CURAE – bridging the gap between regional CMEMS forecasts and coastal high-resolution applications

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1.- <u>Objectives</u>

- Development of two **coastal information systems**, based on **CMEMS** products, addressing *<u>coastal-scale</u>* **hydro-morphodynamic interactions**
- **Generic conclusions** on coastward evolution of CMEMS, based on two study sites with different characteristics, and different numerical approaches
- Routines for **flexible** but robust **interfacing** between CMEMS and coastal applications

CMEMS
- Remote sensing
- Simulations
- Field data

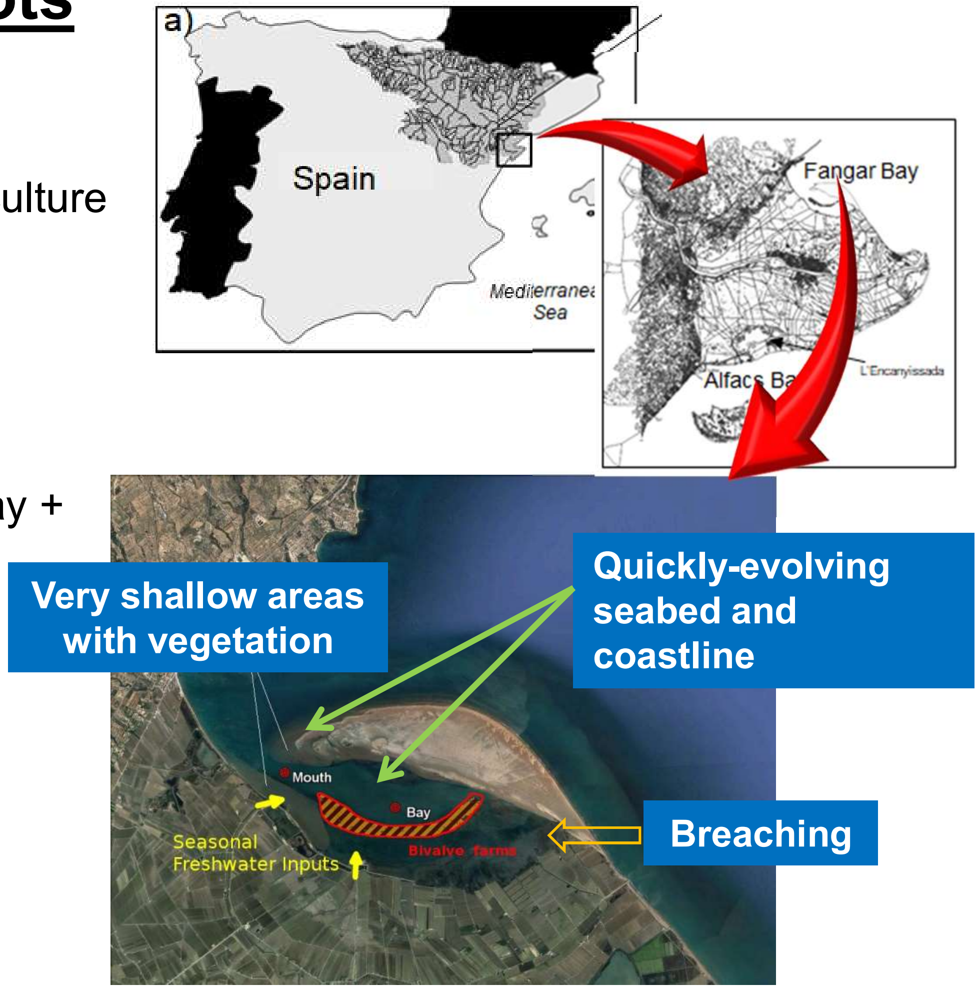
CURAE
- Improved coastal BC
- Downscaling
- Interfacing

2.- Motivation

- *Complex* coastal areas
  - Increasing **anthropogenic pressures**
  - Multiple **conflicting uses**
  - High **socio-economic** importance**,** but ...
- CMEMS products are *limited* in these regions (inner shelf, ROFI..)
  - **Insufficient** time/space **resolution**
  - **Unresolved** coastal **features** (sediment transport, bio bed friction, ...)
  - Boundary conditions **(land discharges…)**
- Coastal users/managers require an enhanced *forecasting* and *analysis* !
  - **Aquaculture** (water quality) → Water / sediment / nutrient fluxes
  - **Dredging** (port access, transport) → Water / sediment fluxes

3.- The CURAE coastal pilots

- **Fangar Bay** - most important bivalve culture area in Spanish Mediterranean
- Highly dynamic bottom / geometry → morphodynamic control
- Nutrient & sediment input + Shallow bay + Closing mouth → poor WQ
- High water temperatures + poor water quality → mortality



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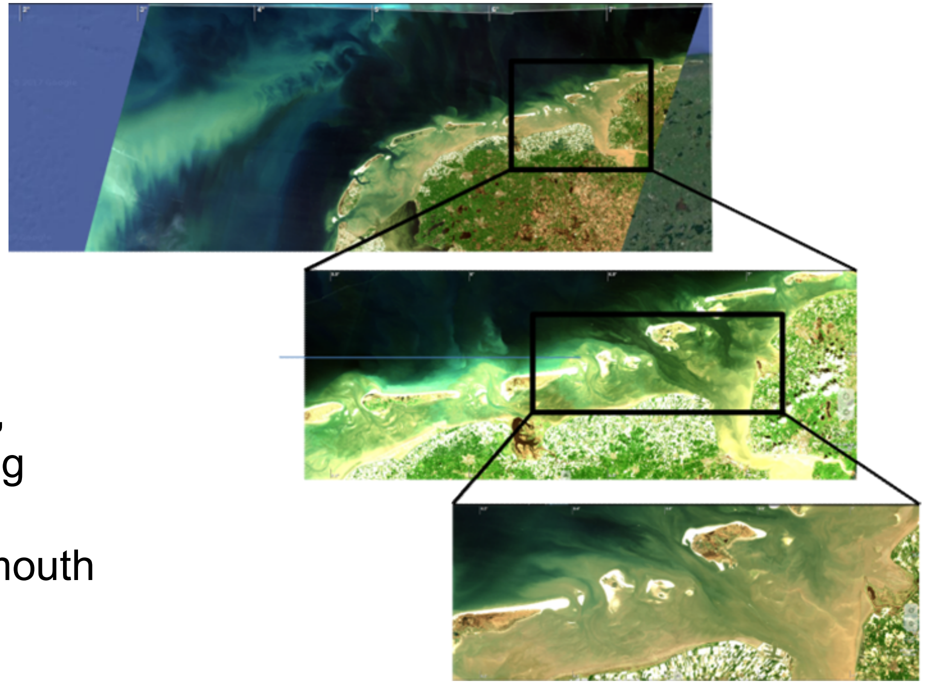
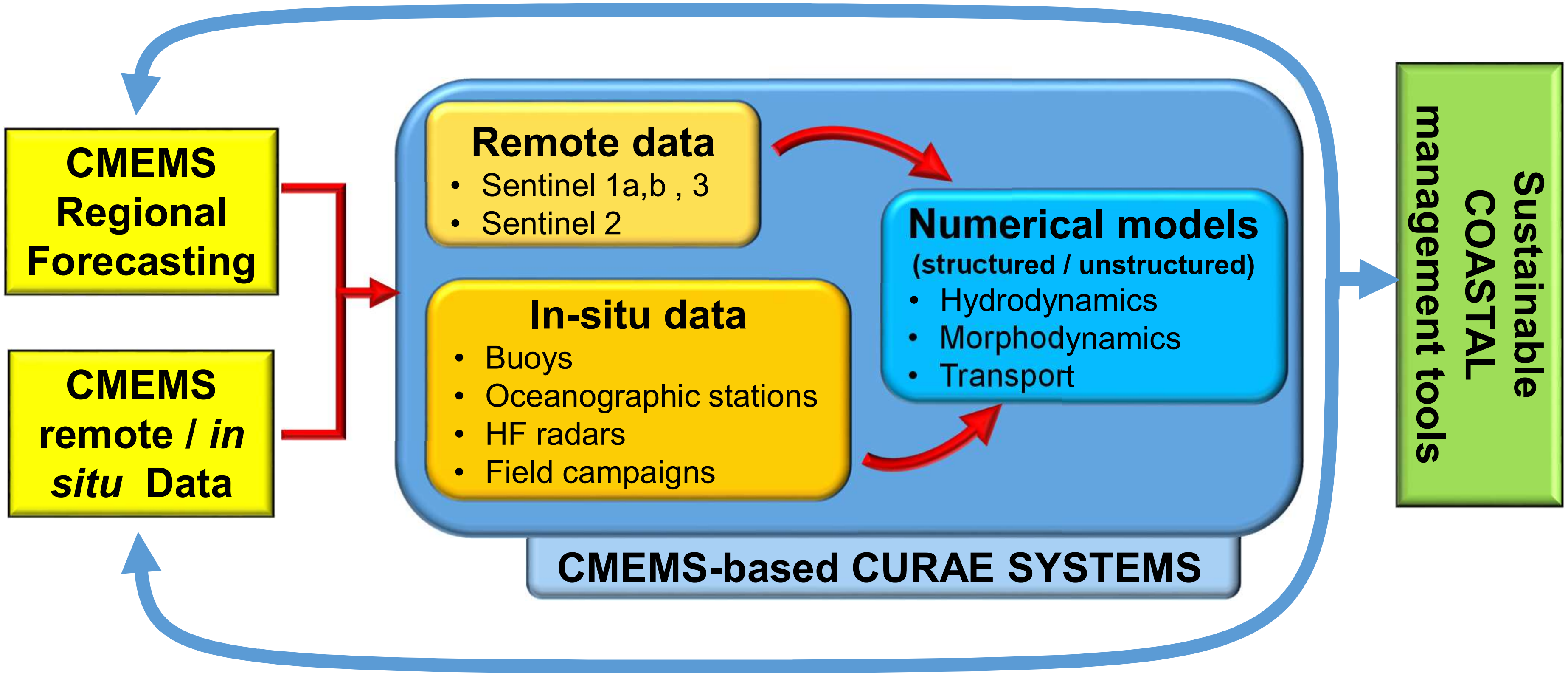
- **Wadden Sea** with Ems, Weser and Elbe estuaries
- Most important port in North Sea
- Highly dynamic bottom / geometry → morphodynamic control
- Co-existing processes (meso/macro tides, waves, river…) & scales → difficult coupling
- Shallow domain + river banks + dynamic mouth → limited water exchanges
- High impact of dredging → limits to interventions



