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INSTITUT NATIONAL
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CHANGER
D'ÉCHELLE

TOWARDS LAND AND SEA VERTICAL UNIFICATION THANKS TO HYDRODYNAMIC LEVELING

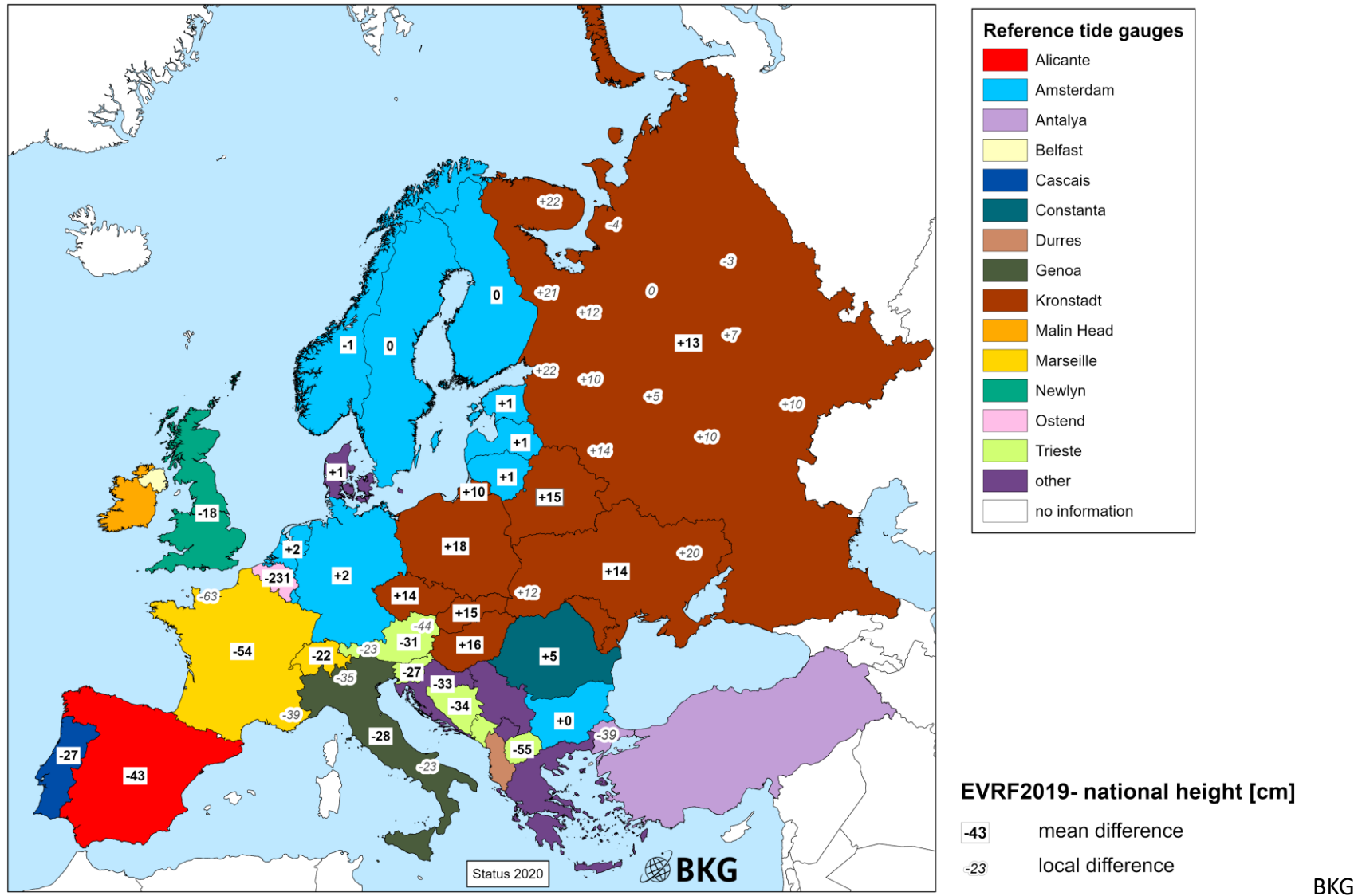
EUREF Symposium, Paris, 2026

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Challenges (1): land vertical datums unification



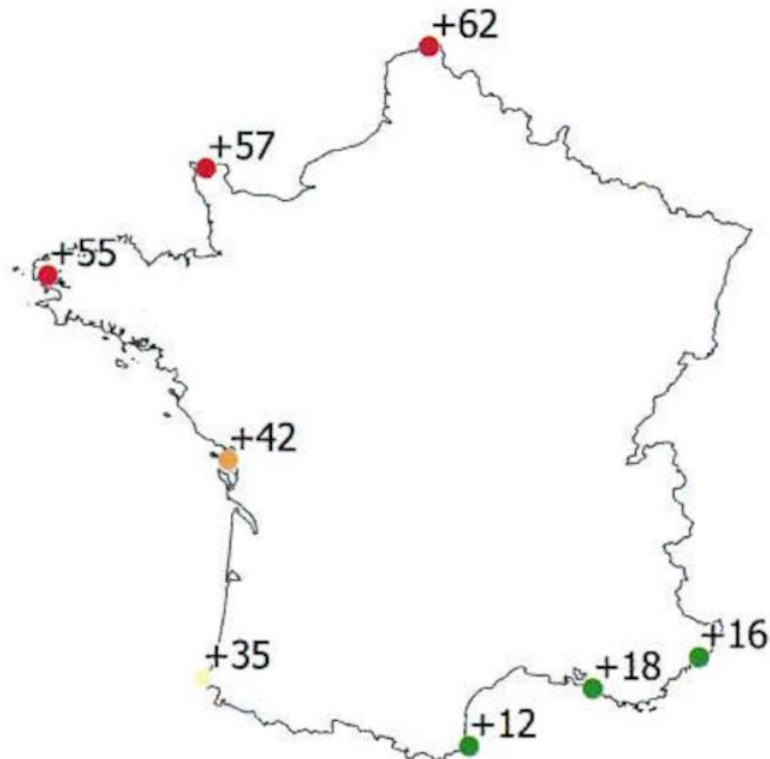
Challenges (2): vertical datum assessment

