor is approached. In the bulk of the sea, the constant saturating value is inversely proportional to the nominal sinking velocity characterising the identical particles. These findings are expected to apply to nominal sinking velocities greater than about 10 m/day.

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Decadal changes in three-dimensional connectivity and accumulation cores in the Western North Pacific

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The western North Pacific (WNP), located in the western Pacific warm pool with complex bathymetry and highly productive ecosystems, is a key junction for water exchange between the Pacific Ocean and Southeast Asian marginal seas. In this complex system, mass accumulation integrates the net effects of circulation, so its evolution serves as a physically meaningful indicator for how circulation variability reshapes three-dimensional transport. Our study applies a three-dimensional Markov-chain framework to investigate water mass transition pathways and accumulation behavior in the WNP over 2003-2022.

Our results identify three preferential water mass accumulation cores: a northern core associated with the Kuroshio recirculation (KR), a southern open-ocean core near the Mindanao Dome (MD), and a marginal-sea core in the southern South China Sea (sSCS). Source-sink analysis from the transition matrix reveals distinct supply pathways for each core: the KR core is primarily supplied by downstream Kuroshio recirculation, the MD core by local recirculation bounded by the NEC-NECC system, and the sSCS core by Luzon Strait inflow trapped in the regional cyclonic gyre. These Markov-derived source patterns are validated by water mass distance analysis in potential density-potential spiciness coordinates.

Inter-layer exchange cannot be ignored in the net accumulation. Upward exchange dominates the MD and sSCS cores, which is consistent with regional upwelling. And downward exchange prevails in the KR core, matching with the mode-water subduction here. Over the two decades, accumulation intensity increased in the KR and sSCS but weakened in the MD, driven by large-scale changes in WNP current and gyre strength, indicating recent circulation changes enhance mass retention in recirculation and marginal-sea systems, while reducing the open-ocean long-term convergence.

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Mechanism in turbulence and high-frequency oscillation due to wave-current interactions in Qiantang River Estuary, Hangzhou Bay, China

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The world-renowned tidal bore forms in the Qiantang River Estuary (QRE) and leads to distinctive hydro-sediment dynamics and the reshaping of coastal geomorphology. This study presents a time series of in-situ data of wave, current, and suspended sediment concentration (SSC) in the tidal bore, covering the spring-neap tidal cycle in 2020. Field data analysis reveals the spring-neap and flood-ebb asymmetries in hydro-sediment dynamics. Current-induced bed shear stress is mostly larger than that induced by waves. The interactions of semi-diurnal tide and shallow water tide play a leading role in the tidal asymmetry. Turbulence, particularly ejection and sweep, contributes to the sediment inception and increased turbidity. Peak turbulent kinetic energy (TKE) and strong high-frequency water level oscillations occur during both flood and ebb tides, driven by different mechanisms. During the flood tides, they are initiated by the breaking of the tidal bore and its secondary waves. During ebb tides, the wave-current interactions enhance TKE and generate intense high-frequency oscillations, which is a process previously under-documented. The findings reveal the dynamic mechanism of turbulence asymmetry and high-frequency oscillation in water level due to current-wave interactions and shed light on the evolution of dynamic geomorphology in macro-tidal turbid estuaries.

Keywords: Turbulence, high-frequency oscillation in water level, tidal bore, wave-current interaction, sediment resuspension

Long-Range Propagation of Mode-1 M_2 Internal Tides from Luzon Strait to Xisha Islands

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The South China Sea hosts one of the strongest internal tidal energies globally. Cross-basin propagation of the diurnal internal tide (K_1) generated in the Luzon (LZ) Strait is established. Conversely, the semidiurnal internal tide (M_2) is typically hypothesized to experience near-field dissipation. Nonetheless, observations indicate that the intense diapycnal mixing required within the deep-water column near the Xisha Islands cannot be solely accounted for by remote diurnal waves or local internal tides, suggesting an energy deficit. To address this, we employed the high-resolution three-dimensional hydrostatic Oceanic Regional Circulation and Tidal Model, which delineate a clear M_2 internal tides pathway from the LZ Strait toward the Xisha Islands. Because of its strong coherence, the first baroclinic mode (Mode-1) functions as the main component for M_2 internal tides can cross the basin. Energetics analysis along the propagation path of internal tides reveals an e-folding decay scale of 267 km for the M_2 internal tides. Despite this long-range propagation, a considerable baroclinic energy flux, estimated at 0.5–1.5 kW/m (approximately 5% of the initial flux), is steadily supplied into the Xisha Islands. This remote energy input promotes significant shear instability ($Ri < 0.25$) within the deep layer around the Xisha Islands slope (600–1000 m). Consequently, this mechanism drives local deep mixing in the waters surrounding the Xisha Islands. This investigation quantifies the energy magnitude of the low-mode M_2 internal tides, theoretically generated through topographic conversion in the LZ Strait, that successfully reaches the Xisha Islands.

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A Tidally and Subtidally Forced Open Boundary Condition for Unstructured-Grid Coastal Modeling

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Accurate open boundary conditions (OBCs) are essential for reliable unstructured-grid coastal downscaling. We implement a tidally and subtidally forced open boundary condition (TST-OBC, Liu and Gan, 2016; 2020) in SCHISM to improve the representation of external forcing and the transmission of internally generated signals in limited-area coastal simulations. Standard OBC treatments in SCHISM show important limitations: the Flather OBC does not readily accommodate complex external subtidal water levels and currents in a fully consistent manner, whereas the Clamped OBC imposes the boundary state too rigidly. Both approaches therefore tend to over-constrain the interior solution, restrict the outward radiation of internally generated disturbances, and promote the accumulation of spurious signals near the open boundary. These errors can propagate into the computational domain and distort the simulated dynamical evolution. The TST-OBC overcomes these limitations by separating tidal and subtidal motions and introducing an active dual-wave transmitting scheme. This formulation enables realistic prescription of external subtidal forcing while allowing internally generated disturbances to leave the domain smoothly. Numerical experiments show that TST-OBC substantially reduces spurious boundary signal accumulation and suppresses artificial rapid jumps near the open boundary. By improving boundary transmission and the treatment of internal reflections, the scheme produces a more realistic simulation of coastal dynamics and provides a robust OBC framework for unstructured-grid regional downscaling.

