Mesoscale Eddy Trajectory Atlas Product Handbook

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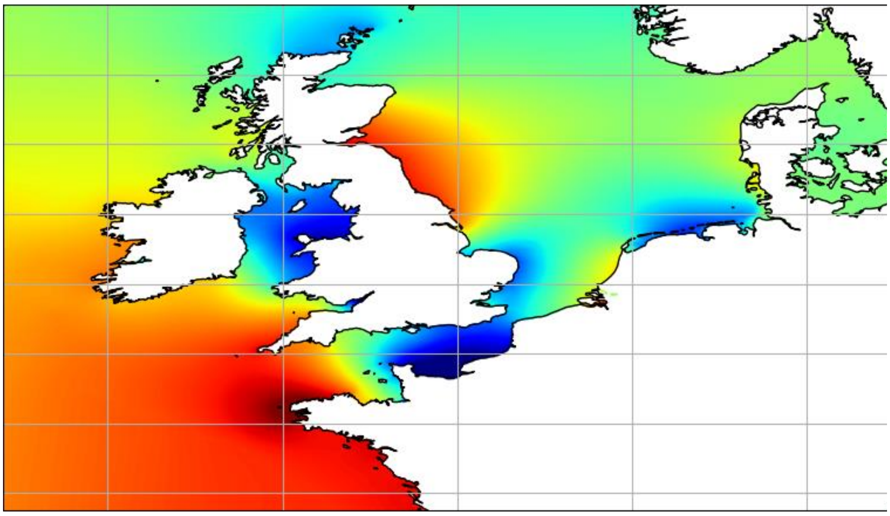

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Chronology Issues:		
Issue:	Date:	Reason for change:
1.0	10/06/2024	1st issue

List of Acronyms:

ADT	Absolute Dynamic Topography (=SLA+MDT)
AVISO+	Archivage, Validation et Interprétation des données des Satellites Océanographiques
CLS	Collecte Localisation Satellites
CMEMS	Copernicus Marine Environment Monitoring Service
CNES	Centre National d'Etudes Spatiales
CTOH	Centre de Topographie des Océans et de l'Hydrosphère
DUACS	Data Unification and Altimeter Combination System
FTP	File Transfer Protocol
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
MDT	Mean Dynamic Topography (difference between Mean Sea Surface (MSS) and Geoid)
NetCDF	Network Common Data Format
SLA	Sea Level Anomaly (a.k.a. sea surface height with respect to a mean sea surface)

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Contents

1. Overview of this document

This document is the user manual for the tidal model FES2022 (Finite Elements Solution) product. This product has been computed by LEGOS, NOVELTIS and CLS, in the frame of a CNES funded project.

2. The FES2022 product

2.1. Versioning of the AVISO+ FES2022 product

AVISO+ distributes the **FES2022b** product version. For clarity, the versioning of FES2022 product follows the one of FES2014:

FES2022a = ocean tide solution computed using FES2014 loading tide effects. This is an intermediate version within the tidal model computation and it is not distributed publicly.

FES2022b preliminary = ocean tide solution computed using FES2022 loading tide effects. Note that this FES2022b preliminary version (noted V1) was distributed only to some spatial agencies (EUMETSAT, ESA).

FES2022b = ocean tide solution computed using FES2022 loading tide effects and using an updated Lakes mask for extrapolated grids (as described in section 3.2).

2.2. Acknowledgments

When using the products, please cite in the text the following :

"The FES2022 Tide product was funded by CNES, produced by LEGOS, NOVELTIS and CLS and made freely available by AVISO". CNES, 2024. FES2022 (Finite Element Solution) Tidal model (Version 2024) [Data set]. CNES. https://doi.org/10.24400/527896/A01-2024.004"

A reference paper is in preparation and will be published soon:

Florent H. Lyard, Loren Carrere, Ergane Fouchet, Mathilde Cancet, David Greenberg, Gérald Dibarboure and Nicolas Picot: "FES2022 a step towards a SWOT-compliant tidal correction", to be submitted to Ocean Sciences.

2.3. User's feedback

Each and every question, comment, example of use, and suggestion will help us improve the future product. You're welcome to ask or send them to aviso@altimetry.fr.

3. Description of the model construction and performances

This section gives a brief description of the FES2022 model construction and performances. The method and the validation diagnostics are further described in a dedicated paper Lyard et al. (in preparation):

Lyard, F.H., Carrere, L., Fouchet, E., Cancet, M., Greenberg, D., Dibarboure, G. and Picot, N.: "FES2022 a step towards a SWOT-compliant tidal correction", in preparation, to be submitted to Ocean Sciences.

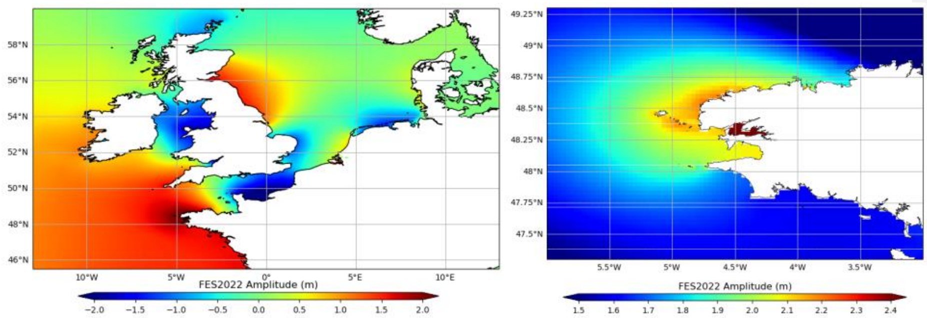

Figure 1: FES2022 total tide amplitude (m) for the date 2024-06-27T19:26:15.000000 with a zoom on the right