The historical way of mean sea level height

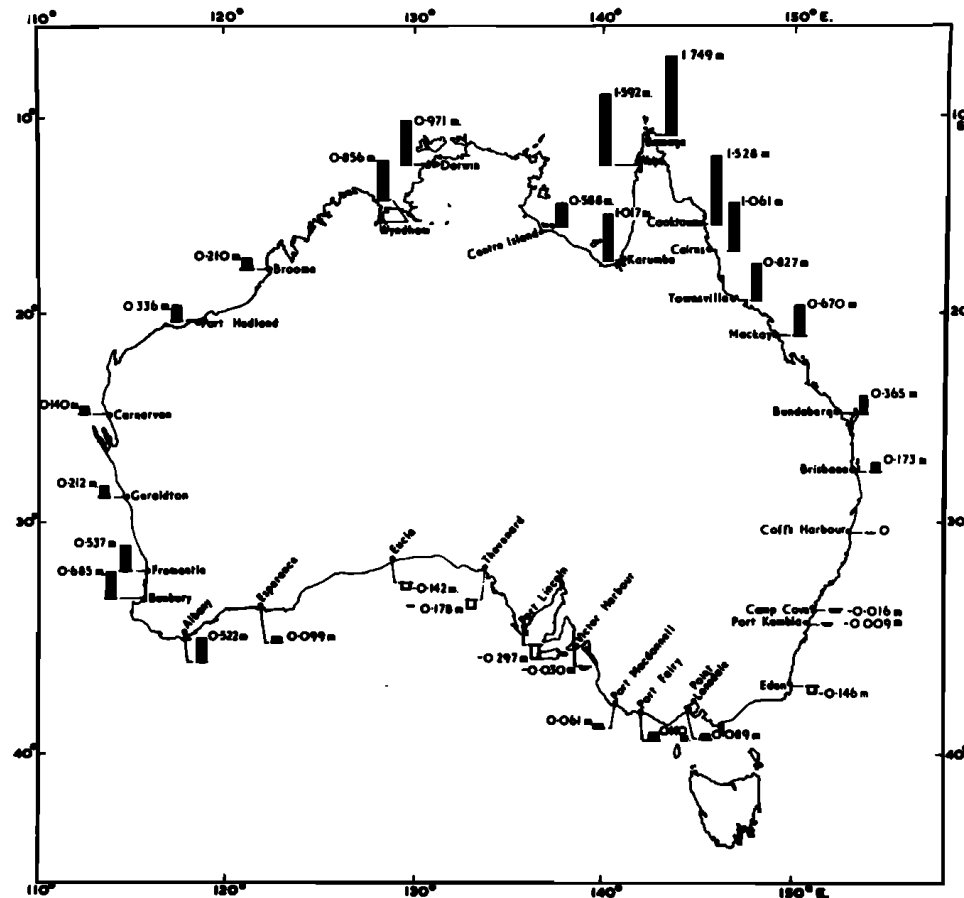
French system IGN69: suspicion of **a south-north slope from the expression of mean sea level in this vertical datum**

(Levallois 1959, Levallois & Maillard 1970, Hottier & Charlot 1979, Kasser 1989, Lavoué et Jamet 2023)

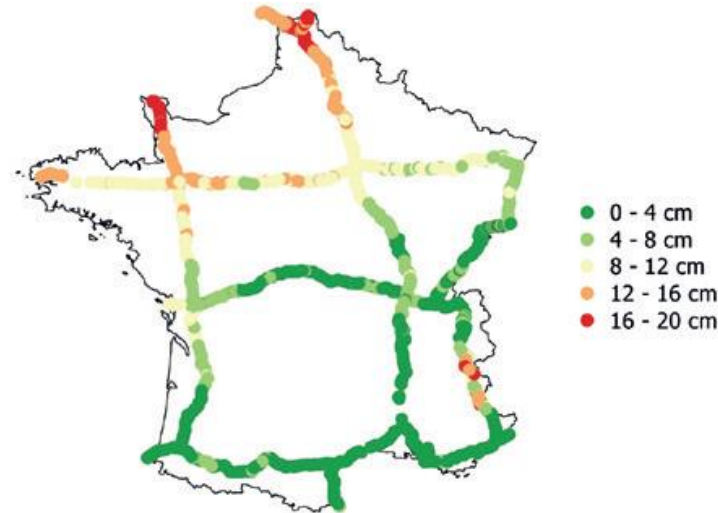
H(MSL) IGN69: inconsistency between levelling and oceanography



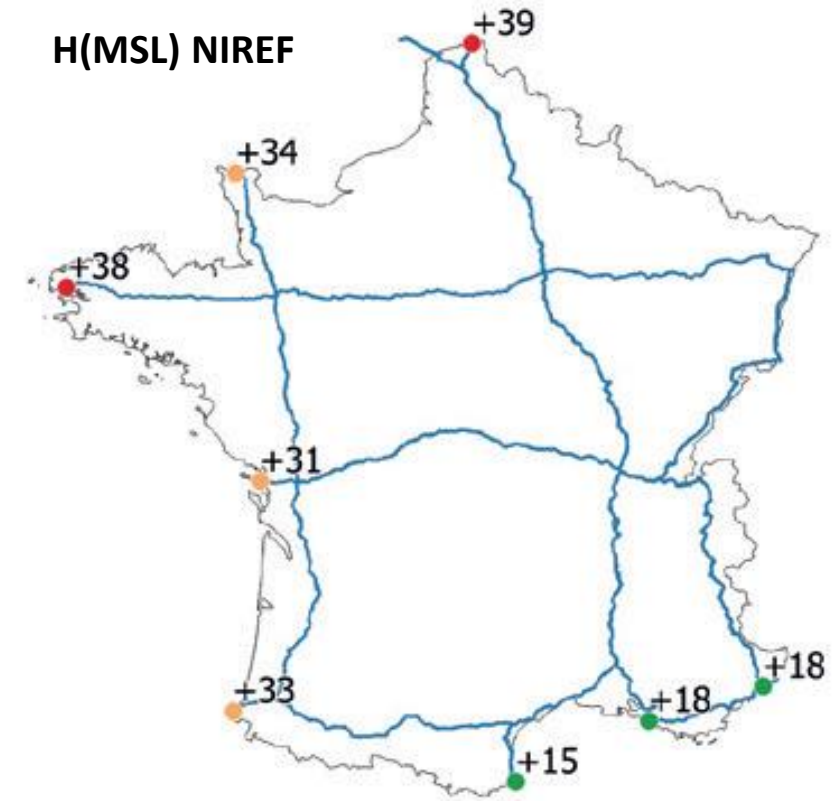
Similar issues in other countries, e.g. Australia (Hamon & Greig, 1972, fixed by **hydrodynamic levelling and the use of the Mean dynamic topography of the ocean** (Featherstone et al., 2012) ; see also the case of Great Britain (Penna et al 2013)