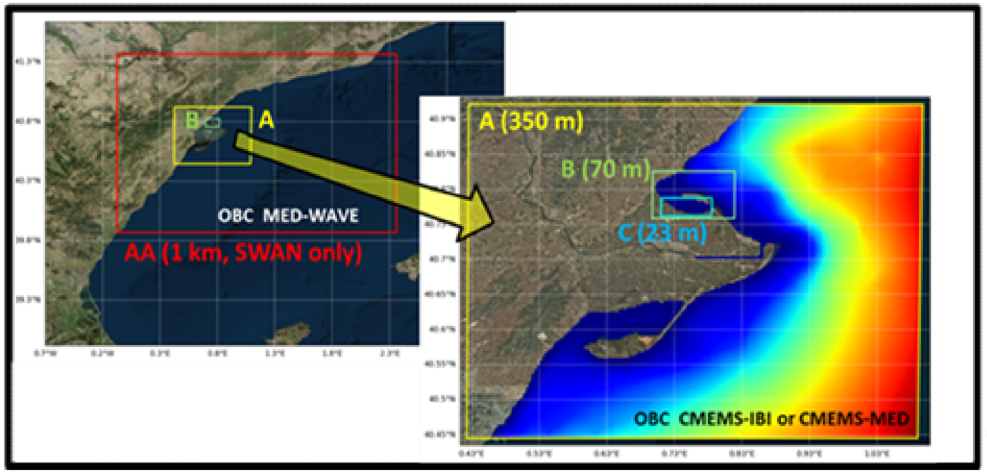
Sentinel-2 RGD images for 16 April, 2016 zoomed to Ems Estuary

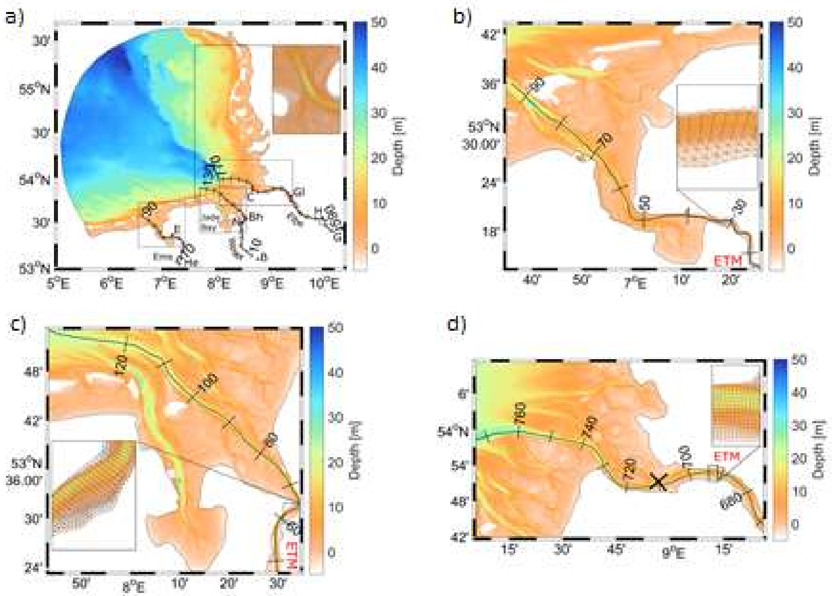
4.- The CURAE approach



- **Structured** grid approach
- **COAWST** model (ROMS+SWAN+CSTMS)
- Coupled to CMEMS-IBI or CMEMS-MED
- Forced by MED-WAV or IBI-WAV (waves)
- Forced by ECMWF (atmosphere)
- *Coastline* updated from **S 2** data

- **Unstructured** grid approach
- **SCHISM** model
- Coupled to CMEMS-NWS
- Forced by CMEMS-NWS
- *Bathymetry* updated from **S 2** data





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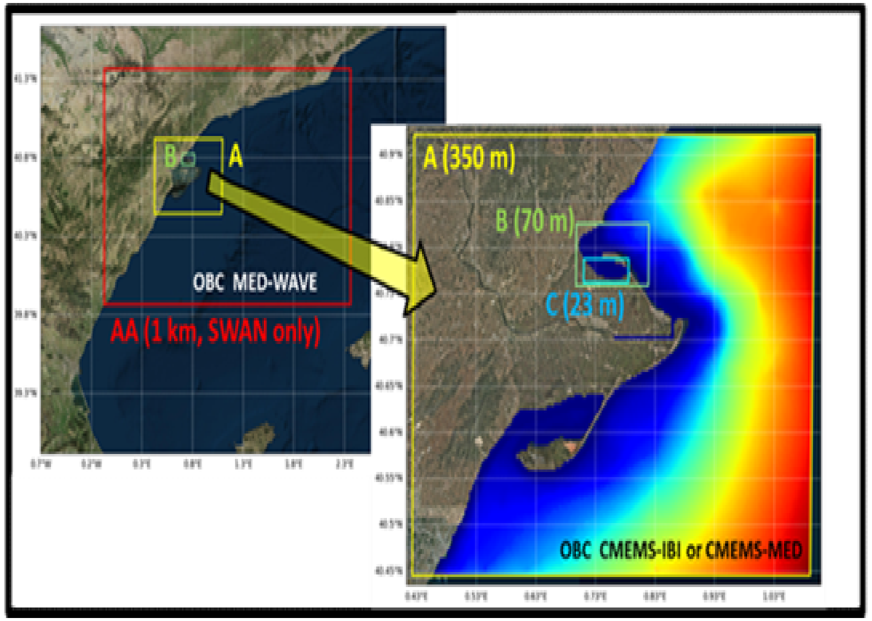
4.1- CMEMS downscaling

a) Fangar Bay

Downscaling ratio 1:5 and 1:3



Grid AA for SWAN only, since Δx for CMEMS wave product is ≅ 4 km

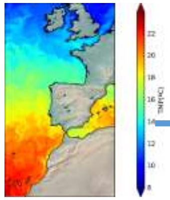
Grids A, B and C are common for both ROMS and SWAN

