Ocean Predict

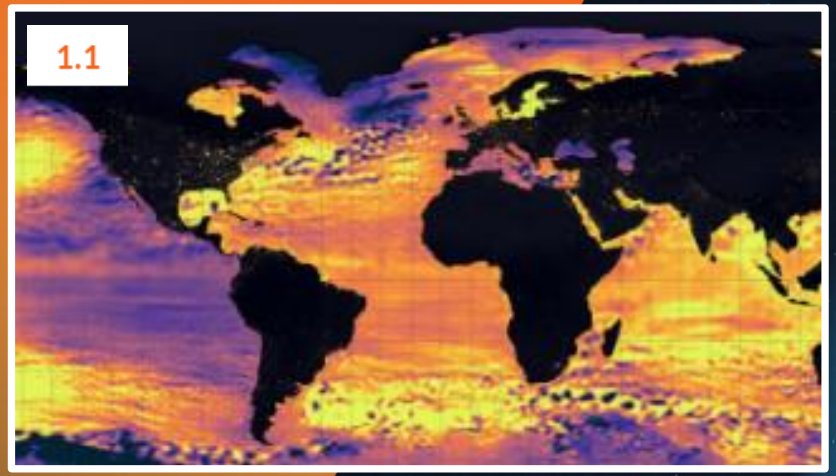
18 Nov. 2024

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

OCEAN PREDICTION: PAST, PRESENT & FUTURE



SCAN FOR DETAILS

10:45 AM ROOM II

SPLINTER SESSION

Ocean Predict

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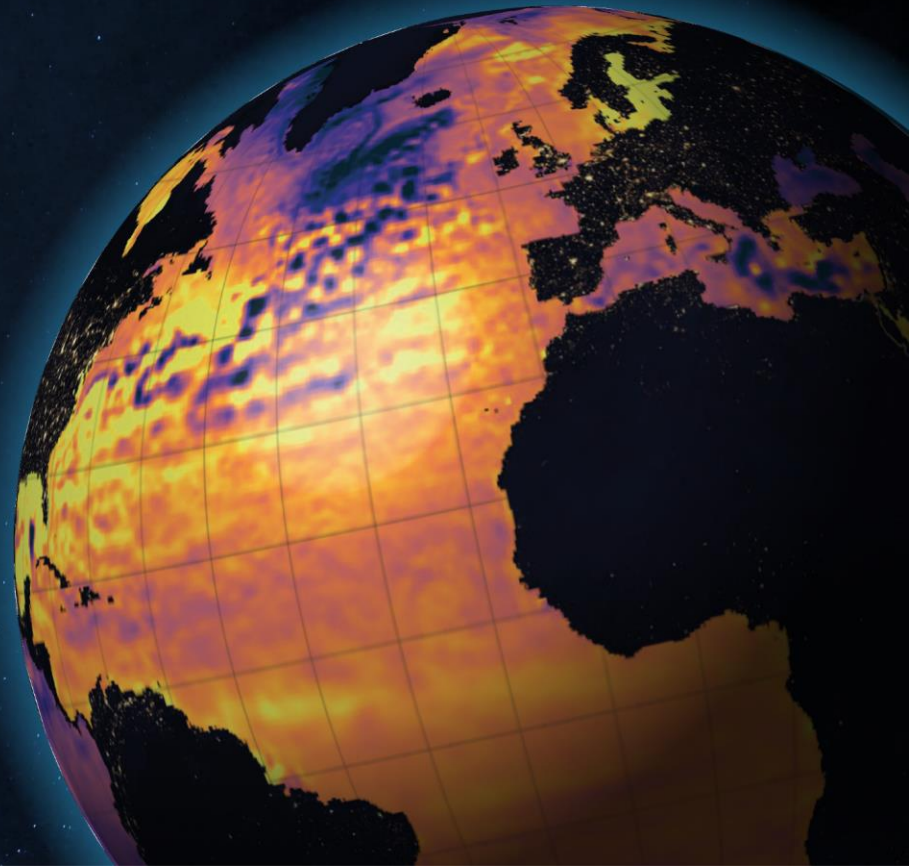
How can ocean reanalyses improve global ocean prediction? Towards a new ocean reanalysis intercomparison exercise



Marie Drevillon, Romain Bourdallé-Badie (Mercator Ocean International), Chunxue Yang (CNR)

and partners of the MER-EP project

Mercator Ocean International (France, EU), CNR (Italy); HCMR (Greece); MIT (USA); NERSC (Norway); BOM (Australia); CMCC (Italy); Metoffice (UK); University of Reading (UK); University of Liège (Belgium); Magellium (France); ACRI-ST (France); JAMSTEC (Japan, TBC); UCSD (US); CSIRO (Australia); ECCC (Canada); OGS (Italy)

Outline (and timeline)

2010…

2020…

2023

2025-2029

The first Ocean Reanalyses Intercomparison Projects: ORA-IP, EOS COST, multi-ORA

The Ocean Monitoring Indicators (OMIs) : an ORA-IP heritage

The Ocean Reanalyses Workshop of the Copernicus Marine Service

Towards a new intercomparison exercise: **MER-EP**

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The Ocean Reanalyses Intercomparison Projects: ORA-IP, EOS COST, multi ORA)

