GOFS16: Global Ocean Forecast System at 1/16º resolution

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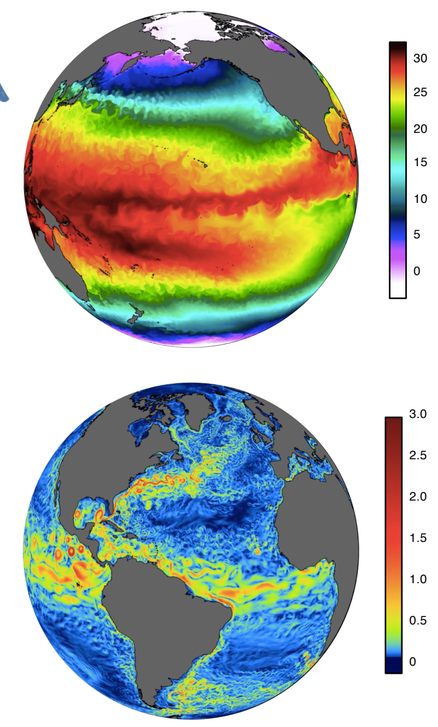
DESCRIPTION OF THE SYSTEM

The Global Ocean Forecast System **GOFS16** is an operational ocean analysis and forecast system that runs daily at the Euro-Mediterranean Center on Climate Change since early 2017. GOFS16 produces **7-day forecasts** of the state of the global ocean and sea ice: **three-dimensional ocean temperatures, salinities and currents, as well as sea ice thickness, concentration and drift.** The system is based on a global eddying ocean (Iovino et al. 2016), combined with a state-of-the-art data assimilation system, OceanVar (Storto and Masina, 2016, capable of assimilating all high resolution space-borne and conventional observing networks, including hydrographic profiles and several satellite data.

Sea surface temperature (SST, in ℃) and ocean surface currents (m/s) as simulated by GOFS16 for 16.11.2018 (daily mean)



PHYSICAL MODEL:
NEMOv3.4 ocean configuration coupled to LIM2 (EVP) sea ice model

Mesh: global tripolar grid with 1/16º (6.9 km) horizontal spacing at the equator (increasing poleward to ~2 km) and 98 vertical levels with partial step
Grid size: 5762 × 3963 × 98 points

Bathymetry: ETOPO2 for the deep ocean, GEBCO for the continental shelves, BEDMAP2 for Antarctica region

Atmospheric Forcing: operational NCEP analyses and forecasts; bulk CORE formulation
Runoff: monthly climatology from Dai et al. 2009 and Antarctic freshwater fluxes (Jacobs et al. 1992)

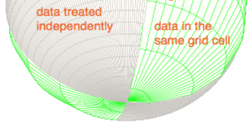
DATA ASSIMILATION SCHEME:
OceanVar is a three-dimensional variational (3Dvar) data assimilation scheme with updates from multiple data sources and nudging schemes for surface temperature and sea ice concentration. The background-error covariance matrix accounts for vertical covariances (modeled through the use of multivariate EOFs) and horizontal correlations (through the application of recursive filters). Horizontal correlation length-scales have been scaled to the 1/16º mesh from the reference 1/4º resolution configuration to maximise the impact of dense satellite datasets such SLA and SST, improving the ocean initial condition for the short-term forecast. Pre-processing of the observations includes background quality checks, thinning of dense datasets w.r.t. the grid resolution.

ASSIMILATED DATA
In situ temperature and salinity: XBT, CTD, Argo, moorings, marine mammals (~3º resolution)