Grid sizes

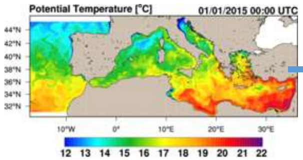
- AA (224x157x1)
- A (162x152x10) – 350 m
- B (147x107x10) – 70 m
- C (272x122x10) – 23 m

Copernicus Marine Environment Monitoring Service – Service Evolution

4.1- CMEMS downscaling

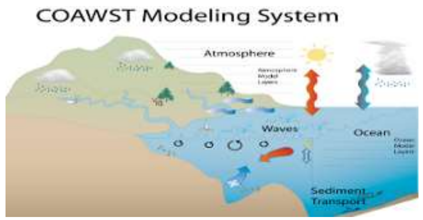


IBI_ANALYSIS_FORECAST_PHYS_005_001



MEDSEA_ANALYSIS_FORECAST_PHY_006_013

INI (A, B, C)
BRY (A)

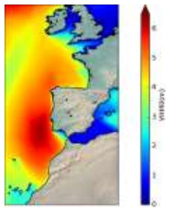


ECMWF

ATM FRC

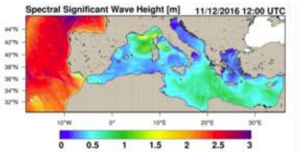
WIND

SWAN
Simulating WAves Nearshore



IBI_ANALYSIS_FORECAST_WAV_005_005

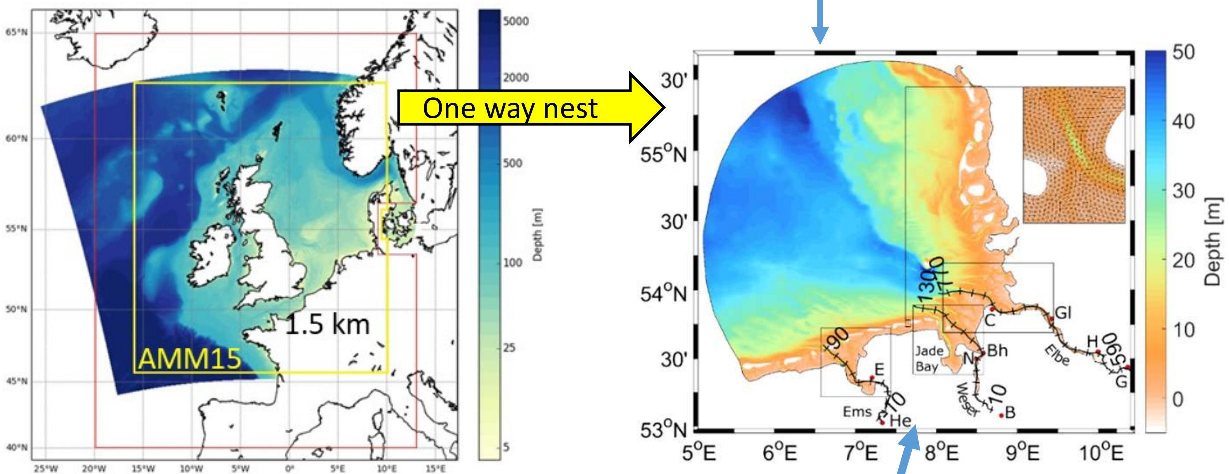
INI (AA, A, B, C)
BRY (AA)



MEDSEA_ANALYSIS_FORECAST_WAV_006_017

b) German Bight

DWD COSMO-EU



[NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_001]

Weir river discharge
(from authorities)

$9 \cdot 10^5$ elements
$4.8 \cdot 10^5$ nodes
Δx = [50 m, 1.5 km]
N_z = 21 S-layers
Δt = 120 s
Hourly, daily forcing

- AMM15 (1.5 km) interpolated as boundary forcing: η (2D), T, S, $\vec{u}$ (3D)
- Seamlessly refined grid from 1.5km to 50m across estuaries to resolve coastal/estuarine baroclinic processes.

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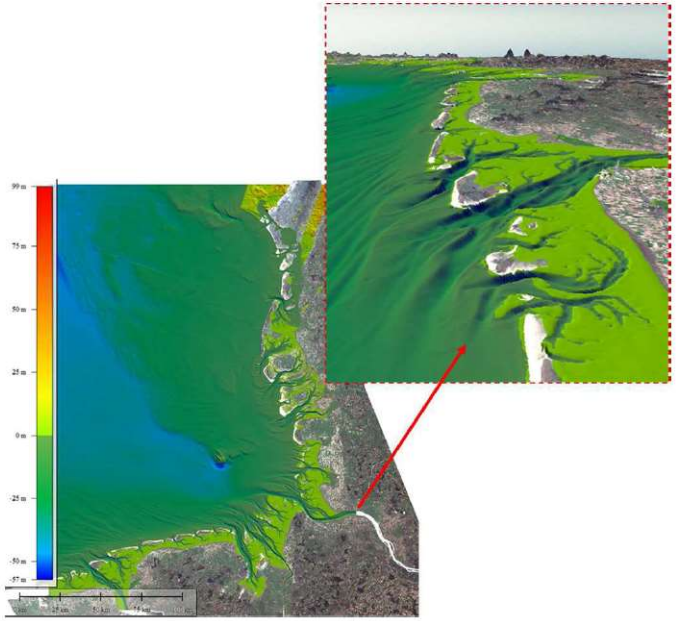
- Morphodynamic feedback constantly reshape nearshore morphology
- Evaluate role of up to date nearshore morphology: CURAE has incorporated S 2 derived bathymetry (SDB)
- The integrated EMODnet 2018 + Sentinel- 2 Bathymetry has been compared to the HR topography data already used in the SCHISM model.
- Differences show the high variability in the area of tidal channels and flats.
- SDB in shallow zones in HR coastal models can reduce errors and improve reliability.