ORA-IP: a first inter-comparison project

- **ORA-IP** started in 2011
- International collaboration CLIVAR/GSOP & GODAE (now OceanPredict) IV-TT
- Reanalyses inter-comparison presented by Essential Oceanic Variables (EOVs)
- Follow up with **EOS COST action** 2014-2018
- Outcomes : reference review articles

Ocean variable
Steric height
Sea level
Ocean heat content
Depth of 20 degree isotherm
Mixed layer depth
Salinity
Surface fluxes and transports
Atlantic meridional overturning at 26°N
Sea ice

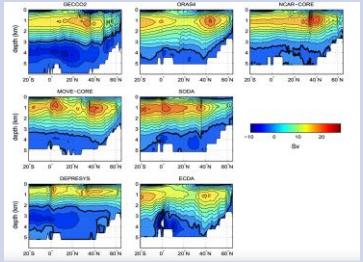
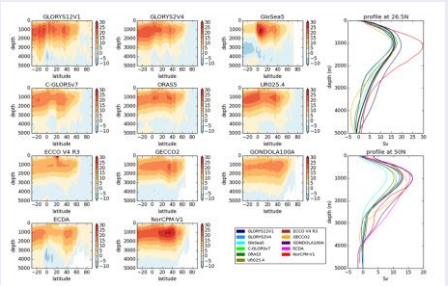
ORA-IP EOVs

Product
ARMOR3Da,b CLS
CFSRc,d NOAA NCEP
C-GLORS05V3e CMCC
ECCO-NRTI JPL/NASA
ECCO-v4g,h MIT/AER/JPL
EN3 v2ai Hadley Center
GECCO2j U. of Hamburg
ECDAk,l GFDL/NOAA
GloSea5m,n UK MetOffice
MERRA Ocean GSFC/NASA/GMAO
GODASo NOAA NCEP
GLORYS2V1(G2V1) Mercator Océan
GLORYS2V3(G2V3) Mercator Océan
K7-ODA(ESTOC)p JAMSTEC/RCGC
K7-CDAq JAMSTEC/CEIST
LEGOSr LEGOS
NODCs NODC/NOAA
PEODASt CAWCR(BoM)
ORAS4u,v ECMWF
MOVE-Cw MRI/JMA
MOVE-G2x MRI/JMA
MOVE-COREy,z mri/jma
SODAaa U. of Maryland and TAMU
UR025.4bb U. of Reading
AVISOcc CLS
SICCldd ESA

ORA-IP Products

Ref: Balmaseda, M. A., Hernandez, F., Storto, A., Palmer, M. D., Alves, O., Shi, L., … Gaillard, F. (2015). The Ocean Reanalyses Intercomparison Project (ORA-IP). *Journal of Operational Oceanography*, *8*(sup1), s80–s97. https://doi.org/10.1080/1755876X.2015.1022329

The legacy of ORA-IPs (examples)

Variable	outcome	examples	reference
AMOC (1)	• the **reanalysis** products tend to **overestimate AMOC mean strength and variance** • the reanalysis products are less consistent in their year-to-year AMOC changes.		Karspeck et al., 2017
AMOC (2)	• At **26.5°N the reanalyses mostly agree** with the independent observational estimates of mean AMOC strength		Jackson et al. 2019

Summary of ocean reanalyses intercomparisons

Ocean reanalyses are the only information we have for **many areas of the ocean**

It is important to **keep intercomparing them on a regular basis**: intercomparison exercizes for in depth assessment + multi-model ocean state monitoring tools

Blue ocean

- good results during the ARGO era -> 20 years in 2025
- Some challenges for the coming years: historical reanalyses, deep ocean and coastal zones …

Green ocean

- Good results in terms of interannual signals of Chl
- Seasonal signals are phased thanks to data assimilation
- some challenges for the coming years: assimilation of pCO2, bio argo …

White ocean

- Good results in terms of sea Ice concentration and average sea ice extent
- improvements needed in sea ice thickness and leads
- Some challenges for the coming years: Marginal Ice Zones …

The Ocean Monitoring Indicators (OMI) an ORA-IP heritage

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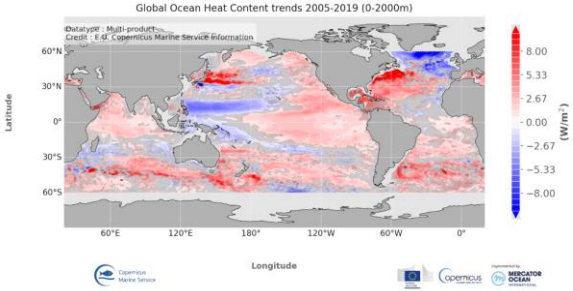
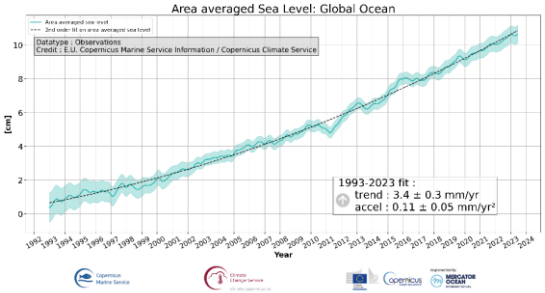
OMI, some examples

