Towards an update of the French vertical maritime reference surfaces

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Introduction

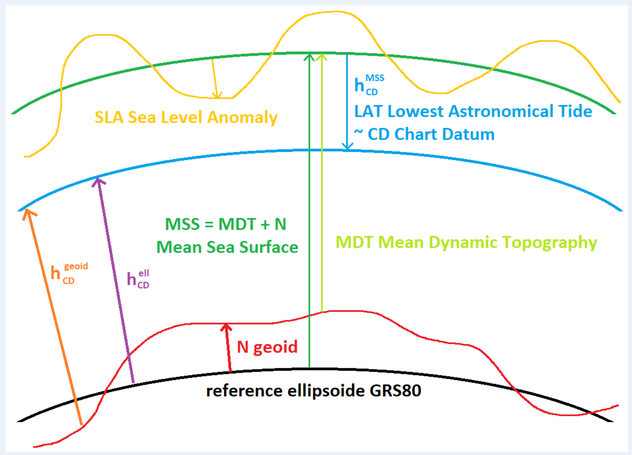
French Chart Datum (CD) ≈ Lowest Astronomical Tide (LAT)

Objective:

Link the CD to the GRS80 reference ellipsoid with two main purposes:

- Ensure the continuity of the land-sea reference system along coastline;
- Facilitate the referencing of bathymetric surveys and hydrodynamics studies to the CD.

Surfaces definition



State-of-the-art methodology:

Australia (AUSHYDROID) – *Keysers et al., 2015*		
Canada (CCCDW) - *Robin et al., 2016* USA (VDATUM) - *Tang et al., 2025* $h_{CD}^{ell} = MDT + N + h_{CD}^{MSS}$	France (BathyElli) - *Tanguy and Pastol, 2014* UK and Irlande (VORF) - *Iliffe et al., 2007* $h_{CD}^{ell} = MSS + h_{CD}^{MSS}$	Netherland (NEVREF) - *Slobbe et al., 2013* h_{CD}^{geoid}

h_{CD} is constrained by tide gauge measurements.

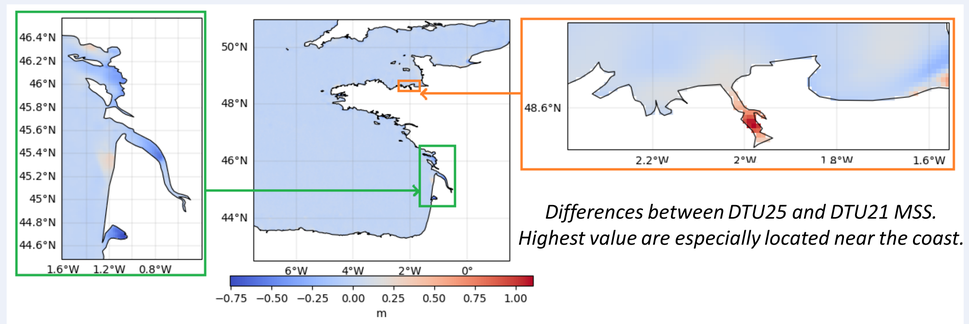
Altimetry

MSS:
- **DTU 2021** : *Andersen et al. 2023*
- **DTU 2025** : *Nilsson et al. 2025*
- **CLS 2022** : *Schaeffer et al. 2023*
- **CLS 2023 hybrid** : *Laloue et al. 2025*
- **CLS 2025** : *Charayron et al. 2025*



