The **Nucleus for European Modelling of the Ocean (NEMO)** is a state-of-the art modelling platform for oceanographic research, operational oceanography, sesonnal forecasts and climate studies. NEMO includes three major components; the blue ocean (dynamics), the white ocean (sea-ice), the green ocean (ocean biogeochemistry). It also allows coupling through interfaces with atmosphere (through OASIS software), waves, ice-shelves and nesting through the adaptive mesh refinement software: AGRIF. Some reference configurations and test cases are also available to the community for easy exploration, set-up and to validation of applications. Various additional tools to use with the platform are also available to the community. The whole platform and its documentation are available under free licence. The evolution and reliability of NEMO are organised and controlled by a European Consortium between CMCC (Italy), CNRS (France), MOI France), NOC (UK), UKMO (UK).

Consortium members agree on long term strategy and yearly plans, sharing expertise and efforts within the NEMO System Team (i.e. the core team of NEMO developers) in order to ensure the successful and sustainable development of the NEMO System as a well-organised, state-of-the-art ocean model code system suitable for both research and operational work.

NEMO distribution includes a limited number of "Reference Configurations" targeting a number of NEMO capabilities. They are also useful guides for new users wishing to gain practical experience towards setting up their own application. They are also used in the testing suite of each new NEMO release. These Reference Configurations are distributed along with input and forcing files. As part of the NEMO code, the NEMO System Team provides user support on these Reference Configurations.

Available Reference Configurations (since NEMO version 4):

AGRIF_DEMO: based on the global configuration at 2° resolution, includes three nested grids a 1:1 grid in the Pacific and two successively nested grids with odd and even refinement ratios over the Arctic ocean, with the finest grid spanning the whole Svalbard archipelago to demonstrate the overall capabilities of AGRIF in a realistic context, including the nesting of sea ice

AMM12: regional configuration of Northwest European Shelf on a regular horizontal grid of ~12 km of resolution, allowing to tests several features of NEMO. In particular, AMM12 accounts for vertical s-coordinates system, GLS turbulence scheme, tidal lateral boundary conditions using a flather scheme

C1D_PAPA: 1D vertical configuration located at the PAPA station l in the north-ern-eastern Pacific Ocean at 50.1°N, 144.9°W

GYRE_PISCES : idealized configuration of a Northern hemisphere double gyre system, in the Beta-plane approximation with analytical forcing. Spatial resolution can be changed at runtime, making it a valuable benchmark

ORCA2_ICE_PISCES: global ocean (dynamics, sea-ice and biogeochemistry) with a 2°x2° curvilinear horizontal mesh and 31 vertical levels (10 levels in the top 100m), using z-coordinate. This realistic configuration is the basic setup for NEMO global configurations

ORCA2_ICE_OBS: triggers the assimilation interface: OBS and ASM components

ORCA2_OFF_PISCES: triggers only the TOP & PISCES components in "offline mode": ocean dynamics are imposed as external forcings

ORCA2_OFF_TRC: same as above with a unique passive tracer (water age, ...) in place of PISCES

ORCA2_SAS_ICE: ocean is reduced to its Stand-Alone Surface (SAS) module

SPITZ12: regional configuration around the Svalbard archipelago at a horizontal resolution of 1/12° and 75 vertical levels; for sea-ice and high latitudes processes

NEMO is interfaced with:

OASIS: the coupler developed at CERFACS, providing clear and modular interfaces with other components of coupled and Earth System models

XIOS: library developed at IPSL, dedicated to high perfomance I/O for climate models

The ocean dynamics component is ideal for climate modelling, re-analyses, seasonal predictions, short-range ocean forecasts and regional process studies. Its horizontal grid uses orthogonal, curvilinear coordinates; the global ORCA grid has a north-pole fold and is almost isotropic. Its vertical grid allows a flexible combination of geo-potential and bathymetric envelope following coordinates (including a z~ coordinate (Leclair & Madec 2011)).