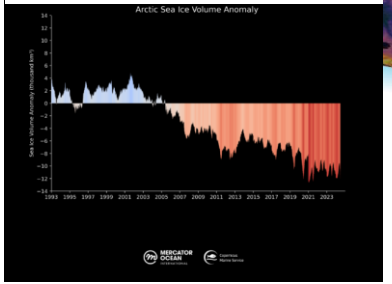
Ocean Heat content trend



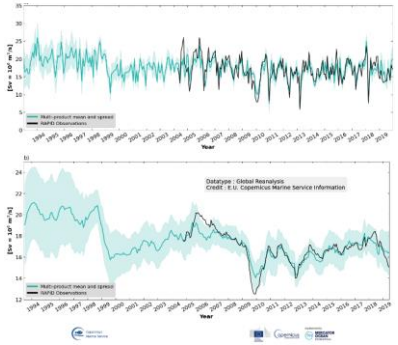
Sea Level trend



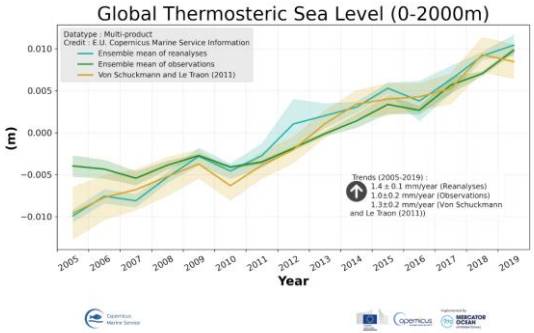
Arctic Sea ice volume anomaly



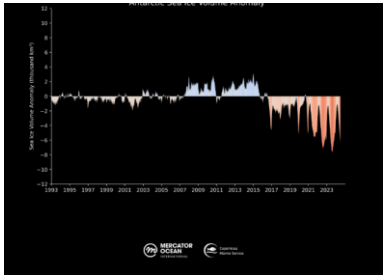
AMOC variability



Global Thermosteric Sea Level (0-2000m)



Antarctic Sea ice volume anomaly



Ocean Predict

The Ocean Reanalyses Workshop of the Copernicus Marine Service (October 2023)

BLUE OCEAN
Currents, temperature, waves, sea level, ...

WHITE OCEAN
Ice coverage, velocity, concentration, Icebergs ...

GREEN OCEAN
CO2, nutrients, oxygen, primary production, ...

Copernicus Marine Service

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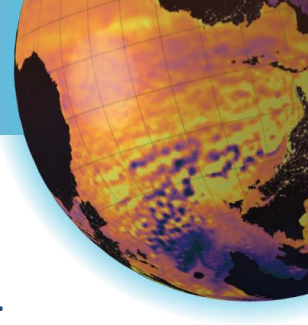


Objectives of the workshop:

- The establishment of **connections with ocean reanalyses specialists** worldwide.
- The establishment of requirements for **historical reanalyses** and other **future improvements** of ocean reanalyses.
- The refinement of **user needs** concerning ocean model reanalyses (blue, white, green)

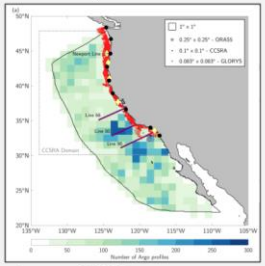
In person participation limited to ~60 persons & online participation open to all

Local organizing committee: Romain Bourdallé-Badie, Marie Drévillon, Vincent Legros (MOi)
+ **scientific committee**: Chunxue Yang (CNR), James Carton (Univ Maryland), Gael Forget (MIT), Emanuela Clementi (CMCC), Annette Samuelsen (NERSC), Laura Tuomi (FMI), Valentina Giunta, Angélique Melet, Karina von Schuckmann, Gilles Garric, Pierre-Yves Le Traon, Antonio Reppucci, Marina Tonani (MOi)

Applications for current and future ocean reanalyses, some highlights

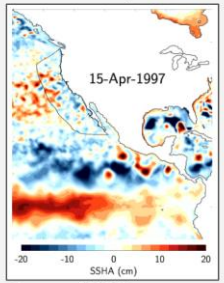
Regional process studies

Evaluation of high-res reanalyses in the CCS



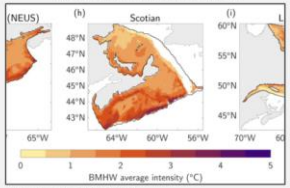
Amaya et. al (2023a)

Coastally trapped waves, S2S sea level prediction



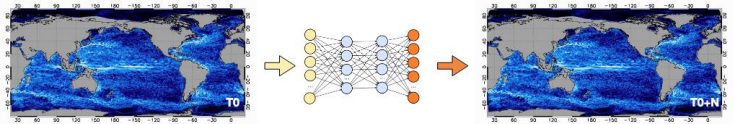
Amaya et. al (2022)

Bottom marine heatwaves around North America



Amaya et. al (2023b)

AI forecasting models



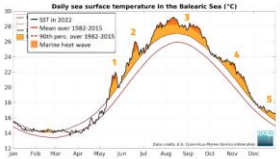
Ocean/sea-ice **reanalyses** will likely be used for training **ML-based prediction** systems