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Physical and Biogeochemical Controls of Hypoxia Durations in the East China Sea

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Coastal deoxygenation is intensifying globally, yet the mechanisms governing its variability across timescales remain poorly understood. In the Yangtze Estuary and the East China Sea, hypoxia exhibits pronounced fluctuations in severity and duration, driven by coupled physical and biogeochemical processes. In this study, we employ the unstructured-grid hydrodynamic model SCHISM coupled with the biogeochemical model CoSiNE to investigate the physical and biogeochemical controls on deoxygenation in the East China Sea. From a spatiotemporal variability analysis using Singular Value Decomposition (SVD), we find that seasonal deoxygenation responds rapidly to physical forcing, particularly temperature, whereas biogeochemical influences, including chlorophyll variability, exhibit delayed effects on system variability. Hypoxia occurs on top of seasonal deoxygenation as episodic events. To further characterize the episodic nature of hypoxia, we introduce an event-based analysis that identifies and classifies hypoxic events as short- or long-duration, enabling systematic quantification of hypoxia dynamics. A Generalized Additive Model (GAM) is applied to depict the nonlinear relationships between dissolved oxygen and key drivers. Driver importance and response functions vary across event types, indicating distinct control mechanisms governing the development and persistence of hypoxia. These findings reveal timescale-dependent controls on coastal deoxygenation and provide a unified framework linking event evolution to underlying drivers, with implications for predicting future hypoxia under climate change.

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Remote wave forcing effects on local circulation in the barrier reef of San Andres Island

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Here the hydrodynamic responses of a barrier reef system with a bounded lagoon under extreme wave events in the Caribbean Sea is studied. The extreme wave events are first selected, and later classified throughout an unsupervised neural network, from a 60 year wind and wave hindcast dataset, so that their spatial pattern distribution and seasonal variability are described according to the dominant wave climate regimes at the basin scale. Then, an offline nesting approach is applied using a phase-averaging model along with a high-resolution phase-resolving hydrodynamic model, revealing the linkage between the extreme waves at the basin scale, and the wave evolution and wave-induced circulation on a barrier reef system constantly exposed to the highest wave heights from a statistical viewpoint. Similar to fringing and lagoon-type reefs, the barrier reef provides an efficient protection against the extreme waves dissipating more than 80% of the incoming wave energy. The infragravity waves generated within the surf zone become as high as the sea-swell waves downstream the reef crest and from the reef flat to the shoreline. In addition, we confirm the inherently 2D-horizontal nature of the wave-driven current responses, so that minor changes in the incoming offshore wave direction (in addition to the height and period of the waves) can lead to cross-shore directed, to along-shore directed or a combined cross/along-shore wave-induced circulation, which ultimately rule the transport between the inner-reef and the open sea waters. Our results provide new and preliminary insights about the influence of basin-scale wave climate conditions on coastal protection as well as on the wave-driven circulation and transport processes in barrier reef systems.

Modeling larval connectivity of *Aristeus antennatus* (red shrimp) through Lagrangian dynamics and network analysis

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In recent years, the artisanal fishery of *Aristeus antennatus* (red shrimp) has experienced a concerning decline in the vicinity of the Ibiza Channel. To investigate the physical mechanisms underlying this trend, we study larval dispersal from the perspective of nonlinear ocean transport and network-based connectivity analysis.

Larval transport in the ocean is shaped by highly heterogeneous and time-dependent flow fields, where advection, vertical structure, and mesoscale variability generate complex patterns of retention, exchange, and dispersal. In this work, we use OceanParcels, a Lagrangian particle-tracking framework in Python, to simulate larval trajectories throughout the full water column at high spatial resolution. The simulations are forced by velocity fields from a numerical ocean model (IBI-MFC, Copernicus) and incorporate species-specific biological traits relevant to the early life stages of *A. antennatus*.

The resulting trajectories are analyzed within a network-theoretic framework, in which different geographical regions are represented as nodes and larval exchanges define weighted connections between them. This approach allows us to identify preferential transport routes, retention areas, and key regions sustaining connectivity across the Ibiza Channel. From a nonlinear-transport perspective, these structures reveal how ocean circulation organizes dispersal pathways and constrains recruitment at ecologically relevant scales.

Our results show that the combination of Lagrangian modeling and network analysis provides a powerful quantitative framework to characterize larval connectivity and to detect dynamically relevant areas for population persistence. This methodology contributes to a better understanding of recruitment processes and may support the design of more effective fisheries management and conservation strategies in the western Mediterranean.

This work is part of a manuscript that has been submitted for publication.

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DAY 4 / HIGH-RESOLUTION MODELING FOR COASTAL AND OPERATIONAL OCEANOGRAPHY: HAZARDS, TRANSPORT, AND MANAGEMENT

** Abstracts are listed in order of appearance in the programme*

Study on sediment dynamics in Batemans Bay, NSW, Australia

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Batemans Bay, a semi-enclosed, funnel-shaped estuary in New South Wales, Australia, is influenced by waves, tides, and river discharge, with significant seasonal variations in wave height and sediment dynamics. The hydrodynamics in Batemans Bay, are dominated by wave-induced processes, with tidal forcing playing a secondary role. To support planned dredging and beach nourishment efforts, this study employs both observation and 3D hydrodynamic-sediment transport modelling to simulate hydrodynamics, sediment transport and bathymetry change under a range of environmental and dredging scenarios. The goal is to improve sediment transport forecasting, support environmentally responsible dredging and beach nourishment operations, enhance shoreline resilience and inform long-term coastal planning in Batemans Bay. This talk provides preliminary observation and modelling results, with assessment to inform dredging strategies, highlighting the importance of precise placement of dumped material to achieve beach nourishment goals effectively.