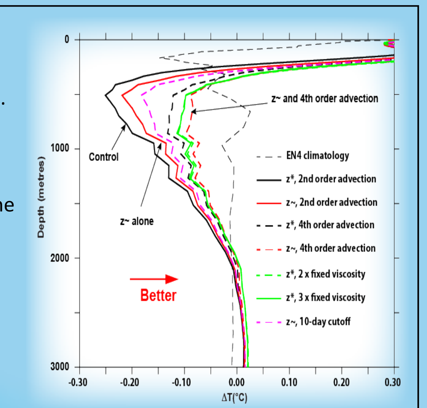
This component uses a leap-frog Robert-Asselin time-step scheme with split-explicit sub-steps for the external mode. It has a wide range of tracer advection schemes and representations of the Coriolis term & momentum advection. It parametrises many sub-grid processes: e.g. has a TKE scheme for the near-surface layer (Madec et al 1998) ; and versions of isoneutral diffusion and eddy induced tracer advection. It uses an MPI domain decomposition and aims to be efficient on scalar and vector machines.

Current developments in progress include:

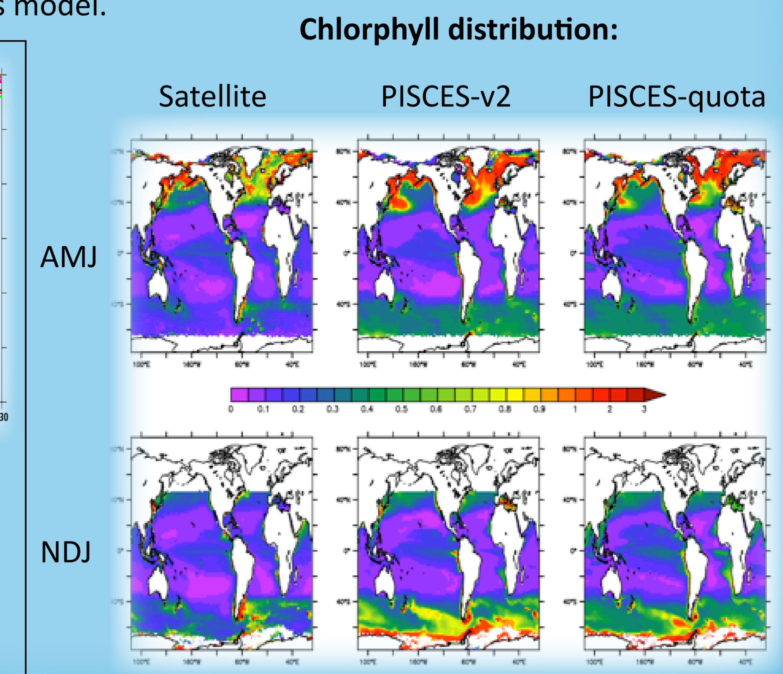
split-explicit RK3 time-step; improved parametisations of unresolved mesoscale motions; sub-mesoscale mixed layer eddies and Langmuir turbulence; tiling (to reduce cache trashing); coarse-grain OpenMP; reduced inter-node communications; mixed precision calculations and porting to GPU-based machines.

PISCES is a component of NEMO designed for biogeochemistry studies at regional and global scales, focusing on biogeochemical processes, ecosystem dynamics, impacts of natural climate variability and future climate change on marine biogeochemistry and ecosystems. Recent developments of PISCES include a quota-based version, a variable lability of particulate organic matter, prognostic ligands of iron and a complete diagenetic sediment module. A two-way coupling framework has also been developed between NEMO-PISCES and APECOSM: upper trophic levels model.