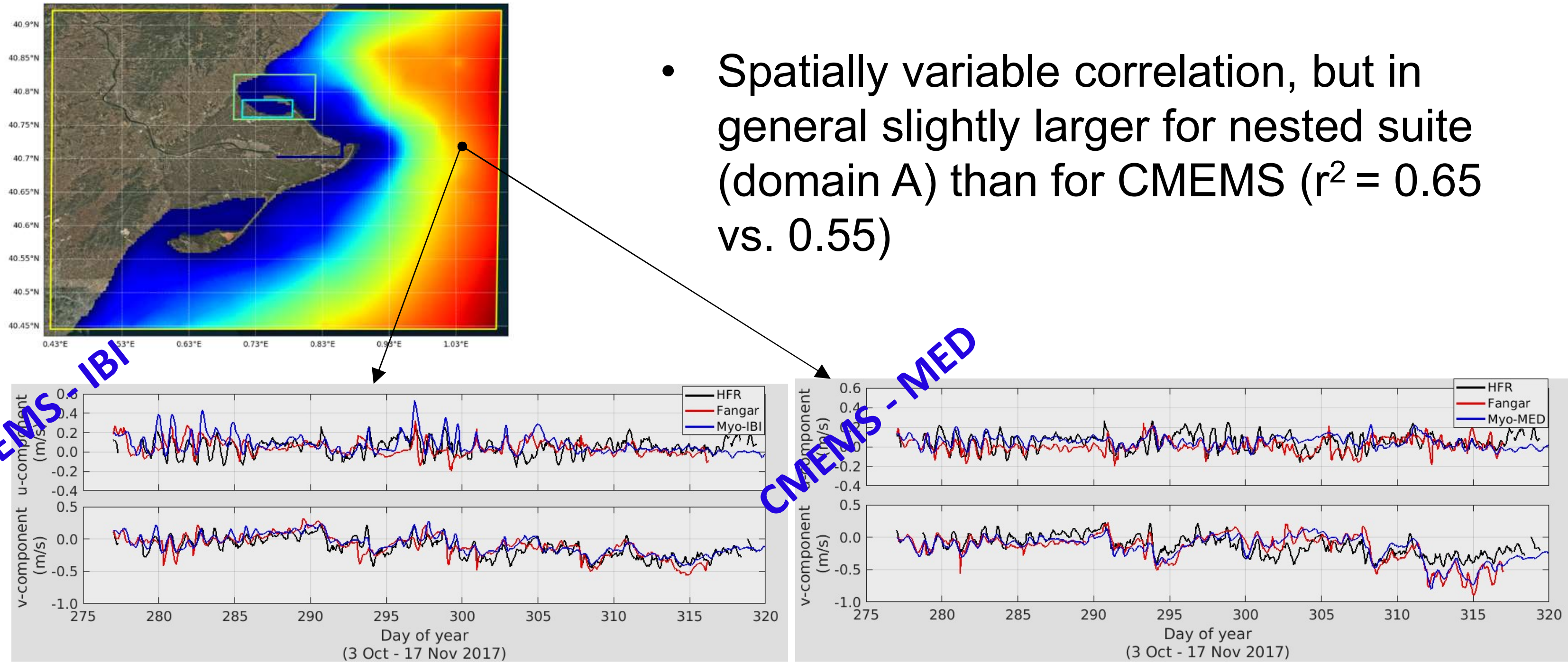


5.- Results

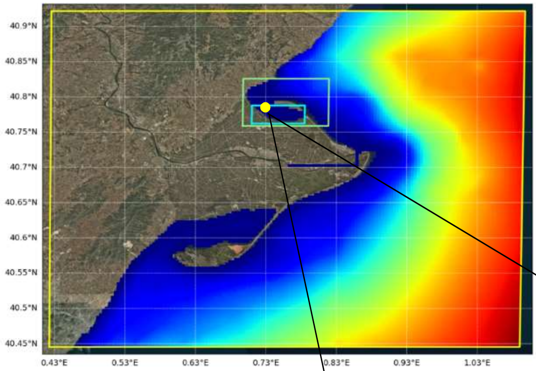
5.1 Fangar Bay

a) Currents - *Offshore* validation with HFR

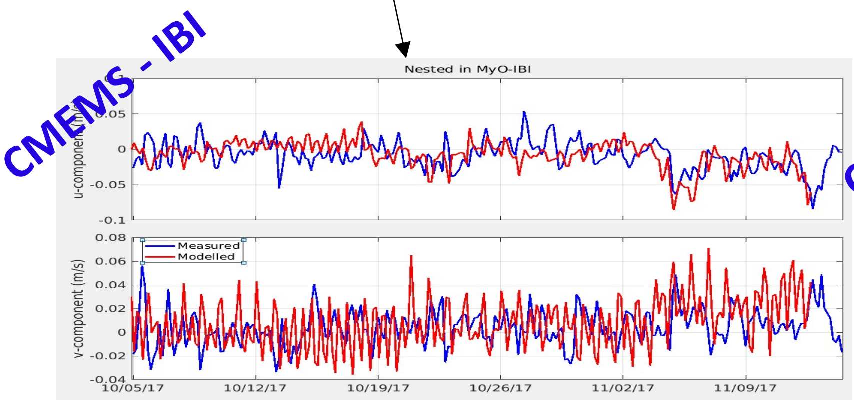
- Spatially variable correlation, but in general slightly larger for nested suite (domain A) than for CMEMS ($r^2 = 0.65$ vs. 0.55)

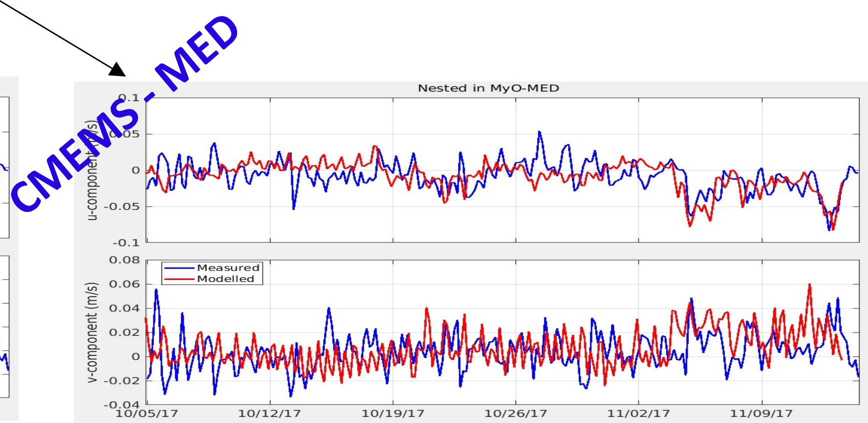


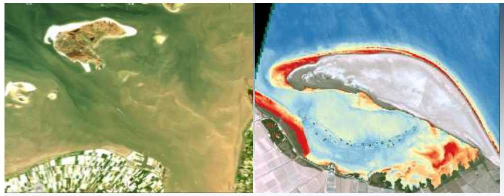
b) Currents – *In-bay* validation with currentmeters



- Good agreement, especially in energetic NW wind events, but also trends with weak currents (~ 5 cm/s)

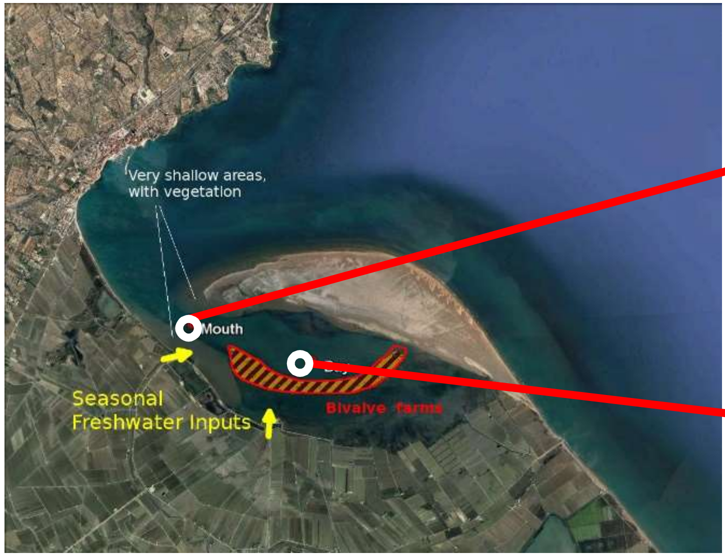


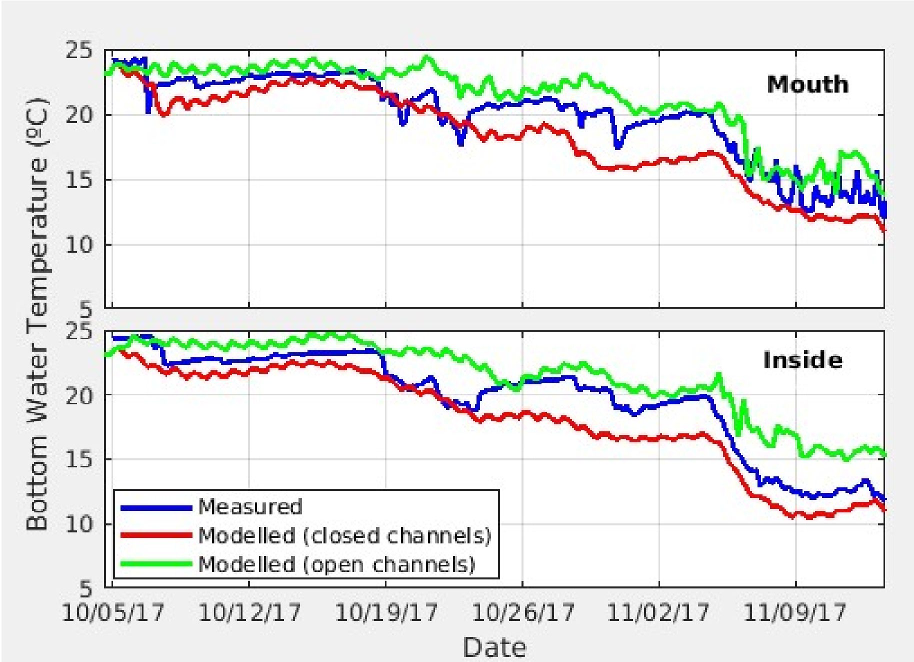




c) Water temperature – *In-bay*

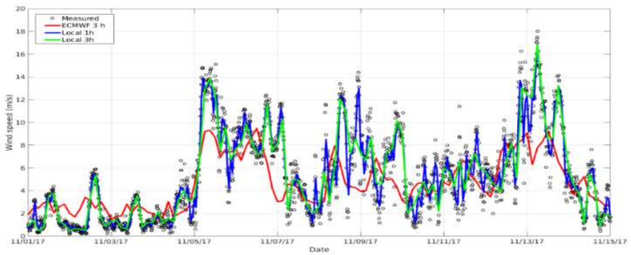
- Good agreement, but highly sensitive to freshwater discharges from the canals! → influence on open sea dynamics



