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ABSTRACTS

Session 2 : Report on the EurASc – CAS WG : Ocean-based climate actions
Chairs : Paul Tréguer and Jing Zhang

Ocean-based climate actions : report of the CAS-EurASc working group

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As a consequence of anthropogenic perturbations the global ocean is warming, acidifying, losing oxygen and sea ice, and sea level is rising. While drastic reduction of the emission of greenhouse gases is urgently needed, which includes ocean energy substitution for fossil energy, we show that the ocean offers numerous opportunities to reduce the causes and consequences of climate change, globally and locally. A wide range of ocean-based measures to enhance societal climate adaptation are currently implemented worldwide to deal either with coastal risks or changes in ocean resources. Ocean-related measures should not be considered as a substitute for climate mitigation on land or non ocean-based adaptation measures, which must be strongly pursued for the benefit of the atmosphere, the ocean, and socio-ecological systems worldwide.

The full report is available here: https://doi.org/10.5281/zenodo.6410659.

Session 3 : Big data management for ocean science and technology
Chairs : Lionel Guidi (on behalf of EurASc) and Huadong Guo (CAS)

Using Artificial Intelligence to sail the Tara-omics datascope

Damien Eveillard
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Recent progress in metagenomics has promoted a paradigm change to investigate microbial ecosystems. These ecosystems are today analyzed by their gene content that, in particular, allows us to emphasize the microbial composition in terms of taxonomy (i.e., « who is there and who is not ») or, more recently, their putative functions. However, understanding the interactions between microbial communities and their environment well enough to predict diversity based on physicochemical parameters is a fundamental pursuit of microbial ecology that still eludes us. This task requires deciphering the mechanistic rules that prevail at the molecular level. Such a task must be achieved by dedicated computational approaches or modelings, as inspired by Systems Biology. Nevertheless, applying standard cellular systems biology approaches is a complicated task. Indeed, the ecosystem's metagenomic description shows many variables to investigate. Furthermore, communities are (i) complex, (ii) mainly described qualitatively, and (iii) the quantitative understanding of the way communities interact with their surroundings remains incomplete. Within this presentation, we will illustrate how systems biology approaches must be adapted to overcome these points in different manners.
1. We will present the application of bioinformatics protocol on metagenomics data, with a particular emphasis on network analysis. In particular, we will use environmental and metagenomic data gathered during the Tara Oceans expedition to improve our understanding of biological processes such as carbon export.
2. We will describe a model of extensive omics knowledge via constraint programming that allows a definition of the ecological concept, such as the niche of organisms.

Chinese Academy of Science Earth Program: Big Data for Sustainable Development Goal 14 and Others

Huadong Guo 1,2

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Chinese Academy of Sciences (CAS) launched the “Big Earth Data Science Engineering Program” (CASEarth) in 2018, and took SDGs research as one of its top priorities. The main objectives for CASEarth to serve SDGs include converting big Earth data into SDGs-related information, providing decision support for SDGs implementation, constructing a big Earth data integration system for SDGs indicators, and investigating the inter-linkages among different components of the Earth system. CASEarth has preliminarily sorted out 20 indicators from six SDGs as a priority,and the six SDGs comprise SDG 14 (Life below water) and SDG 2,6,11,13 and 15. The big Earth data’s value and potential for applications in monitoring and evaluating the marine pollution, ocean acidification,marine ecosystem health management related SDG 14 have been introduced and discussed in this paper.

Artificial Intelligence methods for fisheries management

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Sustainable fisheries depend on good management. This in turn requires knowledge about the current state of the specific stock, the state of the surrounding ecosystem, and the dynamics of the processes involved. One central pillar of this knowledge is acoustics and image data harvested by research vessels. Human expertise needed to scrutinize the ever increasing volumes of data are increasingly becoming a bottleneck, and we are now training and deploying deep learning models to automatically analyze data and identify and quantify species of interest from acoustics and images. An important challenge is the quality of - and sometimes lack of - labeled data for training. But if these challenges can be overcome, we open up exciting opportunities to reanalyze our large troves of historic data, and develop new insights into the history and workings of our marine ecosystems.

