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Global and regional Sea Surface Salinity L4 fields from the multivariate combination of in-situ and multi-sensor satellite data

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esa

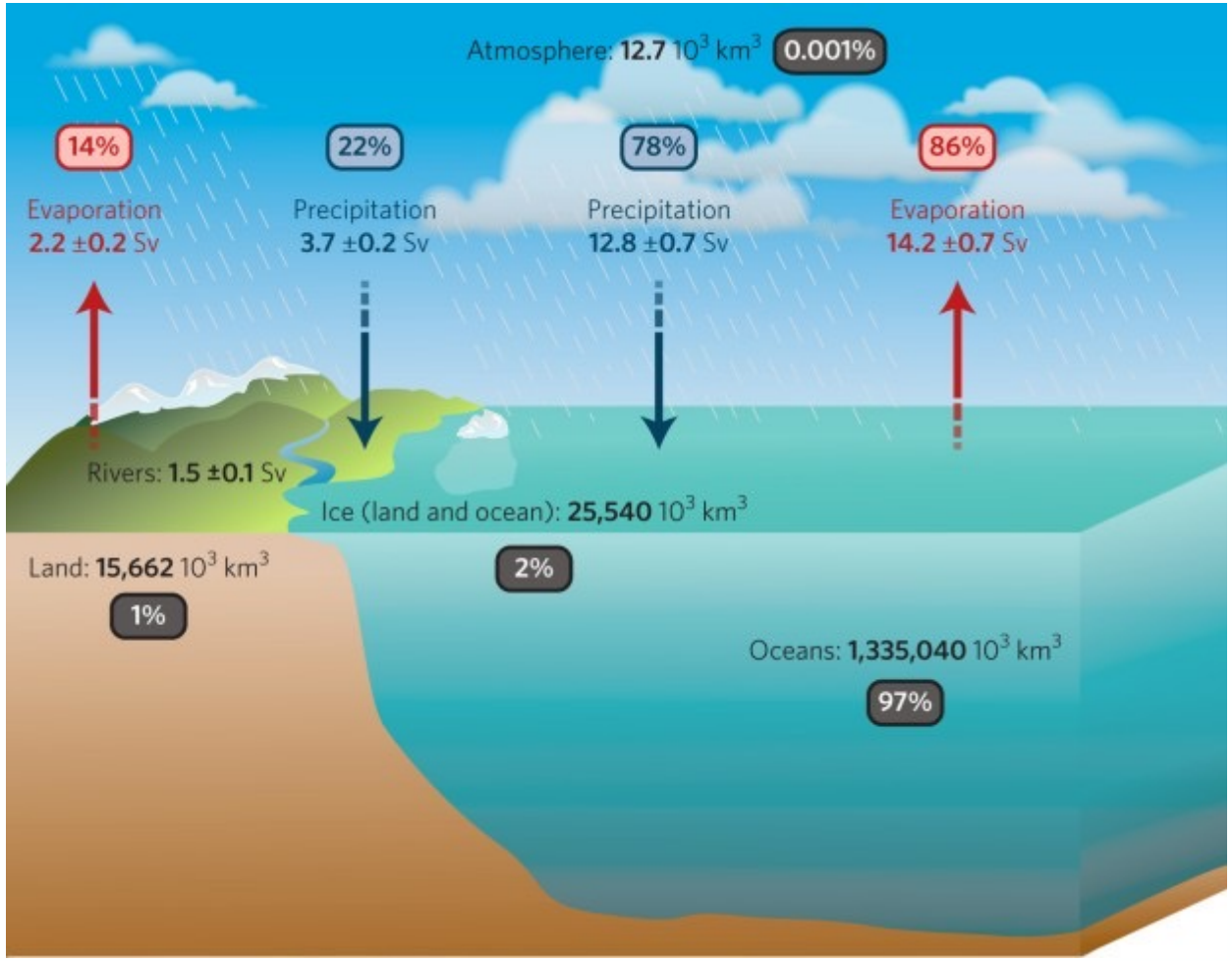
7TH OCEAN SALINITY CONFERENCE 2024

4DMED-sea

Copernicus Marine Service

COPERNICUS MARINE SERVICE
OCEAN MULTI TAC
Until 31 Dec. 2024
Contract 21001L08-COP-TAC MOB-3200

- Sea surface salinity (**SSS**) represents one of the Essential Climate Variables (ECVs) defined by the Global Climate Observing System (GCOS).
- Ocean circulation, climate variability and water cycle are deeply impacted by salinity variations.
- Salinity is strongly affected by freshwater input from rivers, land run-off, ice formation/melting, atmospheric phenomena (precipitation and evaporation).
- The monitoring of salinity along with other bio-physical parameters is crucial for both global and regional seas.

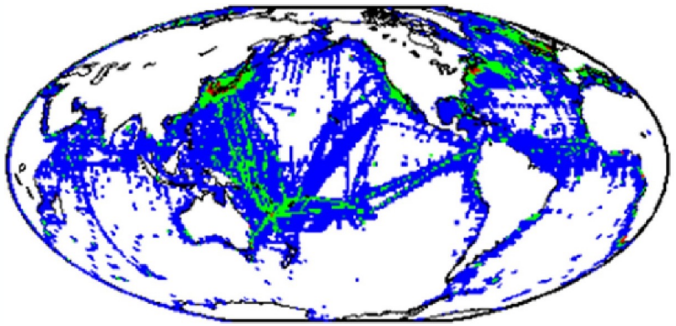


from Durack et al. 2016

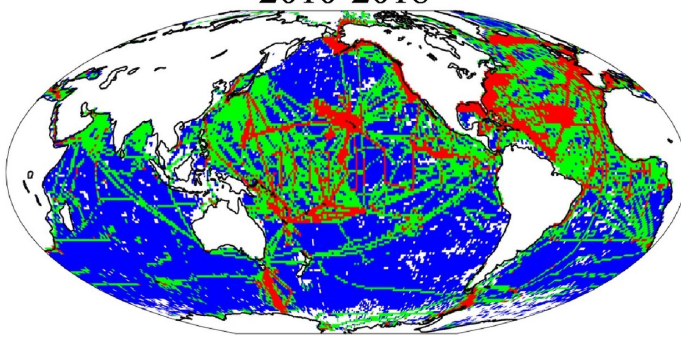
In situ

- An increased number of moorings and floating buoys provide accurate SSS measurements in the global and regional seas, but their coverage in time and space hinders the monitoring of SSS pattern variations and trends.

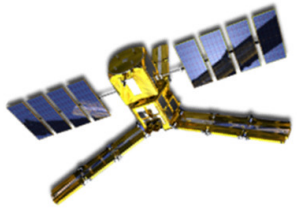
1874-1998



2010-2018

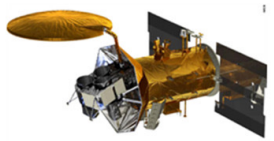


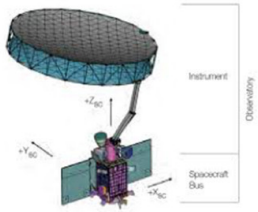
from Reul et al. 2020



SMOS
Interferometric Radiometer
Spatial res: ~43 km (30-80 km)
Swath: ~1000 km
Global coverage: ~2-3 days
Incidence: 0°- 60°
Full polarization
Launched Nov 2009

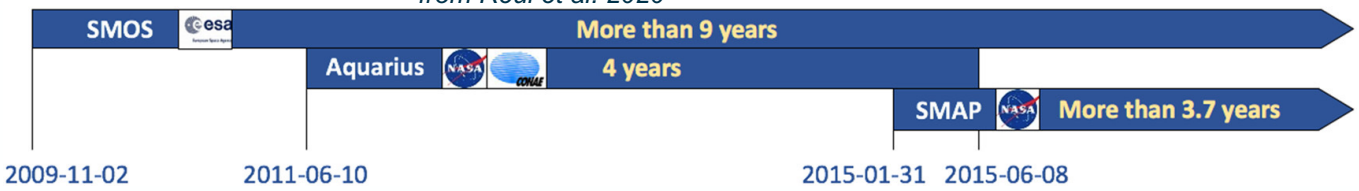
Aquarius-SAC/D
Radiometer & scatterometer
Spatial Res: ~100 km
Swath: ~400 km
Global coverage: ~7 days
Incidence angle: 29°,38° & 46°
Full Polarization
Launched Jun 2011