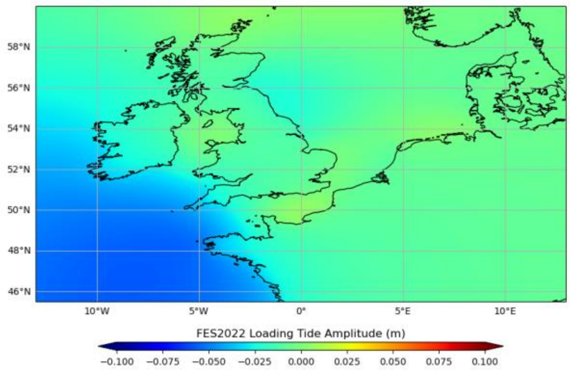

Figure 2: FES2022 load tide amplitude (m) for the date 2024-06-27T19:26:15.000000

3.1. Model construction

FES2022b computation followed a similar method as the one used for previous tidal solution FES2014b (Lyard et al. 2021).

First, an improved global bathymetry and higher resolution coastlines have been constructed based on identified FES2014b local weaknesses and many updates using local databases available. The reference global bathymetry for FES2022 is GEBCO 2020 database. Then many local or regional bathymetric databases have been either collected or produced within the FES2022 project and other CNES projects, and they have been combined to the global GEBCO database. Bathymetry modifications have been selected through the improvement of tidal test simulations.

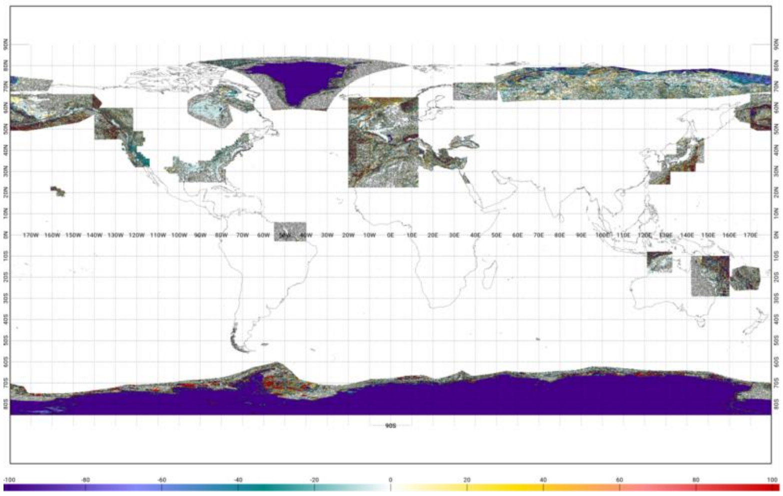

Figure 3: Difference between GEBCO 2020 and the final FES2022 composite bathymetry (m)

A new high resolution finite elements mesh has been computed with many refinements at global and local scales; the FES2022 global mesh has about twice more elements compared to FES2014b. The final FES2022 mesh has about 11 000 000 elements, which is about eight times more than the FES2014 grid.

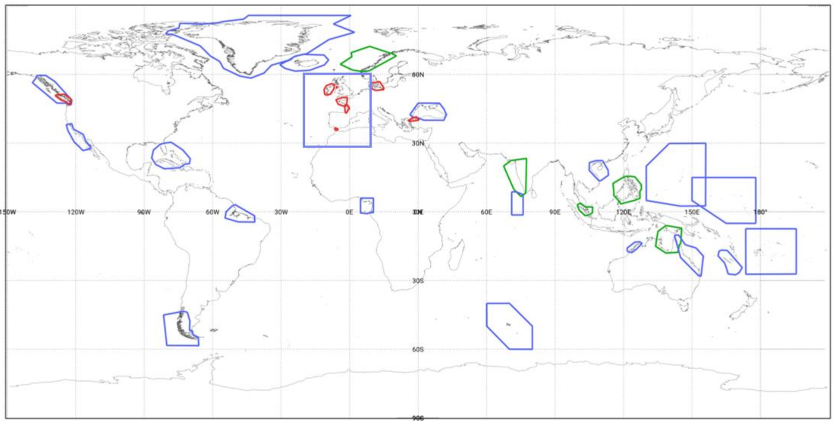

Figure 4: FES2022 mesh coastal refinement areas: 3km (green), 2km (blue), 1km to 500m locally (red)

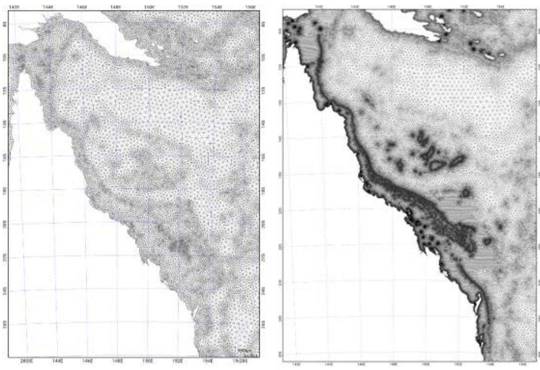

Figure 5: Example on the Great Barrier Reef : FES2014 mesh (left) and FES2022 mesh refined on the reef patterns (right)

A very accurate hydrodynamic solution has been estimated using the T-UGO model (Toulouse-Unstructured Grid Model; Lyard et al. 2006) and the new high resolution FE mesh described above. The model is used either in spectral mode or sequential one, depending on the waves computed. Several model parameters have been tuned to find an optimate hydrodynamic solution including the bottom friction coefficient and the internal tide wave-drag.

The new hydrodynamic solution shows a strong improvement compared to previous FES2014b version. The global RSS (Root Sum Square) to shelf crossovers database (TP-Jason tidal estimations) is reduced by 49 mm compared to FES2014 hydrodynamic solution.