France : legal datum IGN69 and scientific datum NIREF

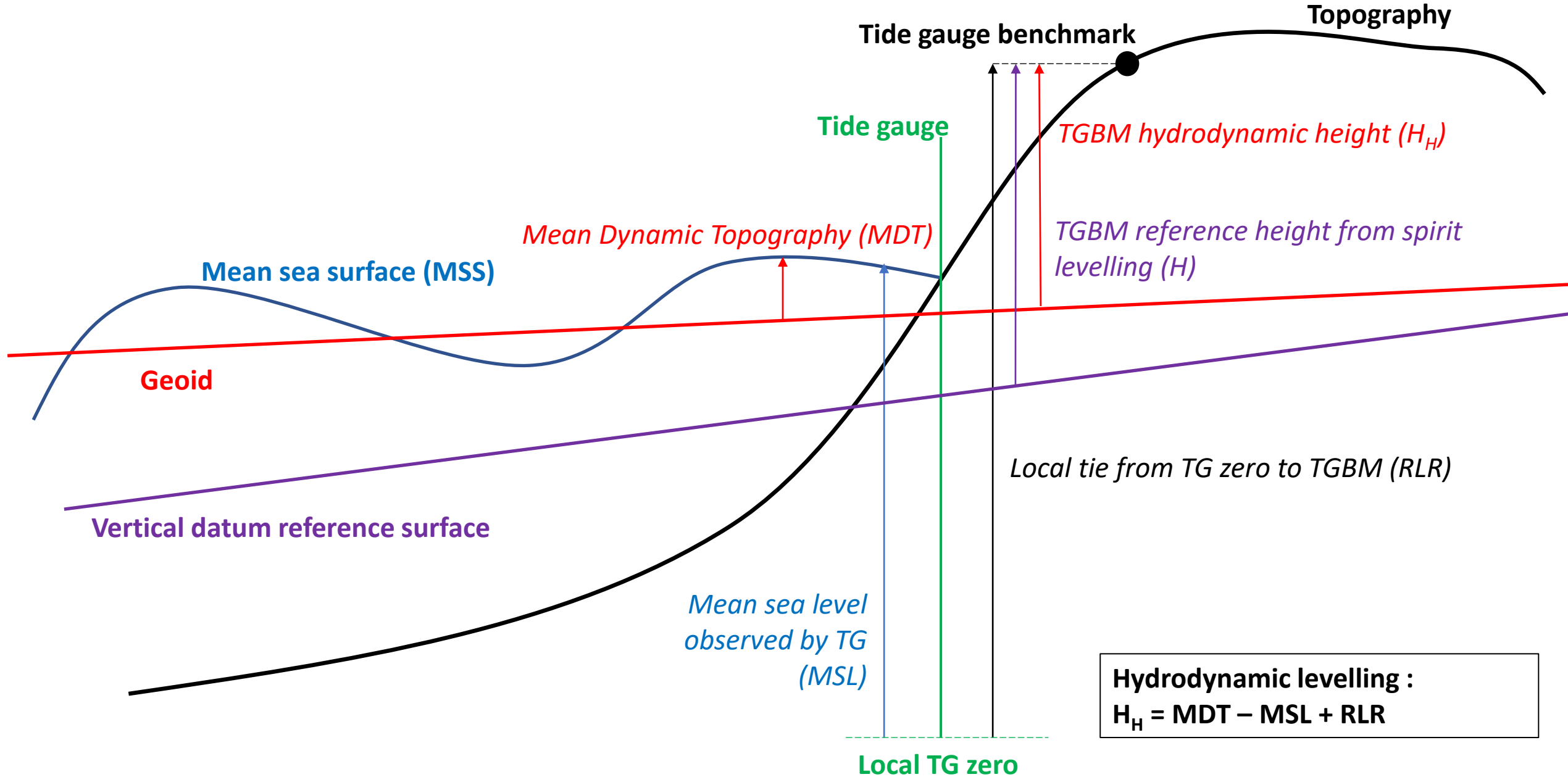


Difference IGN69 vs NIREF



- Can we use data independant from (scientific) spirit leveling to assess existing vertical datums ?
- Can we revisit the « sea level height » approach ?