SMAP
Radiometer & SAR
Spatial res: 40 km
Swath: 1000km
Global coverage : ~2-3 days
Incidence angle: 40°
Full Polarization
Launched Jan 2015

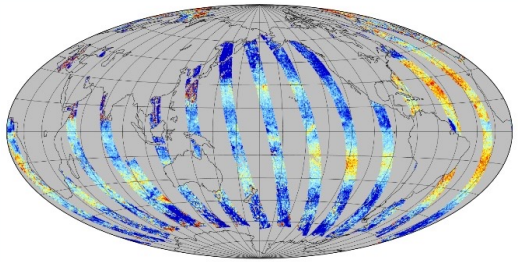
from Reul et al. 2020



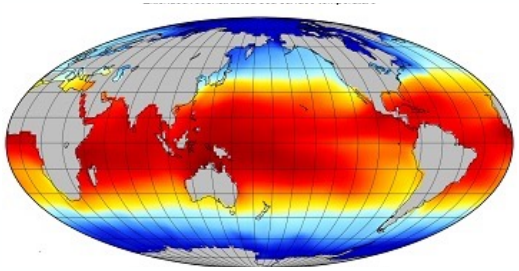
...from satellite

- Conversely, satellite remote sensing provides SSS data at high spatial and temporal resolution, complementing the sparseness of in situ dataset.
- SMOS and then SMAP satellite missions provide SSS data at higher spatio-temporal resolution than Aquarius.

SMOS L3 SSS

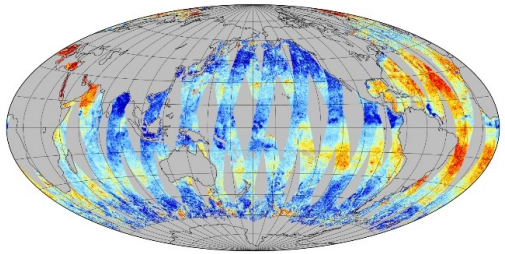


OSTIA L4 SST

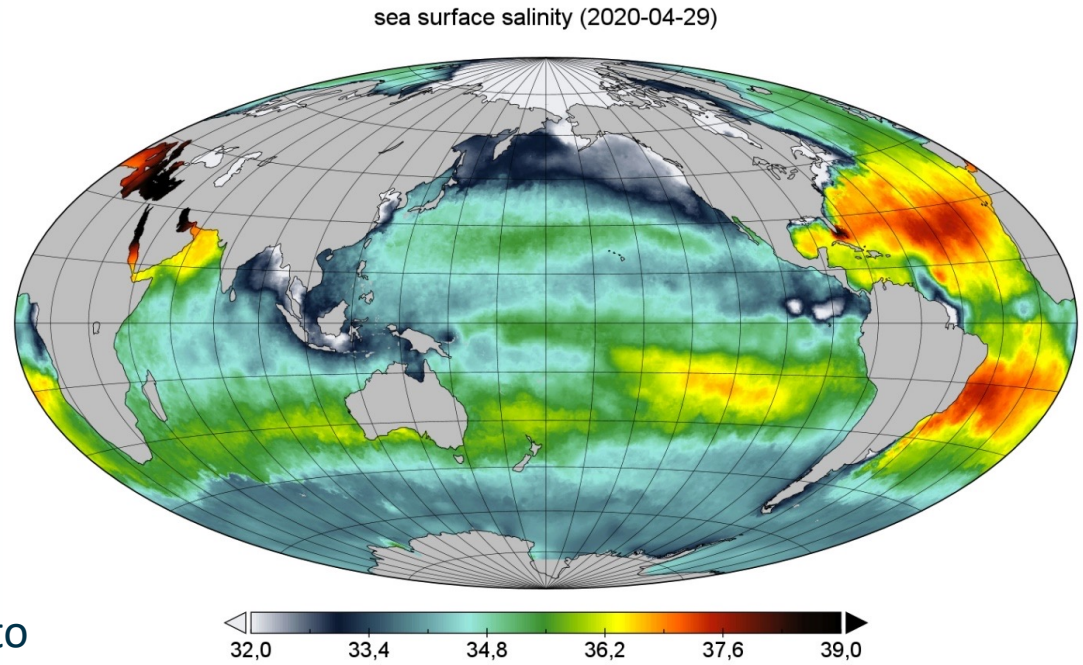


INSITU

SMAP L3 SSS



Multivariate Optimal Interpolation algorithm



Goal of this work:

Provide gap-free (L4) Sea Surface Salinity and Density fields combining in situ and satellite salinity measurements with HR Sea Surface Temperature observations

* Take advantage of concurrent temperature satellite observations to increase effective space-time resolution up to mesoscale.

*Buongiorno Nardelli et al., 2012; Droghei et al., 2018

Multivariate Optimal Interpolation Algorithm

The principles of OI starts from the computation of the desired values ($x_{analysis}$) at the interpolation grid point as a weighted sum of the anomalies of N observations ($y_{observed}$) with respect to the first guess represented by the background (x_{first_guess}) :

$$x_{analysis} = x_{first\_guess} + C(R + C)^{-1}\left(y_{observed} - x_{first\_guess}\right) \quad (1)$$

with C=background error covariance matrix and R=the observation error covariance matrix

$$C = E\left\{\varepsilon_{fg}\varepsilon_{fg}^{T}\right\} = E\left\{(x_{first\_guess} - x_{true})(x_{first\_guess} - x_{true})^{T}\right\} \quad (2)$$

$$R = E\{\varepsilon_{obs}\varepsilon_{obs}^{T}\} = E\{(y_{observed} - x_{true})(y_{observed} - x_{true})^{T}\} \quad (3)$$

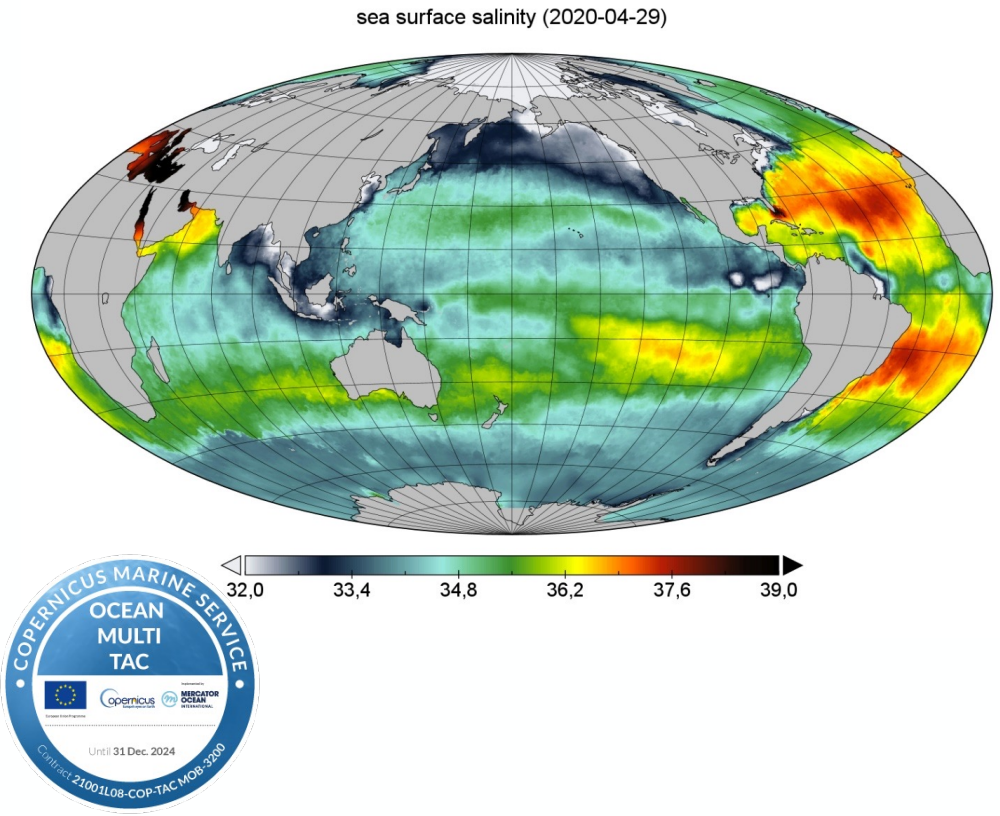
the observation error covariance R is expressed here as a noise-to-signal ratio (dividing it by signal variance) (Buongiorno Nardelli et al., 2016 and Droghei et al. 2018)

- In principle, the background error covariance should be estimated from all available observations, but in case of satellite data, this can become too complex;
- Therefore the background error is approximated by an analytical function of the distance among the samples;
- Depending on the system considered and on the available data, covariance models can also be extended to multidimensional spaces.

