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Editorial: Past Reconstruction of the Physical and Biogeochemical Ocean State

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Editorial on the Research Topic

Past Reconstruction of the Physical and Biogeochemical Ocean State

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INTRODUCTION

Knowledge of the ocean's physical, biogeochemical and ecosystem state and variability is crucial for understanding the evolution of our climate system and better predicting its future. However, the sparseness and inhomogeneous distribution of observations hinder the creation of sound 4-dimensional reconstructions of the past (for an overview of ocean observing systems see the Research Topic Oceanobs'19: An Ocean of Opportunity). Instead, we must rely on a combination of ocean modeling and data analysis to infer past changes. Over the last decade the quality of ocean reanalyses has improved mainly thanks to advances in data assimilation methods and more quality-controlled observation data sets. Reanalyses provide the best-possible state estimate by assimilating observations into a dynamical model (Balmaseda et al., 2015; Masina and Storto, 2017; Storto et al., 2019). In addition, advanced statistical mapping methods (e.g., objective or variational analysis) provide observation-based gridded fields whose resolution depends on the amount of available data (among many Cheng et al., 2017, Ishii et al., 2017; Boyer et al., 2018). For many variables, particularly biogeochemical, the lack of observations more strongly limits the spatial and temporal resolution of these gridded products (Fennel et al., 2019).

The Research Topic gathers contributions aiming at reconstructing the past physical, sea ice and biogeochemical state of the ocean using models in combination with data. Ocean reanalyses and observation-mapping are proposed to further our knowledge, to demonstrate their use in supporting various applications, and to increase confidence in these reconstructions within the scientific community. The products and applications described in this topic provide a foundation for their use in ecosystem-based management, policy advice to support mitigation and adaptation strategies, and in the identification of pathways towards a sustainable ocean.

CONTRIBUTIONS

Reanalyses

Ocean reanalyses are today an important tool for science-based studies and climate investigations. They are also used to initialize prediction systems from sub-seasonal to decadal time scales and to support observational network monitoring. In the framework of the Copernicus Marine Environment Monitoring Service (CMEMS), validated global and European regional eddy-resolving physical and biogeochemical reanalyses are produced for several purposes. In this Research Topic we present four new products which all serve the scientific purpose for providing reliable and accurate estimates of the interannual variability and trends of the global ocean and sea-ice state (Jean-Michel et al.), the Mediterranean physical (Escudier et al.) and biogeochemical (Cossarini et al.) state and the Black Sea physics (Lima et al.). These products represent a step forward towards our understanding of the mechanism of uptake and redistribution of natural and anthropogenic carbon dioxide and heat by the ocean, as well as the quantification of the induced changes in its physical (e.g. reduced ventilation, increased stratification, etc.) and biogechemical (e.g. acidification, deoxygenation) state. The increasingly higher resolution of ocean reanalyses combined with improved data assimilation methods and observation abundance make them well-suited to represent also the mesoscale variability of surface dynamics. In addition, the reanalyses have strong assets which may serve regional or sub-basin applications and downstream services in support of the blue economy of coastal countries.

Climatologies and Observations-Based Products

In addition to the model-based reanalysis products, two categories of observation-based products include climatologies (mean state and seasonal cycle) and monthly (or higher frequency) gridded fields covering many years. Global (Shahzadi et al.) and high resolution regional (Lee et al.) temperature and salinity climatologies derived from irregularly distributed historical observations by means of traditional or more advanced objective analysis techniques are essential and valuable products. The new climatologies benefit from the increased availability of temperature and salinity profiles derived from the Argo program in the 21st century and provide regional ocean products able to represent mesoscale variability similar to altimetry-derived surface current products. Temperature and salinity climatologies serve different purposes, such as initializing and validating numerical ocean models and understanding climate anomalies.

A limitation of observation-based products is that one needs to formulate a statistical relationship to extrapolate the information contained in the observations in space and to other variables (e.g. using an EOF analysis). In Oke et al., such relationships are computed from a static model covariance matrix, using the ensemble optimal interpolation (EnOI) data assimilation technique. The EnOI is implemented using an ensemble that includes anomalies for multiple space- and time-scales: mesoscale, intraseasonal, seasonal, and interannual. However, unlike in reanalysis, the model is not run in between the assimilation step (offline assimilation).