Hydrodynamic leveling principles

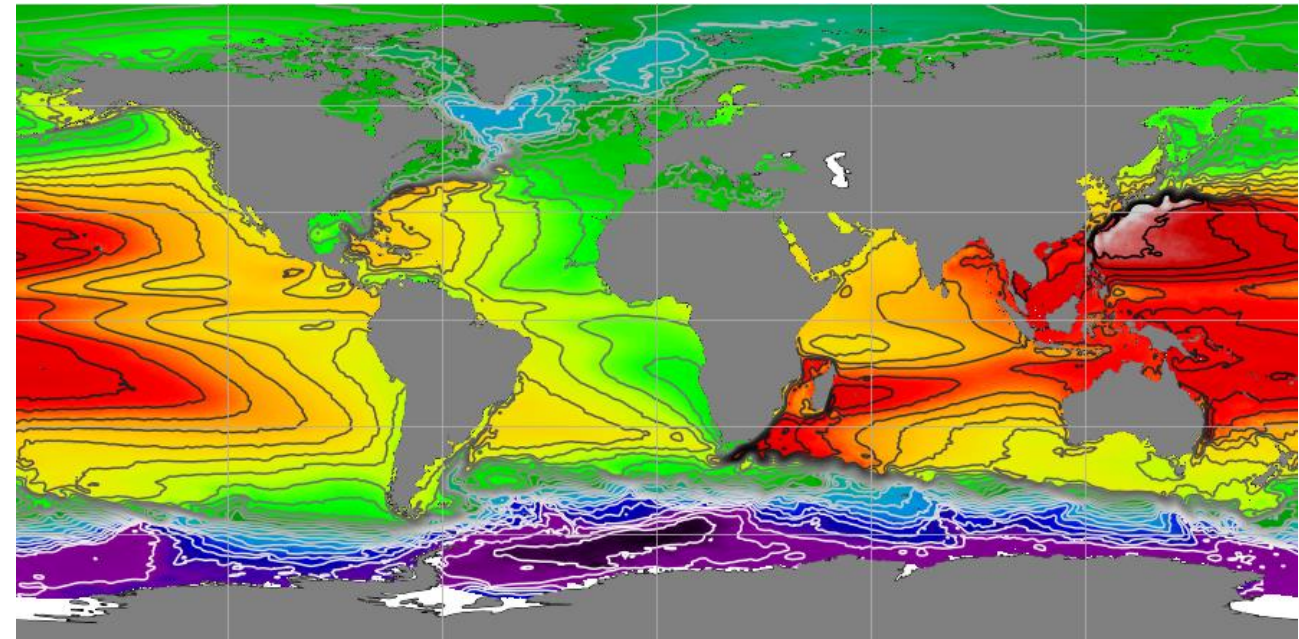
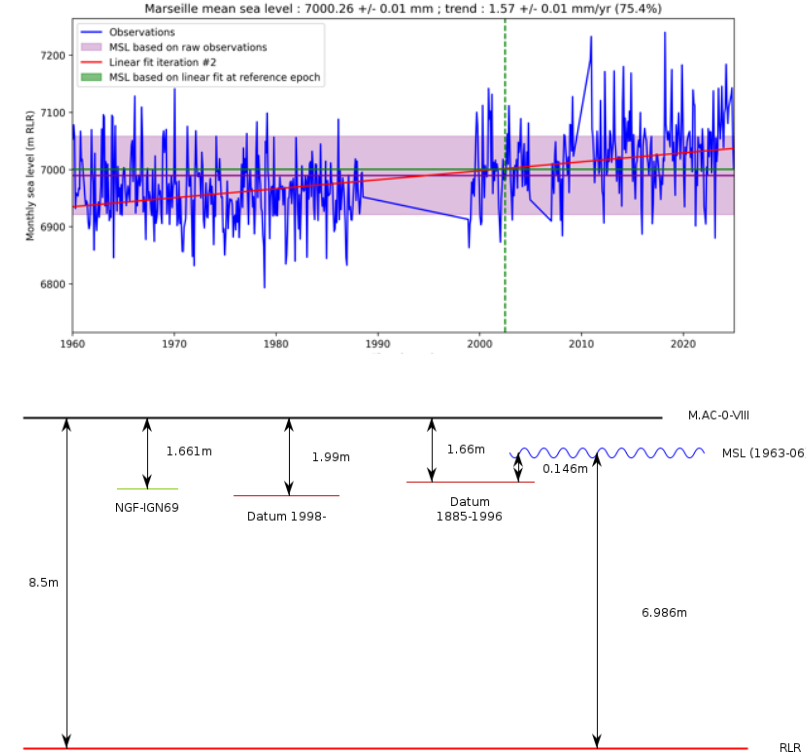


DATA

- Tide gauge monthly mean sea level observations as of 1960 : **MSL calculated at the mean epoch of the MDT reference period**
- Tide gauge **datum constant** (PSMSL 'RLR' vertical distance between fundamental TG benchmark and TG zero)
- **Mean dynamic topography** of the ocean.
Freely available from different working teams:
 - CNES-CLS22
 - DTU22, DTU22H22
 - etc

Large scale: MSSH – Geoid height

Fine scale: operational oceanography in situ data integrated through the geostrophic equation hypothesis



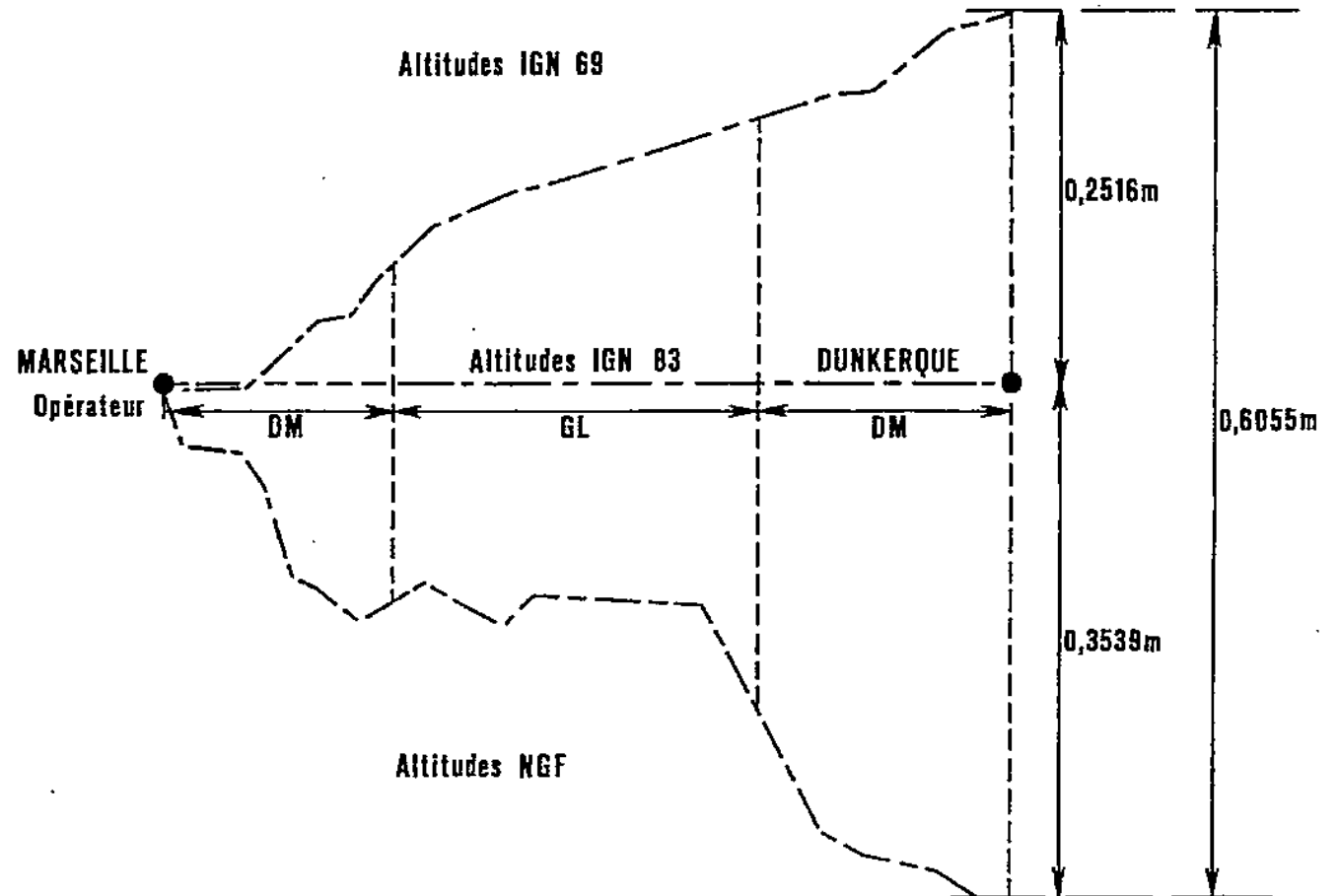
A first proxy of the south-north slope of IGN69