Coastal Zone Information Extraction from satellite images by deep learning

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Coastal zones are ecologically essential and present dramatic dynamic changes. Monitoring these areas is critical in sustainable development and environmental protection. For environment monitoring of the coastal zone, a ground survey is a direct and accurate means, but it is costly and sparse sampling. Remote sensing is an economic and efficient means. Satellite synthetic aperture radar (SAR) has become an essential means to monitor environmental changes in the coastal zone. However, SAR images are difficult for end users to understand. Therefore, accurate and efficient information extraction methods are required.

This talk presents the coastal zone information retrieval from SAR. Two examples are given. The first study is: (a) to develop a deep-learning framework for accurate derive of tidal flats from Sentinel-1 SAR images; (b) to extract the pixel-level waterlines at different tidal phases to construct a multi-year digital elevation model (DEM) series; (c) to understand the morpho-sedimentary evolution in the study area between 2015 $\sim$ 2020. The second study proposed a new deep-learning model suitable for intertidal zone land cover classification using dual-polarimetric SAR data integrated with environmental information.

We believe the proposed model is ready to be generalized to other coastal/intertidal zone areas for environment monitoring.

Big data & cloud computing for climate

Pierre Tandeo
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Since 2018, IMT Atlantique and IFREMER are proposing an intensive 2-week formations for master students about the use of big data technologies. We use the Google Cloud Platform to deal with large oceanographic datasets, coming from in situ and satellite reanalysis, as well as climate simulations coming from CMIP. The goal is to quickly manipulate gigabytes of data and easily perform statistical analysis using appropriate tools. In this course, students work by group on different projects: ENSO index, hurricanes and typhoons, heat contents, sea ice extend, marine heat waves, sea level rise, Atlantic multidecadal oscillation, etc.

Ocean Artificial Intelligence: A New Bridge from Data to Knowledge

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Oceanography is a ubiquitous interdisciplinary science based on observation and experiments, which is characterized by data-intensive and technology diversity. With the development of earth observation technologies, an era of ocean big data with spatial/temporal attributes and non-negligible imbalance on vertical scale advents. Novel and rigorous artificial intelligence (AI) methodologies are employed to process and analyze ocean big data to improve our understanding of marine systems. The integration of oceanography and AI serves as a bridge between ocean data and knowledge discovery. The revolution of deep learning, mainly composed of deep and complex neural networks, has a far-reaching impact on ocean scientific disciplines. This presentation mainly focuses on the applications of associative statistical and physical traction neural networks on ocean data, which can provide the promising solution for problems of data reconstruction, feature detection, and process prediction in oceanography.

Session 4 : Digital Twin of the Ocean (DITTO) component of the Digital Earth Initiatives, Chairs : Martin Visbeck (EurASc) and Dake Chen (CAS)

DITTO Digital Twins of the Ocean Program of the UN Decade of Ocean Science for Sustainable Development (2021-2030)

Martin Visbeck,
GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel Germany

The Vision of the Digital Twins of the Ocean (DITTO) Programme is a world where digital twins are used to support ocean science, ocean protection, ocean governance and a sustainable ocean economy. The Mission of DITTO is to develop and share a common understanding of digital twins of the ocean, to establish best practice in their development, and to advance a digital framework to empower ocean professionals from all sectors around the world to effectively use digital twins.
DITTO will promote co-design of twins with targeted end users, raise awareness of their uses and applications, and demonstrate their potential for decision making across multiple sectors including ocean governance.
The Gemini Principles define a digital twin as "a realistic digital representation of assets, processes or systems in the built or natural environment". In other words, a digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process. In essence a digital twin is a computer program that uses real world data to create simulations that can predict how a product or process will perform. The notion of digital twins is used in engineering, production and asset management since more than 20 years.
Thus a Digital Twin of the Ocean (DTO) is a virtual representation of the real ocean that has a two-way connection with it. Observations from the real ocean, in combination with models, data science and artificial intelligence, are used to create a digital twin that adapts as the real world changes. Manipulating the twin to address 'what if' scenarios can provide information for decision-making and highlight regions of the real ocean in need of better or different observations. A well-constructed digital twin of the ocean will enable a wide range of users to interact with ocean data and information to improve understanding and inform decisions and can support ocean literacy and ocean understanding. They can be used to explore ways in which the ocean will respond to a changing set of conditions, providing a powerful tool for decision making. DTOs will provide ocean researchers, professionals, citizen scientists, educators, policymakers, and the general public alike with the capability to visualise and explore ocean knowledge, data, models and forecasts.