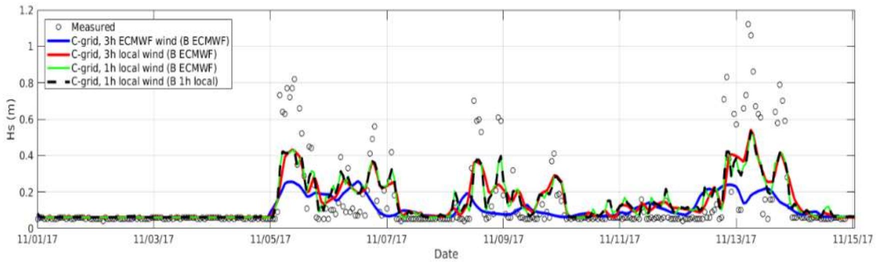


5.- Scientific / technical results

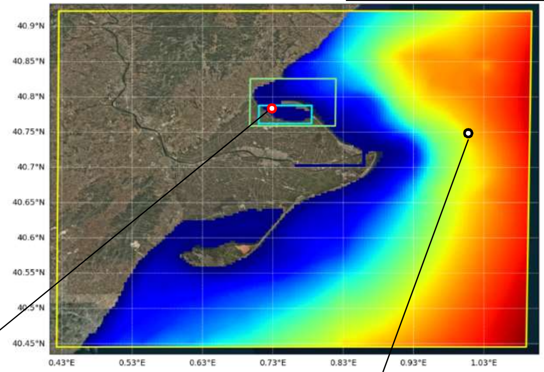
d) Waves

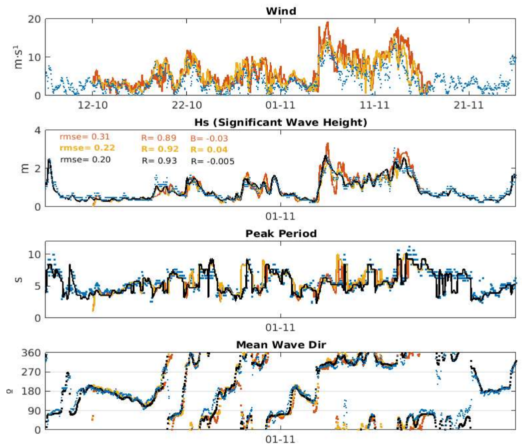


Wind forcing used in the simulations



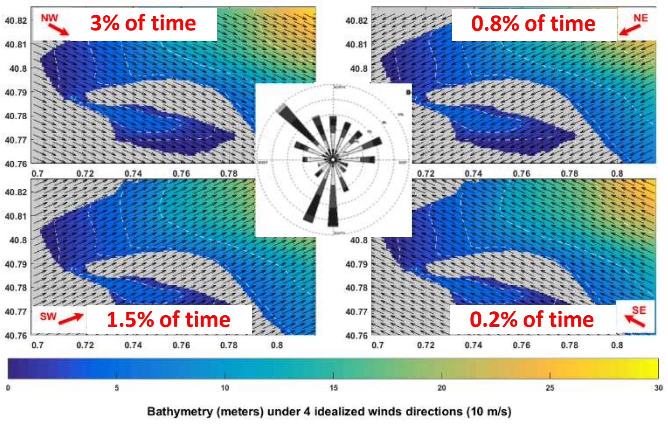
- Significant differences in terms of the atmospheric forcing selected
- In *the bay*, ECMWF resoution is inadequate to simulate wave fields!
- H_s underestimated

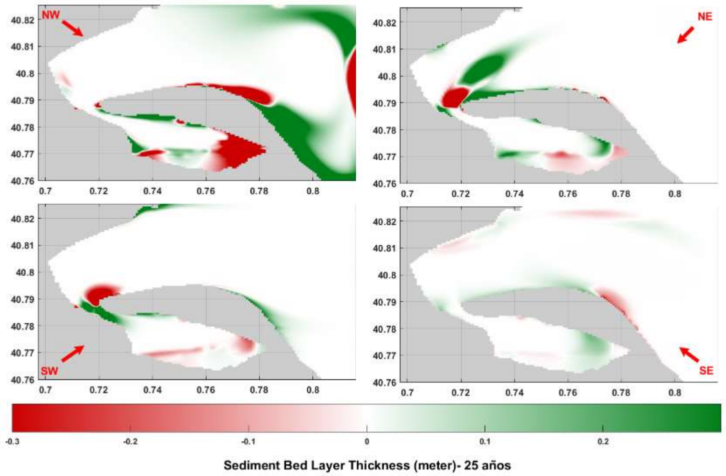


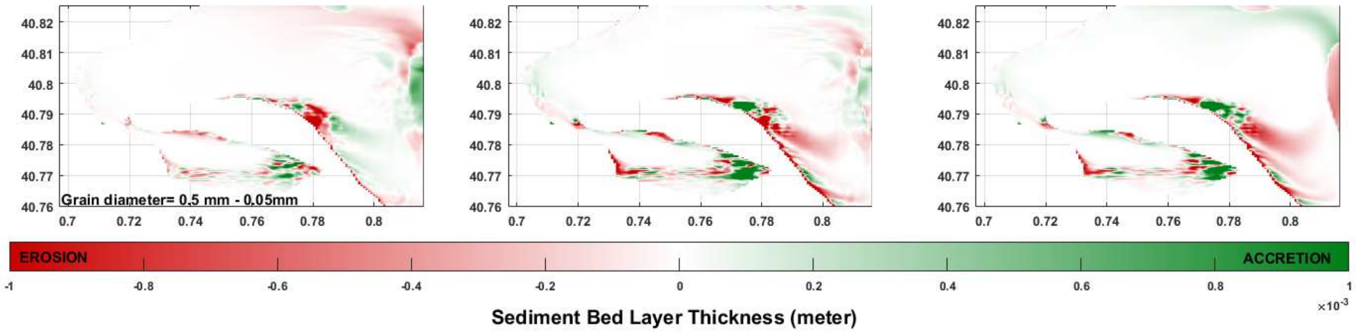


- Slight differences in terms of the atmospheric forcing selected
- In *open sea*, ECMWF is better than AEMET