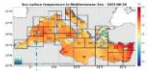
Evolution of OMEMS systems	- May be first at regional scale, at coarse resolution or for surface fields only - May be to be used in conjunction with DA-based forecasts (e.g. for ensemble predictions)
Open science questions	- Are ocean reanalyses good training datasets for ocean predictions ? (density of observations at depth, relative importance of initialisation / model uncertainties vs weather forecast)
Practical requirements	- Need to document the performance of ocean reanalyses as "forecasts" (analysis vs forecasts) - Need a reliable representation of (initialisation and model) uncertainties in ocean reanalyses

Extremes detection, evolution,…

Marine heat waves
Event detection at surface

Example in the Balearic Sea in 2022



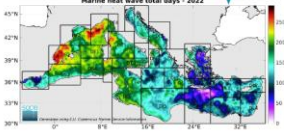


- 1982-present
- daily SST
- continuous
- 5/6km, all basin

(Distributed by Copernicus Marine Service)

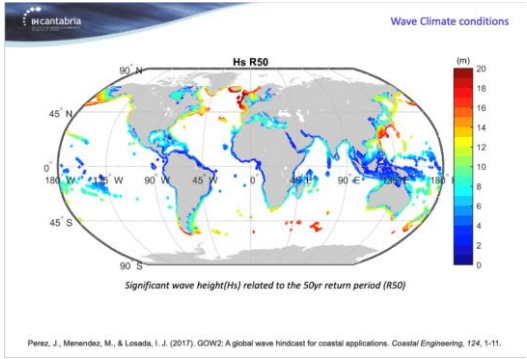
Annual indicators
- Intensity (mean, max)
- Mean duration
- Frequency

Total days



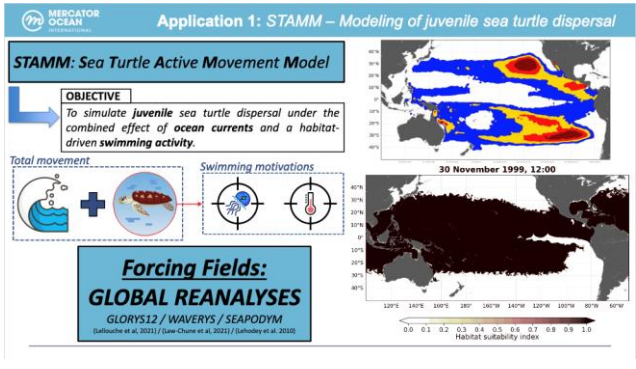
https://apps.socib.es/subregmed-marine-heatwaves

Significant wave height evolution



Perez, J., Menendez, M., & Losada, I. J. (2017). GOW2: A global wave hindcast for coastal applications. *Coastal Engineering*, *124*, 1-11.

Simulation of Sea turtle trajectories



Outcomes of the workshop

Need for higher resolution reanalyses:

- **Including regional high resolution reanalyses for coastal users**, including consistent waves and biogeochemistry
- including **uncertainty information (ensembles)**

Need for longer time series:

- **Ensembles** of reanalyses global and regional **covering 1950-now** needed for ocean reporting activities
- Will also benefit to seasonal to decadal prediction and historical period for IPCC
- training datasets for AI applications

Future improvements expected:

- (flow dependant) **model corrections for past periods** could be learned using AI
- Improvement of atmospheric forcing, for example ERA6 (improvement in the precipitations,…)
- **Assimilation of green observations**, river nutrients and atmos. Deposition

SCAN ME

Summary available at https://doi.org/10.1175/BAMS-D-24-0034.1

Need to setup a new evaluation and intercomparison framework :

- Based on **“use cases” (=> users oriented)**
- Including all marine variables (Blue/White/Green/Wave)
- At global and regional scale
- Using state of the art of all reanalyses available

A new intercomparison exercise: MER-EP

Marine Environment Reanalyses – Evaluation Project

Ocean Predict

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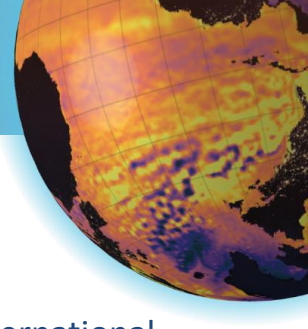
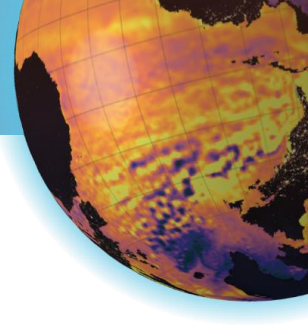
MER-EP as a UN decade project



- **A project for ForeSea and DITTO**, submitted end of August 2024 in the call for UN decade actions
- **an international collaboration framework** with no direct funding, in kind contributions from international partners
- PIs: Drévillon Marie & Bourdallé-Badie Romain (MOi); Yang Chunxue (CNR)
- Partners who already joined MER-EP: Moi (France); CNR (Italy); HCMR (Greece); MIT (USA); NERSC (Norway); BOM (Australia); CMCC (Italy); Metoffice (UK); University of Reading (UK); University of Liège (Belgium); Magellium (France); ACRI-ST (France); JAMSTEC (Japan, TBC); UCSD (US); CSIRO (Australia); ECCC (Canada); OGS (Italy)
- Programs which support MER-EP initiative:

Contact us to join the project!