The fundamental building blocks to support a Digital Twin of the ocean are:
An Observing system : A co-design between users and developers of the observing networks needed for digital twins of the ocean will create a positive and continual feedback loop between both where information from the digital twin can be used to inform and optimise the observing network whilst benefiting from it.
A Data Space that provides access to ocean observations through data communication and management in a timely way following common data principles.
The Data Space includes tailored computing capacity (often cloud based), an information management framework, a forum for setting data standards and protocols, and a system for data mapping architectures and data lineage to track data transformations.
A Data Analytics and Prediction Engine to maximise the understanding and value from these data.
The Prediction Engine provides tools to add value to ocean observation through predictive modelling, emulation, and artificial intelligence / machine learning to create, manipulate and analyse marine

information. Digital twins incorporate the additional capacity for the user to modify the prediction engine to explore options, scenarios, and
consequences.
An Interactive and Provisioning layer allowing users to visualise, interact with and tailor the data, scenarios and models to meet their needs.
This layer provides a powerful interface to the information and tools in the data engine that is easy to adapt and use, and represents one of the characteristic features of digital twinning. These provisioning layers are tailored towards human users and are often visually pleasing front-end interfaces with easy, intuitive access. Machine-to-machine provisioning is also common, in which case the provisioning layer is tailored to enable federating with other twins or systems.
An Outreach and Training capability to train developers, experts and users of digital twins respecting the capabilities and realities of the diverse international communities.
Digital twins are not new. However, their application to the earth system and ocean domains is relatively recent. Support to develop international capacity and capabilities is needed to ensure that observations and other data are accessible through appropriate Data Spaces, that models and analytics systems are available and usable to all and that DTO information can be developed and applied to serve diverse international communities' user needs.

The UN Ocean Decade global program DITTO will support the global development of Digital Twins of the Ocean buy establishing several working teams to facilitate interoperability, best practices, capacity building, capability sharing and knowledge exchange.

Digital Twin Ocean for Guangdong-Hong Kong-Macao Greater Bay Area

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The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is at the forefront of China's economic growth. For regional disaster prevention, environment protection and sustainable development, it is of great importance to build a Digital Twin Ocean (DTO) system for the GBA. Collaborating with a variety of stakeholders, we plan to construct a data lakehouse for full lifecycle governance of ocean-related data, to develop data-knowledge coupled marine forecasting techniques, to realize online computation and multi-dimensional visualization, and to set up a decision-making service platform for marine ecosystem-based management. By integrating data and models from different sources into an accessible and interactive framework, this DTO will serve as a powerful tool for marine monitoring, forecasting as well as management for the GBA.

The European Digital Twin Ocean infrastructure, models and applications

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Mercator Ocean International, France

The development of a European Digital Twin Ocean (DTO) framework is leading to a strong mobilisation of different teams in Europe, with the support of the European Commission. It aims to provide a reliable and open framework capable of integrating community innovations in digital twinning. The objective is to make ocean knowledge available to citizens, entrepreneurs, policymakers, decision-makers and scientific experts alike, thus enabling them to become partners in knowledge generation, explore desirable futures and develop ocean management scenarios and assemble their own twins,

with the overarching goal of ensuring a safe, healthy and productive ocean. The EDITO Infra and EDITO-Model Lab projects, recently selected under the EU Horizon Europe research programme, are first building blocks of this construction. EDITO Infra will provide the foundation – the infrastructure – for the further development of the European DTO initiative, hosting the deployment of multiple DTO applications from ongoing and future digital twin projects and supporting the deployment of new generation of ocean models and tools. Complementary, as an interactive and user driven initiative, EDITO-Model Lab will deliver a Virtual Ocean Model Lab including (i) a core model suite including global high-resolution models and coastal configurations, (ii) downstream user toolkits and (iii) a developer's toolkit for a sustainable ocean. The Virtual Ocean Model Lab will be an interactive and co-development environment to operate models. The core model suite will be based on modelling and simulation software, artificial intelligence algorithms and specialised tools to form a new service capacity for accessing, manipulating, analysing and understanding marine information. Intermediate and downstream stakeholders will find digital tools, data and information for 'focus applications' that refer to the Mission Lighthouses and the sustainable Blue economy, including 'what-if scenarios' to find solutions to natural and man-induced hazards. The presentation will outline the expected outcomes of these two pillar projects and how they contribute with other projects to wider community work in Europe and the world, particularly in the context of the UN Decade.