In the work by Alvera-Azcarate et al. combining at least three satellites has been shown to improve the representation of ocean color variability at 1 km resolution over the Greater North Sea during the period 1998–2020. The multidecadal product allows an analysis of interannual variability and the indication of an earlier spring bloom tendency in the North Sea.

Applications

Using reanalyses and observation-based gridded fields at high spatial resolution is necessary to resolve the mesoscale variability and its contribution to the ocean dynamics and thermodynamics. By means of an eddy detection technique, Bonaduce et al. show that mesoscale eddies represented in a Mediterranean reanalysis represent a significant contribution of the ocean dynamics in the Mediterranean Sea as they account for a large portion of the sea-surface height variability at temporal scales longer than 1 month and for the kinetic energy both at the surface and at depth. Furthermore, temperature anomalies driven by long-lived eddies can affect up to 15–25% of the monthly variability of the upper ocean heat content in the Mediterranean basin.

Yang et al. investigated the contribution of mesoscale ocean eddies to the Atlantic meridional heat transport (MHT) variability, which in turn drives the decadal climate changes recently observed in the North Atlantic and found that the increase of eddy population due to the increase of horizontal resolution in an eddy-resolving global reanalysis (Jean-Michel et al.) does not affect the MHT anomalies significantly.

An alternative to the deterministic production of eddy-resolving reanalyses and observation-based products is the generation of coarser resolution ensemble of reanalyses which allows for uncertainty estimation and optimization of poorly-constrained model parameters. The ensemble approach is particularly valuable for example in data-sparse region such as the Antarctica, where Iovino et al. showed that an eddy-permitting ensemble of reanalyses is capable to reproduce the observed regional spatial and temporal variability of different sea-ice classes (marginal and pack ice).

In another contribution, Singh et al. demonstrated the ability of ensemble data assimilation methods (dual one step ahead smoother) to provide high-quality and improved biogeochemical (BGC) parameters that strongly reduce model bias within an Earth system model by assimilating salinity and temperature profiles and surface biogeochemical (Phytoplankton, Nitrate, Phosphate, Silicate, and Oxygen) observations.

PERSPECTIVES

Model-based and observation-based past reconstructions of the ocean state are complex products which will benefit from the information of the integrated observing system, and the arrival of new datasets from satellites (e.g., Surface Water and Ocean Topography mission) and *in situ* observations (e.g., Deep Argo and BGC Argo). Questions of how to mitigate discontinuities in the observation spectrum will be central to better integrate all the components of the observing system and make the best use of ocean observations also improving quality control procedure.

A key activity for ocean or coupled reanalyses is their use by the climate community to estimate the past and present energy, water and carbon budgets (among many Abraham et al., 2013, von Schuckmann et al., 2018; Meyssignac et al., 2019), and to provide uncertainty of these estimates. It is thus important to further investigate their ability to provide accurate and reliable estimates of the interannual variability and trends of essential climate variables through continuous evaluation and development of refined data assimilation techniques and multi-model ensemble approaches. The novelty of the methods used for the products presented in this Research Topic includes: combining objective analysis with model based covariance, multiscale optimisation approach, eddy-resolving reanalyses, the verification of eddy characteristics and phytoplankton from remote sensing data, and the estimation of model parameters to reduce model biases.

The challenges that this community is facing span from the need to progress in the context of coupled earth system reconstructions (Baatz et al., 2021), which also require to improve assimilation methods to include the non-Gaussian distributions of biogeochemical and sea-ice observations, to the need of dealing with data-sparse regions and periods to respond to the demand for longer time series and backward in time extensions. These kinds of products are now expected to inform on past and near-present oceanic conditions to supply ocean monitoring indicators with a reliable accuracy, be used to track the health signs of the ocean and changes in line with climate change, and serve policy-makers to implement and adapt environmental strategies. The demand by end-users for products with higher spatial and temporal resolution, especially in coastal regions experiencing increasing threats, adds new challenges involving the difficulties of taking into account the multivariate assimilations of physical and biogeochemical variables, to account for tides, waves, accurate bathymetry, and in general a more realistic representation of coastal hydrological processes.

AUTHOR CONTRIBUTIONS

SM wrote the first draft of the manuscript taking into account all the papers published in the Research Topic. All co-editors made inputs to the initial draft, contributed to the manuscript revision, and read and approved the submitted version of the manuscript.

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