- Marseille-Dunkerque hydrodynamic and official height difference: the historical proxy to the south-north slope of IGN69:

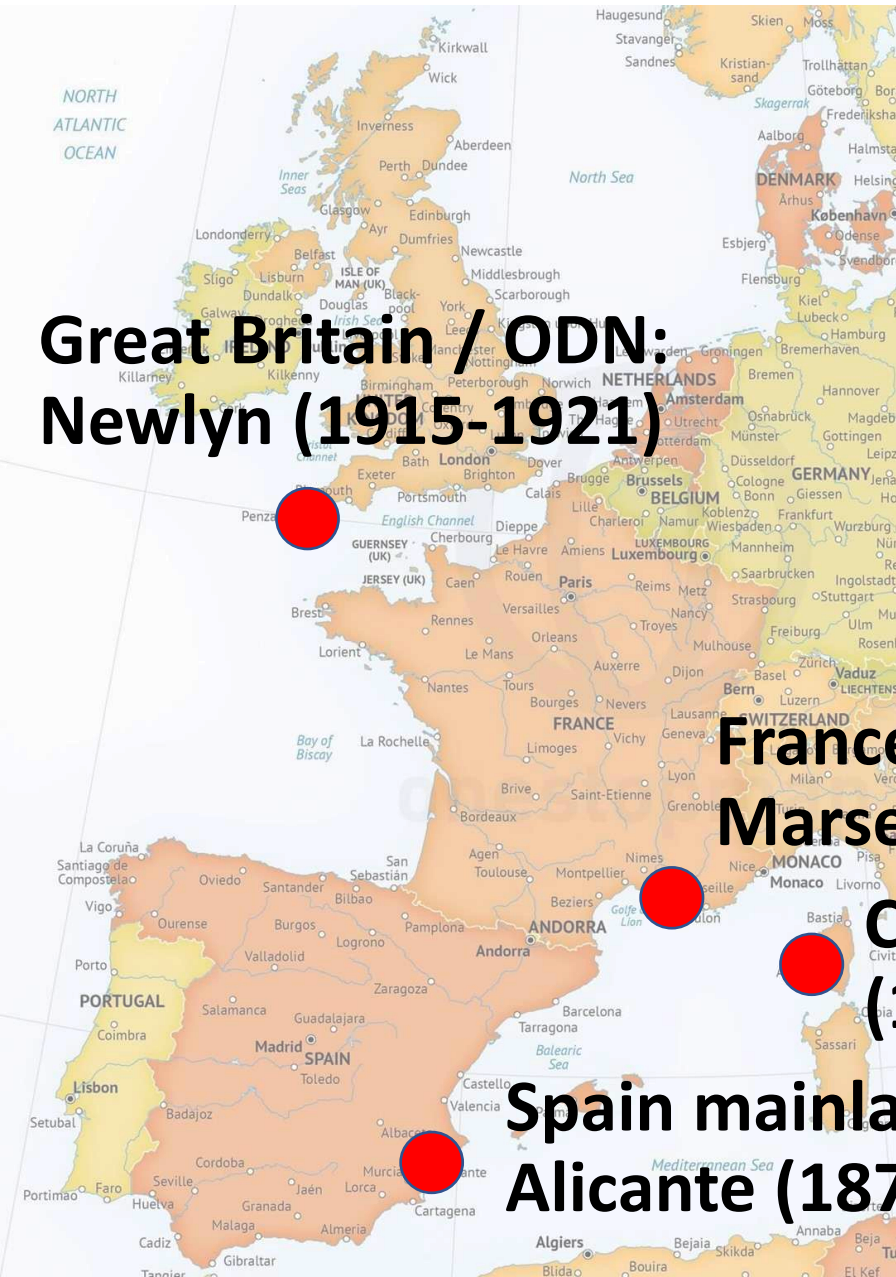
-0.2539 +/- 0.0790 m

NB: **uncertainty probably overestimated** due to non consideration of covariances at any step of the processings

- Confirmation of 1989 calculation relying on 1983 first NIREF measurements
(-0.2516 m, Kasser 1989)