Digital twin ocean and its application for Chinal coastal regions

Fei Chai
Xiamen University, China

With over 2 billion people relying on the marine resources, the East Asian seas have nourished rapid economic growth over the past decades. But this comes at the expense of ocean health. Coastal-SOS - "Coastal Zones Under Intensifying Human Activities and Changing Climate: A Regional Programme Integrating Science, Management and Society to Support Ocean Sustainability", a UN Ocean Decade endorsed project aims to provide solutions for the sustainable development of coastal ocean through effective integration of science, governance, and society. Numerical modelling is a key programmatic effort, serving synthesis analysis, mechanistic studies, and most importantly, predictions, which will contribute to construct the next generation of product: the data-model fully integrated Digital Twin Ocean. One of the expected outcomes of this project is a decision-making support system and toolbox aided by numerical modelling and the Digital Twin Ocean initiative that will result in integrated coastal management and development of marine spatial planning and ecosystem conservation practices. I will review the existing observational data and modelling work in Xiamen Bay and Changjiang Estuary which are two pilot sites and discuss plan of constructing a Digital Twin Ocean in these regions.

Digital Twin opportunities in support of the Biodiversity Agenda

Isabell Susa Pinto
CIMAR and University of Porto, Portugal

Marine biodiversity underpins the health of the Ocean and is responsible for many of its ecosystems services as food, feed and biomass to many other applications, climate regulation, coastal protection and inspiration and enjoyment for people around the world. But this biodiversity is in sharp decline due to human activities, pollution and climate change. So a number of international, regional and National initiatives were created to better manage and protect biodiversity and to rebuild life in the ocean. But to do this effectively we still need to know much more about marine biodiversity but also to predict how, when and where it will change to allow for corrective measures. So there is a need increase biological observations and to fully include marine biodiversity data in the Digital Twin of the Ocean where all the observations of ocean parameters, in combination with models and artificial intelligence, can create a tween that mimics the ocean conditions. This can then be used to test scenarios adequate to provide information for decision-makers regarding important subjects as e.g. fisheries and aquaculture management, HABs control, placement and management of networks of marine protected areas, protection of routes for highly migratory species and other measures necessary to fully recover marine life. These tweens can also be used to visualise the effects of action and inaction and be used to create awareness and encourage the correct actions from people. They can also be useful to identify the key gaps in data and knowledge that need to be filled to better direct future research.

The ocean model development and its support to digital twin

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Ocean digital twin, as a new concept, is receiving more and more attention from scientific community. Ocean model is a vital pillar for ocean digital twin. However, how to accurately simulate and predict the ocean remains a problem for more than half century, especially for the simulation of the summer mixed layer in the upper ocean. Too weak turbulence and incorrect air-sea fluxes are two keys to improve ocean models. Small scale surface waves have not been considered in ocean general circulation model, because the later has much large spatial and time scales. We revealed that surface waves play key role in enhancing the turbulence in the upper ocean, and regulating the air-sea momentum and heat fluxes. The surface wave-circulation fully coupled model can dramatically improve the simulation and prediction of the global ocean, and as a result, can firmly support ocean digital twin.

S5 : The Global Coastal Ocean
Chairs : Nadia Pinardi (EurASc) and Nianzhi Jiao (CAS)

The Global Coastal Ocean: the CoastPredict solution

Nadia Pinardi,
University of Bologna (IT)