Summary



MER-EP : a UN decade project to evaluate marine environment reanalyses to **better use their potential for ocean monitoring and prediction**

By sharing “best practices” derived from the studies and use cases:

- Guidelines on how to use reanalyses
  - for monitoring the state of the ocean
  - for training AI forecasting models
  - as environmental forcing for ecosystem models
  - ...
- methods and tools to handle the data

People/institutes interested to join this international effort are welcome:

- Data sharing
- Specific validation studies
- Working on downstream applications using reanalysis
- Exchange on how to better address user requirements

Next steps

- **November: MER-EP structure construction**
  - Participants can modify/add “use cases”
  - Teams position themselves on the case studies they want to participate in
  - Participants list in the necessary variables and the tools they plan to use
  - Participants contact us or contact each other to define a common strategy and share the work

- **December: MER-EP Finalization**
  - General organization: ask people to finalize to position themselves in sections. Discussion to choose a point of contact for each section, a list of reanalyses/observations for each use case.
  - **Finalization of MER_EP structure**
  - Creation of dedicated mailing lists

European Commission

Copernicus Marine Service

EU4oceanobs
INTERNATIONAL OCEAN GOVERNANCE
EU COMPONENT TO GLOBAL OCEAN OBSERVATIONS

MERCATOR OCEAN INTERNATIONAL

esa

Australian Government
Bureau of Meteorology

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

Met Office

NERSC

Canada

Ocean Predict

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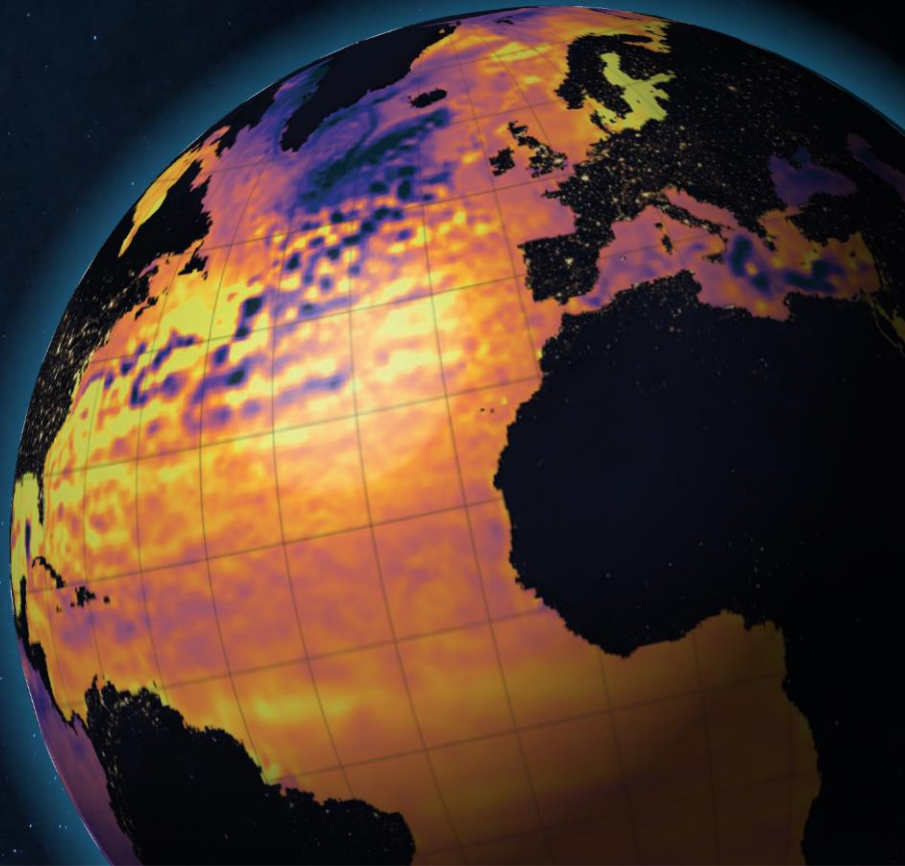
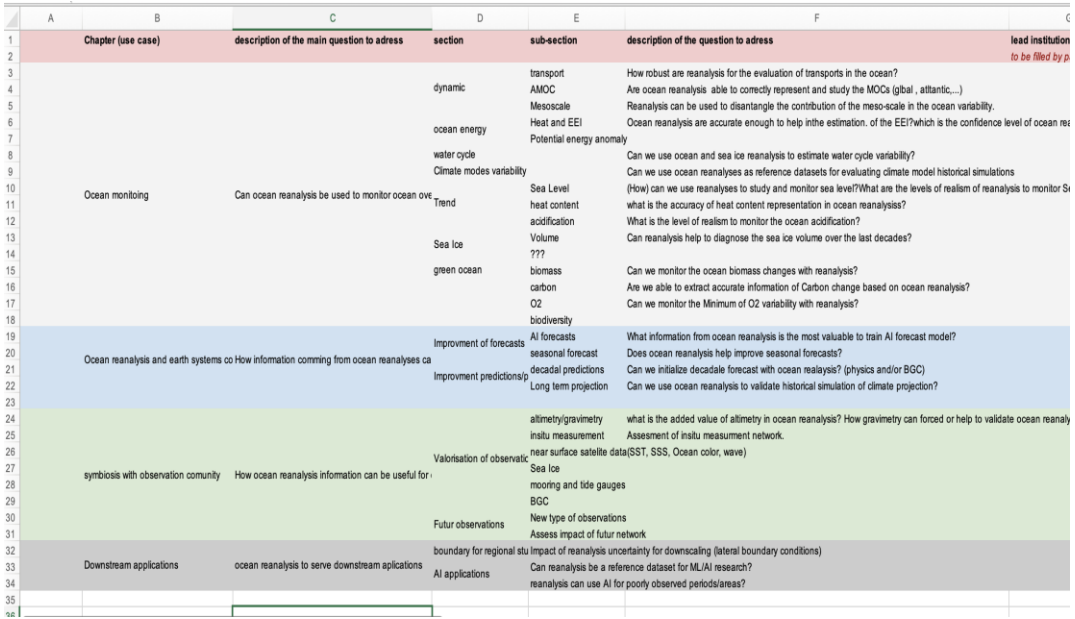
Supplementary material