Vertical datum origins connexion



**Great Britain / ODN:
Newlyn (1915-1921)**

**France mainland / IGN69:
Marseille (1885-1896)**

**Corsica / IGN78: Ajaccio
(1912-1937)**

**Spain mainland / REDNAP:
Alicante (1870-1874)**

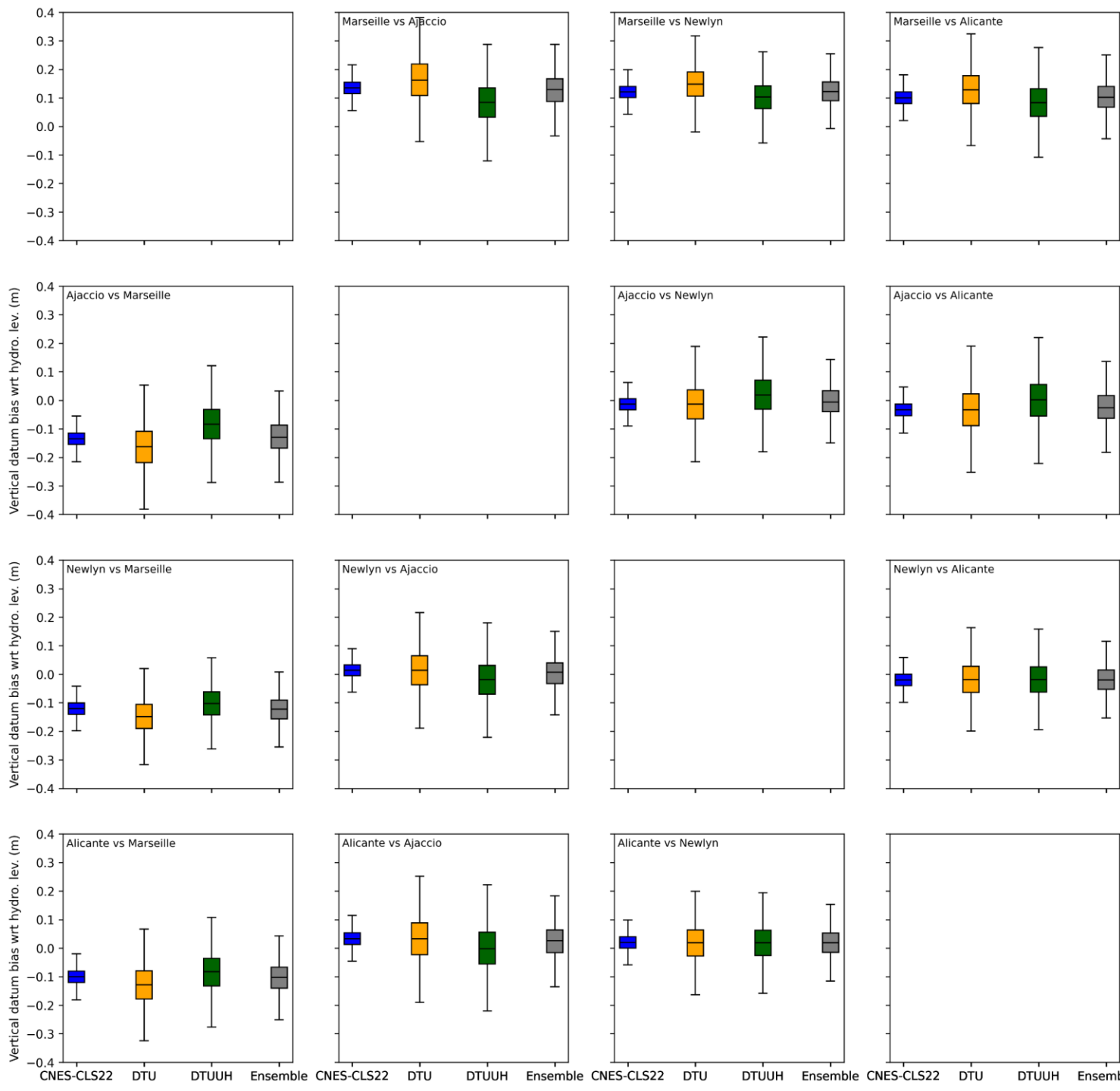
- **Rigorous vertical datum comparison must be assessed at their origin, not at their connexion**
- For TG A and B origins of their respective vertical datums (1 and 2), the bias is calculated as $(H_D(A) - H_D(B)) - (H_H(A) - H_H(B))$
- Vertical datums origins height differences reveals:
 - Sea level variations between reference periods
 - Dynamic topography differences between locations
 - Any possible arbitrary added constant

IGN69 origin (Marseille) is below all datums
(ensemble values):

- IGN78 (Ajaccio): 0.1255 ± 0.0734 m
- ODN (Newlyn): 0.1237 ± 0.0571 m
- REDNAP (Alicante): 0.1042 ± 0.0640 m

Good agreement between MDT models

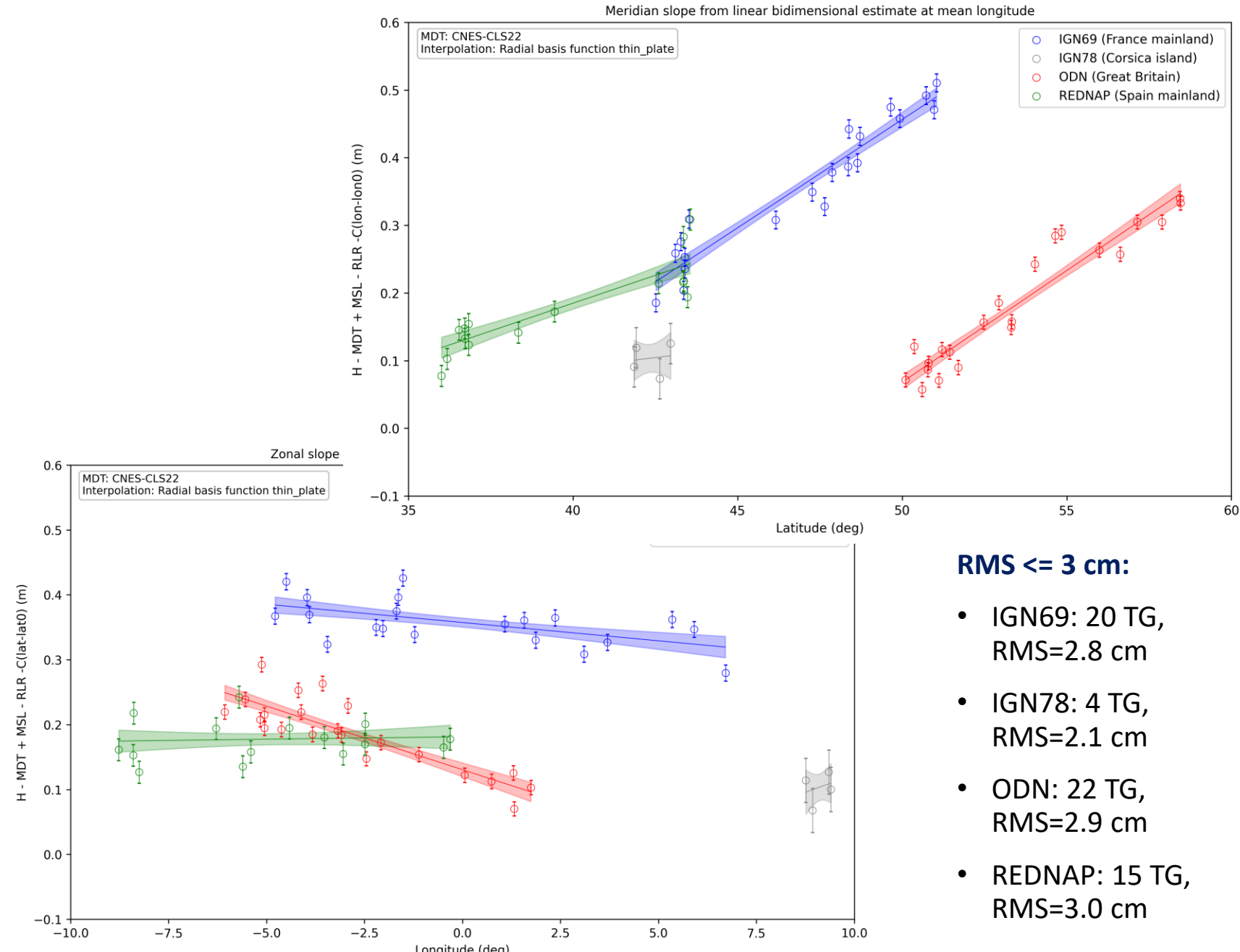
NB: uncertainties still probably overestimated
(same method as for Marseille-Dunkerque)