The Global Coastal Ocean concept, at the centre of the UN Decade Program CoastPredict https://www.coastpredict.org/, "considers all coastal ocean regions as an interface area. In particular that area extending inshore from the estuarine mouths to river and urban settlements and offshore from the surf zone to the continental shelf and slope where waters of continental origins meet open ocean currents."
Atmosphere, land, ice, hydrology, coastal ecosystems, open ocean and humans interact on a multiplicity of space and time scales that need to be understood and observed and modeled with proper scientific methods and consideration of uncertainties. This concept helps to design solutions for a healthy and safe ocean and achieve many of the targets of the Sustainable Development Goals, as well as increasing coastal resilience for the human population and the ecosystems.
The key science paradigm is to concentrate the attention on the prediction issues requiring an integrated approach of observing and modelling that will allow to improve our understanding, test theories and hypothesis, reduce uncertainties from events to the climate time scales. CoastPredict is part of the Global Ocean Observing System (GOOS) strategy to design and implement a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS and CoastPredict will provide: 1) accurate descriptions of the present state of the coastal oceans; 2) continuous forecasts of the future coastal ocean conditions as far ahead as possible; 3) the basis for predictions of climate change impacts on the coasts.

Ocean Negative Carbon Emissions: A United Nations ocean decade program

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The ocean is the largest active carbon pool on Earth, acting as the key regulator to global climate change, and thus has great potential for carbon negative emission. The Global Ocean Negative Carbon Emissions (Global-ONCE) program has been approved by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO) in the framework of the United Nations' call for Decade Actions of Ocean Science for Sustainable Development and the United Nations Decade Initiative Plan. Global-ONCE UN decade program will last for 10 years starting from 2022. Global ONCE is joined by 78 partner organizations from 33 countries, including the North Pacific Marine Science Organization (PICES), the International Council for the Exploration of the Sea (ICES), the Integrated Marine Biosphere Research (IMBeR), Ocean-based

negative emission technologies (Ocean NETS), etc. The objectives of Global ONCE are to provide the data, knowledge, opportunities and practices to enable society to evaluate mitigation approaches to climate change. These include the establishment of a network of instrumented marine monitoring stations and research facilities to evaluate ONCE approaches such as integrated land-ocean managements, seaweed cultivations, ocean alkalinity enhancement, nutrient fertilization, artificial upwelling and recovery of marine ecosystems; formulation of decision rules for initiation and evaluation of these approaches; facilitation of co-designed interdisciplinary collaborative research on key carbon sequestration processes; development of technical and personnel capacity and enhancement of knowledge exchange between scientists, policymakers, industries and societies; implementation through careful co-design and development of ONCE technologies, development of ONCE protocols and standards for carbon sequestration in the ocean; co-producing best practice manuals, professional and science-popularization training, and providing evidence-based advice to the IPCC and COP meetings of the UN Framework Convention on Climate Change. (For more information, see https://www.global-once.org)

Global ONCE is supported by the Intergovernmental Oceanographic Commission (IOC), the United Nations Educational Scientific and Cultural Organization (UNESCO) , the United Nations' Ocean Decade Actions; the National Natural Science Foundation of China (NSFC) and the Ministry of Science and Technology (MOST).

Regional Digital Twins: initial steps in the Western Mediterranean Sea, responding to science and society challenges from events to climate

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Regional Digital Twin Ocean -DTO- initiatives represent key opportunities for integrated and multidisciplinary response to society challenges such as climate change and the blue economy from a local to regional and global perspective. Marine research infrastructures are essential pillars of these DTO initiatives: they have well-defined missions and are driven by a clear twofold approach: scientific excellence and impact on society. Reliable and open data together with society engagement are also essential building blocks to assure response to stakeholders needs, requiring FAIR data and TRUST digital data repositories, as well as integrated and collaborative approaches that facilitate the transfer of knowledge.

Regional DTO's such as SOCIB, the Balearic Islands multi-platform observing and forecasting system provide knowledge, data, resources, as well as tools for decision support, and products and services around three essential themes: ocean and climate change, ocean health, and real-time services. At SOCIB, a critical mass of scientists, engineers and technicians are working together under a common goal and along the whole value chain. This allows the active participation in outstanding international research initiatives and collaborations such as Calypso, EuroSea, Jerico-RI, Copernicus Marine, EMODnet among others, and also the response to society needs such as heat waves, meteo-tsunamis, rip currents, or sea level rise in beaches. Highlights of ongoing SOCIB activities in the Mediterranean Sea will be presented together with new forward-looking 2030 ocean integration initiatives aligned with CoastPredit, Ocean Observing Co-Design and DITTO UN Ocean Decade endorsed programs.