MER-EP structure proposition

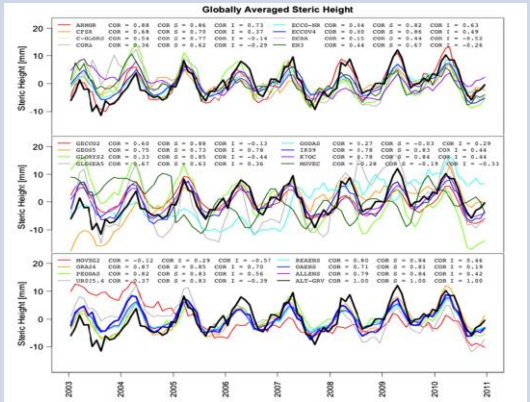
- **Use case1 (chapter1)**
  - Section1.1
    - Subsection1.1.1
    - Subsection1.1.2
    - …
    - Subsection1.1.N
  - Section1.2
    - Subsection1.2.1
    - Subsection1.2.2
    - …
    - Subsection1.2.N
- **Use case2 (chapter2)**
  - Section2.1
    - Subsection2.1.1
    - Subsection2.1.2
    - ….

Example of table

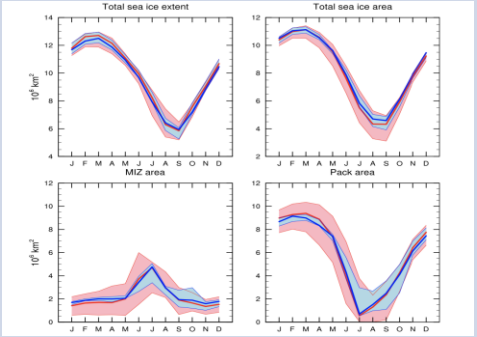
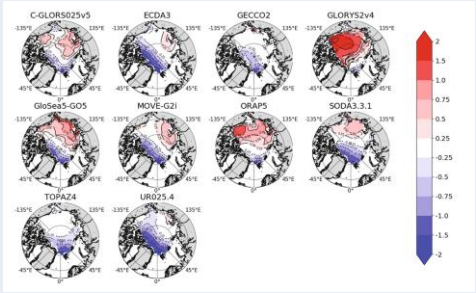


	Chapter (use case)	description of the main question to adress	section	sub-section	description of the question to adress	lead institution
						to be filled by p
	Ocean monitoing	Can ocean reanalysis be used to monitor ocean ove	dynamic	transport	How robust are reanalysis for the evaluation of transports in the ocean?	
				AMOC	Are ocean reanalysis able to correctly represent and study the MOCs (glbal , atltantic,...)	
				Mesoscale	Reanalysis can be used to disantangle the contribution of the meso-scale in the ocean variability.	
			ocean energy	Heat and EEI	Ocean reanalysis are accurate enough to help inthe estimation. of the EEI?which is the confidence level of ocean rea	
				Potential energy anomaly		
			water cycle		Can we use ocean and sea ice reanalysis to estimate water cycle variability?	
			Climate modes variability		Can we use ocean reanalyses as reference datasets for evaluating climate model historical simulations	
			Trend	Sea Level	(How) can we use reanalyses to study and monitor sea level?What are the levels of realism of reanalysis to monitor S	
				heat content	what is the accuracy of heat content representation in ocean reanalysiss?	
				acidification	What is the level of realism to monitor the ocean acidification?	
			Sea Ice	Volume	Can reanalysis help to diagnose the sea ice volume over the last decades?	
				???		
			green ocean	biomass	Can we monitor the ocean biomass changes with reanalysis?	
				carbon	Are we able to extract accurate information of Carbon change based on ocean reanalysis?	
				O2	Can we monitor the Minimum of O2 variability with reanalysis?	
				biodiversity		
	Ocean reanalysis and earth systems co	How information comming from ocean reanalyses ca	Improvment of forecasts	AI forecasts	What information from ocean reanalysis is the most valuable to train AI forecast model?	
				seasonal forecast	Does ocean reanalysis help improve seasonal forecasts?	
			Improvment predictions/p	decadal predictions	Can we initialize decadale forecast with ocean realaysis? (physics and/or BGC)	
				Long term projection	Can we use ocean reanalysis to validate historical simulation of climate projection?	
	symbiosis with observation comunity	How ocean reanalysis information can be useful for	Valorisation of observatic	altimetry/gravimetry	what is the added value of altimetry in ocean reanalysis? How gravimetry can forced or help to validate ocean reanaly	
				insitu measurement	Assesment of insitu measurment network.	
				near surface satelite data	(SST, SSS, Ocean color, wave)	
				Sea Ice		
				mooring and tide gauges		
				BGC		
			Futur observations	New type of observations		
				Assess impact of futur network		
	Downstream applications	ocean reanalysis to serve downstream aplications	boundary for regional stu	Impact of reanalysis uncertainty for downscaling (lateral boundary conditions)		
			AI applications	Can reanalysis be a reference dataset for ML/AI research?		
				reanalysis can use AI for poorly observed periods/areas?		