Deep-sea mining vehicle, Mining vehicle plume, Sediment transport, Numerical simulation

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The impact of deep-sea mining plumes on the environment has raised significant concerns. Environmental assessment relies on computational results of plume strength, which consists of two components: mid-water discharge plume and mining vehicle plume. The mining vehicle plume are simulated by the Mixture multi-phase model to discover the interaction between vehicle, seawater and sediment layer. -The results confirm that mining vehicle plume within typical vehicle speed ranges cannot be neglected compared to the mid-water discharging plume. The mining vehicle plume can be divided into three components: the columnar plume, the turbidity current, and the collector plume. The columnar plume constitute the primary source terms for large-scale transport. The columnar plume, produced during the vehicle's startup, demonstrates a bidirectional speed effect: in the low-speed range, increasing the vehicle speed enhances the kinetic energy input to strengthen the source term, whereas at higher speed, the columnar plume detaches prematurely from the vehicle's influence zone, resulting in suppressed plume strength. This study provides reference values for the source strength of deep-sea mining plume, facilitating the estimation of their large-scale propagation range. The findings offer valuable insights for planning mining operations while minimizing environmental impacts on the deep-sea ecosystem.

Keywords:

Deep-sea mining vehicle, Mining vehicle plume, Sediment transport, Numerical simulation

The Brazilian contribution to SurgeMIP initiative

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The absence of long series of observed sea level in many parts of the world is a real limitation for understanding some major coastal flood events. In this context, the numerical representation of sea level variability based on global ocean circulation models is an alternative to quantify this important environmental variable. Astronomical tides are also determinant, as well as the combination with meteorological forcing responsible for subtidal variability. In this context, the SurgeMIP initiative (Bernier et al. 2024) congregates researchers around the world to establish a systematic comparison of numerical results for storm surges in a global perspective. The aim of this work is to present the efforts invested by the Brazilian group of MASTER/IAG based on customized POM structure, able to include tidal potential as well as atmospheric pressure effects in a global domain with 0.3 longitude by 0.25 latitude resolution. The base meteorological forcing given by ERA5 was considered from 2013-2018 and the skill was determined based on 550 GESLA stations around the world. Different model setups were considered for 2D and 3D simulations, and the factor separation technique was employed to evaluate forcing relevance and combination. The representation in narrow shelves and fast meteorological forcing is very low compared to wide and long shelves in extratropical areas, as expected; in any case, the skill of the model is displayed in an interactive interface for basic statistics and time series visualization

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Exploiting high resolution bathymetric datasets in high-order finite element coastal models

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In coastal areas, bathymetric data are nowadays available at resolutions significantly higher than those of the computational mesh. This disparity poses several challenges for high-order finite element discretizations of the shallow water equations: the mesh may not be aligned with strong bathymetric gradients, and the finite element method must be able to represent such gradients, as well as sub-grid bathymetric features, within individual elements. The choice of approximating the water depth h with a polynomial basis, although straightforwardly mass-conserving, is only justified under strong smoothness assumptions for the bathymetry over the element. Real bathymetries are typically irregular, which is reflected in a lack of regularity of h, also in those elements for which $h = 0$ at some location, as a result of localized drying. Therefore limiters or smoothing techniques must be activated on high-order bathymetry, which is unfortunate for very accurate bathymetric datasets. In [1], a finite difference method that employs the free-surface as prognostic variable and fully exploits high-resolution bathymetric datasets has been proposed, including a rigorous and mass-conserving formulation of wetting and drying with a sub-grid irregular bathymetry. The purpose of this work is to present a high-order adaptive finite element solver for the shallow water equations, which is also capable of exploiting high resolution bathymetries. We establish several properties of the resulting numerical scheme with sub-grid bathymetry: water depth positivity under a CFL condition that depends on the accuracy of the sub-grid bathymetry and a consistent discretization of passive tracers with the continuity equation. The spatial discretization is based on a high-order Discontinuous Galerkin (DG) method, as implemented in the deal.II library [2]. In this framework, we test the robustness of the proposed method also with dynamic Adaptive Mesh Refinement to simulate the tidal circulations in complex coastal environments.

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A relocatable HRES wave forecast system for coastal wave energy infrastructures management

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In the transition towards renewable energy, coastal wave power has emerged as a promising energy resource. However, integrating small-scale turbines into existing coastal infrastructures requires precise, high-resolution forecasting tools that can characterize local resources and ensure structural safety during extreme events. This study presents an automated, modular, and relocatable wave prediction system designed to support wave turbines installations in various port environments. All operational scripts are hosted in a public repository, facilitating rapid deployment in new coastal domains.

The system architecture uses a nested grid approach, where regional forecasts from Puertos del Estado (1.4 km resolution) serve as boundary conditions for a local SWAN (Simulating WAves Nearshore) model. This allows a high-resolution local grid of 200 meters, capturing smaller scale coastal processes. In addition, a transformer-based deep learning module is implemented to estimate wave characteristics directly at the turbine's location, reducing the need for computationally expensive higher-resolution models.

The validation was conducted in two stages. First, comparisons with offshore buoy data (Cala Millor and Alcudia) showed RMSE values of 0.12–0.17 m and a correlation coefficient of 0.92. However, performance deteriorated near the coast due to complex bathymetry and interactions with coastal structures. This was particularly evident in the Palma case, where tide-gauge observations revealed systematic nearshore biases (RMSE of 0.26 m). To address this, a deep learning module trained with in situ data was introduced, reducing Palma's RMSE to 0.11 m.

In conclusion, the proposed system provides a practical tool for coastal wave resource management. Its relocatable design enables a simple evaluation of different scenarios, supporting the selection of optimal installation sites. By combining traditional numerical models with deep learning, the system accurately predicts nearshore wave conditions. Moreover, under real operating conditions, data collected by the turbines could enable continuous re-training of the model, improving accuracy over time.