e) Sediment – erosion/accretion in the bay for idealized wind cases



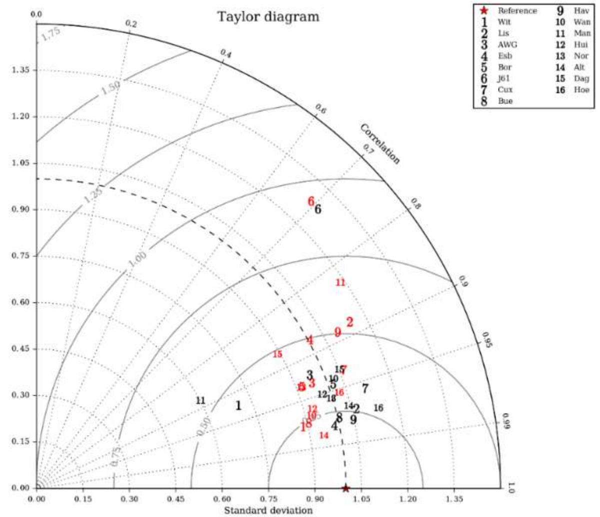




5.2 German Bight

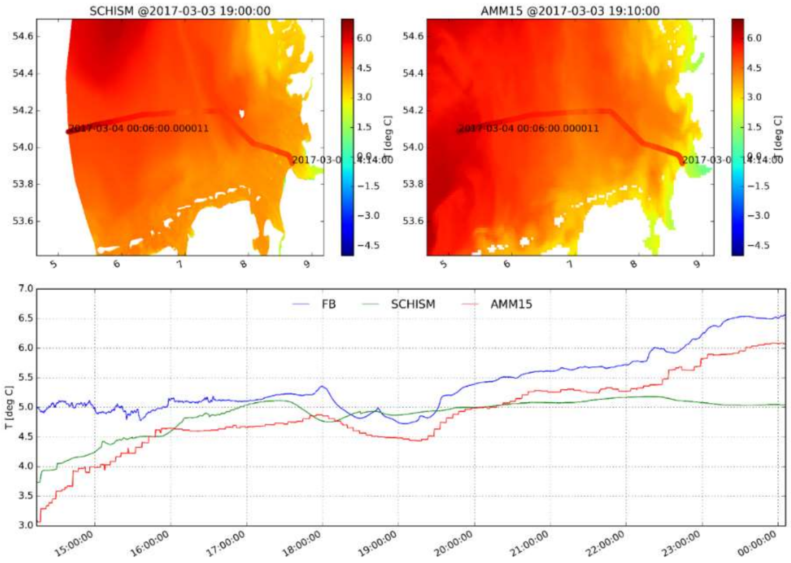
a) Comparison SCHISM vs. AMM15

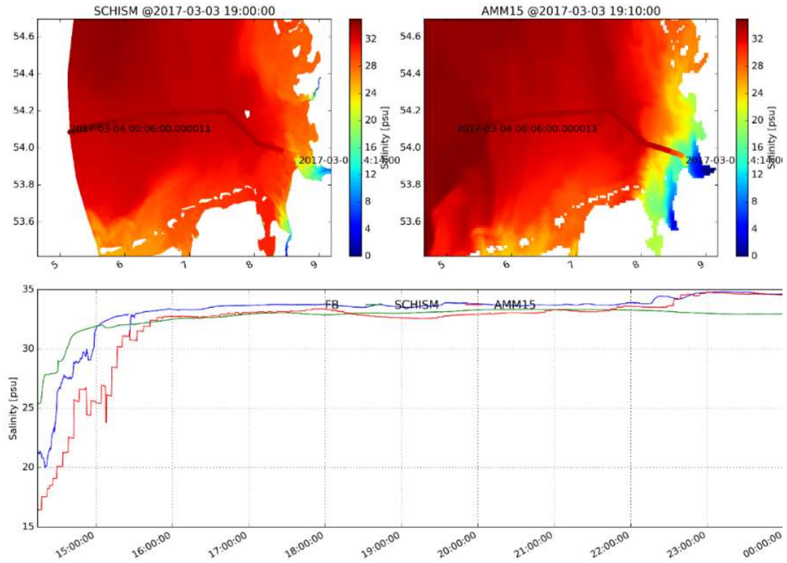
- Slightly better performance for nested model, due to improved bathymetry
- RMSE reduces by 10 - 20 cm
- Correlation increases around 0.05
- SCHISM/AMM15 tend to over/underestimate variability



SSH at different tidal stations (black – SCHISM; red – AMM15)

b) T and S from FerryBox data





Temperature
- Similar negative bias
- Better spatial correlation in AMM15
- SCHISM is closer in the estuary

Salinity:
- Better salinity front with SCHISM
- Otherwise similar performance

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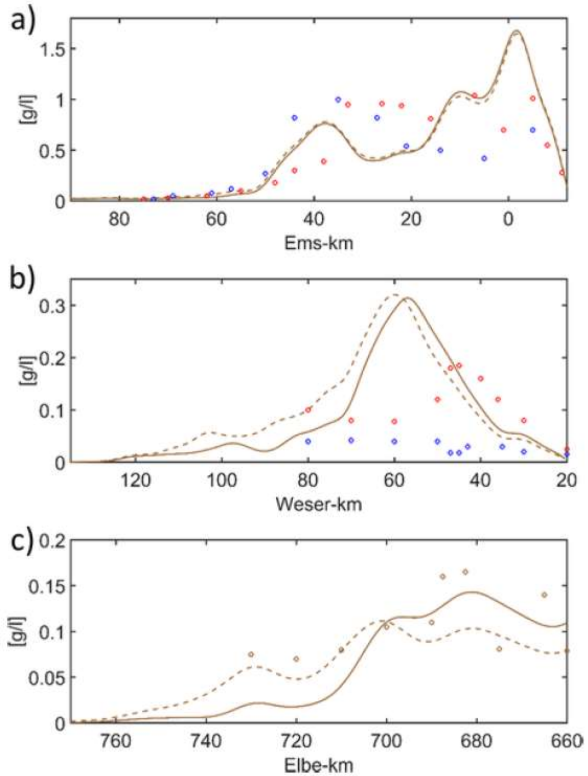
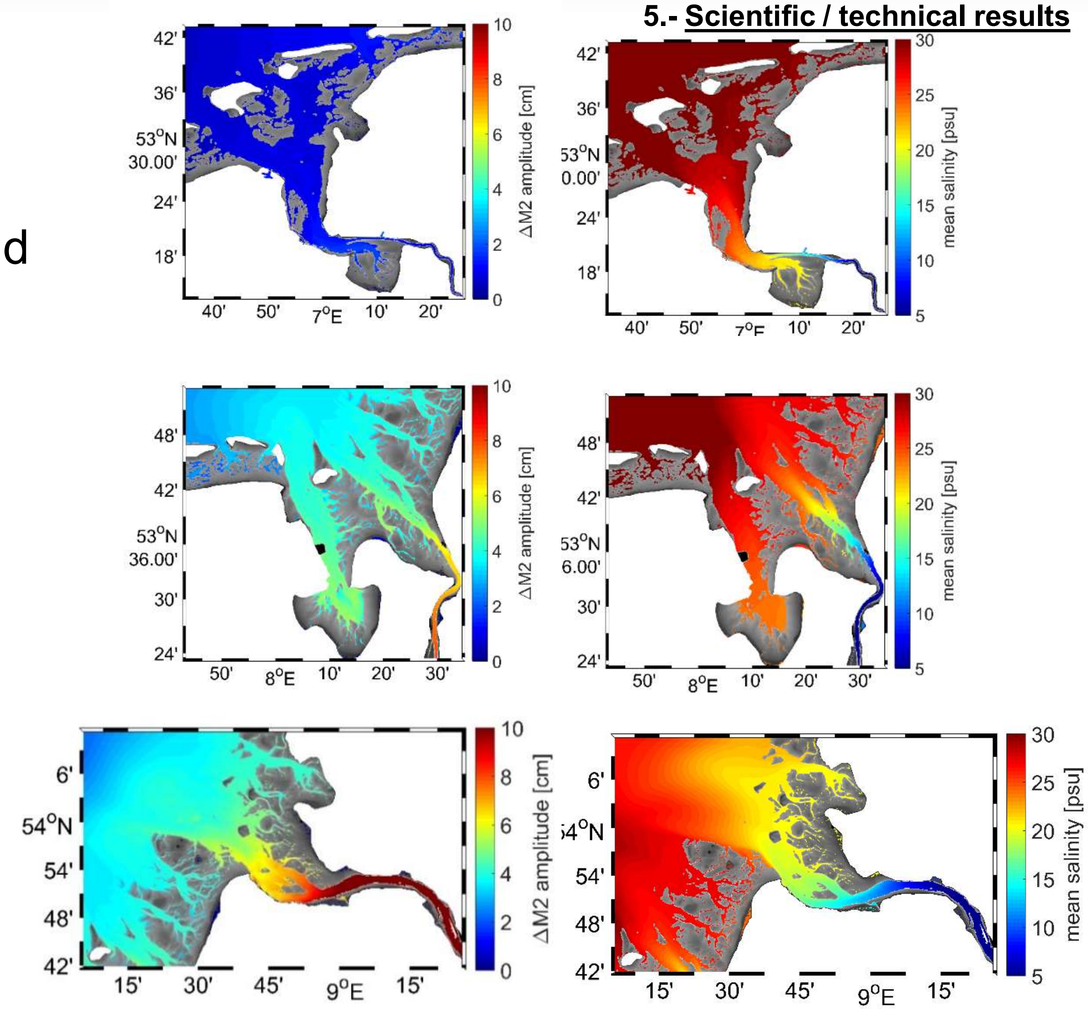
c) Dependence of tidal and SPM dynamics on density variations