Then, an improved assimilation dataset has been computed using both long-term altimetry time-series and tidal gauges measurements. The reference altimeter tidal database has been constructed using the following long-term missions: TP-J1-J2-J3, TPN-J1N-J2N and ERS-EN-AL, which span the period 1992-2020. All up-to-date altimetry standards for instrumental and geophysical corrections (L2P 2021, Lievin et al. 2020), including Zaron IT correction (2019) have been used. This new altimeter database allows a better quality of the tidal estimations, more points estimated and going closer to the coast.

As the reference altimeter missions are not available in polar regions, a specific tidal database for high-latitudes was also constructed using a combination of all high-latitudes altimeter measurements available.

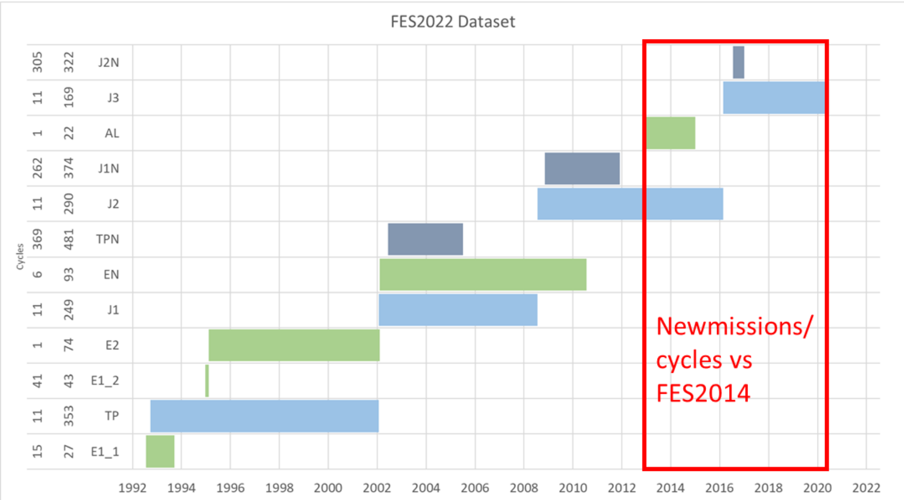

Figure 6: description of the altimeter database used to produce the new reference FES2022 tidal estimations

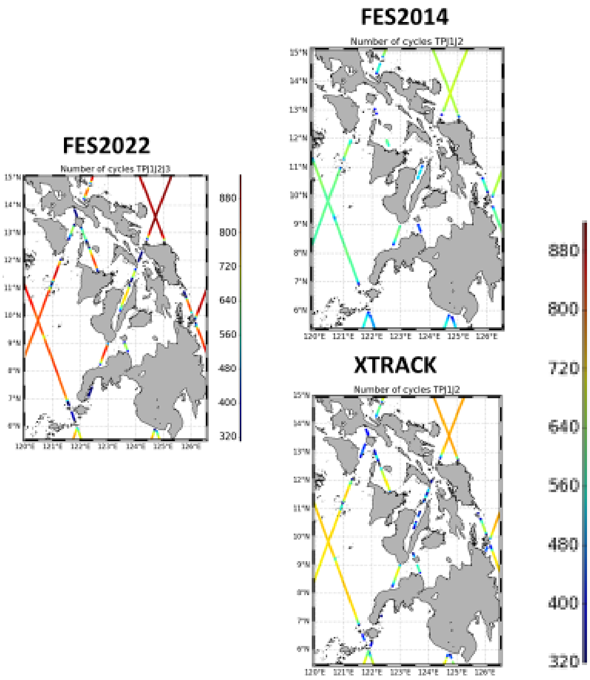

Figure 7: comparison of the coastal resolution of the different altimeter tidal estimations in the Philippines area: FES2022, FES2014 and XTRACK (LEGOS/CTOH: https://www.legos.omp.eu/ctoh/catalogue/?uuid=a9a22957-727e-4450-8243-ff4708021910 ; Birol et al. 2017).

A specific assimilation ensemble of simulations has been constructed using regional perturbations on bottom friction coefficient, on wave-drag coefficient and on bathymetry.

The FES2022 model has been constrained through assimilation for 16 tidal components listed below. However, only a limited selection of altimeter and tidal gauges tidal data have been assimilated in the model to compute an optimized tidal solution (cf. Figure 8 and Table 1). Moreover, all tidal constituents are not constrained at each assimilated location, as the smallest tidal constituents can be more difficult to accurately estimate.

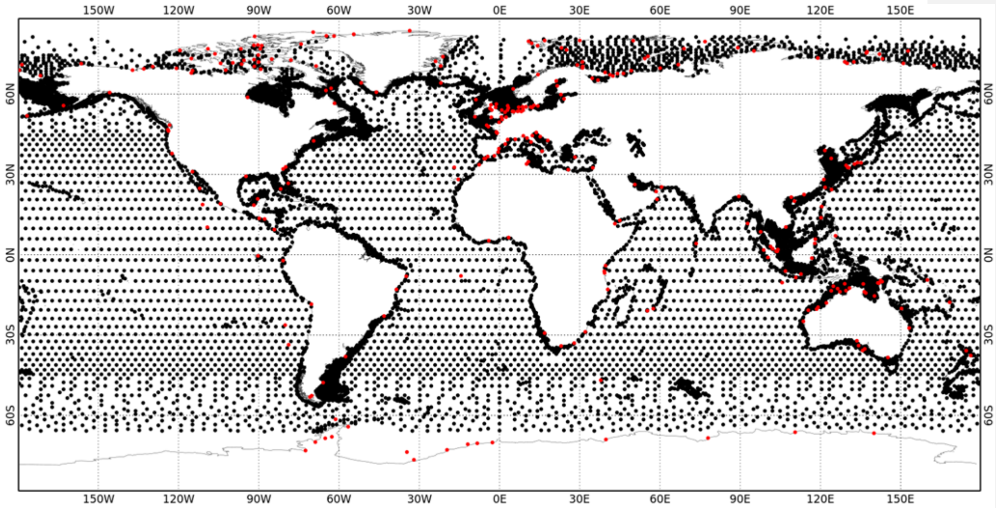

Figure 8: localization of the data assimilated in the FES2022 tidal solution: altimeter data in black and tidal gauges in red.