The legacy of ORA-IPs (examples)

Variable	outcome	examples	reference
Steric Sea Level	• A **significant high correlation** at both global and regional scale with satellite observations , and the ensemble of **ocean reanalyses outperforms** that of **objective analyses**, in particular in the Southern Ocean. • The ensemble of reanalyses and objective analyses are in good agreement • **large uncertainties remain for the inter-annual trends**.		Storto et al., 2017

The legacy of ORA-IPs (examples)

Variable	outcome	examples	reference
Sea Ice (1)	• The comparison reveals an **overall agreement** in the reconstructed concentration fields, mainly because of the constraints in surface temperature imposed by direct assimilation of ocean observations, prescribed or assimilated atmospheric forcing and assimilation of sea ice concentration. • The seasonal cycle is consistent as well.		Chevallier et al., 2017
Sea Ice (2)	• For the **multi-ORA mean state**, we found that **deviations** from observations were typically smaller than **individual ORA anomalies**, often attributed to offsetting biases of individual ORAs.	 **The 2000–2012 mean difference of the ORAs to the ITRP sea-ice thickness (m) in February–March**	Uotila et al., 2019

Agenda of the workshop

Session 1: Applications for current and future ocean reanalyses (1/2 day)

- current Copernicus marine multi-year products offer
- users of reanalysis products (from survey + presentations)

Session 2: Evaluation of ocean reanalyses (1 day)

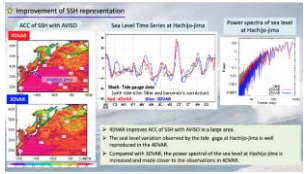
- Strengths and weaknesses of ocean reanalyses, for physics, sea ice, biogeochemistry, waves
- Link with climate community

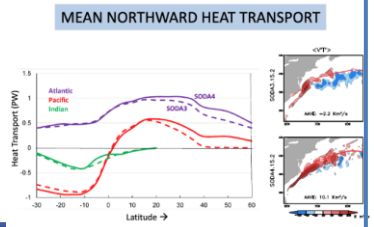
Session 3: Future improvements of ocean reanalyses (1/2 day)

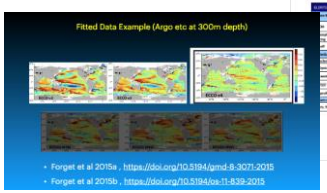
- Presentations from atmospheric reanalyses (including ERA5/ERA6)
- Presentations focusing on different components to improve future blue/white/green ocean reanalyses.
  - ➢ Which observations available for assimilation in ocean reanalyses?
  - ➢ Which improvements for models, data assimilation, machine learning?

Session 2: Evaluation of ocean reanalyses, example

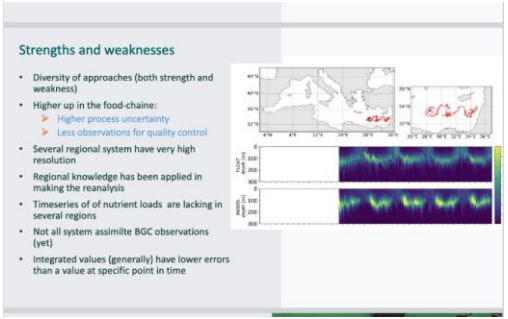
Status of physical reanalysis (white/blue)



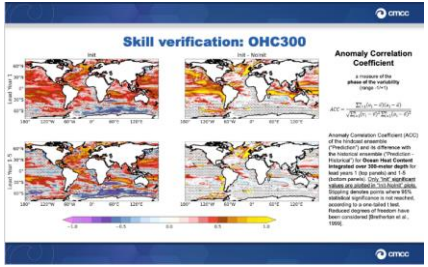




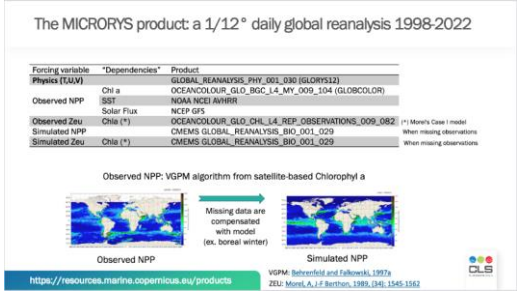
Status of BGC reanalysis



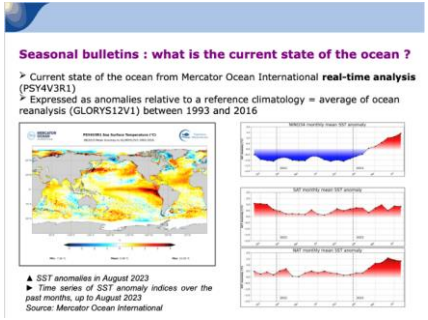
Status of reanalysis for decadal predictions