- Control run and barotropic experiment → impact of density on tides and sediment distribution?
- 3 estuaries (Ems, Wesser, Elbe, different runoff)
- 8 classes of non-cohesive sediment - 0.06 to 2 mm



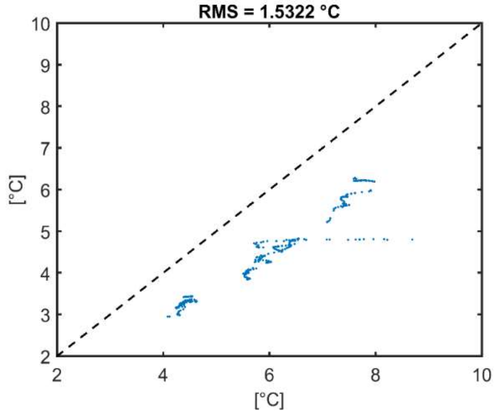
- **Sorting by grain size and gradients**
  - Maxima of grain size classes: distributed differently along estuary
  - Salinity front traps sediments: maxima located further seaward than in barotropic experiment.
  - Secondary maxima in upriver direction are damped

- **Tidal amplitudes**
  - Increasing river runoff increases tidal amplitude and reduces bottom friction (stratification)
  - Density affects tidal amplitude: Ems ≈ 6 cm and in Elbe > 10 cm of M2 amplitude (5%)
  - Density affects tidal asymmetry in frontal area (contribution similar to M4 magnitude)



d) Sensitivity to atmospheric forcing

FerryBox Validation

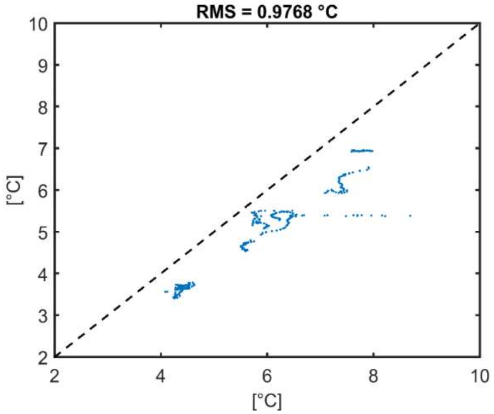


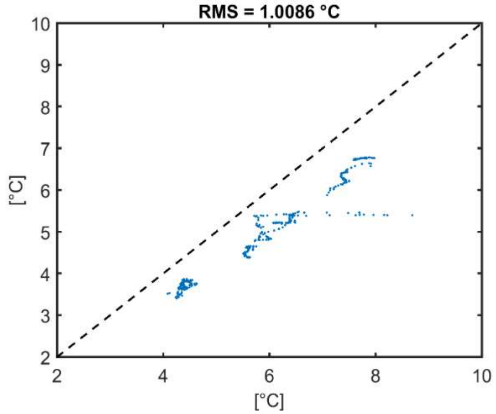
- Atmospheric forcing sensitivity using
  - a) Different forcings (CMEMS ERA5 vs G. Weather Service DWD)
  - b) Tuned cloud parameterization for incoming short wave radiation

- Strong correlation with observed SST (DWD & CMEMS)

- Reduced negative CMEMS bias. Overall RMSE from **1.54**ºC to **0.98**ºC

- Results can be systematically improved with new observations

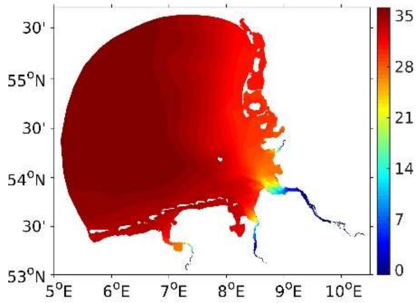




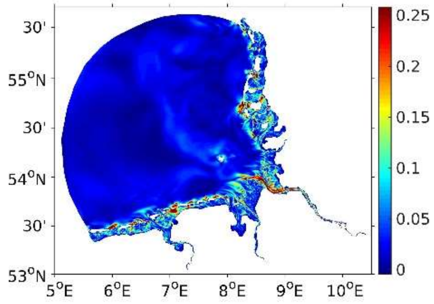
e) Sensitivity to river forcing (Q_R)

- Q_R from weirs (CR) *vs*. Q_R from LAMBDA (HM)
- HM trend to over-predict Q_R, increasing buoyancy forcing in Elbe plume and N. Frisian Wadden Sea
- Velocity changes with Q_R comparable to monthly mean in CR
- River forcing has a strong effect on simulated S and circulation fields

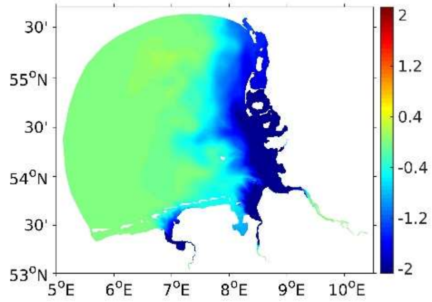
<Salinity (CR)>



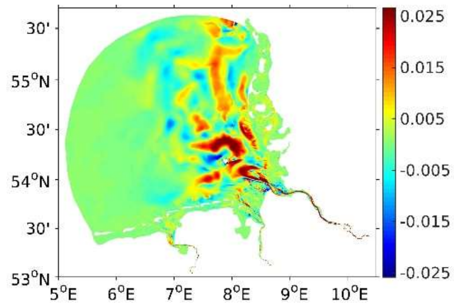
<Velocity (CR)>



LAMBDA- CR



LAMBDA - CR



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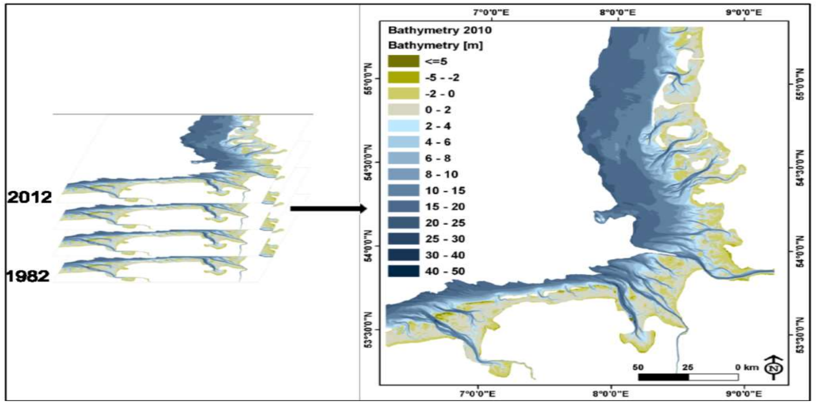
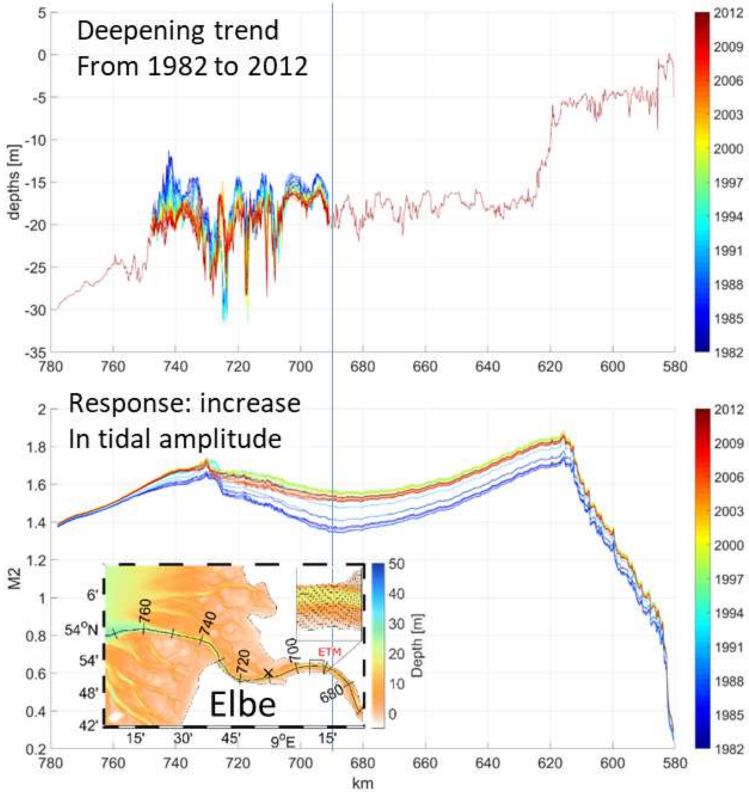
e) Sensitivity to morphodynamic changes