SWOT

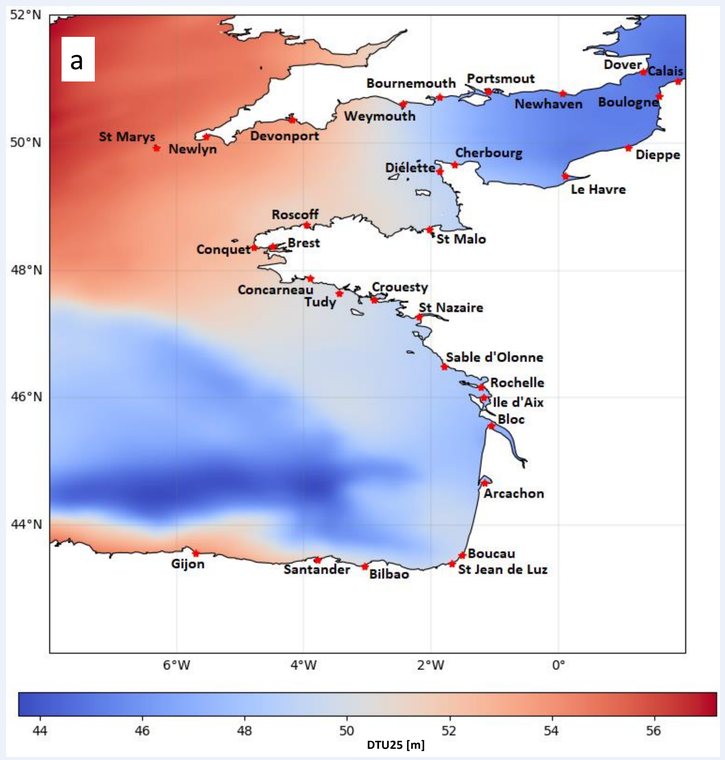
Reference period: 1993-2012 (centered on 2003)
Reference ellipsoid: Topex (except CLS23 hybrid and CLS25 = WGS84)
Corrected for the dynamic atmospheric effect (DAC).
Inclusion of SWOT (Surface Water Ocean Topography) data only in 2025 MSS.

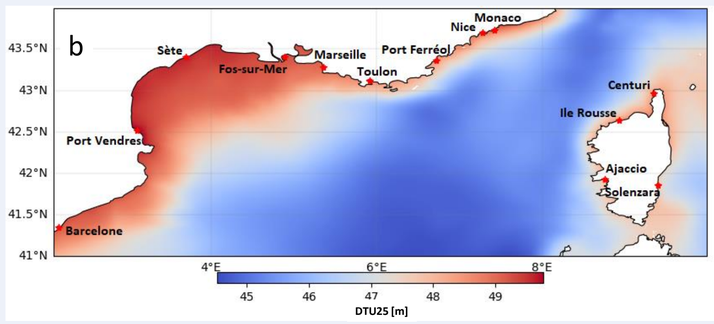


Differences between DTU25 and DTU21 MSS. Highest value are especially located near the coast.

Tide Gauge

Map of the tide gauge positions in Atlantic (red stars) (a) and Mediterranean sea (b) superimposed on the DTU25 MSS (m).





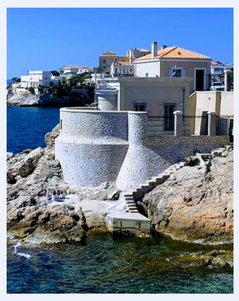
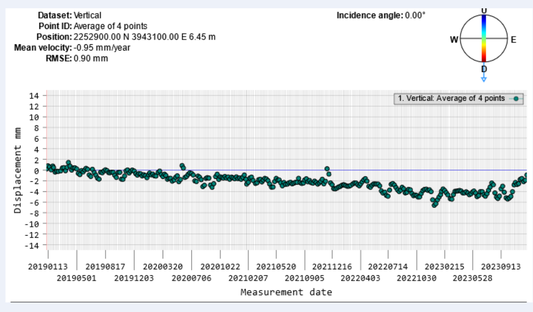
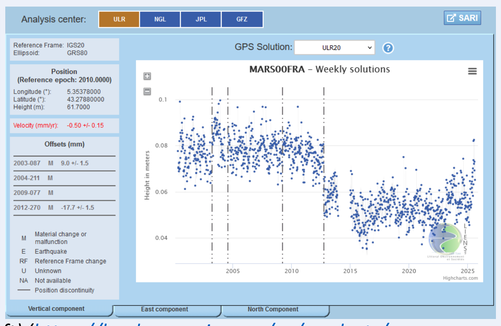


Photo of Marseille's tide gauge

- Download of the mean sea level records from PSMSL database.
- Correction for DAC using Aviso product (doi:10.24400/527896/a01-2022.001) to compare with MSS models on 1993-2012 period.