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From multi-platform observations to model-ready data services

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Operational ocean forecasting systems critically depend on the seamless integration of heterogeneous observational data to support model initialization, data assimilation, and validation. However, a major bottleneck remains the insufficient availability and timely delivery of high-quality observations, particularly in coastal areas, limiting the systematic exploitation of data assimilation capabilities. Ensuring the availability, consistency and accessibility of these datasets requires scalable, interoperable and robust management infrastructures to handle the full lifecycle of ocean observations, from acquisition and quality control to near-real-time dissemination and long-term preservation. To address these challenges, this work presents the integrated data lifecycle implemented at the Balearic Islands Coastal Observing System (SOCIB). It describes how observations from diverse platforms —including remote sensing, HF radars, ocean gliders, Argo floats, in situ ship-based, moorings, and tide gauges—are ingested and processed into standardized, discoverable, and model-ready datasets. Through automated processing pipelines and multi-level quality control procedures, SOCIB ensures timely access to high-quality, model-ready data through interoperable data services .

These capabilities overcome key barriers to advanced data assimilation and operational validation, supporting SOCIB's modeling systems, including WMOP (high-resolution ocean model), BRIFS (meteo-tsunami early warning system), and SAPO (wave forecasting system). The data generated by these platforms follow a structured, end-to-end lifecycle integrating automated ingestion, multi-level quality control—from real-time flagging to delayed-mode scientific validation—metadata standardization, and dissemination through interoperable services within a unified data management framework aligned with FAIR principles. This framework is supported by data management platforms and catalog services, ensuring traceability, reproducibility, and consistent data governance. By bridging observational and modeling systems, SOCIB's ecosystem enables reliable, data-driven forecasting in the Western Mediterranean and supports emerging initiatives such as regional and European Digital Twins of the Ocean.

Keywords: *Operational oceanography, Data assimilation, Western Mediterranean, Multi-platform observations, Data management.*

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These efforts contribute to advancing integrated ocean observing and forecasting frameworks aligned with emerging European initiatives, including the Digital Twins of the Ocean. The activities were conducted within the European Union-funded FOCCUS project (G.A. 101133911).

WMOP, a decade of operational forecasting supporting ocean science and marine applications: challenges and opportunities for integration into digital twin architecture

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Over the past decade, the Western Mediterranean OPerational forecasting system (WMOP Refs.1,2), developed by SOCIB, has provided continuous, high-resolution (~2 km) ocean predictions using a regional configuration of the Regional Ocean Modeling System (ROMS) and the integration of advanced data assimilation (DA) techniques. Initially developed for operational oceanography, WMOP has evolved into a versatile framework underpinning both scientific research and marine applications.

This work provides a comprehensive overview of WMOP's trajectory, combining system evaluation, scientific advances, and applications. Model performance is assessed through comparisons with in situ and satellite observations using the EDITO Validation Toolbox, developed within the framework of the EDITO Model Lab project. The system's long-term consistency provides a unique basis for examining the evolution of forecast skill as a function of improvements in model physics, DA schemes, and the expansion of observational data streams.

Scientific highlights supported by WMOP include advances in DA of multi-platform observations (Refs.3,4) , ocean variability, and multi-scale processes, and the characterization of frontal instabilities (Refs.5,6), thus contributing to improved understanding of fine scale dynamics in the Western Mediterranean. In parallel, it has demonstrated strong societal impact through critical marine applications, most notably via its integration into the operational services of the Spanish Maritime Safety and Rescue Agency.

Finally, we discuss the main challenges and opportunities for integrating WMOP into emerging Digital Twin of the Ocean (DTO) frameworks. These include issues related to performance, scalability, interoperability, and the integration of AI-based approaches. We argue that mature operational systems such as WMOP can serve as the essential physical engine for DTO architectures, provided they undergo targeted developments to meet the interactive and high-performance demands of next-generation, user-driven ocean services.

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POSTERS

** Abstracts are listed in order of appearance in the programme*

Assessing coastal profiling floats drift and high resolution shelf modelling in the Balearic Sea

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The coastal ocean remains challenging to predict due to complex circulation and the lack of in-situ sustained observations to constrain and improve ocean models. Developments in profiling float technology enable their deployment in shallow seas. Within SOCIB's Digital Twin of the Ocean (DTO) framework, we present a pilot experiment using a coastal autonomous profiling float (Arvor-C from nke Instrumentation) conducted over the shelf south of Mallorca, in the Cabrera Archipelago National Park during the 2025-2026 winter season. This study aims to evaluate the capability of the Arvor-C float to operate over the continental shelf and to assess its potential to support the SOCIB Western Mediterranean OPerational forecasting system (WMOP) and its nested high-resolution Balearic Sea OPerational system (BSOP) forecasting systems. The Arvor-C incorporates two technological adaptations to reduce its drift in coastal environments: increased profiling speed and a bottom-contact mechanism designed to temporarily ground the float on the seafloor. Two consecutive deployments at ~50 m depth yielded 49 daily profiles enabling the assessment of float performance, drift characteristics, and reproducibility of observed dynamics. The float exhibited a systematic offshore displacement averaging ~400 m between cycles, reaching the shelf break after 33 and 16 days in each deployment. Differences in residence time between deployments are consistent with contrasting wind regimes and varying alignment between surface currents and wind forcing. However, surface currents alone do not fully explain the observed drift magnitude. Lagrangian particle tracking and high-resolution BSOP simulations are used to explore the contributions of surface winds and subsurface circulation on the float's drift. Float observations compared with models enable evaluation of vertical thermohaline structure and support Lagrangian analyses of coastal model skill. This experiment highlights the potential of joint Coastal Argo observations and high-resolution modelling to establish and understand 4D coastal ocean variability towards DTOs.