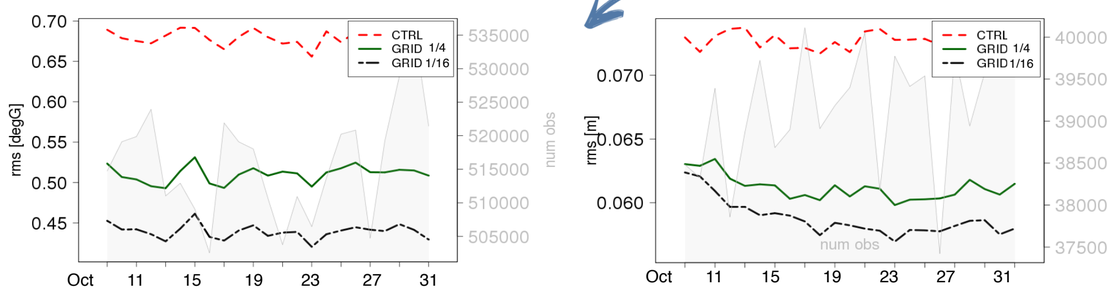
Along-track satellite altimetry: Altika, Jason-3, Sentinel-3, CryoSat2 (14 km resolution)

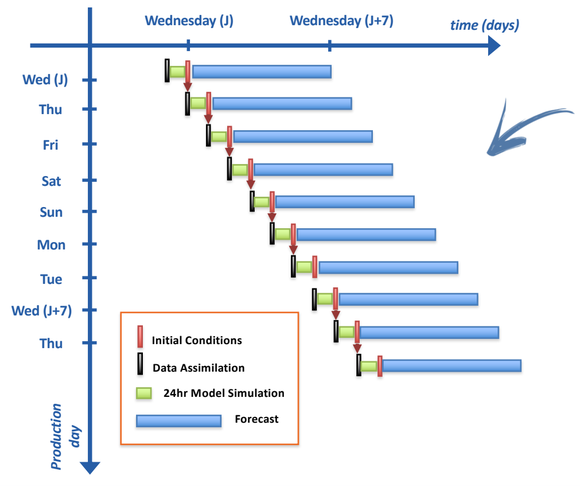
SST data from Metop-A/AVHRR and GCOM-W/AMSR-2 (up to ~4 km resolution), SSS relaxation toward NOAA 1/4º Analyses (15 days)

Sea ice concentration satellite data processed by NCEP



Evolution of RMSE for SST and sea level anomaly (SLA) in 3 runs: CTRL w/o assimilation, GRID1/4 and GRID1/16 with low and high-res assimilation, respectively. Number of observations in grey.





OPERATIONAL CHAIN:
The chain consists of daily cycle of a 7-day-long forecast, initialized by a former (daily) analysis. At each cycle, the chain starts one day back, assimilates all observations available for that day and runs nowcast and forecast afterwards.

GOFS16 represents the CMCC efforts in pushing global forecasting systems to compete with regional operational systems in term of resolution and accuracy of mesoscale predictions.

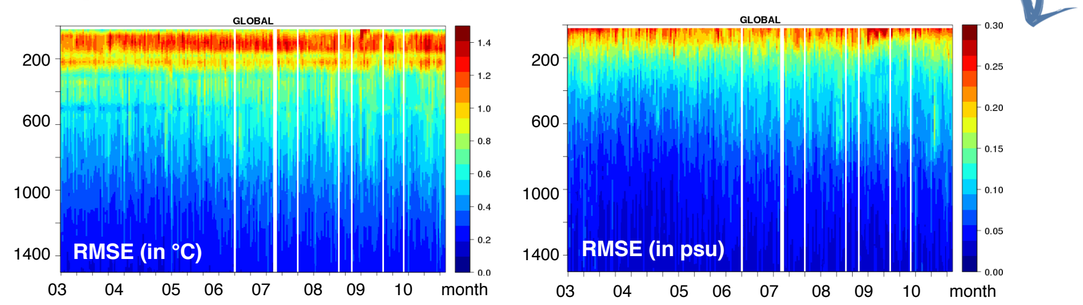
MAIN REFERENCES: *Iovino et al.*, A 1/16º eddying simulation of the global NEMO sea-ice–ocean system, Geosci. Model Dev., 9, 2665-2684, 2016. *Storto and Masina,* C-GLORSv5: an improved multipurpose global ocean eddy-permitting physical reanalysis, Earth Syst. Sci. Data, 8, 679-696, 2016. *Trotta et al.,* A Structured and Unstructured grid Relocatable ocean platform for Forecasting (SURF), Deep-Sea Res. II, 133, 54-75, 2016. *Coppini et al.*, SeaConditions: a web and mobile service for safer professional and recreational activities in the Mediterranean Sea, Nat. Hazards Earth Syst. Sci., 17, 533-547, 2017. *Dai et al.,* Changes in continental freshwater discharge from 1948-2004, J. Climate, 22, 2773-2791, 2009. *Jacobs et al.*, Melting of ice shelves and the mass balance of Antarctica, J. Glaciol., 38(130), 375-387, 1992.