Assimilated data	FES2014b	FES2022
Altimetry points	12 022	13 489
Tide gauges	600	295

Table 1: number of measurements assimilated in the FES tidal solutions

The FES2022 ocean tide atlas in composed of 34 waves computed as follows:

- 16 assimilated waves: M2, S2, K1, O1, P1, Q1, Nu2, Mu2, N2, K2, Eps2, L2, Lambda2, M4, 2N2 and J1
- 18 non assimilated waves, computed from the sequential simulation using FES2022 tide loading: M3, M6, M8, Mf, MKS2, Mm, MN4, MS4, MSf, MSqm, Mtm, N4, R2, S1, S4, Sa, Ssa, T2

To provide a FES2022 geocentric tide solution for altimeter data correction, a new loading tide solution has also been estimated to guaranty the compatibility of the tide solution with FES2022 ocean tide solution. The FES2022 ocean loading tide atlas (radial component) is also composed of 34 waves computed as follows:

- 16 waves computed from FES2022a assimilated solution: M2, S2, K1, O1, P1, Q1, Nu2, Mu2, N2, K2, Eps2, L2, Lambda2, M4, 2N2 and J1
- 18 waves computed from the FES2022a sequential atlas: M3, M6, M8, Mf, MKS2, Mm, MN4, MS4, MSf, MSqm, Mtm, N4, R2, S1, S4, Sa, Ssa, T2

Note that the construction of a global geocentric tide model is an iterative process to take into account the tidal loading effects with accuracy. Two iterations were needed to perform the final FES2022b solution:

FES2022a = ocean tide assimilated solution computed using altimeter data corrected from FES2014 loading tide effects. This is an intermediate version within the tidal model computation, and it is not distributed publicly.

The FES2022a ocean tide solution was used to compute the FES2022 loading tide solution.

FES2022b = ocean tide assimilated solution computed using altimeter data corrected from FES2022 loading tide effects.

To ease distribution and use, the tidal atlases are interpolated and distributed on a cartesian regular grid of 1/30°, which allows keeping a good local accuracy compared to the FE native grid.

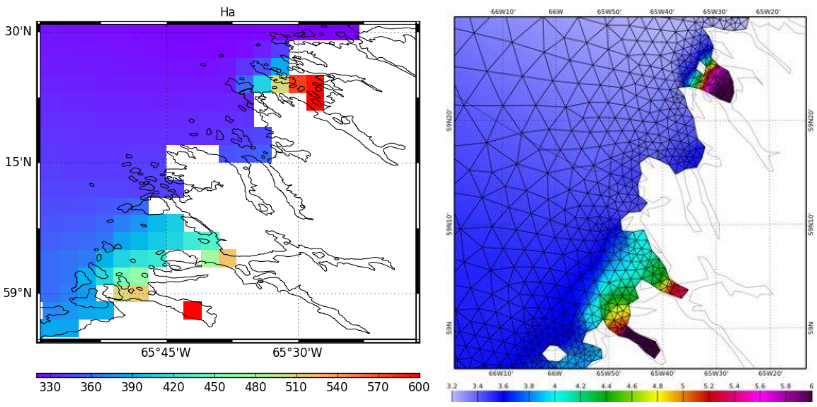

Figure 9: comparison of the cartesian and finite element grids - zoom in a fjord north of Canada

3.2. Description of the extrapolated procedure

An extrapolation procedure is applied on ocean tide cartesian grids. This extrapolation aims at minimizing missing ocean tide solution in coastal regions and particularly in fjords or estuaries that are not well sampled by the native global FES mesh.

A basic extrapolation procedure is performed over 20 pixels over the coasts (cf example on figure below). Then a global lakes and enclosed seas mask is applied to ensure that a zero tide correction is applied on these surfaces (cf example below). The lakes mask has been refined compared to FES2014.

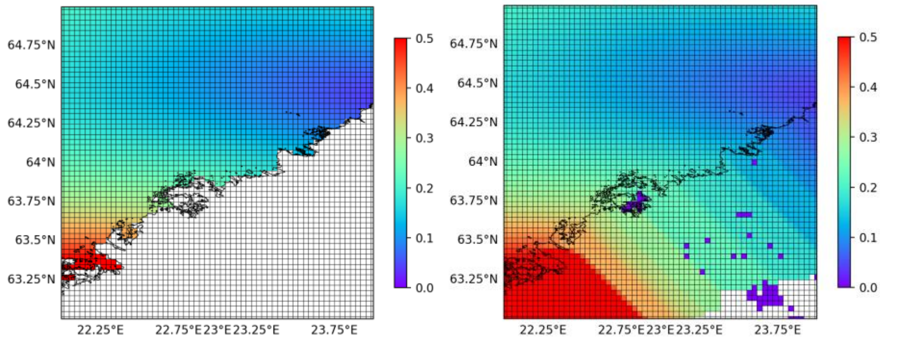

Figure 10: M2 amplitude (m) on the cartesian grid (left) and the extrapolated cartesian grid (right) on the Finland coast

Note that a specific mask file is provided to indicate which points of the cartesian grid come from the native grid or from the extrapolation procedure (cf Figure 11).

