Synthetic report

Executive summary. The third China–Europe Frontier Forum on "Progress in Ocean Science and Technology" (FFPOST2) held in Shanghai and on line on 18-19 November 2024 in the framework of the UN decade of Ocean Science for Sustainable Development (2021-2030). About 30 participants attended, with livestreams occurring about 6000 persons. Twenty-four invited speakers presented communications. Progress are remarkable regarding the usability of Ditigal twin oceans and of the AI in physics and biogeochemistry and in coastal management. All carbon dioxide removal (CDR) deployments will lead to compensatory CO_2 efflux or reduced influx from all natural reservoirs, stressing the need for all realistic land-based, ocean-based and blue carbon CDR. Carbon sinks due to fisheries are being assessed, extension of the Oxygen Minimum Zone has been shown. Impacts of sea-level rise and extreme events like heat waves are key issues for the near future. First economic costs of the flooding of the coastlines are now available. Spectacular progress in observation tools and networks of the ocean have been highlighted.

Recommendations: 1- To contribute to UNOC 2025 and preceeding OOSC 2025 in close link with "*towards IPOS*" (International Panel for Ocean Sustainability) 2- to organize a 4th CAS – EurASc Frontier Forum in Europe in 2026.

Highlights of the thematic sessions:

Artificial intelligence and Twin oceans, session chaired by *Pierre Tandeo* (IMT Atlantique, France) and *Yan Du* (SCSIO-CAS, China). For *Alain Arnaud* (Mercator Ocean International) digital twin is an interactive platform for the community where you find data, model, visualization, decision, impact. There are different levels of access: low (explore, decision) to expert (create, contribute). So far, it is hard to go from a digital model to the real ocean. The coastal ocean is important, but *Dake Chen* (SIO, CAS) shows it is difficult to model large bays because they are complex: affected by ocean, rivers, biogeochemistry, and meteorology. There is a necessity for a nested model (regional and high resolution model for the bay), a tool for forecasting (based on AI), a visualization tool, and a decision making service. To the question: what are the main challenges for a digital twin of the ocean?, the answer is: digital twin concept is not new, but for the ocean, the main challenges are the data and how to use new technologies (like AI). *Quentin Febvre* (Ifremer, France) is using deep learning for spatio-temporal interpolation of satellite data. He presented clearly the general concepts of machine learning (optimization, structure, regularization). He made the relationship between optimal interpolation, data assimilation, and variational neural network. Yan Du (SCSIO-CAS, China) is studying the multiscale ocean dynamics from observations and satellites. There is a need to go from the surface measurements (dense) to the interior of the ocean (few observations), or use proxy data like (SST) to estimate surface currents. Deep learning methods and physical constraints are used to make some predictions. *Erwan*

Le Roux (IMT Atlantique, France) proposes a method to predict indicators using different models. He tries to mimic the model chain using symbolic regression methods. He wants to make some predictions of model climate scenarios that have not been already simulated. *Changming Dong* (Nanjing University of Information Science and Technology, China) talked about the huge amount of data. He defined the big data concept. He introduces the machine learning concept (cost function, architecture, feature extraction). He shows some applications: detection of features, forecast variables, parameters of ocean components, and solving governing equations. Exchanges with audience highlight that data assimilation is an incredible tool to manipulate sparse data, incomplete data, and noisy measurement at the same time. Moreover, it can take into account dynamical models (coming from the physics-equations or data-AI). Thus, data assimilation is useful to interpolate-extrapolate the available data, giving a physical consistency. But more importantly, data assimilation is able to predict an error in the estimation. This uncertainty quantification is very important in a digital twin of the ocean, where the final goal is to make decisions, and without a quantification of the uncertainty, we cannot conclude.

Ocean ecosystems and carbon Cycle, session chaired by *Yuntao Zhou* (Shanghai Jiao Tong University, China) and *Louis Legendre* (Sorbonne University, France). Recent estimates show that the carbon sink of fisheries (including algae, shellfish and capture stock) is the largest blue carbon sink in China's coastal ocean (*Qisheng Tang,* YSFRI-CAFS, China). All carbon dioxide removal (CDR) deployments will lead to compensatory CO_2 efflux or reduced influx from all natural reservoirs, stressing the need for all realistic land-based, ocean-based and blue carbon CDR (*Louis Legendre,* Sorbonne University, France). The volume of global oxygen minimum zones (OMZs) expanded by 10 million km^3 from 1960 to 2022, i.e. more than ten times previous estimates; OMZs limit suitable habitats for most marine species (*Yuntao Zhou,* Shanghai Jiao Tong University, China). The representation of ecosystem structure in marine ecosystem models using Plankton Functional Types shapes the predicted carbon dynamics at the global and regional scale (*Corinne Le Quéré,* University of East Anglia, UK)). Radiolarian proxies were established to assess regional biogenic deposition under climate change and to reveal the evolution of upper and intermediate ocean circulation in the North Pacific during the Deglacial and Holocene periods (*Lanlan Zhang,* SCSIO, CAS, China). Restorations of coastal ecosystems provide desirable outcomes in terms of spatial quality, biodiversity values, and ecosystem functioning (*Laura Airoldi*, University of Padova, Italy).