Regional Digital Twins represent new ways of international partnership to reach high level goals & grand challenges that will be leading to major science breakthroughs and new ways of more efficient and science based coastal and ocean management and responsible research and innovation, to

guarantee healthy oceans in a sustainable planet for future generations. In this general context, SOCIB next decade 2024-2033 Regional Digital Twin Ocean Plan will be finally outlined.

Geological carbon pumps：From subduction zone to coastal ocean

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Abstract: The Geological Carbon Pump (GCP) includes all those geological time-scale processes on the Earth surface and in the Earth interior that cause organic or/and inorganic carbon to be removed from and released into the atmosphere. It is a mechanism that sequesters carbon dioxide (CO2) for weeks to hundreds of years or even hundreds of millions of years for different geological processes. Together with physical, chemical and biological carbon pumps, geological carbon pump constitutes long-term Earth's CO2 source and sink, and these major processes in the global carbon cycle have removed carbon dioxide from the atmosphere or hydrosphere to the lithosphere or lower mantle. The object to propose the definition of geological carbon pump is to completely separate the modern carbon cycle from the short- and long-term carbon cycles of the geological past. The purpose needs an interdisciplinary research to cover all processes related to the geological carbon pump and how it functions, while paying close attention to the relevant gelogical timescales in the global carbon cycle. Note that we focus mainly on the long-term carbon cycling to make the habitable Earth, we do not delve into detailed mechanisms, fluxes, reservoirs of carbon sequestration or storage due to the removal of dissolved organic and other matters. Topics will include a short introduction to the different carbon pumps (biological, carbonate/chemical, physical and geological), followed by a detailed GCP in active continental margin and deep carbon pumps, GCP in passive continental margin and reef-related carbonate pumps, deep-time evolution of GCPs and the habitable Earth system, and GCP as an inorganic way from capture to storage or from source to sink. This topic will emphasize all kinds of GCPs in coastal ocean, and the roles of the geological carbon pump in shaping the habitable Earth, triggering deep-time mass extinctions and deep-past global sea-level and cliamtic changes, promoting great oxidation events. We also cover specific aspects of carbon tectonics through Earth system rather than plate tectonics in solid Earth.

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Extreme Sea Levels in a changing climate

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The global warming associated with the ongoing climate changes is expected to drive increasing Extreme Sea Levels (ESLs) along our coasts. This is mostly due to the Sea Level Rise (SLR) induced by

the thermal expansion of our oceans and by the ice melting, which by the end of the century are projected to intensify in all the Representative Concentration Pathway (RCP) scenarios.
Another important driver are changes in the meteorological extremes in an evolving climate, which will lead to extreme sea states locally more or less intense. Our current knowledge indicates a future increase of rough sea states mainly in the Southern Hemisphere, while for the Northern Hemisphere, and in particular for the Mediterranean Sea our projections indicate a probable decrease in intensity and frequency of extreme storms. However, this tendency is affected by a large uncertainty, and the coarse resolution of the models used for global assessments comes with a limited capability of reproducing the effects of the mesoscale on local extremes.
The current scientific evidence indicates that under a moderate scenario such as RCP4.5 and a high-end scenario such as RCP8.5 ESL could rise globally by 34-76 cm and 58-172 cm respectively. Under these scenarios ESL rise would render a large part of the tropics exposed annually to the present-day 100-year event from 2050. By the end of this century this applies to most coastlines around the world, implying unprecedented flood risk levels unless timely adaptation measures are taken.

Multiple pollutants stress the coastal ecosystem with climate and anthropogenic drivers

Yonglong Lu
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Coastal ecosystem health is of vital importance to human well-being. Field investigations of major pollutants along the whole coast of China were carried out to explore associations between coastal development activities and pollutant inputs. Measurements of target pollutants such as PFAAs and PAHs uncovered notable levels in small estuary rivers. The Yangtze River was identified to deliver the highest loads of these pollutants to the seas as a divide for the spatial distribution of pollutant compositions. Soil concentrations of the volatile and semi-volatile pollutants showed a cold-trapping effect in pace with increasing latitudinal gradient. The coastal ecosystem is facing high ecological risks from metal pollution, especially copper (Cu) and zinc (Zn), while priority pollutants of high risks vary for different kinds of protected species, and the ecological risks were influenced by both climate and physicochemical properties of environmental matrices, which should be emphasized to protect and restore coastal ecosystem functioning.