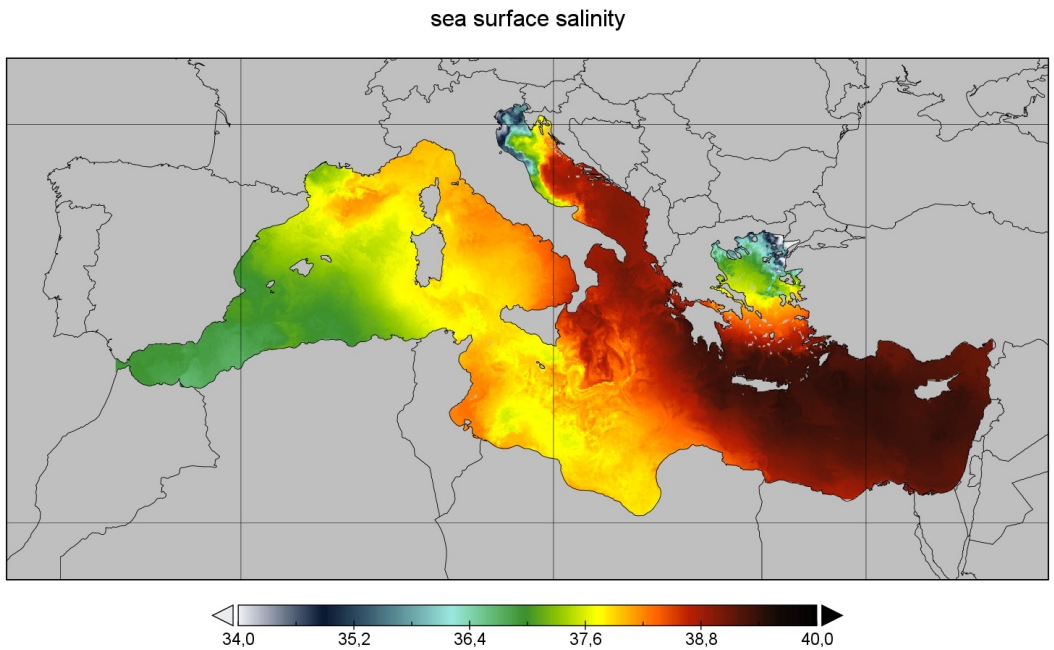
$$C(\Delta r, \Delta t, \Delta SST) = e^{-\left(\frac{\Delta r}{L}\right)^2} e^{-\left(\frac{\Delta t}{\tau}\right)^2} e^{-\left(\frac{\Delta SST_{filtered}}{T}\right)^2} \quad (6)$$

- Here multidimensional covariance model includes space-time differences (Δr, Δt) but also high-pass filtered thermal differences ($\Delta(SST)_{filtered}$), thus forcing the interpolated field to follow the local surface isotherms;
- More weight is given to the observations placed on the same isotherm of the interpolation point;
- Since HR SST can provide information on mesoscale structures, its inclusion in the computation of SSS can improve the effective resolution of salinity fields.

Global SSS/SSD L4 product (Copernicus MOB-TAC)



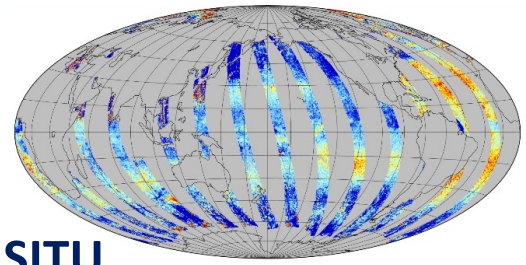
Regional SSS/SSD L4 dataset (ESA-4DMED-SEA)



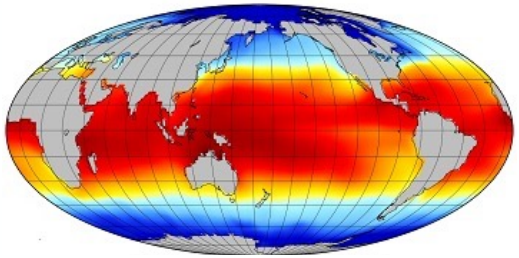
4DMED-sea

GLOBAL L4 daily SSS/SSD at 1/8° grid of resolution

SMOS L3 SSS

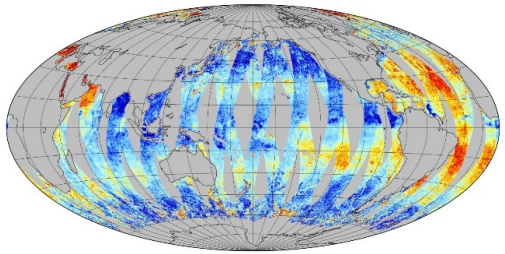


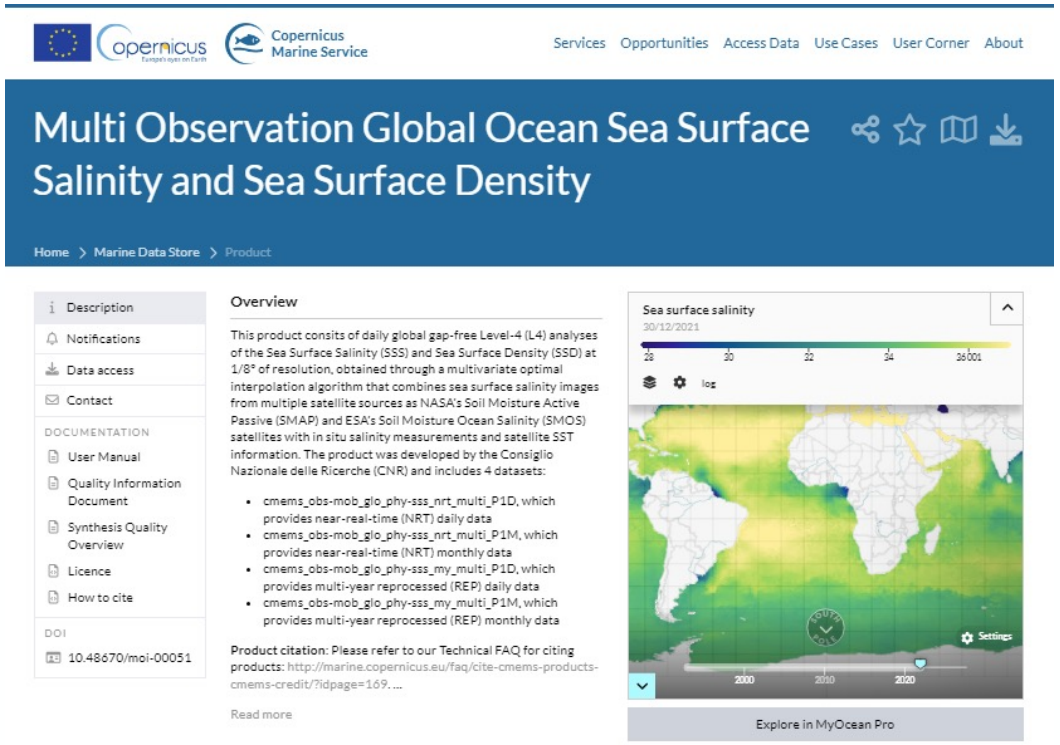
OSTIA L4 SST



INSITU

SMAP L3 SSS



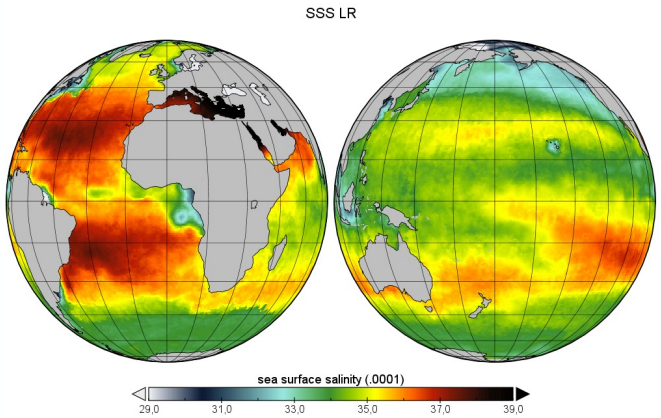


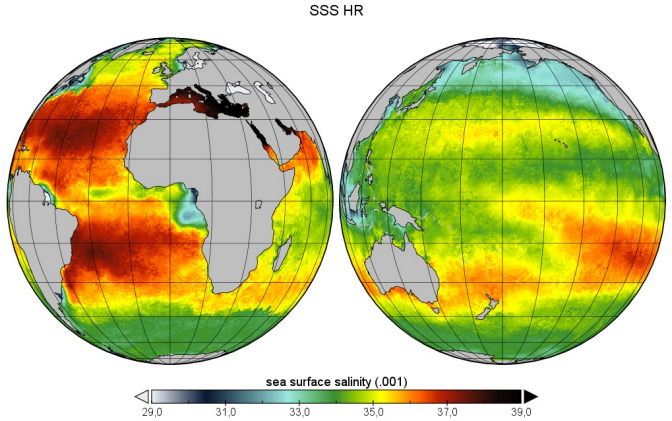
*November 2023 release

- cmems_obs-mob_glo_phy-sss_nrt_multi_P1D
- cmems_obs-mob_glo_phy-sss_nrt_multi_P1M
- cmems_obs-mob_glo_phy-sss_my_multi_P1D
- cmems_obs-mob_glo_phy-sss_my_multi_P1M