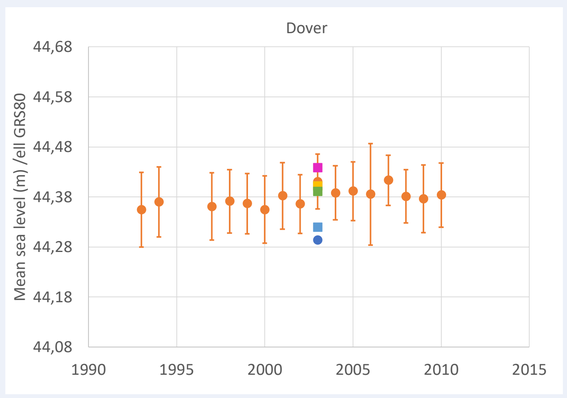


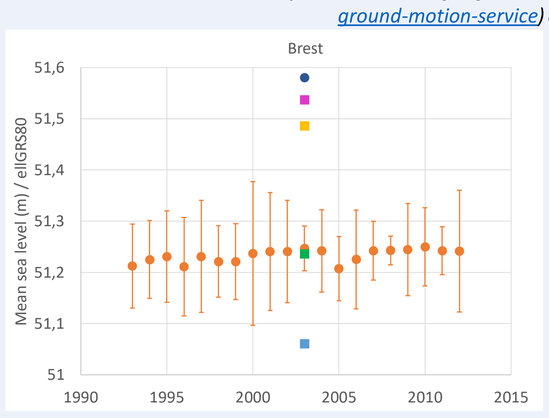
Subsidence of Marseille's tide gauge measured by InSAR (left) (https://land.copernicus.eu/en/products/european-ground-motion-service) and permanent GNSS (right) (https://www.sonel.org)

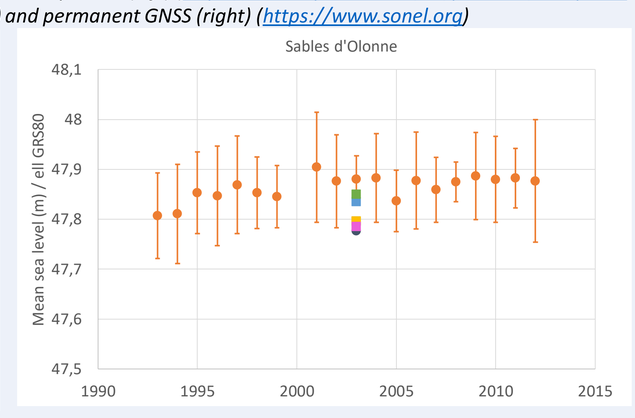
Tide gauge name	Difference between tide gauge data and MSS models (m)				
	CLS15	CLS22	DTU21	DTU25	CLS25
Newlyn	0,106	0,086	0,050	0,026	0,077
Devonport	-0,018	0,008	-0,080	0,021	0,051
Weymouth	-0,041	-0,033	-0,030	0,025	0,017
Bournemouth	0,034	0,026	0,011	-0,063	0,031
Portsmouth	0,387	0,324	0,135	0,133	0,314
Newhaven	0,041	0,011	-0,005	-0,006	0,010
Dover	-0,084	0,023	-0,059	0,012	0,060
Calais	0,152	0,091	0,073	0,263	0,084
Le Havre	-0,122	-0,063	-0,447	-0,075	-0,011
Cherbourg	0,304	0,292	0,027	0,027	0,253
Saint Malo	0,173	0,169	0,173	-0,045	0,159
Roscoff	0,372	0,276	0,175	0,102	0,192
Le Conquet	0,124	0,103	0,054	0,060	0,099
Brest	0,348	0,254	-0,172	0,004	0,304
Concarneau	-0,042	-0,080	-0,057	-0,038	-0,081
Port Tudy	0,030	-0,002	-0,004	-0,018	0,006
Saint Nazaire	-0,132	-0,086	-0,104	0,042	-0,036
Sables d'Olonne	-0,087	-0,068	-0,028	-0,013	-0,078
La Rochelle	0,160	0,242	-0,173	0,207	0,228
Boucau	0,102	0,105	-0,033	-0,096	0,090
Bilbao	-0,168	-0,134	-0,133	-0,204	-0,105
Santander	0,302	0,235	0,198	0,034	0,180
Gijon	-0,019	-0,072	-0,017	-0,050	-0,073
Barcelone	-0,005	0,007	-0,031	0,041	0,020
Port-Vendres	-0,177	-0,141	-0,168	-0,117	-0,126
Sete	-0,070	-0,057	-0,058	-0,007	-0,017
Marseille	-0,926	-0,910	-0,170	-0,111	-0,817
Toulon	-0,295	-0,221	-0,212	-0,174	0,164
Nice	0,043	0,031	-0,269	-0,124	0,015
Monaco	0,268	0,308	0,308	0,331	0,302
Ajaccio	-0,165	-0,107	0,644	0,277	-0,093