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On the effect of different grid resolutions and mixing schemes on mesoscale dynamics in coastal ocean models: a case-study in a shallow, semi-enclosed basin (northern Adriatic Sea)

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The northern Adriatic Sea, due to the discharge from the Po and other rivers, can be described as a region of freshwater influence (ROFI). Together with fluvial inflows, other defining features are the strong atmospheric forcing, mainly Bora and Sirocco wind regimes, and tidal motions, most noticeably in peripheral environments such as the Venice Lagoon.

Furthermore, vertical processes such as stratification contribute in defining horizontal dynamics, for example Rossby radius of deformation variability, therefore affecting the mesoscale dynamical field.

Here we investigate and characterise the mesoscale variability of the northern Adriatic basin via numerical experiments, and assess how different vertical grid discretisations and turbulence parametrisations can affect it, using the MITgcm numerical ocean model.

After some tuning simulations, we select a subset of four among these setups and use them to run 5-year long simulations of the northern Adriatic hydrodynamics.

We find that increased vertical resolution results in better agreement with temperature and salinity observations, both remotely sensed (satellite SST) and sampled in situ (temperature and salinity profiles). Regarding vertical mixing schemes, GGL outperforms KPP, at times independently of the resolution under consideration.

By studying the mesoscale dynamical field we find that the Rossby radius of deformation responds mainly to the change in vertical grid resolution rather than to the mixing parametrisations. Instead, the summer stratification improved by the GGL scheme leads to more stable, wider eddies and more variability in the transport of fresh water of riverine origin from the coast towards the open sea, helping explain the observations of lower open sea salinity in summer with respect to winter.

We conclude that turbulent mixing parametrisations in ROFI ocean models can be as important as vertical resolution in determining the overall properties of both the water column and the basin-wide dynamics by shaping the mesoscale range of motion.

Diagnosing Fluid Parcel Retention in Oceanic Flows through Local Absolute Dispersion: Application to the Mediterranean Sea

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Residence time is commonly used to evaluate water quality of a given marine area by computing the rate of fluid particle interchange with surrounding waters. However, its classical definition has a two-fold dependence on the initial location of the particles and on the boundaries of the analyzed region, common to all initial locations, leading to ambiguous time mixing scales. We propose a new approach based on a generalization of the original definition of the escape time, conventionally defined to provide a global quantity, toward a local measurement around localized points, which we call finite-scale escape time (FSET). The FSET informs on the local retention properties of the flow around a point. This new definition introduces a measure of the absolute dispersion with the spatial separation as an independent variable, allowing us to reveal retention structures of different sizes and their contribution to particle dispersion in geophysical flows. Computing the local escape time by a proper selection of the parameters, we are able to identify flow structures and regions in the fluid flow susceptible to strongly trap drifting particles or tracers, such as biogeochemical particles, microplastics or other pollutants. We apply this new Lagrangian metric to study retention properties throughout the Mediterranean basin using satellite altimetry and drifter trajectories. Our findings show a high temporal variability in regional retention, characterized by a range of temporal and spatial scales from monthly to seasonal and larger. Additionally, we analyze the scale dependence of the absolute dispersion showing the different scales that contribute to the dispersion depending on the data resolution. This novel metric enables the assessment of relevant dynamical length scales in hydrodynamical models.

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Linking Surface Filaments to Vertical Transport in the Ibiza Channel

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While horizontal transport driven by mesoscale and submesoscale structures has been widely studied, their impact on vertical transport and three-dimensional Lagrangian pathways is still not fully understood [1,2]. In this study, we investigate the three-dimensional transport properties associated with two surface submesoscale frontal filaments in the Ibiza Channel by combining Finite-Size Lyapunov Exponent (FSLE) diagnostics with targeted Lagrangian trajectories and velocity fields from a CROCO model at 500 m of horizontal resolution. FSLE fields computed at successive depths reveal a vertical extension of the dynamical structures up to about 50 m, although their intensity decreases with depth, indicating a progressive weakening of horizontal mixing and transport organization.

Vertical velocity analyses highlight the presence of downward motions aligned with the filament cores, suggesting a strong coupling between horizontal convergence and vertical transport. Lagrangian particle trajectories confirm that particles located near the filaments at subsurface levels undergo downward displacement while maintaining horizontal aggregation clustering, consistent with the atracting nature of these structures. We observe that tidal forcing modulates the net penetration of surface particles into deeper layers associated with these submesoscale flow features. These findings demonstrate that surface Lagrangian coherent filaments play a significant role, specially at submesoscales, in driving vertical transport in the upper ocean, emphasizing the importance of considering fully three-dimensional processes when characterizing ocean transport.

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Continuous Data Assimilation in Quasi-Geostrophic Turbulence

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Oceanic flows are characterized by very high Reynolds numbers, posing a significant challenge for numerical modeling because the eddy viscosity required for numerical stability often over-dissipates small-scale energy and lacks the necessary backscatter. This results in a biased representation of dynamics within ocean models. Continuous Data Assimilation (CDA), a downscaling framework inspired by the theory of determining modes, has been mathematically established for several classes of geophysical fluid models, including Rayleigh–Bénard convection and the planetary geostrophic equation. In these settings, CDA yields solutions that converge exponentially to the reference state by prescribing resolved low Fourier modes (large scales) to constrain the unobserved high Fourier modes (smaller scales). However, the behavior of CDA in extremely high Reynolds number systems, such as the ocean, remains unclear. Here, we quantify the critical number of Fourier modes required for CDA to recover the full state across systems with different Reynolds numbers, as well as the temporal retention of recovery when observations are temporally discrete. We implement CDA in a forced-dissipative simulation of two-dimensional turbulence governed by barotropic quasi-geostrophic dynamics. This model serves as a simplified paradigm for studying multiscale ocean dynamics. For the Fourier-based version of CDA, we show that the critical number of Fourier modes increases approximately linearly with Reynolds number. For CDA using realistic nodal grid observations, the interpolator introduces artificial signals into the unresolved scales, while viscosity is ineffective at damping them in high Reynolds number systems. For temporally discrete observations, erroneous small-scale signals can further contaminate the large scales through multiscale interactions. Once the nodal observations resolve the critical number of Fourier modes, full-state recovery is also achieved despite interpolation-induced contamination. These results provide theoretical insights for CDA-based downscaling in regional ocean models, showing how high-resolution gridded data, including future SWOT products, can extend the predictability across scales.