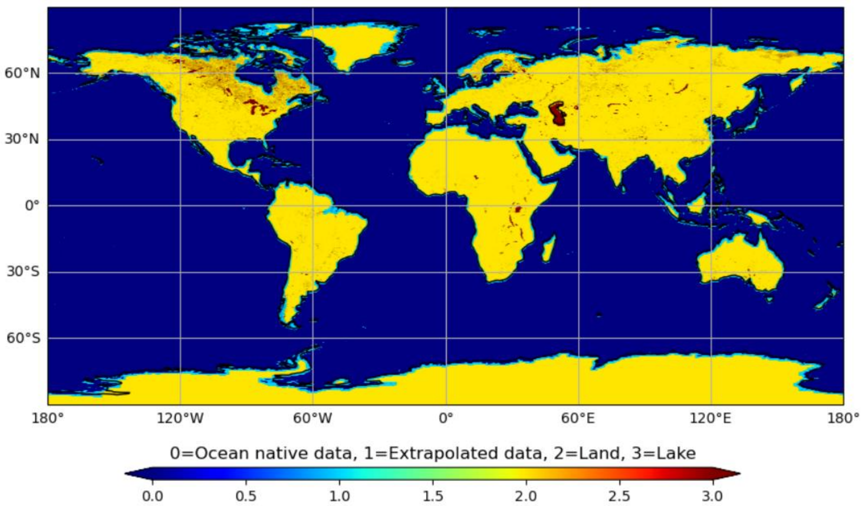

Figure 11: mask file provided for FES2022B grids.

3.3. Model performances

When compared to other available global tidal models, the new solution FES2022 performs very well particularly in shallow waters regions and in coastal and polar seas (cf Figures below).

Note that the significant improvement noted in coastal seas is likely explained by the more realistic reference level used in FES2022 (2m) compared to FES2014 (10m), in particular for regions where the bathymetry database is accurate enough.

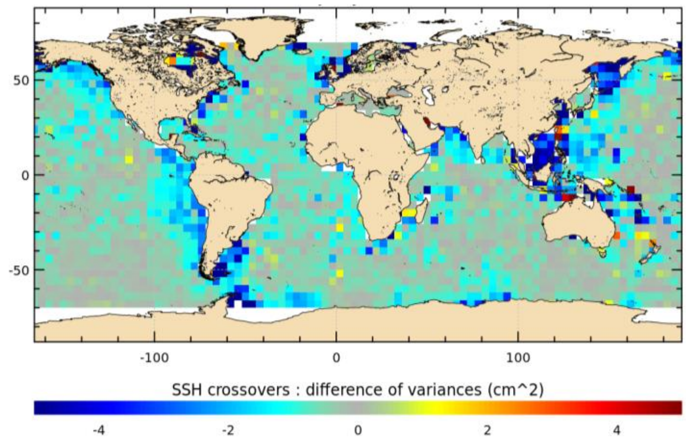

Figure 12: maps of reduction of Jason-3 SSH crossovers variance when using the new FES2022b tidal model instead of FES2014b model (in cm²). Blue regions indicate a significant variance reduction when using the new FES2022b model.

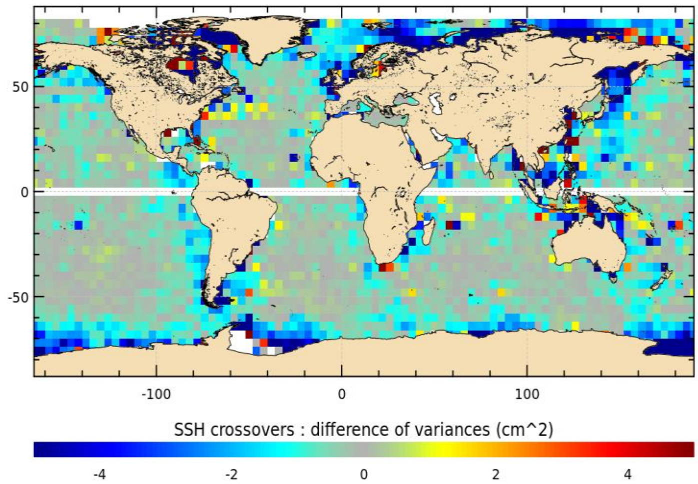

Figure 2: maps of reduction of S3A SSH crossovers variance when using the new FES2022b tidal model instead of FES2014b model (in cm²). Blue regions indicate a significant variance reduction when using the new FES2022b model. A strong variance reduction is also noted in polar seas in northern and southern hemispheres.

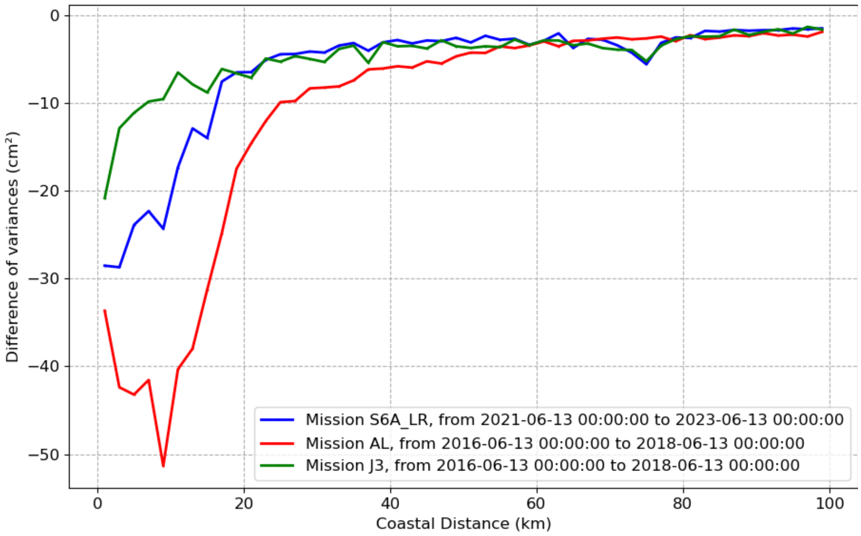

Figure 13: SLA variance difference when using FES2022b tide model instead of FES2014b as a function of coastal distance, for 3 altimeter missions, in cm². The variance reduction when using FES2022b model is very significant when we get closer to the coast (distance < 60km).