GLOBAL L4 daily SSS/SSD at 1/8° grid of resolution

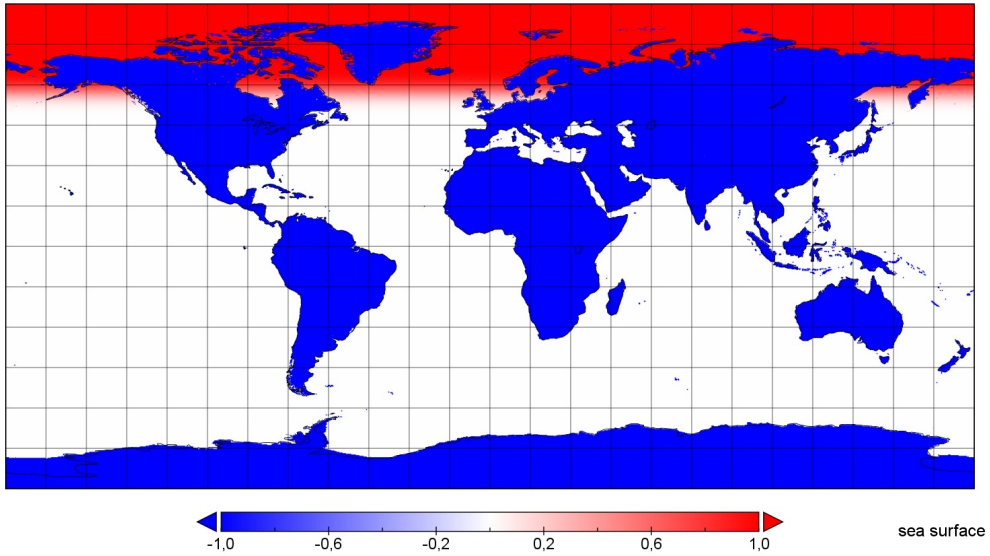
Copernicus GLO SSS/SSD L4 v8.0_LR	*Copernicus GLO SSS/SSD L4 v1_HR*
Method: OI	*Method: OI*
Satellite platform: SMOS+SMAP	*Satellite platform: SMOS + SMAP*
Temporal resolution: weekly	*Temporal resolution: daily*
Grid resolution: 1/4°	*Grid resolution: 1/8°*
Background: Global climatology	*Background: Arctic + Global climatologies*



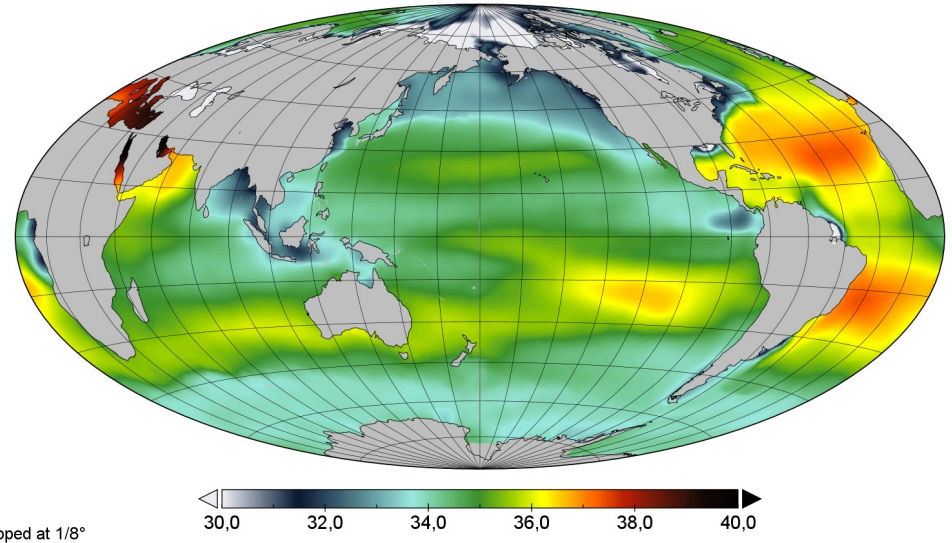


This v1 HR version includes a new background which combines Arctic and Global climatologies by using a new ad hoc mask (to blend progressively the ARCTIC and GLOBAL monthly climatologies)

Mask for artic and global climatology blending remapped at 1/8°

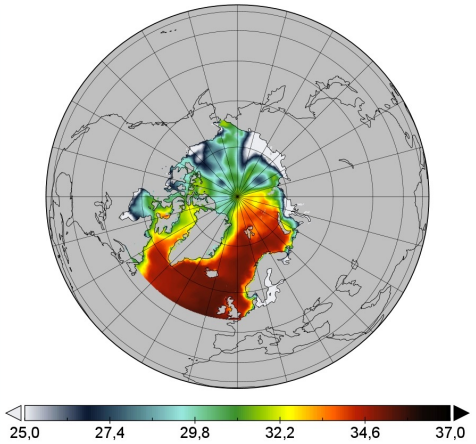


Background mapped at 1/8° (Artic & Global Clima blended)

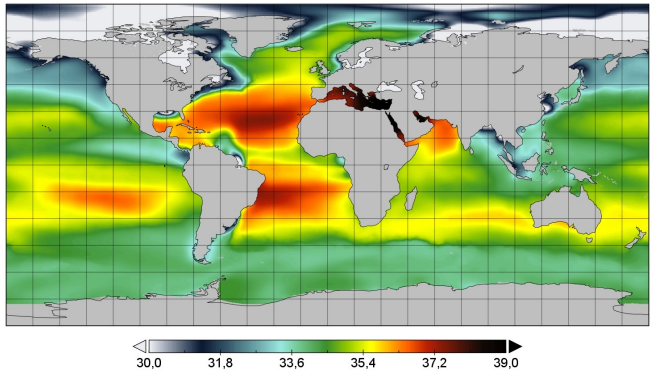


- The ARCTIC monthly climatology is obtained from daily surface salinity and temperature fields that have been extracted from the ARCTIC_MULTIYEAR_PHY_002_003 model from Copernicus portal (see also Xie et al. 2022 results)
- The global climatology is obtained from an upsize of the previous version of the global SSS/SSD L4 weekly product