Investigation within the RENUMERATE project by A. Megann & M. Luneva of impact of z~ coordinate, advection schemes and viscosity on the thermocline in 30-year integrations

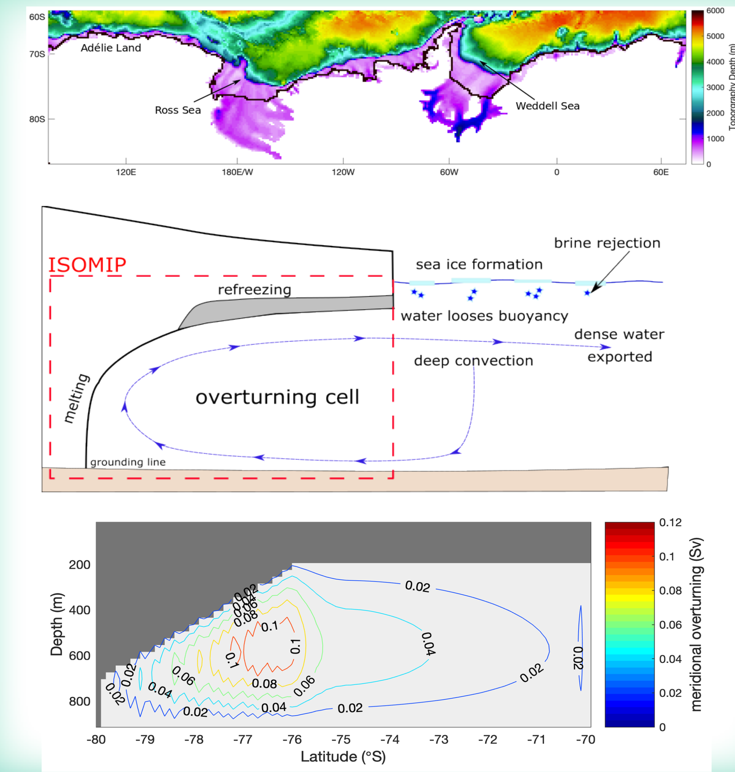


Global mean temperature change between years 1 and 30

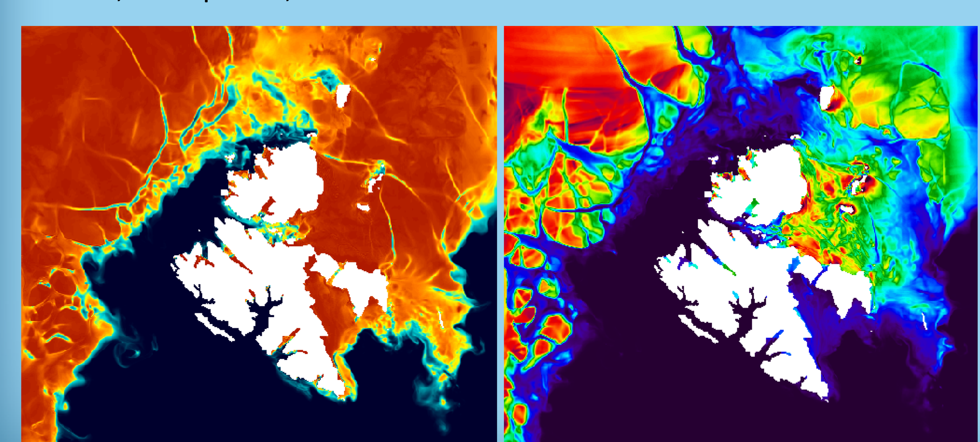


NEMO test cases are simple applications, available as demonstrators of NEMO functionalities. They are intended as a simple way for users to get hands on experience of NEMO, for training courses and as components of a NEMO testing suite. Test cases are contributions added by developers or by any user, and are available, separately from the NEMO reference:
https://github.com/NEMO-ocean/NEMO-examples.

For example: the **ISOMIP** test case is used to improve understanding on how to better simulate sub-ice shelf cavity circulation. Ice-ocean interactions are key-players in Earth's system and thus obtaining a better understanding of these processes and explicitly simulating sub-ice shelf cavities in global models is presently regarded as a priority.