3.4. Main improvements compared to FES2014b

Main improvements compared to previous FES2014b tidal solutions are listed below:

- Improved bathymetry in many shallow waters and coastal areas;
- Globally enhanced and refined high-resolution mesh:
  - Off shore resolution : 30 km
  - Shelf resolution : 10 km
  - Coastal resolution : 4 km and until 2km-500m locally
  - FES2022 mesh has about 11 000 000 elements, about eight times more than the FES2014 grid
- Globally enhanced altimeter and tidal gauges datasets:
  - Altimeter tidal estimations are derived from long-term altimeter time-series (1993-2020), using up-to-date altimetry standards for instrumental and geophysical corrections (Lievin et al. 2020). This new altimeter database allows a better quality of the tidal estimations, more points estimated and going closer to the coast.
  - A more complete and validated TG database has been prepared for the project.
  - A part of these datasets was used for the assimilation process and most of the data were used for the validation process;
- Improved T-UGO model version for both the spectral and sequential modes
- Improved assimilation ensembles simulations

4. Description of the FES 2022 product

4.1. Product general content and specifications

Thirty-four barotropic tide components are available for download, for 2 variables:

- FES2022 ocean tide elevations
- FES2022 ocean loading tide

List of the 34 waves included in FES2022 tidal spectrum:

- 19 Main Tides: 2N2, Eps2, J1, K1, K2, L2, Lambda2, M2, M3, Mu2, N2, Nu2, O1, P1, Q1, R2, S1, S2, T2
- 6 Long Period Tides: Mf, Mm, MSqm, Mtm, Sa, Ssa
- 9 Non linear Tides: M4, M6, M8, MKS2, MN4, MS4, Msf, N4, S4

The data are distributed on a regular cartesian grid with 2-minutes resolution. Each file contains amplitude and phase for one wave.

Concerning Ocean Tide Elevations, we provide:

1. The 2-minutes cartesian grids directly interpolated from the native finite element grid;
2. The extrapolated 2-minutes cartesian grids computed from the n°1 grid above (see section 3.2). A mask file is also provided to indicate the pixel that have been interpolated in the n°2 grid.

The prediction algorithm is also distributed on AVISO+, to compute tidal amplitudes at any location of the world ocean. More details are given in the following section 4.2

4.2. Prediction algorithm

The official tidal prediction algorithm, **LIBFES**, is available here:
https://github.com/CNES/aviso-fes/tree/2.9.7

The LIBFES library has the following characteristics:

- C code with some python scripts examples
- Uses the Schureman definitions for the astronomic angles
- Deals with cartesian grids only

The official version **v2.9.7** must be used to compute FES2022B tide.
This version of the algorithm can read all the FES2022 cartesian grids: elevation and loading tide. We guarantee the results obtained with this code, but not if using any other prediction code.

To use the code, please cite: "The code used to compute FES2022, was developed in collaboration between Legos, CLS and CNES and is available under GNU General Public License".

4.3. Nomenclature of files

4.3.1. Gridded product: structure and semantic of provided NetCDF files

In addition to the conventions described above, the files are using a common structure and semantic:

XX_fes2022.nc.xz with XX = WAVE and with a xz compression

4.4. NetCDF

The products are stored using the NetCDF CF format. NetCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The NetCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. The NetCDF software was developed at the Unidata Program Center in Boulder, Colorado. The NetCDF libraries define a machine-independent format for representing scientific data. Please see Unidata NetCDF pages for more information on the NetCDF software package: http://www.unidata.ucar.edu/packages/netcdf/

NetCDF data is:

- Self-Describing. A NetCDF file includes information about the data it contains.
- Architecture-independent. A NetCDF file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers.
- Direct-access. A small subset of a large dataset may be accessed efficiently, without first reading through all of the preceding data.
- Appendable. Data can be appended to a NetCDF dataset along one dimension without copying the dataset or redefining its structure. The structure of a NetCDF dataset can be changed, though this sometimes causes the dataset to be copied.
- Sharable. One writer and multiple readers may simultaneously access the same NetCDF file.

The NetCDF version provided here is version 4 “classic”.

4.5. Structure and semantic of NetCDF files

You will find hereafter the definitions of the variables defined in the FES2022 product. The variables are the same for the all types of files delivered.

Name of variable	Type	Content	Unit
latitude	int	Latitude value of measurements	degrees_north
longitude	int	Longitude value of measurements	degrees_east
amplitude	float	Sea surface height amplitude due to non equilibrium ocean tide at XX frequency	cm
phase	float	Sea surface height phaselag due to non equilibrium ocean tide at XX frequency	degrees

Table 2. Overview of the FES2022 tidal elevation files (with XX=WAVE)

Name of variable	Type	Content	Unit
latitude	int	Latitude value of measurements	degrees_north
longitude	int	Longitude value of measurements	degrees_east
amplitude	float	Loading tide amplitude at XX frequency	cm
phase	float	Loading tide phase at XX frequency	degrees

Table 3. Overview of the FES2022 loading tide files (with XX=WAVE)

Name of variable	Type	Content	Unit
latitude	int	Latitude value of measurements	degrees_north
longitude	int	Longitude value of measurements	degrees_east
mask	float	Mask : 0=Ocean native data, 1=Extrapolated data, 2=Land, 3=Lake	-

Table 4. Overview of the FES2022 mask file

5. How to download a product

5.1. Registration

To access data, registration is required. During the registration process, the user shall accept using license for the use of AVISO+ products and services.