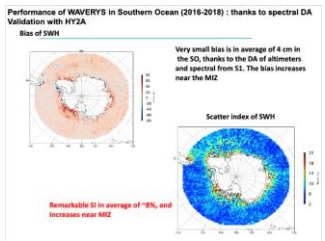
Status of high trophic levels reanalysis

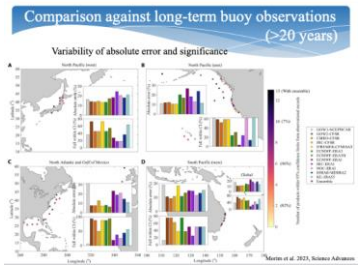


Status of reanalysis for seasonal forecasts



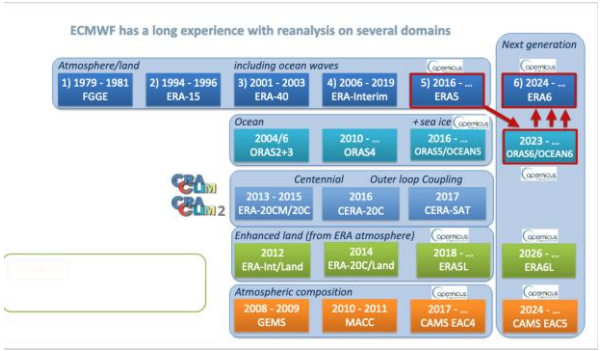
Status of wave reanalysis





Session 3: Future improvements of ocean reanalyses, example

Atmospheric reanalysis



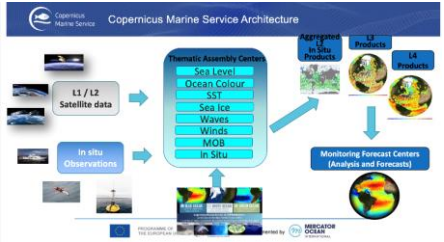
Numerical model

Met Office — Potential for improvement of ocean models

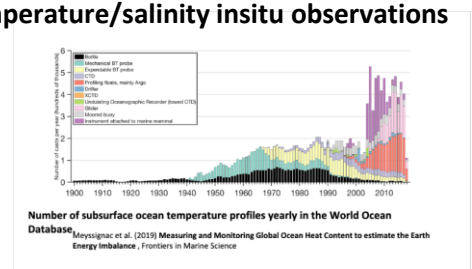
- Will only discuss physical ocean models, not sea-ice, surface fluxes, boundary conditions, ensembles etc.
- Just going to cover a few areas where improvement is possible or care is needed:
  1) Representation of mixed layer processes (improvement possible)
  2) Making best use of horizontal resolution (care is needed)
  3) Attention to very low-order representations (improvement possible)
  4) Avoiding unphysical transfers or cascades (care is needed)
- Re-analyses are less sensitive to model shortcomings than ocean-only simulations

NEMO 2013-2017 Development Strategy is at https://zenodo.org/record/7361464

Description of available ocean observations



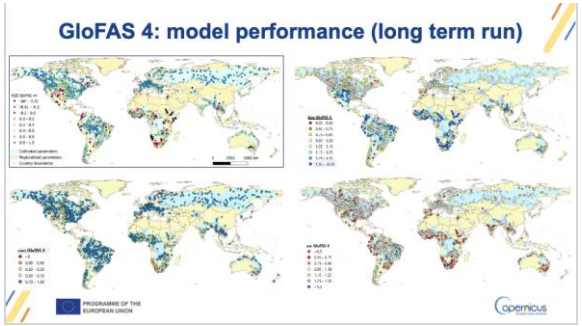
Temperature/salinity insitu observations



Number of subsurface ocean temperature profiles yearly in the World Ocean Database

Meyssignac et al. (2019) **Measuring and Monitoring Global Ocean Heat Content to estimate the Earth Energy Imbalance**, Frontiers in Marine Science

Freshwater from rivers



Data assimilation methods

Met Office — Model bias and data assimilation

- All the components of a reanalysis system can generate biases:
  - Model
  - Surface forcing
  - Observations
  - Error covariances in the assimilation
  - Interactions between assimilation increments and the model
- Bias can be diagnosed from data assimilative systems (Dee, 2005) either using the analysis increments or the innovations (obs-minus-background):

$$\langle \delta x^a \rangle \approx \langle K e^o \rangle - \langle KHe^b \rangle, \qquad \langle \delta y \rangle \approx \langle e^o \rangle - \langle He^b \rangle$$

$K = BH^T(HBH^T + R)^{-1}$

e^o is obs error

e^b is model background error

$\langle . \rangle$ is time average

- Ideally, we want to understand the cause and reduce/remove source of biases, but they can be corrected as part of the DA.

BGC insitu observations