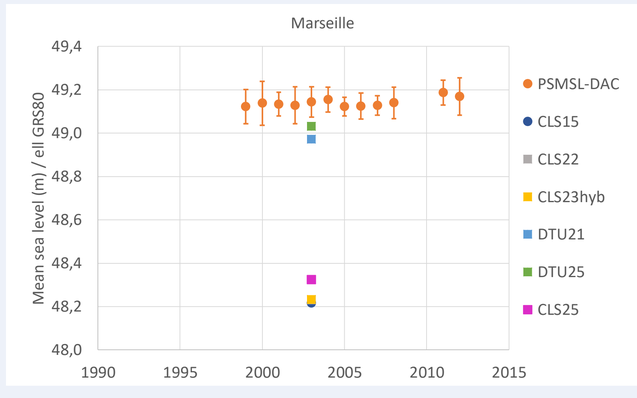
Mean sea level differences between tide gauge data and MSS models on 1993-2012 period. Smallest values are highlighted in blue.

➢ **Better consistency with DTU25 MSS**





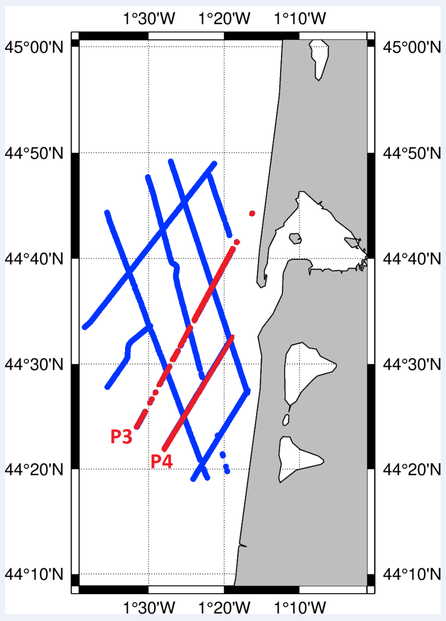




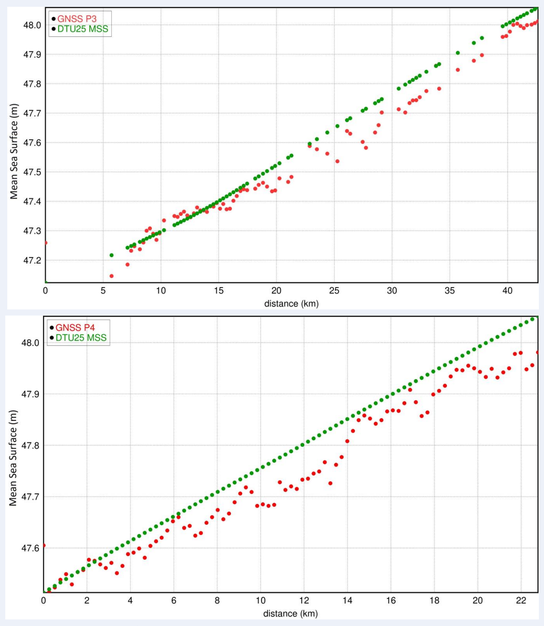
Annual mean tide gauge measurement (at Dover, Brest, Sables d'Olonne and Marseille) corrected for the dynamic atmospheric effect (DAC) on 1993-2012 period compared to MSS models. (CLS22 and CLS23hyb are superimposed.)