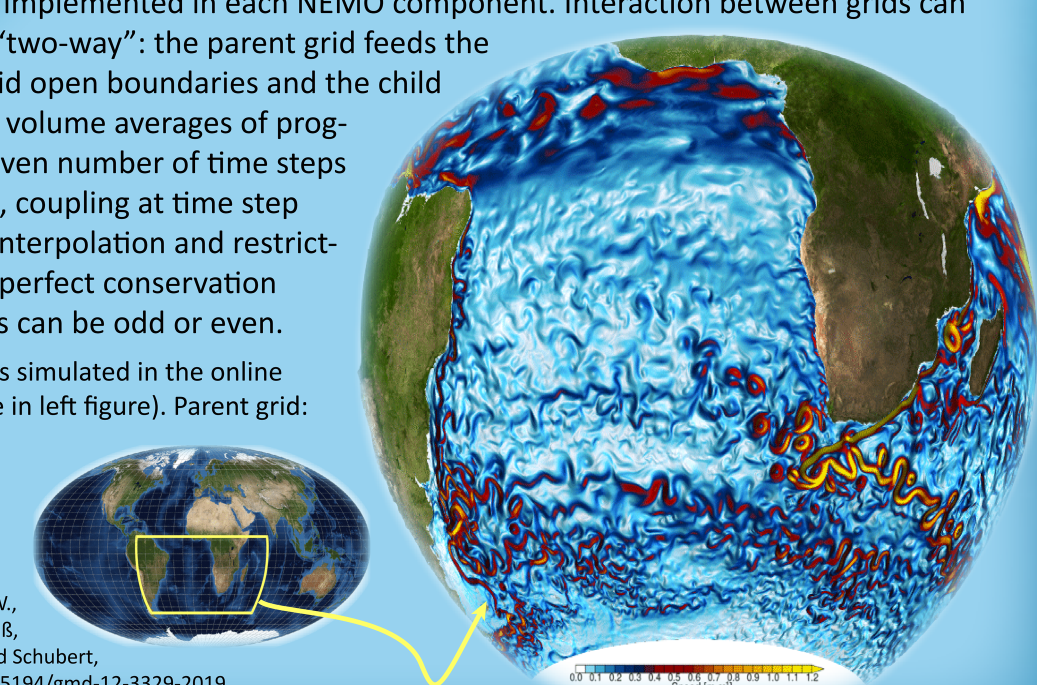
The sea-ice component SI3 (Sea-Ice modeling Integrated Initiative) combines features of the previously used CICE, GELATO and LIM models. It is implemented in NEMO since version 4.0. It treats ice thermodynamics as purely vertical and ice dynamics as purely horizontal, assuming sea ice is a 2D plastic continuum using the adaptive EVP method of Kimmritz et al. (2016). Several growth and melt processes are considered: new ice formation in open water, basal growth and melt, snow-ice formation and seawater freezing into ridges, and surface melting. Ice transport, sub grid-scale variations in ice thickness, dynamic variations in snow, melt ponds, and brine inclusions are also considered.



Ice fraction (left) and thickness (right) as simulated in a regional configurationat 1/36° around Svalbard (courtesy C. Rousset)

AGRIF (Adaptive Grid Refinement In Fortran) is a library (http://agrif.imag.fr, Debreu Et al, 2008) allowing space and time refinement over rectangular regions.The AGRIF interface is fully implemented in each NEMO component. Interaction between grids can be "two-way": the parent grid feeds the child grid open boundaries and the child grid provides volume averages of prognostic variables once a given number of time steps are completed. Grid matching, coupling at time step frequency as well as suitable interpolation and restriction operators, ensures nearly perfect conservation properties. Refinement factors can be odd or even.

Snapshot of surface speed (m s^{-1}) as simulated in the online two-way nested area (yellow frame in left figure). Parent grid: global ¼°; Nested grid: 1/20°.