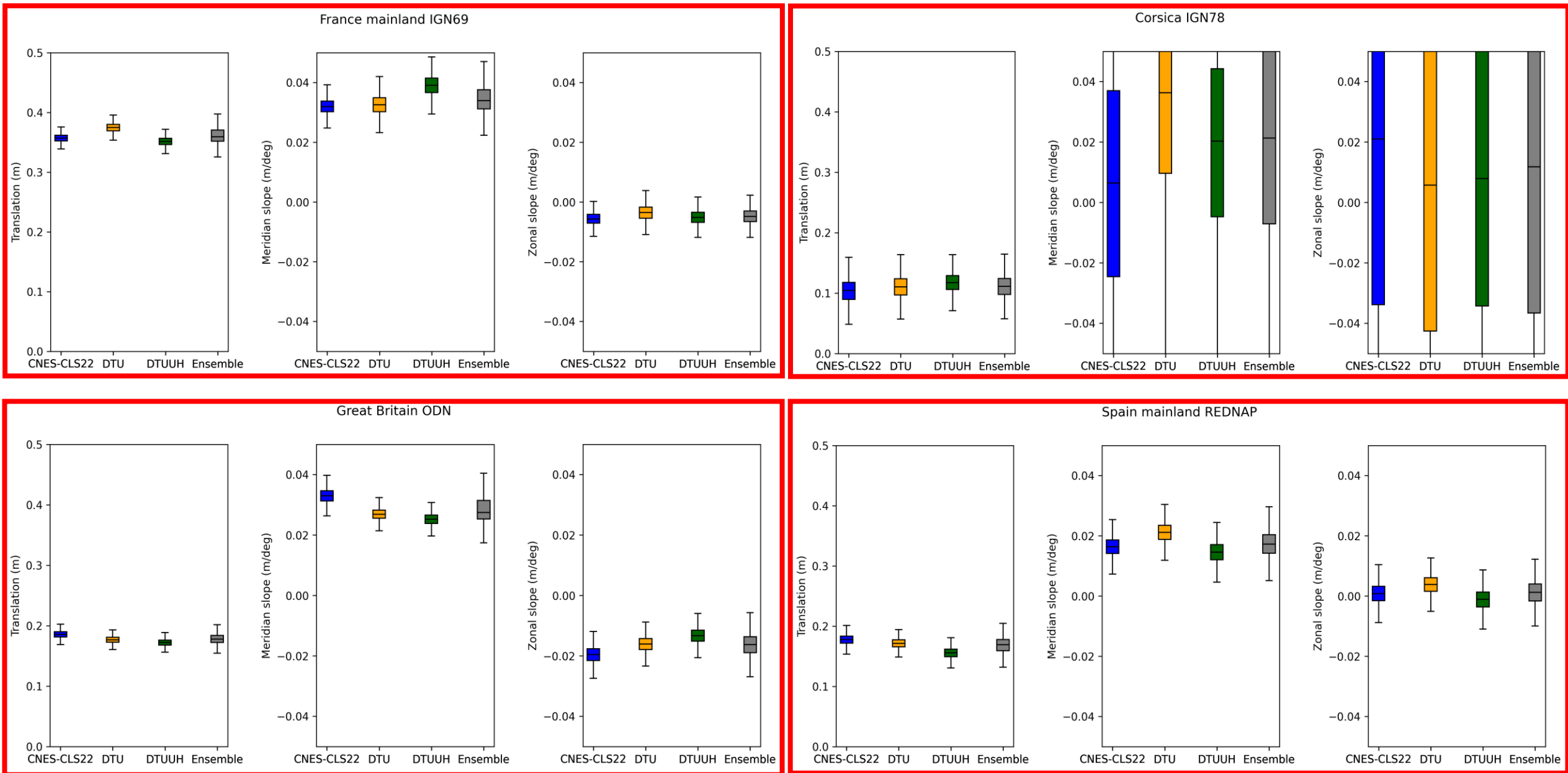
RIGOROUS EXISTING DATUMS ASSESSMENT

- We can process the **difference between height based on spirit leveling vertical datum and hydrodynamic leveling ($H_D(A) - H_H(A)$)**, and **adjust by least squares the mean bias, and south-north and west-east slopes** with $H_D - H_H = A + B\varphi + C\lambda$

- Figures: slopes estimated with CNES-CLS22 MDT for vertical datums IGN69, IGN78, ODN, and REDNAP (top right: meridian slope; bottom left: zonal slope)