GNSS

25 surveys used to enhance surface models, particularly near the coasts, by incorporating short wavelengths



Position of 9 GNSS profiles west of Cap Ferret measured in 2008

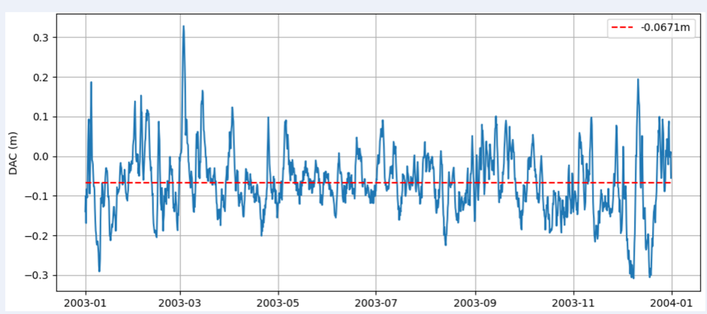


GNSS profiles P3 and P4 compared to DTU25 MSS referenced to 2008. (Beginning of the profiles North.)

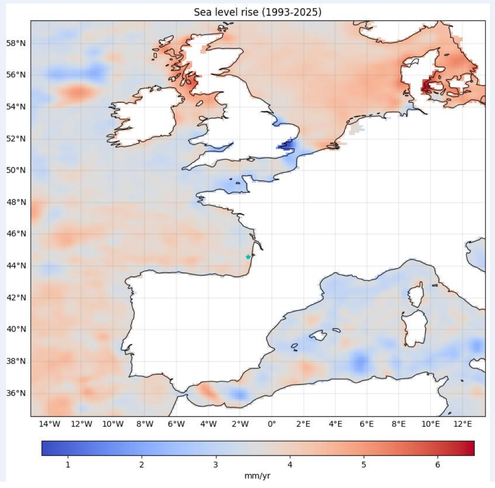
- Correction of MSS for mean 2003 DAC (6,7cm) and sea level rise ((2008-2003)*0,38 = 2cm) given by 1993-2025 SLA analysis (doi:10.48670/moi-00148) to refere to 2008.
- Correction of GNSS for :
  - Tide (CstFRANCE or FES models);
  - Surge;
  - Boat attitude.

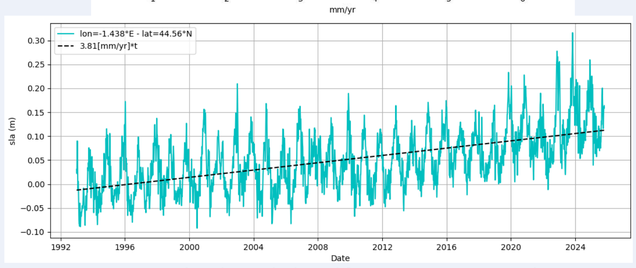


Beautemps-Beaupré boat



Dynamic atmospheric correction (DAC) given west of Cap Ferret





Sea level rise deduced from 1993-2015 SLA data.

Conclusion

- Improvement of the MSS accuracy thanks to SWOT data → Highest consistency between tide gauge data and DTU25 MSS
- Enhancement of the MSS models through the integration of short-wavelength information provided by GNSS surveys

Future work:

- Inclusion of the tide gauge subsidence in the mean sea level study;
- MSS, tide gauge and GNSS data fusion to define the mean sea level before removing LAT surfaces and hence, map the CD ellipsoidal height in Metropolitan France.

Acknowledgement

We thank Philippe Schaeffer (CLS) for sharing his expertise on MSS models.