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Data-assimilated upper ocean temperature with machine learning

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Accurate representation of upper-ocean temperature is essential for ocean models that aim to resolve submesoscale features. The thermal structure of the upper ocean is governed by multiple interacting processes, including winds, currents, and mesoscale eddies, spanning a wide range of spatial and temporal scales. Resolving these processes numerically often requires high-order schemes and significant computational resources. As an alternative, data-assimilation techniques have been widely used to improve model hindcasts and forecasts. Previous approaches commonly rely on regression-based methods that relate satellite-derived sea level anomalies (SLA) to model temperature fields, thereby adjusting geostrophic structures and circulation. In this study, we develop a physics-informed machine-learning framework within a data-assimilation system. This approach integrates high-resolution satellite SLA observations with in situ temperature profiles from Argo floats. By combining physical constraints with data-driven learning, the proposed method improves the representation of upper-ocean temperature and circulation. As a result, it enhances model performance at finer spatial scales and strengthens predictive capability.

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Physics-Driven Sea Surface Temperature and Ocean Front Forecasting Network

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Ocean fronts are vital marine phenomena, reacting to shifts in hydrological elements and serving as zones of increased growth for marine life. Sea surface temperature (SST) data, with high-precision observations, are key in studying fronts. However, accurately forecasting SST sequences and ocean fronts remains challenging due to the limitations of deep learning models, which often fail to capture the complex physical phenomena influencing fronts. To address this issue, we propose the physics-driven SST and ocean front forecasting network (PTFFNet), which integrates deep learning(DL) with physical oceanography. PTFFNet leverages DL's strength in handling nonlinear processes and identifying complex patterns, while embedding physical constraints to adhere to fundamental oceanic principles. Built on a generative adversarial network (GAN) framework, PTFFNet includes a physical feature extraction module, a physical information embedding module, a spatiotemporal conditional encoding module and a GAN forecast module. The physical feature extraction module, based on the continuity equation, derives essential physical information like position and intensity. This data is processed by the physical information embedding module and then integrated into the generator. This approach enhances the model's capability to forecast SST patterns and front characteristics through adversarial training with the discriminator network. Comprehensive testing shows that PTFFNet outperforms current advanced models in forecasting SST and ocean front sequences with greater accuracy and reliability.

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Impact of Ocean Physical Conditions on Oceanic Carbon Pumps and Atmospheric Carbon Dioxide during the Last Glacial Maximum

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Climate models fail to fully reproduce the lower atmospheric carbon dioxide (CO2) concentrations during glacials. We assess the impact of uncertainty in ocean physical fields on glacial atmospheric partial pressure of CO2 (pCO2) using a single offline ocean biogeochemical model forced with multiple Paleoclimate Modeling Intercomparison Project (PMIP)-derived physical fields, thereby isolating the contribution of ocean physical field differences to atmospheric pCO2 changes. The simulated pCO2 decrease averaged 40.3 ± 7.8 ppmv, with substantial inter-model spread driven by sea-surface-temperature (SST)-dependent CO2 solubility (−30.1 ± 5.6 ppmv), variations in the organic-matter pump efficiency linked to water-mass age (−21.6 ± 6.6 ppmv), and SST-contrast-driven gas-exchange pump responses (6.2 ± 9.4 ppmv). Proxy comparisons quantify the contributions of SST decrease and the organic-matter pump to glacial CO2 drawdown, indicating that improved ocean physics leads to more efficient CO2 uptake via SST-driven solubility (35 ppmv) and the organic-matter pump (30 ppmv).

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Back to basics: A multi-model framework to support native oyster (Ostrea edulis) restoration (ECODREDIT project)

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Oysters, like other filter-feeding bivalves, play an important role in marine biogeochemical cycles and are among the most economically valuable shellfish species1. The European flat oyster (Ostrea edulis), indigenous to Europe, has experienced a severe population decline due to historically unmanaged fisheries, increased freshwater runoff and parasitic infections2. Ireland was once one of the main producing countries in Europe. In this context, the ECOCREDIT (Establishing an Ecosystem Credit Framework for Oyster Fisheries Restoration) project aims to support the restoration of Ostrea edulis in Galway Bay, on the west coast of Ireland, by integrating scientific knowledge, marine modelling, and sustainable economic growth.
To contribute to these goals, numerical modelling is applied to quantify the physical, biogeochemical and biological conditions controlling oyster habitat suitability. The modelling framework integrates a hydrodynamic model, ROMS3, with the Fennel4–6 biogeochemical module and will incorporate an organism-level bioenergetic approach through the implementation of a Dynamic Energy Budget (DEB) model for Ostrea edulis. The DEB theory7 describe the energy dynamics of an individual organism at its different life stages based on uptake, storage and utilization
The Galway Bay ROMS configuration, used in this study, is based on a three-level nested configuration, including the Northeast Atlantic and Connemara model. The Galway Bay configuration has a horizontal resolution of ca. 70 m and 8 terrain-following (sigma) vertical levels. The hydrodynamic and biogeochemical models are run online and forced with realistic meteorological, riverine, tidal, and boundary conditions, and have been thoroughly calibrated and validated8–10. The DEB model code already implemented for a mussel species11 will be adapted to the Ostrea edulis. The modelling approach will provide insight into environmental drivers, nutrient fluxes, and habitat suitability to support oyster restoration planning and contribute to the development of a functional biodiversity and nutrient credit framework.