sea surface salinity remapped at 1/8°

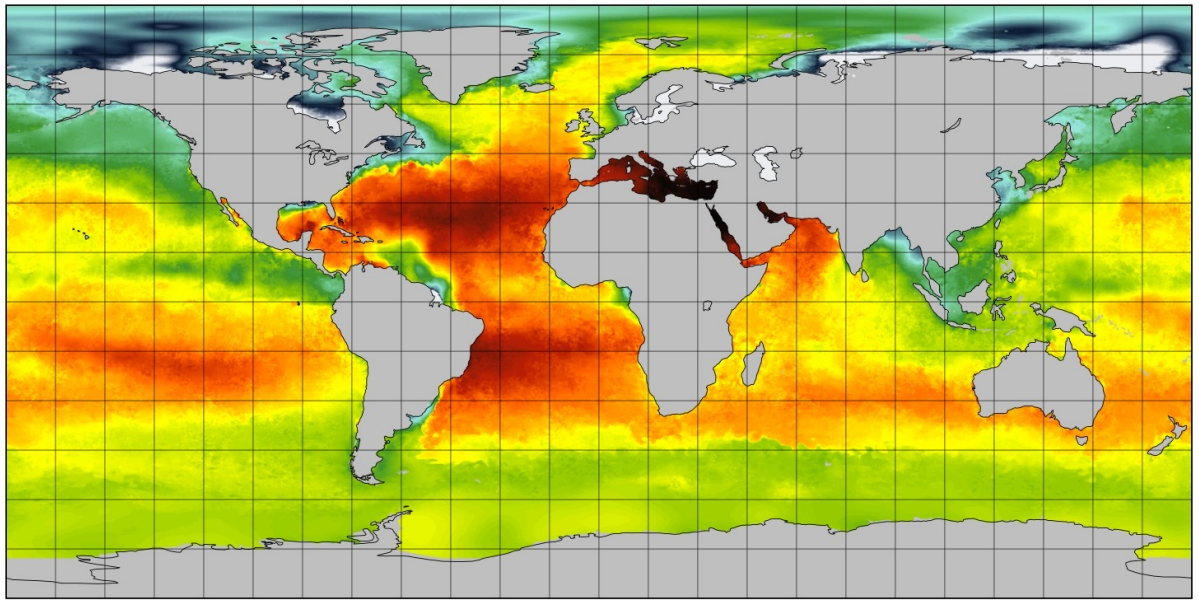


sea surface salinity remapped at 1/8°

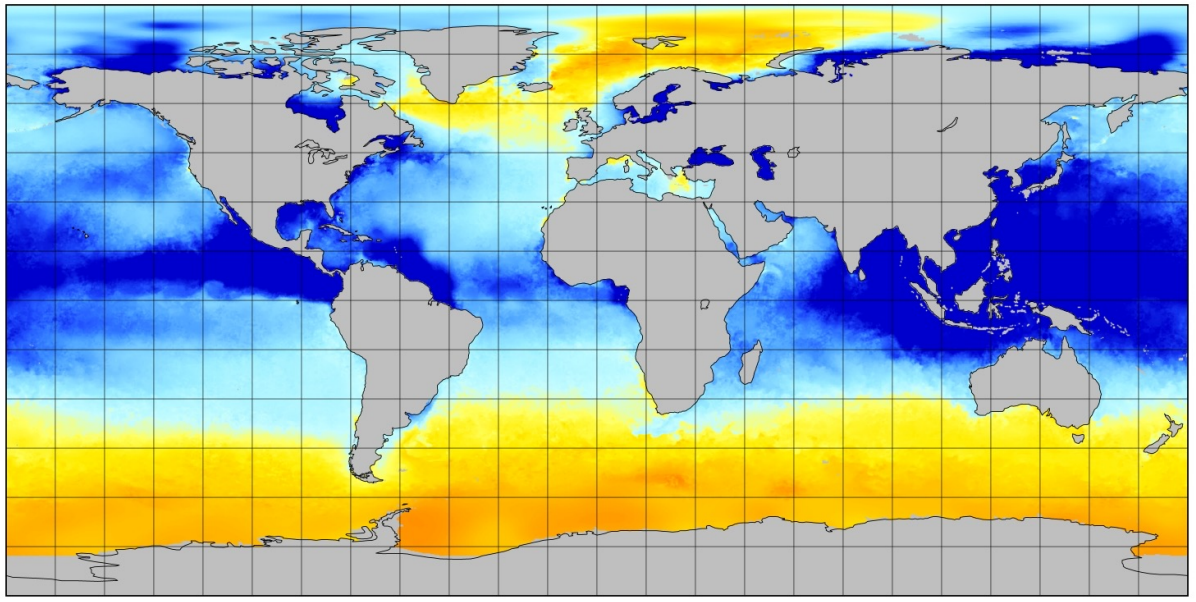


All 2D SSS/SSD fields are assessed by comparison with independent thermosalinograph (TSG) data extracted from INSITU_GLO_TS_ASSIM_REP_OBSERVATIONS_013_051 product.

Sea Surface Salinity L4 1/8°



Sea Surface Density L4 1/8°

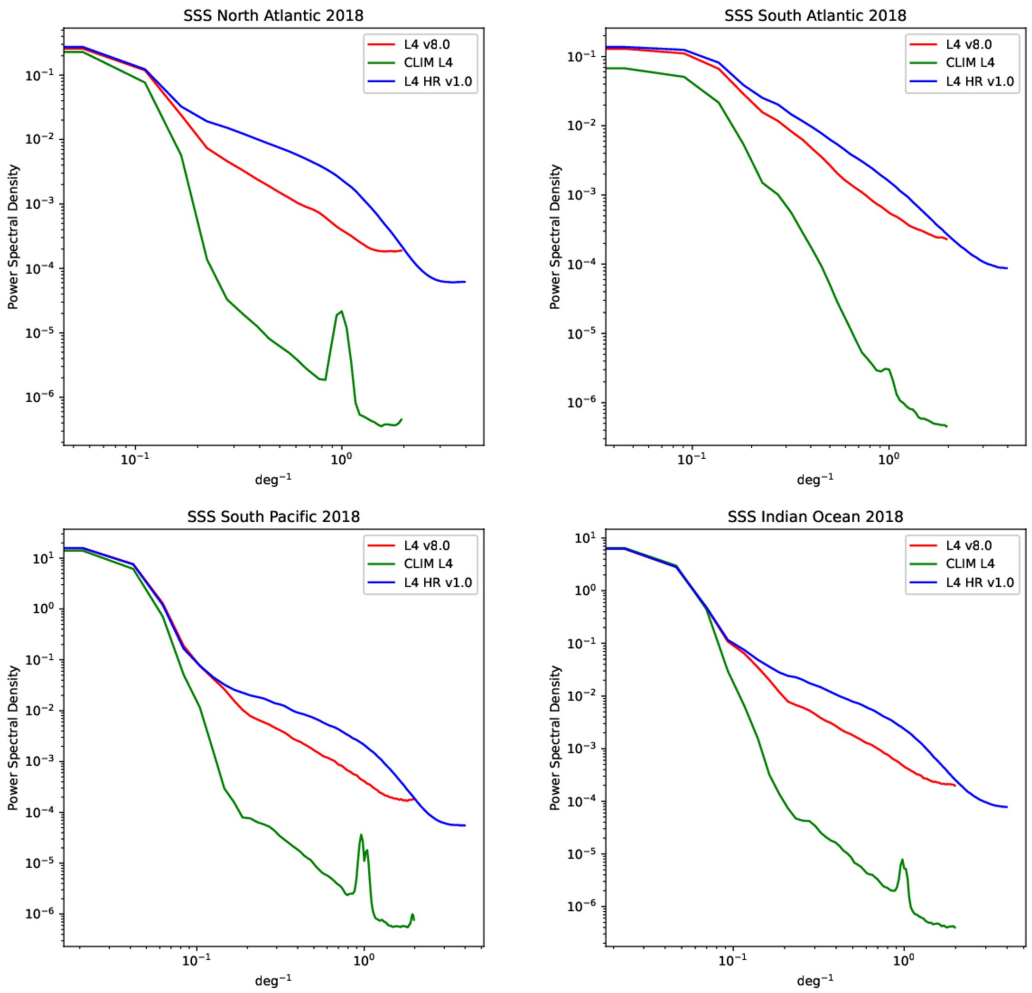


RMSD surface salinity (psu)	RMSD surface density (kg/m^3)
cmems_obs-mob_glo_phy-sss_my_multi_P1D	cmems_obs-mob_glo_phy-sss_my_multi_P1D
0.48±0.04 (0.79±0.02) *	0.38±0.03 (0.71±0.01)*