Schwarzkopf, F. U., Biastoch, A., Böning, C. W., Chanut, J., Durgadoo, J. V., Getzlaff, K., Harlaß, J., Rieck, J. K., Roth, C., Scheinert, M. M., and Schubert, R.GMD., 12, 3329–3355, https://doi.org/10.5194/gmd-12-3329-2019

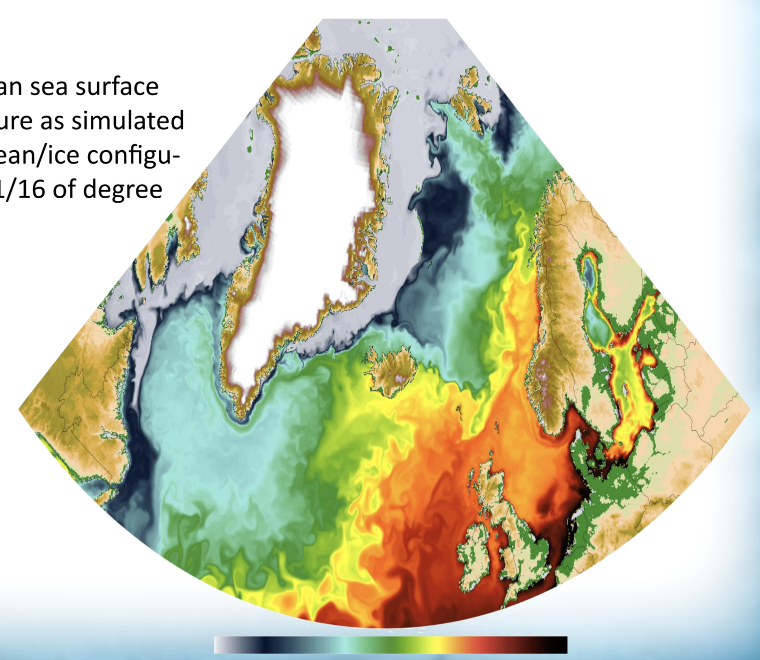
2020 NEMO System Team .

NEMO Project Manager C. Lévy (1) - NEMO officers: A. Coward (4), D. Iovino (5), S. Masson(7), G. Samson (3), A.Young (2) - Leaders of Working groups: M. Bell (2), J. Chanut(3), T. Lovato(4), M. Vancoppenolle(1) and R. Bourdalle Badie(3), C. Bricaud, L. Brodeau (8), D. Calvert(2), D. Carneiro (2), S. Ciliberti (5), E. Clementi (5), Italo Epicoco (5), C. Ethé (1), D. Ford (2), O. Hernandez (3), D. Lea (2), T. Lovato (5), G. Madec (1), N. Martin (7), P. Mathiot (2), M. Miroslaw (2), S. Müller (4), S. Mocavero (5), E. O'dea (2), R. Person (6), C. Rousset (1), S. Rynders (4), D. Storkey (2), S. Techene (1), O.Tinto (9)

(1) CNRS, (2) Met-Office, (3) MOI, (4) NOC, (5) CMCC, (6) IRD, (7) SU, (8) Ocean Next, (9) BSC