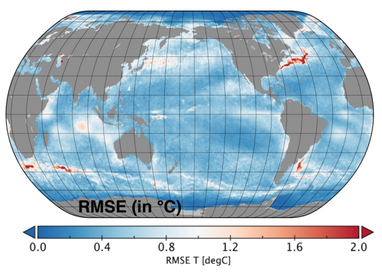
Acknowledgments: AMSR2 data produced by Remote Sensing Systems and sponsored by NASA AMSR-E Science Team and NASA Earth Science MEaSUREs Program, www.remss.com. AVHRR data distributed by the Land Processes Distributed Active Archive Center, http://lpdaac.usgs.gov. Altimeter and in situ products from EU Copernicus Marine Service Information website. Drifter data from NOAA Global Drifter Program.

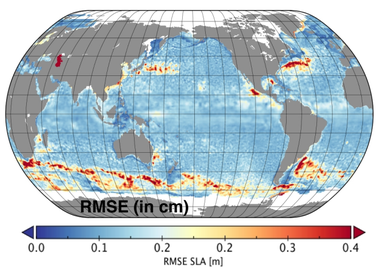
VALIDATION METHODOLOGY

A rolling validation tool runs every 2-3 weeks (waiting near-real-time products to be completed) and provides a check on the quality of the analysis and forecast products 3D fields of temperature (T), salinity (S) and surface currents are validated in the global ocean and regional domains. Here the time period March – October 2018 is shown (if not otherwise indicated).

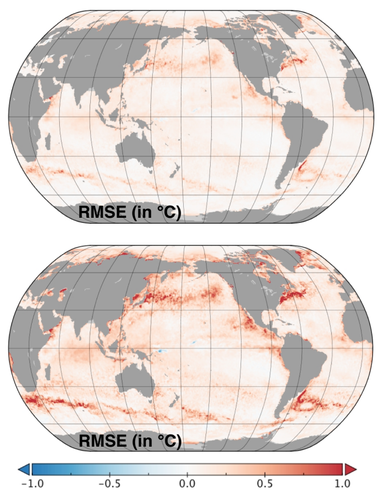
Time evolution of T and S RMSE for the analysis against CMEMS near-real-time in situ products. Maxima correspond to the the mixed layer depth (with the main contribution from the steep thermocline in the equatorial Pacific).

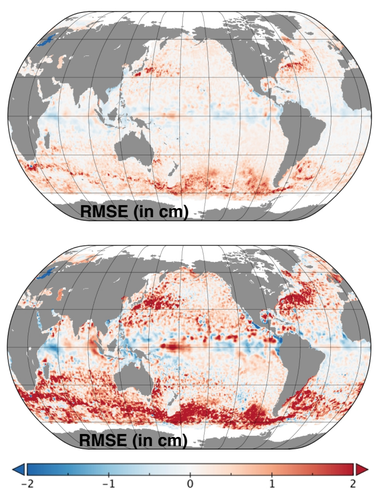






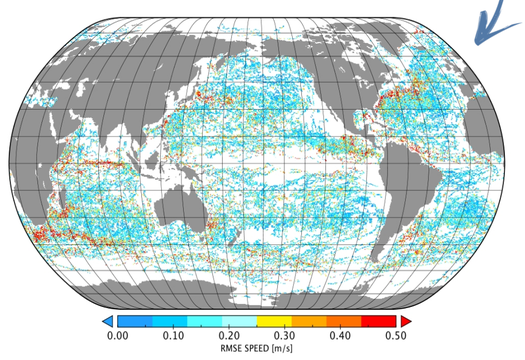
SST and SLA RMSE of analysis against daily OI-SST data from NOAA and AVISO data.