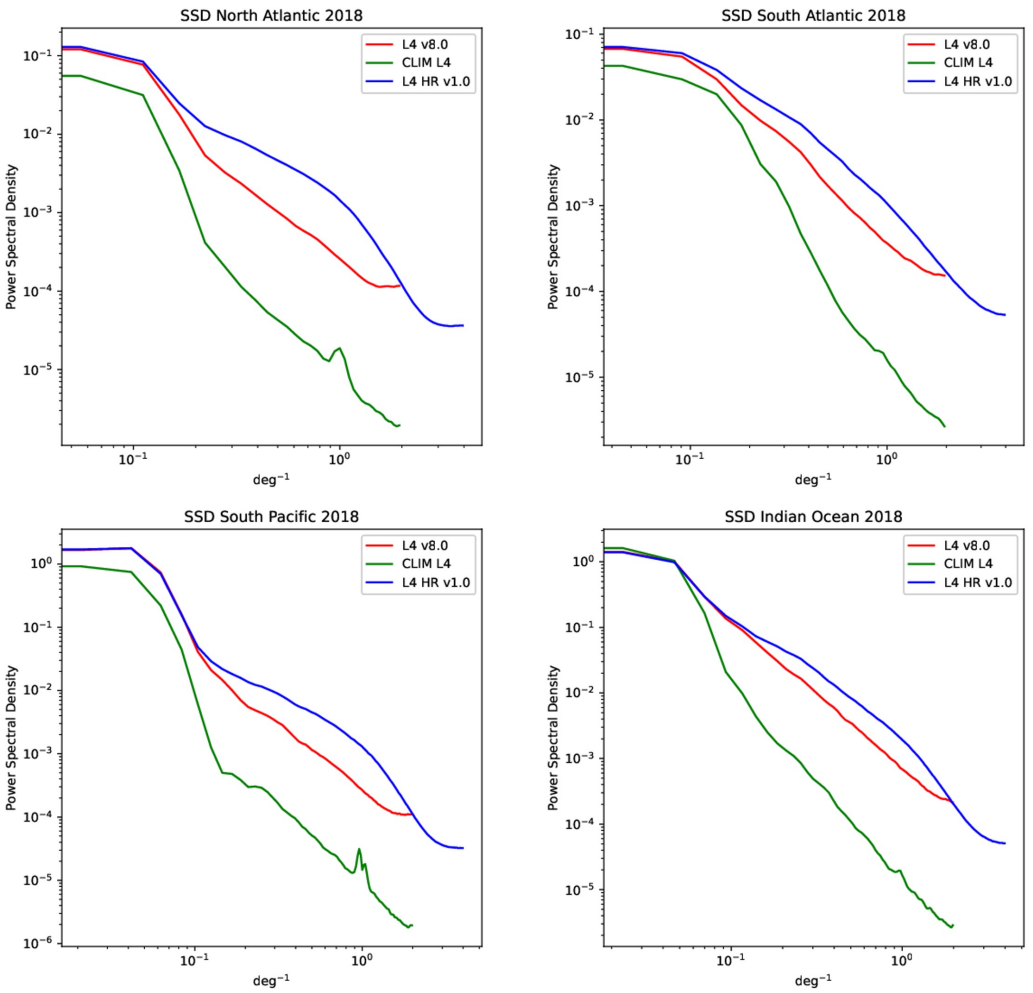
*Values in parentheses were obtained including coastal areas.

Table: RMSD between reprocessed surface salinity and density fields and independent TSG measurements (TSG matchups to data >200km offshore) over the period 2010-2019 (95% confidence intervals were estimated through bootstrapping) (QUID-Eis_Nov23).

SSS



SSD



As expected, the SSS/SSD PSD computed from the background field shows an abrupt variance drop already at low wavenumbers (<0.2 deg^{-1}). Conversely, the new Copernicus Marine Service SSS L4 v1.0 HR spectra (whatever the area considered) show the highest variance even at lower wavenumbers, with an effective resolution of about four/eight times the grid resolution.

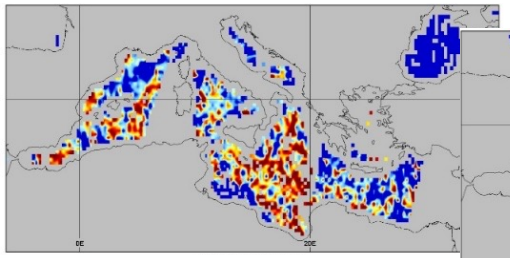
REGIONAL L4 daily SSS/SSD at 1/24° grid of resolution

- ***GOAL***

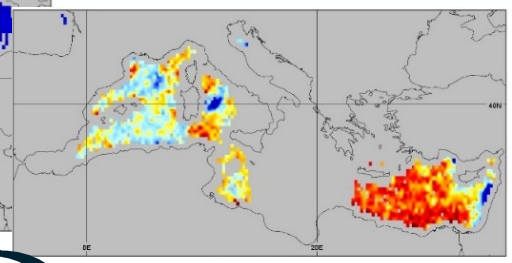
- Improve and optimize the SSS L4 fields based on the multivariate optimal interpolation algorithm, developed by Buongiorno Nardelli (2012, 2016) and tested by Sammartino et al. (2022), which combines in situ, SMOS, SMAP, HR SST data.
- Refined background with a focus on the main river mouth areas/Higher resolution

Product Name	4DMED_SSS_SSD_REP_2D
Geographical coverage	Mediterranean Sea [Lon -6.06° to 36.10°, Lat 30.27° to 45.99°]
Horizontal resolution	1/24°
Variables	Sea Surface Salinity, Sea Surface Salinity Error, Sea Surface Density, Sea Surface Density Error
Temporal coverage	From 2016 to 2022
Temporal resolution	Daily field
Number of vertical levels	1 level (0 m depth)
Format	Netcdf 4.0 CF1.7

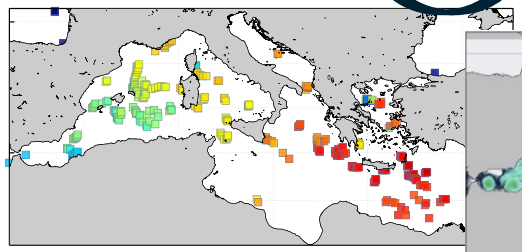
SMOS L3 SSS



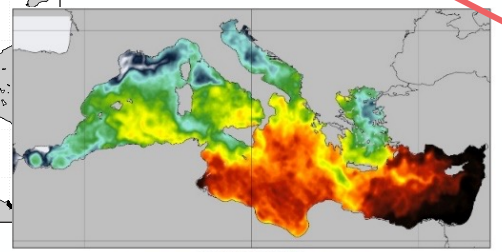
SMAP L3 SSS



IN SITU SSS



L4 UHR SST



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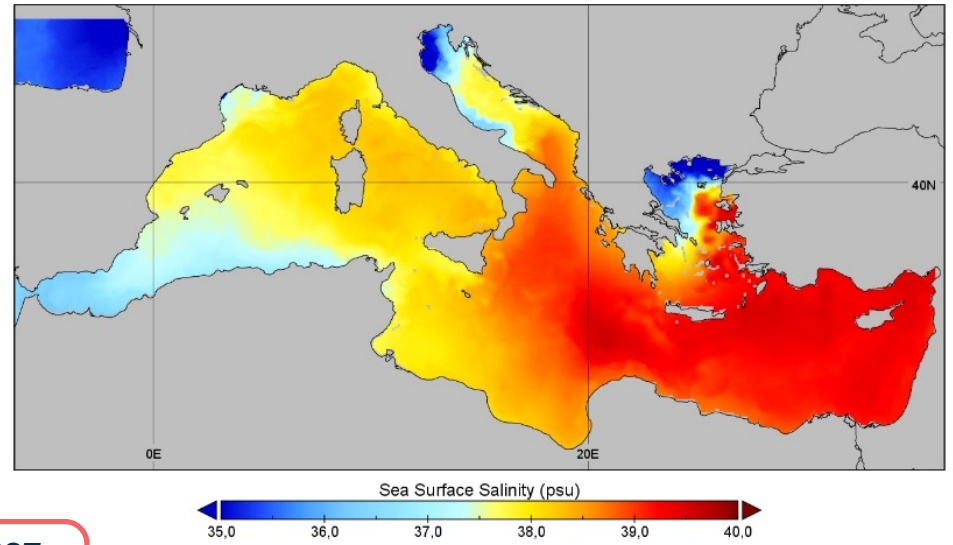
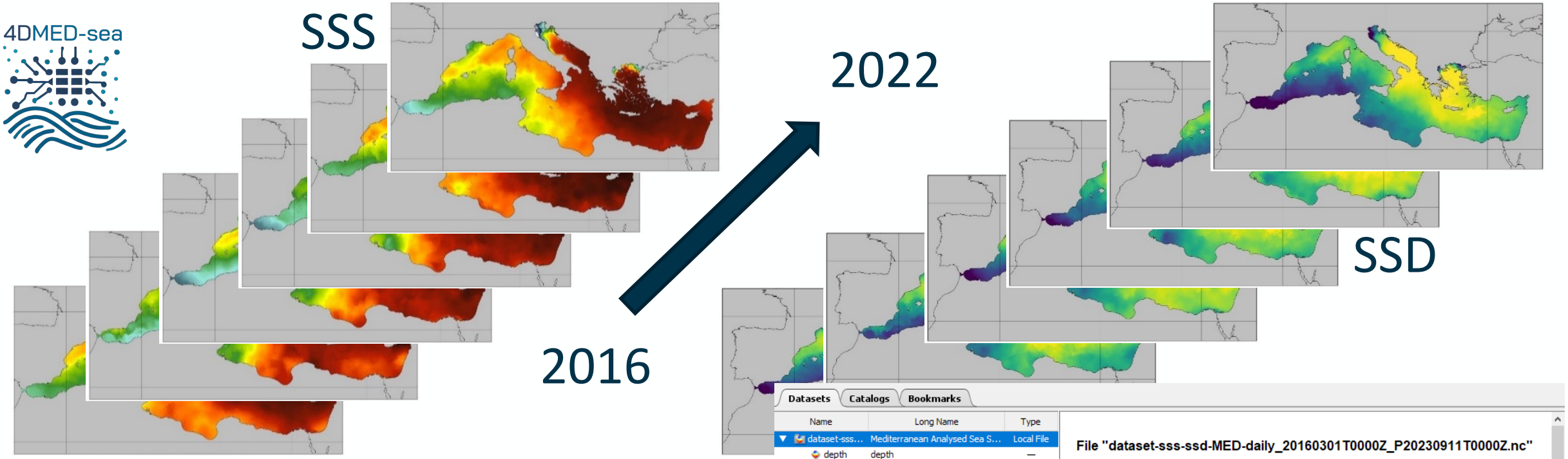
Future developments for L4 SST processing see poster of Sabatini M., CNR-ISMAR