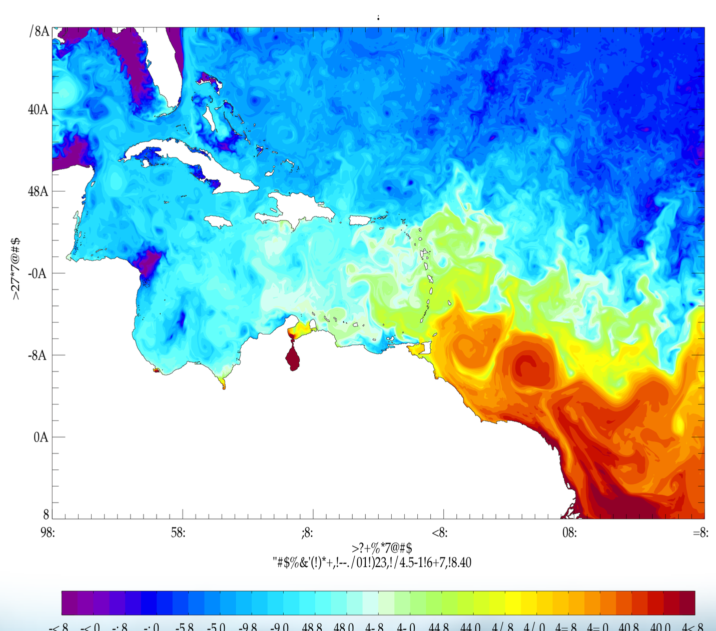
CMCC develops and uses the NEMO platform for a variety of global and regional applications. NEMO forms the dynamical core of the state-of-the-art global ocean/sea ice configurations from laminar to eddying resolutions (e.g. the global 1/36° ocean in development in collaboration with Mercator-Ocean). NEMO is also the base the GOFS16 ocean short-range forecast and a set of CMCC ocean systems in the framework of CMEMS, for the global ocean, the Mediterranean and the Black Seas. On climate timescales, NEMO underpins the CMCC ocean modelling capability and contribution to CMIP6 exercises; the CMCC-CM global coupled model provides climate projections at 1°, 1/4° resolutions, as well as underpinning seasonal forecasting. Recent development contributes to the sea ice model, ocean-waves coupling and ocean-biogeochemistry interactions.

5-day mean sea surface temperature as simulated by the ocean/ice configuration at 1/16 of degree

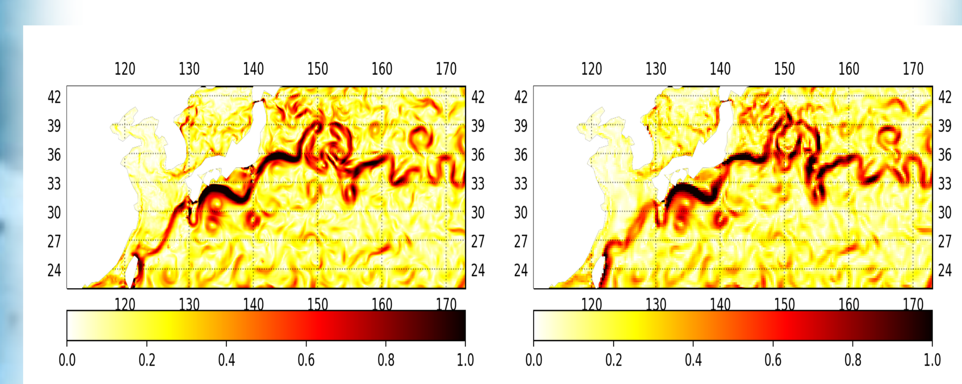


CNRS is a very active contributor to NEMO development since the very beginning, reflecting the multiple motivations of its research teams on the understanding of ocean processes (dynamics, sea-ice and biogeochemistry) and its relation to climate. Scientific interests concern various space and time scales, from local to global and from paleoclimate to present days projections. High resolution is used only when the cost is valuable to scientific objectives.

Example: ENERGETICS results (Atlantic and Mediterranean seas at 1/36° for NEMO 4.0.2 coupled with OASIS MCT v4 to WRF 4.1.5 at 1.12°. Outputs through XIOS 2.5. Computing cost on 9503 nodes 6 hours for 1 simulated month on Jean-zay, IDRIS). Daily mean Sea Surface Temperature in January (S. Masson and J.M. Molines personal communication)