Coastal ocean and sustainability of society session chaired by *Qing He (CAS, China)* and *Anny Cazenave (CNES, France)*. Six presentations were dedicated to coastal stresses suffered by populations and ecosystems as a result of climate change, human activities and natural phenomena. Extreme events are the focus of *Svetlana Jevrejeva (SJ)* and *Weiqing Han (WH)*' presentations. *SJ* shows that 100-year return period of extreme sea levels will become annual by 2030-2040 in the tropics because of sea level rise. *WH* explains that the decadal variability of extreme sea levels and marine heatwaves has become more intense in the recent decades in the tropical Indian and Pacific oceans due to climate change and natural phenomena, with important interactions between these two oceans. In her presentation, *Quing He* explains how the recent years decrease in sediment supply has strongly modified the morphology of the Yangtse river estuary. She discusses the complex hydrodynamic response the different areas of the estuary, their interactions and their impact on navigation. *Chenghu Zhou* highlights the importance of remote sensing data to monitor the evolution of coastal zones. Focusing on the Guangdong-Hong Kong-Macao Bay region, he shows the high value of such data for the monitoring of urban development and of other factors affecting the coasts. *Ben Horton*'s presentation deals with future sea level rise in Singapore and Southeast Asia, and explains how different kind of paleo data can help in constraining future changes. He also addressed the impacts of future extreme events as well as of vertical land motions on urbanized areas. Finally, *Hui Liu* discusses

the respective carbon footprint of aquaculture and capture fisheries, and highlights the challenges posed by strategies dedicated to reduce the carbon footprint of these activities.

During the discussion, *Tanya Brodie Rudolph* shows the progress made by "Towards IPOS (International Pannel for Ocean Sustainability)" which is supported by China, the European Commission, and 27 scientific institutions, in the perspective of its acknowledgment by the United Nations at the United Nations Ocean Conference (June 2025, Nice, France).

Ocean technology and Observations, session chaired by *Xinyuan Diao (IO, CAS, China) and Hervé Claustre (IMEV-CNRS, France)*. This session was organized around six presentations. One was dedicated to the development of a very large research infrastructure designed to install a laboratory on the ocean floor to study cold seep ecosystems (*Si Zhang*, CAE, SMSE, China). One other brought a large overview of the present as well China prospective in satellite development and launch with respect to ocean observations (*Mingsen Lin,* SORA-MNR, CAS, China*)*. This presentation covered a wide range of satellite missions in their multidisciplinary dimension including, for example, sea level-rise, ocean sea-state or ocean color. Another talk focused on the development of a clean, and cost-effective sampling systems for trace element that can be easily implemented on various research vessels and that cope with the requirements of the international Geotraces program (*Xinyuan Diao,* IO, CAS, China*)*. The BGC-Argo program was highlighted as part of the three other presentations (*Hervé Claustre*, IMEV-CNRS, France; *Nathan Briggs*, NOC, UK; *Griet Neukermans*, Ghent University, Belgium). It is an efficient network to fill our chronical observations gaps and to explore key biogeochemical processes, especially the Biological Carbon pump. Presentations were highlighting different and innovative ways of characterizing the nature of particles (size, mineral vs organic) and/or to quantify their contribution to carbon flux. Overall, the BGC-Argo floats appear to be a very attractive technology that can easily accommodate a variety of new sensors for exploring new research topics or become the pillar of observation systems designed to support science-based decision. Altogether all the presentations and the following discussion have clearly shown the importance of technological development to support or future observation systems for monitoring and addressing new key science questions. Therefore, it is very important to insist on the importance to continue funding research and development project related to technology. In the same time, it is critical that the developed technology, once established and validated, become a clear component of ocean observation and monitoring systems. At the time, we are entering in the era of big data and in line of the requirements of the future DTO with respect to upstream data lake, the sustainability and associated funding of the observation systems is more critical than ever to respond to the upcoming societally relevant topics.

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