Optimally Interpolated Med L4 SSS

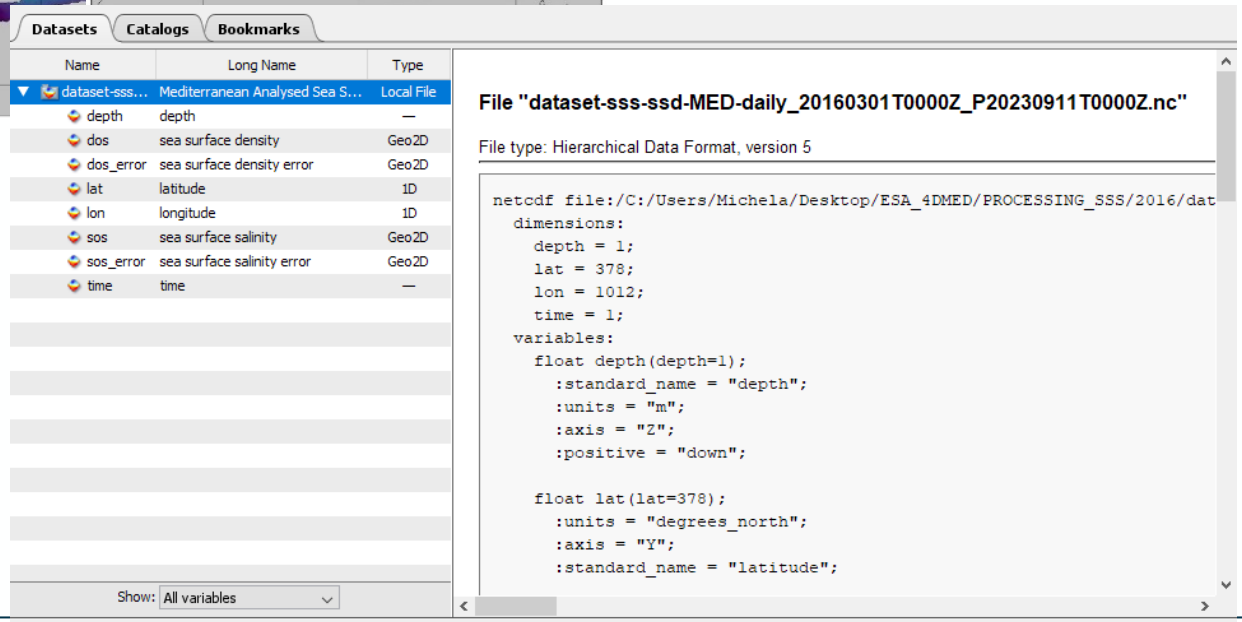
http://ricerca.ismar.cnr.it/4DMED/Project.html

4DMED-sea

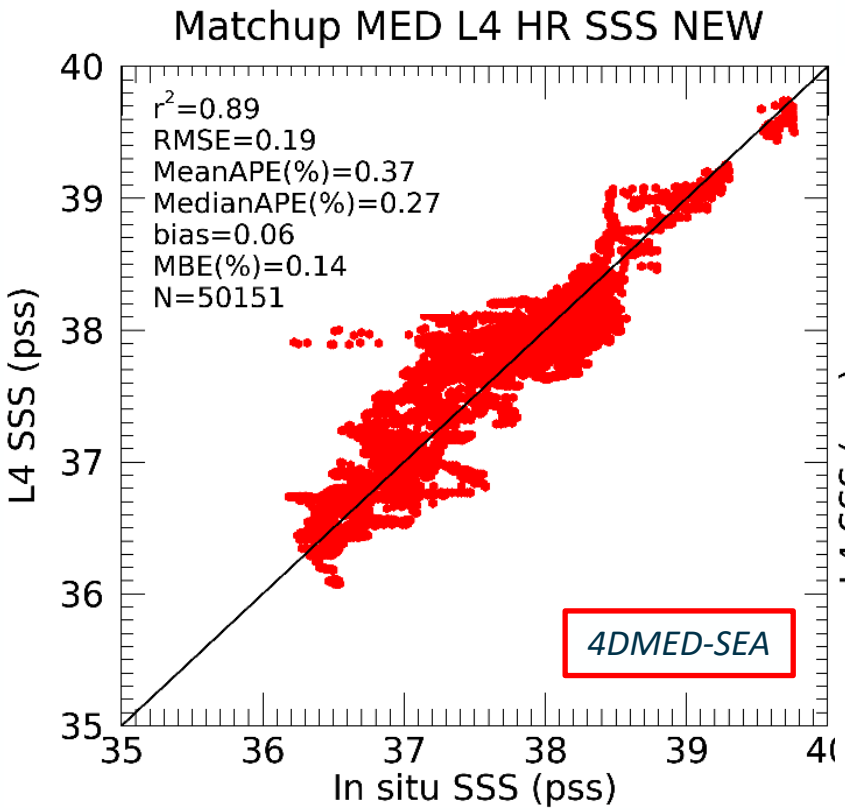


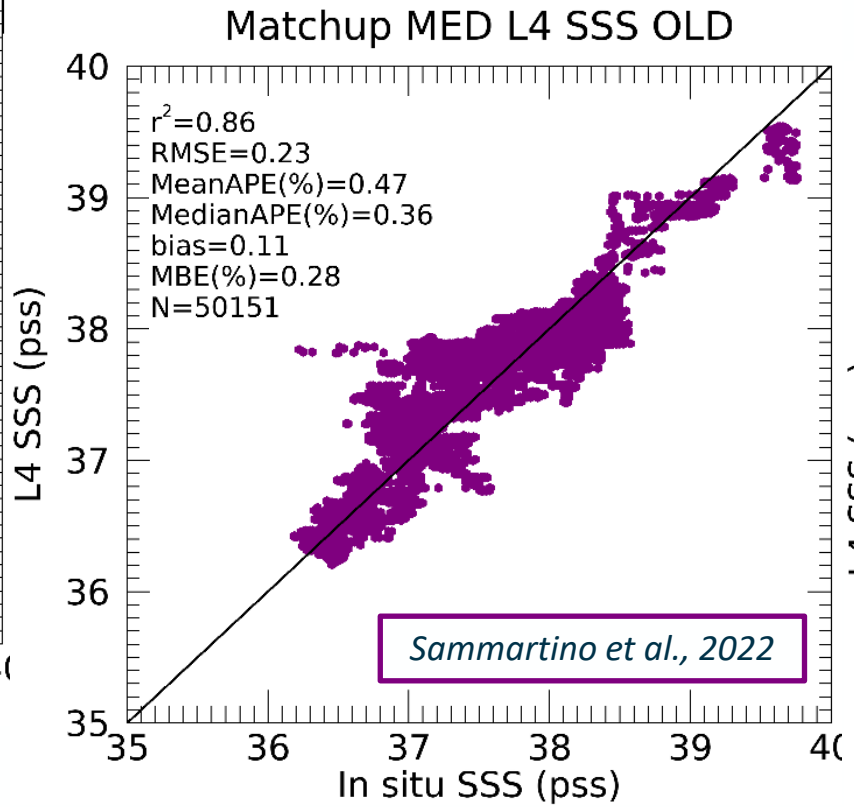
The dataset from 2016-2022 has been publicly released and is accessible in a netcdf format via the following Zenodo address: https://doi.org/10.5281/zenodo.10822461 and on the website of the project:
http://ricerca.ismar.cnr.it/4DMED/Project.html