A Comparative Analysis of Clustering Algorithms for Characterizing Surface Ocean Variability in the Western Mediterranean

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Understanding regional dynamical structures in the sea is fundamental to characterize energy transfer and transport properties. In this work, we study the potential of clustering techniques to identify regional patterns, persistent or recurrent configurations, out of daily snapshots of sea surface temperature and kinetic energy in a region of the western Mediterranean Sea. From the methodological perspective, we use different clustering techniques: K-means, Self-Organizing Maps and InfoMap to ensure that the patterns found are coherent across methods. Our results show that K-means and Self-Organizing Maps consistently delineate four distinct clusters of sea surface temperature configurations, aligned with the seasons even after removing the annual cycle, which indicates the persistence of seasonal structures beyond a mean effect in the temperature field. The study of surface kinetic energy, characterized by higher spatial and temporal variability, reveals more complex circulation regimes. While K-means and Self-Organizing Maps provide a robust and convergent classification of the dominant large-scale energy patterns, InfoMap uncovers finer-scale features such as localized jets and eddies. InfoMap, in particular, provides a complementary perspective to the partition-based methods, validating subtle yet significant hydrodynamic structures and acting as an anomaly detector for extreme events.

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Pathways of Wastewater Dispersal in the Southern Ocean: From Coastal Outfalls to Large-Scale Circulation

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According to the Protocol on Environmental Protection to the Antarctic Treaty, the Antarctic region is designated as a "natural reserve, devoted to peace and science". However, current regulations permit the discharge of sewage and domestic liquid wastes directly into the sea, often requiring only basic maceration for larger stations. Recent environmental monitoring has detected antibiotic resistance genes and altered microbial communities in coastal sediments, raising significant concerns about the potential for wastewater-associated microorganisms to disperse beyond the immediate vicinity of outfalls and into the open ocean.

This study investigates the connectivity between coastal research station outfalls and the Antarctic Circumpolar Current (ACC), which serves as a major pathway for large-scale transport around the continent. To evaluate these dispersal dynamics, the research employs Lagrangian particle tracking forced by high-resolution (1/12°) ocean circulation fields from the GLORYS12V1 reanalysis. Virtual particles are released from various coastal and semi-coastal stations, which are classified into three distinct sea-ice regimes: ice-free, semi-permanent, and permanent ice cover. This classification allows for the modulation of initial dilution, residence times, and release depths (ranging from 5 to 100 meters) based on contemporaneous sea-ice conditions.

A key methodological contribution is the definition of a daily operational southern ACC boundary based on sea-surface height (SSH) contours. This boundary is used to diagnose "incorporation events," identifying exactly when and where coastal wastewater may enter the large-scale circumpolar flow. It is important to emphasize that this study is currently in a work-in-progress phase. Ongoing efforts are focused on refining the sensitivity of export pathways to sea-ice drift and further validating the residence time diagnostics across different seasonal cycles.

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Estimation of Vertical Velocities in the Mediterranean Sea Using Machine Learning Approaches

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Vertical ocean velocities play a crucial role in understanding ocean dynamics. Yet they remain the most challenging quantities to measure and model. In this work, we explore methodologies to estimate three-dimensional vertical velocities in the Mediterranean Sea by exploiting the incompressibility constraint of seawater and high-resolution oceanographic reanalysis data. The initial part of this study is based on velocity fields extracted from the Copernicus Marine Service (CMEMS) Mediterranean Sea Physics Reanalysis product, providing horizontal velocity components on a regular latitude-longitude grid with a horizontal resolution of approximately 1/24° and 141 vertical depth levels [1]. The divergence of the horizontal velocity field was used as the primary predictor for vertical velocity through the continuity equation for incompressible flow. Spatial derivatives of the horizontal velocity components were computed using finite difference schemes with adaptive stencils designed to handle land boundaries and irregular bathymetry consistently. Two complementary approaches were developed and compared: a linear regression model and a machine learning model, both trained to predict the vertical velocity at multiple vertical levels from the horizontal divergence field computed at each grid point. Model performance was evaluated using standard statistical metrics [2] including R^2, RMSE, and normalized RMSE, computed over multiple subregions of the Mediterranean domain. Results demonstrate that both approaches successfully capture the main spatial patterns of vertical velocity, with the machine learning model providing improved accuracy particularly in regions of complex bathymetry and strong mesoscale activity. Extension of the approach to data sets including submesoscale features is under way.

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Wave-induced drift of pumice: transitions from forward to backward transport

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Floating pumice rafts generated by eruptions of submarine volcanoes can be transported over large distances, yet the role of surface waves in controlling pumice drift remains poorly constrained. Wave-induced transport is often parameterized indirectly in numerical simulations despite limited experimental observations. Here we investigate the wave-induced drift of floating pumice using laboratory wave-tank experiments under controlled wave forcing. Natural pumice and analog cubes with characteristic sizes of 5–10 cm and a range of densities were subjected to regular waves with frequencies of 1.0–1.6 Hz and varying wave steepness. Pumice motion was quantified using video-based tracking. Pumice with positive freeboard consistently drifted in the direction of wave propagation, with velocities increasing with wave frequency and amplitude. When normalized by theoretical Stokes drift, velocities collapsed into a similar range across pumice densities but showed systematic dependence on wave steepness, indicating the importance of nonlinear wave effects. The corresponding Keulegan–Carpenter numbers (KC ≈ 1–3.4) place the flow in a regime where viscous form drag associated with asymmetric wave–body interaction becomes significant. In contrast, pumice approaching neutral buoyancy exhibited persistent drift opposite to the wave direction under certain conditions. Velocity and orientation records reveal a subharmonic response with a dominant period approximately twice that of the incident wave. Step-like modulation of the pumice tilt angle at this doubled period produces alternating large and small forward excursions, skipping large drift events every other cycle. These results demonstrate that wave–pumice interactions evolve with buoyancy and size and can alter both the magnitude and direction of drift. During intermediate stages of pumice raft evolution, when fragment size approaches the wave orbital excursion, such interactions play a critical role in transport and should be explicitly considered in pumice dispersal models following eruptions of submarine volcanoes.