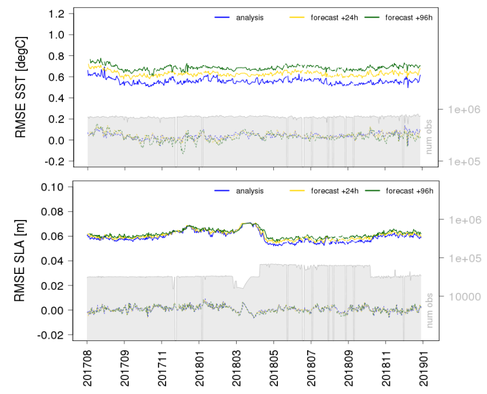




Evolution of SST and SLA RMSE within the forecast time window (at 2nd and 6th day). Errors are compared with the analysis: RED (BLUE) regions means the error is bigger (smaller) than assimilated run. Mean errors remain small for several days after assimilation is turned off. Hotspots of major mesoscale instabilities saturate more rapidly, showing a faster decay of temporal auto-correlation respect to the initial condition.

Example of validation with independent data: spatial RMSE between GOFS analysis speed and drifting buoys speed along drifter trajectories (daily mean at 15m within the period Oct 2017 to Jun 2018)



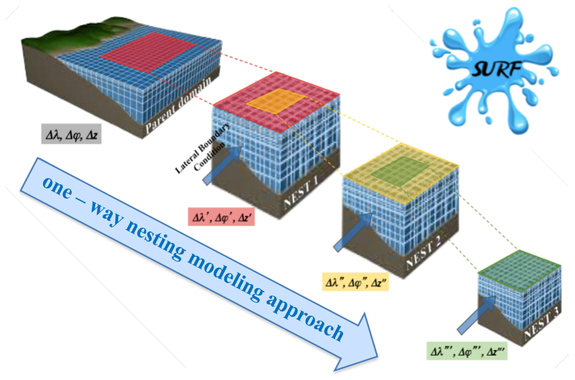


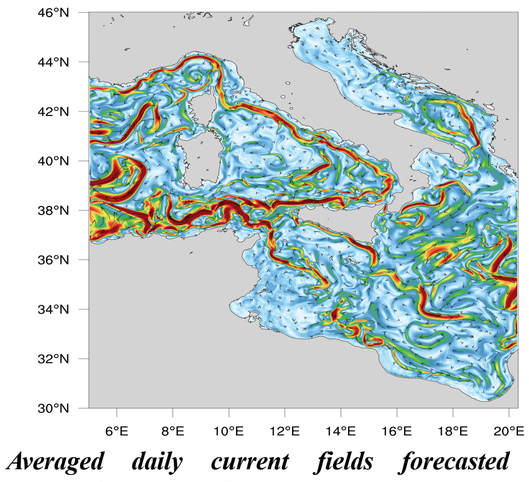
Evolution of RMSE (solid lines) and bias (dashed lines) of surface temperature (at 1m) and SLA for analysis, 1st and 4th day forecast against observed data. Number of available observations in grey.

DOWNSTREAM SERVICES

GOFS16 provides initial and lateral boundary conditions to a set of regional forecast systems. The downstream service has been developed for ocean forecast at ground-breaking resolution for safety of offshore operations.
The service includes the provision of ocean sea level, currents, temperature and salinity forecasts up to **1/64º resolution** in the following areas: Gulf of Mexico, Caribbean Sea, Britain, Mediterranean Sea,, Black Sea, Caspian Sea, Red Sea, Gulf of Guinea, Angola, Mozambique, South China Sea and Australia.

Downscaling is realized with the Structured and Unstructured Relocatable ocean platform for Forecasting, **SURF** (Trotta et al. 2016), a short-time modelling system, based on the NEMO fields at high spatial and temporal resolutions, rapidly deployable in any world ocean region.
SURF represents a component of an advanced decision support system to increase safety of offshore operations, oil spill forecasting, search and rescue operations, navigation routing (see Coppini et al. 2017).





Averaged daily current fields forecasted for 02.04.2018 by a SURF configuration of the Central Mediterranean Sea at 2km resolution.