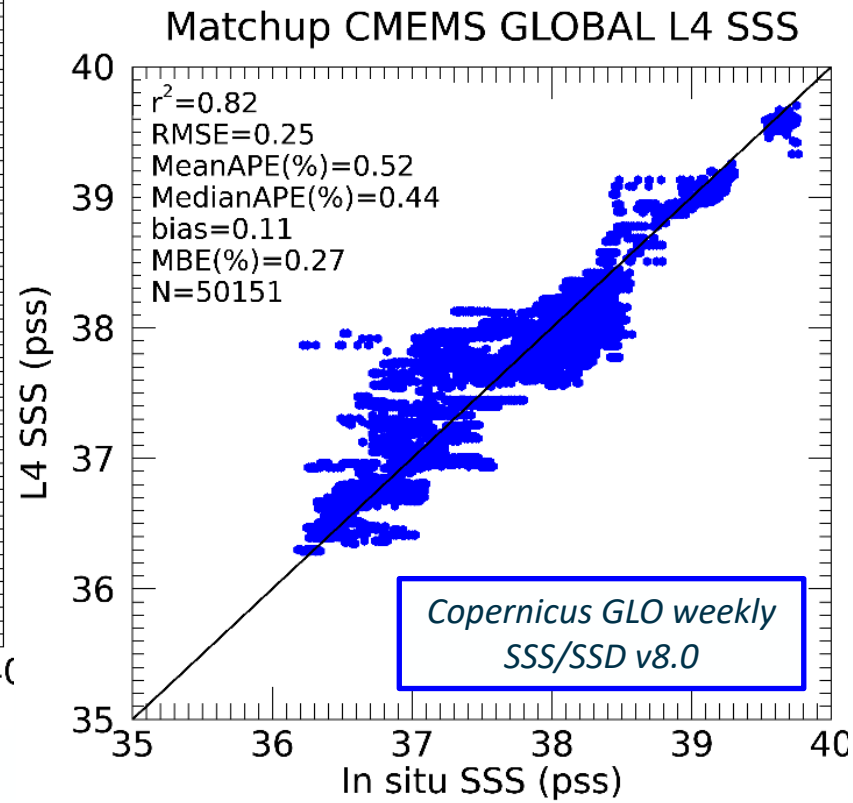
The time series has been extended back to 2008 within the context of ITINERIS project



A comparison against an independent TSG dataset for the year 2017-2018 has been carried out to evaluate the performances of the optimized algorithm with respect to the global (Copernicus GLO SSS/SSD weekly v8) and regional previous version of the dataset (Sammartino et al. 2022).

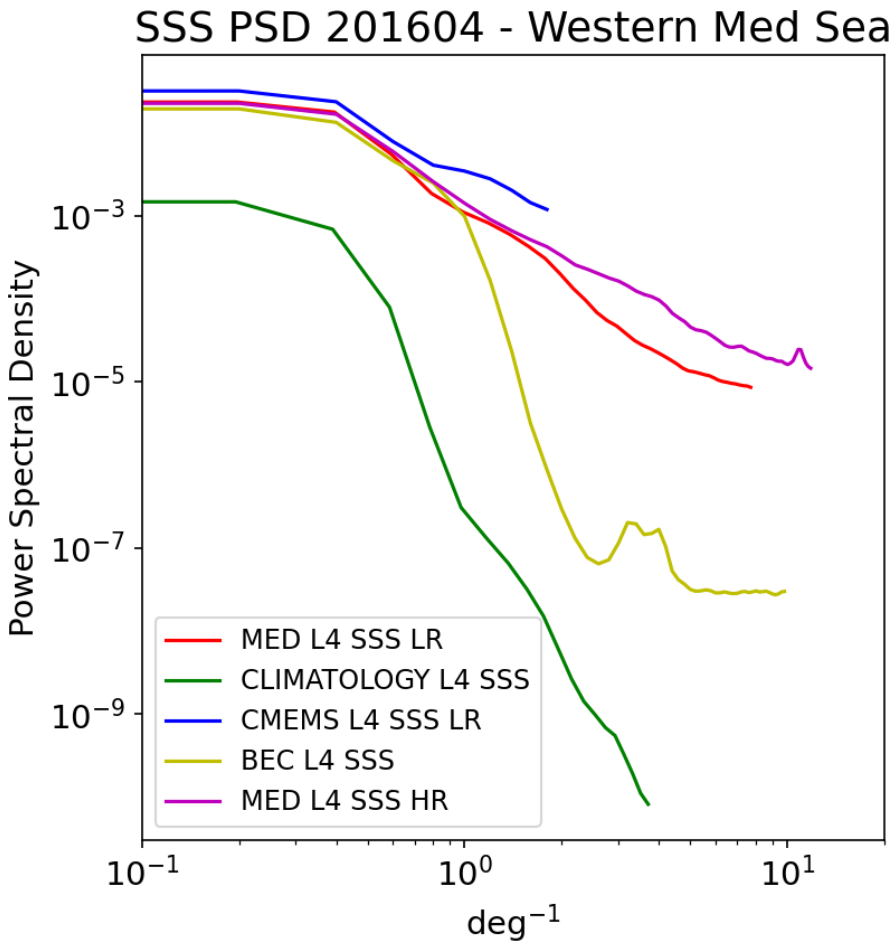


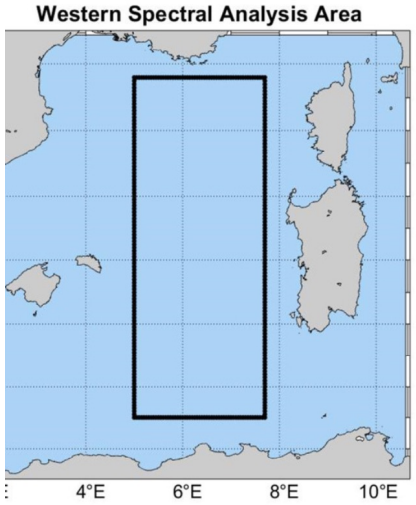




- The new SSS fields outperforms the other datasets

Power Spectral Density analysis





- In situ Climatology L4 SSS shows the steepest decrease among all the datasets (0,5 deg^{-1})
- BEC L4 SSS shows an abrupt drop, between 1–2 deg^{-1},with a variance that still decreases until smaller scales (>3 deg^{-1})
- MED HR shows the highest effective spatial resolution with respect the other datasets, followed by the MED LR.
- In the WestMedSea the MED HR shows highest spatial variance in the mesoscale (>2 deg^{-1}) than the MED LR.

- The combination of **in situ, multi-sensor satellite observations and HR SST** satellite data provide daily gap-free SSS maps that overcome the sparseness of in situ datasets;
- At Global scale the SSS/SSD L4 Global daily product (MULTIOBS_GLO_PHY_S_SURFACE_MYNRT_015_013) showed a **higher effective resolution** with respect to the previous version (v8.0);
- In the SSS/SSD L4 Global product there is still room for improvement for the estimate of SSS in **Arctic areas**,
- Compared with the global and previous regional version, the **new Med L4** SSS/SSD HR showed the best **statistics**;
- **Med Sea spatial power spectral density** analysis and the comparison with TSG data demonstrated that the new Med HR SSS/SSD L4 product improved in terms of the effective resolution (**mesoscale**);
- An estimate as much as possible accurate of SSS become crucial for the monitoring of the oceans, especially in enclosed basin such as **Med Sea** (**hot spot**) or remote and critical areas such as **Arctic Sea** where its estimate still remain challenging;
- Significant contributions from future satellite missions (e.g. **CIMR** - Copernicus Imaging Microwave Radiometer) will guarantee **continuity in space-based SSS monitoring** and accurate mesoscale-resolving L4 SSS analyses


Thank you for your attention!