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Numerical Study of Circulation and Sea Ice over the Labrador Sea and Adjacent Waters

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Circulation in the Labrador Sea plays a very important role in regulating the global ocean circulation and the Earth's climate system. Large atmospheric cooling in winter destabilizes the upper water column and results in open-ocean convection for dense surface waters to sink to deeper layers over the central Labrador Sea This winter convection leads to the formation of Labrador Sea Water, which is an intermediate water mass that contributes to large-scale ocean circulation. In addition to winter convection, circulation and hydrography in the Labrador Sea are also affected by boundary currents, sea ice, winds, neat heat/freshwater fluxes at the sea surface, and other processes. An advanced circulation-sea ice modelling system with nesting capacity is used to simulate sea ice, currents, and hydrography in the Labrador Sea and adjacent coastal waters. This nested-grid modelling system is based on the Regional Ocean Modelling System and Community Ice CodE. It has a high-resolution (~1.4 km) child model (CM) for the LS and adjacent coastal waters nested inside the coarse-resolution (1/12o) parent model (PM) for the northwest Atlantic (NWA). This nested-grid modelling system has a significant advantage of resolving fine-scale features of hydrodynamics in the Labrador Sea and coastal waters of Baffin Island by the CM, while the large-scale features of circulation and hydrography over the NWA are reproduced by the PM. The PM simulations for the three-year period 2020–2022 and the CM simulations for 2020–2021 are used to examine distributions and variability of sea ice, currents, and hydrography and their temporal and spatial variability over the study region.

Enhancing Coastal Monitoring and Forecasting with Foccus

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Since 2024, the UN Ocean Decade-endorsed Horizon Europe FOCCUS project (Forecastingand Observing the Open-to-Coastal Ocean for Copernicus Users, foccus-project.eu), is working to enhance the coastal dimension of the Copernicus Marine Environment Monitoring Service (CMEMS) in Europe. FOCCUS brings together European Member StateCoastalSystems(MSCS) andusersinordertoenhanceexistingcapabilities.Theconsortiumconsistsof19partnersfrom 11 countries with a wide range of expertise in oceanography, observationalscience,advanced modeling, and technology development, exemplifying the value of international collaboration towards developing marine science capabilities. As its primary goals, FOCCUS is developing innovative coastal products focusing on three key areas:i)improvingnewcoastalobservations by fusing high-resolution remote sensing and in-situ data and implementingnewtechnologies and approaches,includingtheuseofArtificialIntelligence(AI)methodstoimproveaccuracy;ii) developing advanced hydrology and coastal models including a pan-European hydrological ensemble for improvedriverdischargepredictions,andestablishingaunifiedcoastalsystemby testing new methodologies in MSCS production chains while taking advantage of stochastic simulation, ensemble approaches, and AI technology; and iii) demonstrating innovative products and improved co-produced services that address both environmental and societal challenges, enhancing the performance and societal relevance of coastal ocean forecasting systems in and downstream of CMEMS. FOCCUS is aligned with international initiatives and fosterscoll aboration,emphasizingco-productionandcollaborationwithend-users, policy-makers, and local communities. In this way the project can address the complex challenges of coastalregionswo rldwideandsupportdecision-makingprocessesforsustainable coastal management and climate adaptation strategies. FOCCUS is providing the high-quality, trusted marine knowledge needed to support a sustainable blue economy and build climate resilience for both European and global communities.

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Drivers for the vertical structure of Suspended Particulate Matter along the Inner Continental Shelf of the Western Black Sea

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Most of the sediment in the Black Sea is delivered to the western basin through riverine discharge from the Danube Delta. The sediment load of the Danube plume spreads over several kilometers across the continental shelf into the deep ocean. While high concentrations of suspended particulate matter (SPM) can still be associated with the plume in distant regions, these concentrations may merge with locally induced resuspension processes on the inner shelf. Simulations using SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model [1]), coupled with the Wind Wave Model (WWM) and the morphological module SED3D, were used to identify the drivers controlling SPM concentrations in the western Black Sea. The model setup also incorporates seabed morphology across the entire domain, enabling a more precise representation of sediment fractions. Results across different coastal compartments characterize the transition from plume-influenced regions to areas dominated by locally induced turbidity driven by wind waves and currents, explaining variability in the vertical structure of SPM. The cross-shore decay of SPM concentration along the inner shelf reveals contrasts between littoral compartments. While the north-south contrast is primarily attributed to the Danube plume, additional differences arise from variations in bed shear stress along the inner shelf.

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Future coastal flooding associated with Posidonia oceanica decline under climate change

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Mediterranean coastal areas are increasingly exposed to climate-change impacts, including marine warming, sea-level rise and extreme storm events. Posidonia oceanica meadows play a key role in coastal protection by attenuating wave energy and reducing coastal flooding. However, continued warming is expected to drive substantial degradation of these ecosystems, potentially weakening this natural protective function.

This study assesses how projected changes in P. oceanica meadows may influence coastal flooding in Cala Millor Bay, Mallorca, under future climate scenarios. Future meadow conditions were estimated from CMIP6 sea-surface temperature projections under SSP2–4.5 and SSP5–8.5. These projections were used to generate spatially explicit meadow-density scenarios for selected time horizons and ensemble uncertainty percentiles. Extreme storm conditions were characterized from a long-term wave hindcast combined with in situ AWAC observations and an extreme-value analysis.

Representative storm events were then applied as forcing in XBeach hydrodynamic simulations incorporating vegetation–wave interactions.

Results indicate a progressive reduction in meadow density and spatial extent throughout the twenty-first century, with the largest losses under SSP5–8.5. The simulations show that lower seagrass density is associated with larger maximum inundated areas, particularly for high-intensity storms and late-century scenarios.

These findings highlight the critical role of P. oceanica meadows as nature-based coastal protection systems, showing that their climate-driven decline may weaken a natural barrier against flooding and should therefore be explicitly considered in future Mediterranean coastal flood-risk assessments.

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