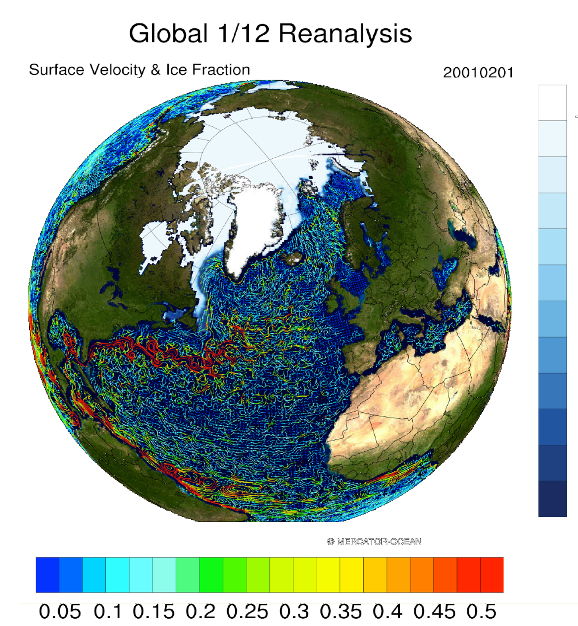


The Met Office is both an active user and developer of the NEMO model with applications spanning a range of spatial and temporal scales. On climate timescales, NEMO underpins the ocean modelling capability for the Met Office and UK CMIP6 contributions; the HadGEM3-GC3.1 global coupled model provides climate projections at 1°, 1/4° and 1/12° resolutions, as well as underpinning seasonal and decadal forecasting. NEMO also forms the dynamical core of the FOAM operational ocean short-range forecast. Recent development contributions include a new vertical mixing scheme, OSMOSIS, in collaboration with NERC and NCAS; and ocean-ice-sheet coupling for UKESM in collaboration with NOC.

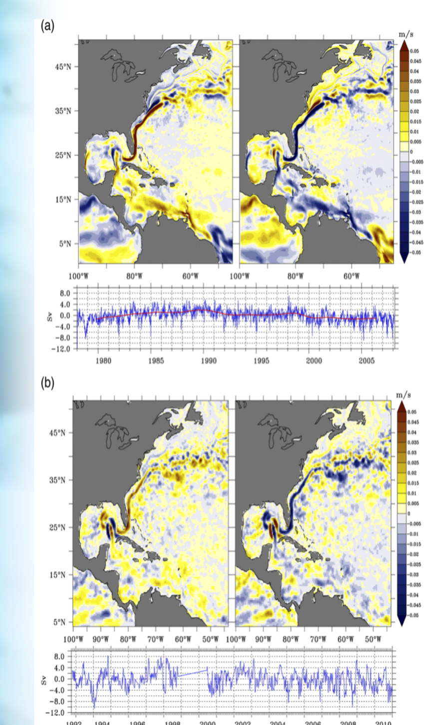


5-day average of Kuroshio surface currents from ORCA025 vs eORCA12 FOAM analysis.

Mercator-Ocean relies on the NEMO modelling platform to issue global and regional forecasts and reanalysis of oceanic physical and biogeochemical properties, as well as sea-ice. We develop and operate state-of-the-art model configurations at 1/12° (global) and 1/36° (regional with explicit tides and global prototype) resolutions widely used in the scientific community and the private sector in the framework of CMEMS. We are also strongly involved in NEMO recent and future evolutions such as vertical physics (GLS, ABL), numerics (time-splitting, vertical coordinates, coarsening) and zooming capacities (AGRIF).



The National Oceanography Centre (NOC) maintains and runs various NEMO configurations. The Southampton site specialises mainly in global configurations whilst regional and coastal studies are conducted from our Liverpool offices. In both cases, coupled simulations are also undertaken in collaboration with the UK Met. Office. NOC also develops and runs biogeochemical models with NEMO



Example analysis from:
Loop Current Variability as Trigger of Coherent Gulf Stream Transport Anomalies, Hirschi et al.
https://doi.org/10.1175/JPO-D-18-0236.s1

(top) Composites of absolute surface velocities for ORCA12. The positive and negative composites show the anomalous surface velocity pattern coinciding with (bottom) the positive and negative transport anomalies in the Florida Straits. The red lines in the bottom panel are the transport anomalies in the Florida Straits smoothed with a Parzen filter (window length of 1255 days).
(bot): As in (top), but for geostrophic surface velocities inferred from AVISO.