- if not registered on AVISO+, please, fill the form and select the product 'FES (Finite Element Solution - Oceanic Tides Heights)' on http://www.aviso.altimetry.fr/en/data/data-access/registration-form.html
- if already registered on AVISO+, please request the addition of this 'FES (Finite Element Solution - Oceanic Tides Heights)' on your personal account on https://www.aviso.altimetry.fr/en/my-aviso-plus.html (in page 'My Products')

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5.2. Access Services

Note that once your registration is processed (see above), AVISO+ will validate your registration by e-mail as soon as possible (within 5 working days during working hours, Central European Time). The access information will be available in your personal account on https://www.aviso.altimetry.fr/en/my-aviso-plus.html.

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7. Appendix A. Product header

7.1. Ocean tide file

```
netcdf m4_fes2022 {
dimensions:
	lat = 5401 ;
	lon = 10801 ;
	nv = 2 ;
variables:
	int nv(nv) ;
		nv:_FillValue = 2147483647 ;
		nv:comment = "Vertex" ;
		nv:units = "1" ;
	double lat(lat) ;
		lat:_FillValue = 1.84467440737096e+19 ;
		lat:long_name = "latitude" ;
		lat:units = "degrees_north" ;
		lat:bounds = "lat_bnds" ;
		lat:valid_min = -90. ;
		lat:valid_max = 90. ;
		lat:axis = "Y" ;
	double lon(lon) ;
		lon:_FillValue = 1.84467440737096e+19 ;
		lon:long_name = "longitude" ;
		lon:units = "degrees_east" ;
		lon:bounds = "lon_bnds" ;
		lon:valid_min = 0. ;
		lon:valid_max = 0. ;
		lon:axis = "X" ;
	float phase(lat, lon) ;
		phase:_FillValue = 1.844674e+19f ;
		phase:long_name = "Sea surface height phaselag due to non equilibrium ocean tide
at M4 frequency" ;
		phase:grid_mapping = "crs" ;
		phase:coordinates = "longitude latitude" ;
		phase:units = "degrees" ;
	float amplitude(lat, lon) ;
		amplitude:_FillValue = 1.844674e+19f ;
		amplitude:long_name = "Sea surface height amplitude due to non equilibrium
ocean tide at M4 frequency" ;
		amplitude:grid_mapping = "crs" ;
		amplitude:coordinates = "longitude latitude" ;
		amplitude:units = "cm" ;
	float lon_bnds(lon, nv) ;
		lon_bnds:_FillValue = 1.844674e+19f ;
```

```
		lon_bnds:comment = "longitude values at the west and east bounds of each pixel."
;
		lon_bnds:units = "degrees_east" ;
	float lat_bnds(lat, nv) ;
		lat_bnds:_FillValue = 1.844674e+19f ;
		lat_bnds:comment = "latitude values at the north and south bounds of each pixel."
;
		lat_bnds:units = "degrees_north" ;
	int crs ;
		crs:_FillValue = 2147483647 ;
		crs:grid_mapping_name = "latitude_longitude" ;
		crs:semi_major_axis = 6378136.3 ;
		crs:inverse_flattening = 298.257 ;
		crs:comment = "This is a container variable that describes the grid_mapping used
by the data in this file. This variable does not contain any data; only information about the
geographic coordinate system." ;

// global attributes:
		:license = "https://www.aviso.altimetry.fr/en/data/data-
access/fileadmin/documents/data/License_Aviso.pdf" ;
		:title = "FES2022 tide elevations" ;
		:product_version = "b" ;
		:summary = "New global barotropic tide solution using finite element mesh, T-UGO
barotropic model and data assimilation of altimetry and tidal gauges" ;
		:project = "FES2022" ;
		:cdm_data_type = "Grid" ;
		:contact = "aviso@altimetry.fr" ;
		:references =
"https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_FES2022.pdf" ;
		:Conventions = "CF-1.6" ;
		:credits = "authors : LEGOS, NOVELTIS, CLS ; owner : CNES" ;
		:date_created = "2024-05-16 08:15:03" ;
		:history = "2024-05-16 08:15:03:creation" ;
		:geospatial_lat_resolution = 0.0333333333333314 ;
		:geospatial_lat_units = "degrees_north" ;
		:geospatial_lon_resolution = 0.0333333333333333 ;
		:geospatial_lon_units = "degrees_east" ;
		:doi = "10.24400/527896/a01-2024.004" ;
}
```