Good agreement between MDT models



Discussing our slopes estimates

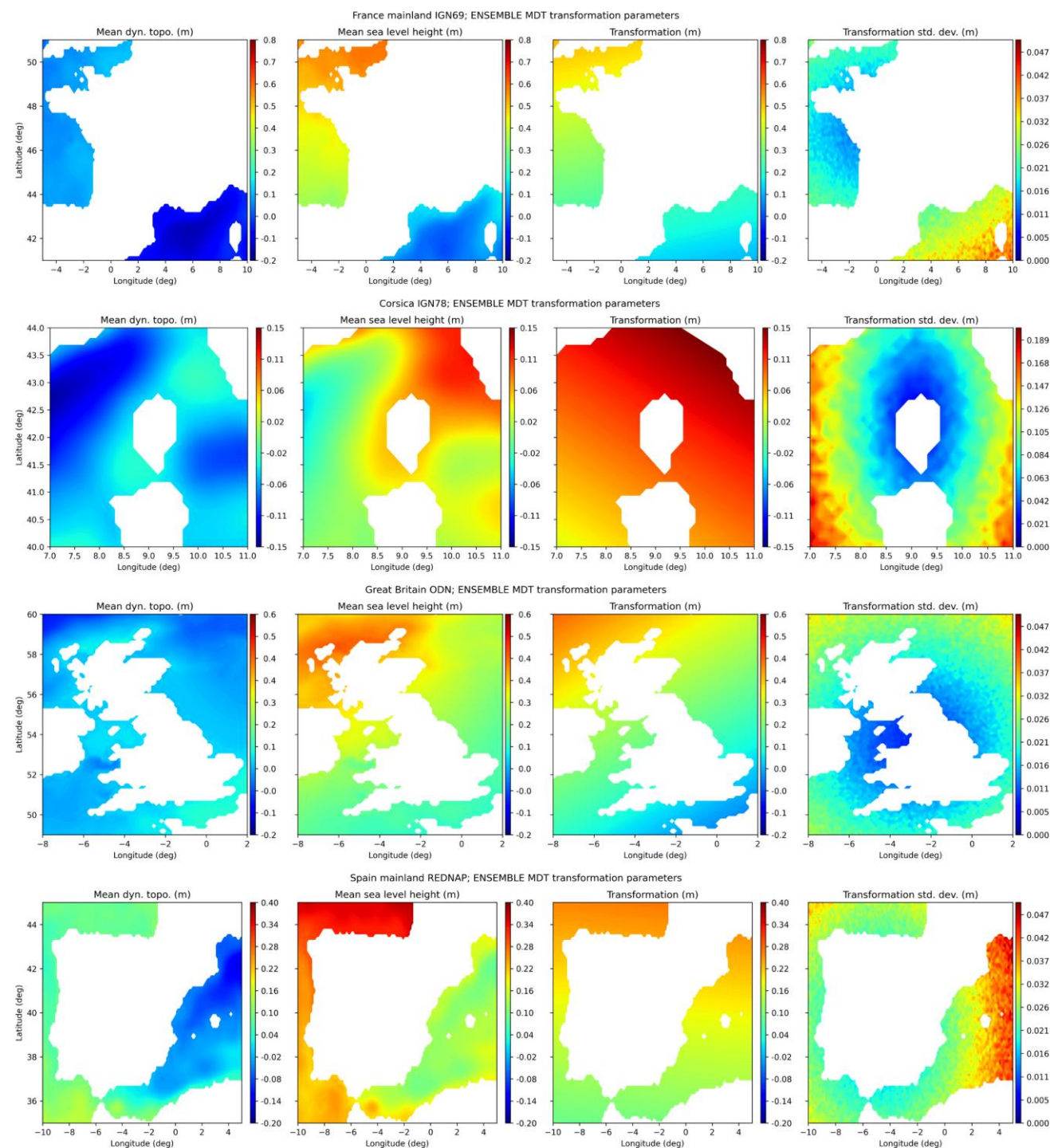
Slopes (cm/deg)	IGN69 Meridian	IGN69 Zonal	ODN Meridian	ODN Zonal	REDNAP Meridian	REDNAP Zonal
Our study (ensembles)	3.5 +/- 0.4	-0.4 +/- 0.3	2.8 +/- 0.4	-1.6 +/- 0.4	1.8 +/- 0.4	0.1 +/- 0.4
Afrasteh et al 2023 (Hydro. Lev. From simulated MDT on Atlantic ocean)	1.01	0.76				
Penna et al 2013 (id.)			2.3 +/- 0.4			
Rulke et al 2012 (Geoid adjust.)	5.8	2.2	4.2	2.2	3.1	1.6

To our knowledge, no such study on Corsica

Another practical application: Using transformation parameters to express space altimetry products in national vertical datums

Rows (top to bottom): France mainland, Corsica, Great Britain, Spain

Columns (left to right): MDT wrt to associated geoid, same surface wrt to official datum, transformation surface, associated standard deviation (generally ≤ 3 cm)



CONCLUSIONS

- Confirmation of **existing meridian and zonal slopes of historical vertical datums based on spirit leveling** by independant observational data
- Easy **connection between territories separated by the sea** (mainlands/islands, archipelagos, etc)
- Hydrodynamic height differences to be introduced in leveling adjustments to **constrain future vertical datums to be aligned on global geoid model at large scale**

Next steps: Geodesy (first)

- Work on TG **MSL preprocessing** (long tides cycles, inverse barometer effect)
- Ongoing scientific leveling measurements to **connect NIREF network to remaining tide gauges** in order to
 - constrain leveling adjustment with hydrodynamic height differences
 - vertically unify France mainland and Corsica
- Introduce **vertical velocities** (e.g. in Scandinavia) and **reference epoch** to assess the EVRF
- If you are interested, I/we can **assess your national vertical datums by hydrodynamic levelling**

Next steps (tools for adaptation to sea level rise):

- Keep on working on **transform any marine gridded information to official datums** (Copernicus SLA, sea level simulations, etc)

Thanks for your attention

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Effect of offshore vs coastal MDT on datums slopes estimates

- Open ocean MDT: OOMDT
 - Coastal MDT: CMDT = OOMDT + K
- $$\Rightarrow H - (\text{OOMDT} + K - \text{MSL} + \text{RLR}) = A + B\varphi + C\lambda$$
- Effect only on coefficient A (mean bias)
 - If uncertainty/spread associated to K, effect on uncertainties associated to A, B, C
 - So, roughly, no effect on slopes (B, C) best estimates
 - Same way on reasoning for possible atmospheric permanent component on sea level / inverse barometer effect