7.2. Load tide file

```
netcdf n2_fes2022 {
dimensions:
	lat = 5401 ;
```

```
    lon = 10801 ;
    nv = 2 ;
variables:
    int nv(nv) ;
        nv:_FillValue = 2147483647 ;
        nv:comment = "Vertex" ;
        nv:units = "1" ;
    double lat(lat) ;
        lat:_FillValue = 1.84467440737096e+19 ;
        lat:long_name = "latitude" ;
        lat:units = "degrees_north" ;
        lat:bounds = "lat_bnds" ;
        lat:valid_min = -90. ;
        lat:valid_max = 90. ;
        lat:axis = "Y" ;
    double lon(lon) ;
        lon:_FillValue = 1.84467440737096e+19 ;
        lon:long_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:bounds = "lon_bnds" ;
        lon:valid_min = 0. ;
        lon:valid_max = 360. ;
        lon:axis = "X" ;
    float phase(lat, lon) ;
        phase:_FillValue = 1.844674e+19f ;
        phase:long_name = "Loading tide phase at N2 frequency" ;
        phase:grid_mapping = "crs" ;
        phase:coordinates = "longitude latitude" ;
        phase:units = "degrees" ;
    float amplitude(lat, lon) ;
        amplitude:_FillValue = 1.844674e+19f ;
        amplitude:long_name = "Loading tide amplitude at N2 frequency" ;
        amplitude:grid_mapping = "crs" ;
        amplitude:coordinates = "longitude latitude" ;
        amplitude:units = "cm" ;
    float lon_bnds(lon, nv) ;
        lon_bnds:_FillValue = 1.844674e+19f ;
        lon_bnds:comment = "longitude values at the west and east bounds of each pixel."
;
        lon_bnds:units = "degrees_east" ;
    float lat_bnds(lat, nv) ;
        lat_bnds:_FillValue = 1.844674e+19f ;
        lat_bnds:comment = "latitude values at the north and south bounds of each pixel."
;
        lat_bnds:units = "degrees_north" ;
    int crs ;
```

crs:_FillValue = 2147483647 ;
crs:grid_mapping_name = "latitude_longitude" ;
crs:semi_major_axis = 6378136.3 ;
crs:inverse_flattening = 298.257 ;
crs:comment = "This is a container variable that describes the grid_mapping used by the data in this file. This variable does not contain any data; only information about the geographic coordinate system." ;

// global attributes:
:license = "https://www.aviso.altimetry.fr/en/data/data-access/fileadmin/documents/data/License_Aviso.pdf" ;
:title = "FES2022 loading tide" ;
:product_version = "b" ;
:summary = "New global loading tide solution computed from the FES2022 ocean tide model - vertical displacement" ;
:project = "FES2022" ;
:cdm_data_type = "Grid" ;
:contact = "aviso@altimetry.fr" ;
:references = "https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_FES2022.pdf" ;
:Conventions = "CF-1.6" ;
:credits = "authors : LEGOS, NOVELTIS, CLS ; owner : CNES" ;
:date_created = "2024-06-03 07:14:34" ;
:history = "2024-06-03 07:14:34:creation" ;
:geospatial_lat_resolution = 0.0333333333333314 ;
:geospatial_lat_units = "degrees_north" ;
:geospatial_lon_resolution = 0.0333333333333333 ;
:geospatial_lon_units = "degrees_east" ;
:doi = "10.24400/527896/a01-2024.004" ;

7.3. Mask file

netcdf mask_fes2022B {
dimensions:
lat = 5401 ;
lon = 10800 ;
nv = 2 ;
variables:
int nv(nv) ;
nv:_FillValue = 2147483647 ;
nv:comment = "Vertex" ;
nv:units = "1" ;
double lat(lat) ;
lat:_FillValue = 1.84467440737096e+19 ;
lat:long_name = "latitude" ;

```
        lat:units = "degrees_north" ;
        lat:bounds = "lat_bnds" ;
        lat:valid_min = -90. ;
        lat:valid_max = 90. ;
        lat:axis = "Y" ;
    double lon(lon) ;
        lon:_FillValue = 1.84467440737096e+19 ;
        lon:long_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:bounds = "lon_bnds" ;
        lon:valid_min = 0. ;
        lon:valid_max = 359.966666666667 ;
        lon:axis = "X" ;
    float mask(lat, lon) ;
        mask:_FillValue = 1.844674e+19f ;
        mask:long_name = "Mask : 0=Ocean native data, 1=Extrapolated data, 2=Land,
3=Lake" ;
        mask:grid_mapping = "crs" ;
        mask:coordinates = "longitude latitude" ;
    float lon_bnds(lon, nv) ;
        lon_bnds:_FillValue = 1.844674e+19f ;
        lon_bnds:comment = "longitude values at the west and east bounds of each pixel."
;
        lon_bnds:units = "degrees_east" ;
    float lat_bnds(lat, nv) ;
        lat_bnds:_FillValue = 1.844674e+19f ;
        lat_bnds:comment = "latitude values at the north and south bounds of each pixel."
;
        lat_bnds:units = "degrees_north" ;
    int crs ;
        crs:_FillValue = 2147483647 ;
        crs:grid_mapping_name = "latitude_longitude" ;
        crs:semi_major_axis = 6378136.3 ;
        crs:inverse_flattening = 298.257 ;
        crs:comment = "This is a container variable that describes the grid_mapping used
by the data in this file. This variable does not contain any data; only information about the
geographic coordinate system." ;

// global attributes:
        :license = "https://www.aviso.altimetry.fr/en/data/data-
access/fileadmin/documents/data/License_Aviso.pdf" ;
        :title = "FES2022 mask for extrapolated tide elavations" ;
        :product_version = "b" ;
        :summary = "Mask to differentiate native data and extrapolated data for FES2022
tide elevation grids" ;
        :project = "FES2022" ;
```

```
		:cdm_data_type = "Grid" ;
		:contact = "aviso@altimetry.fr" ;
		:references =
"https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_FES2022.pdf" ;
		:Conventions = "CF-1.6" ;
		:credits = "authors : LEGOS, NOVELTIS, CLS ; owner : CNES" ;
		:date_created = "2024-06-11 09:23:49" ;
		:history = "2024-06-11 09:23:49:creation" ;
		:geospatial_lat_resolution = 0.0333333333333314 ;
		:geospatial_lat_units = "degrees_north" ;
		:geospatial_lon_resolution = 0.0333333333333333 ;
		:geospatial_lon_units = "degrees_east" ;
		:doi = "10.24400/527896/a01-2024.004" ;
}
```