- Strong morphodynamics control
- Multi decadal data available to derive different bathymetries
- Deepening trend, increasing tidal amplitude (up 20 cm sea side) due to reduced friction/increase volume inflow
- Relative M2 increase wrt M4 (tidal channels) indicating decrease in tidal asymmetry

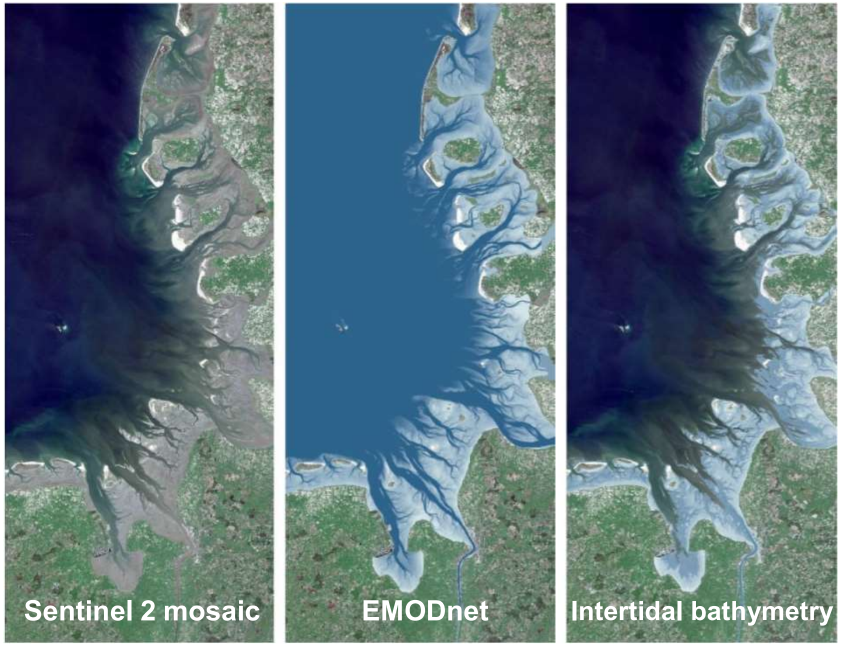


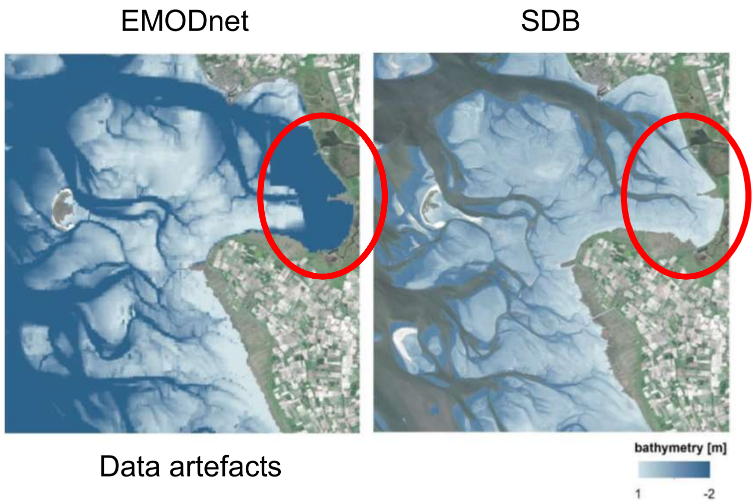


Elbe salinity front unaffected in location but temporal changes in salinity range

5.3 Satellite derived bathymetry

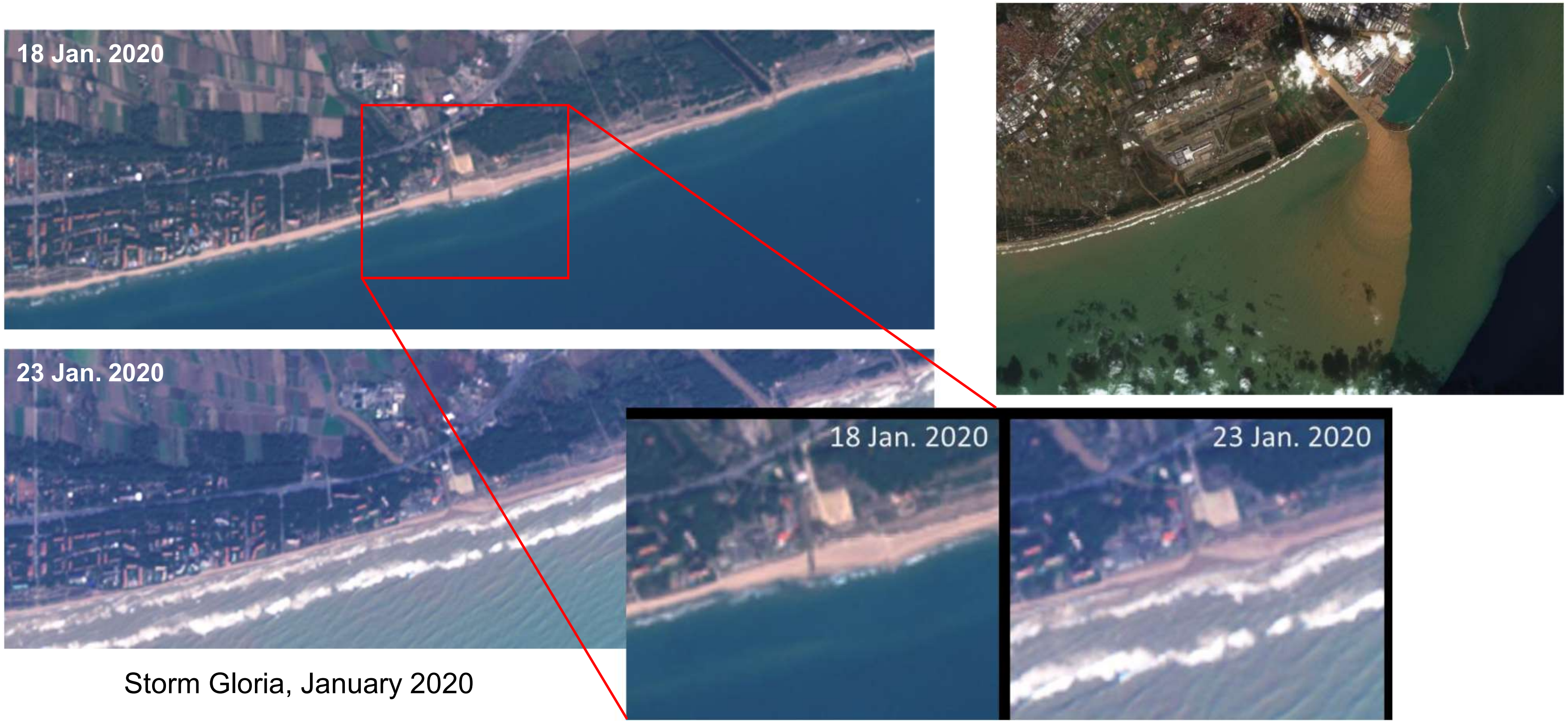
- Historical data and EMODnet outdated → errors in dynamic regions
- Merging of remote-sensing (active areas) with EMODnet (stable areas)
- Data challenge: merging different scales (what to keep and how to decide)





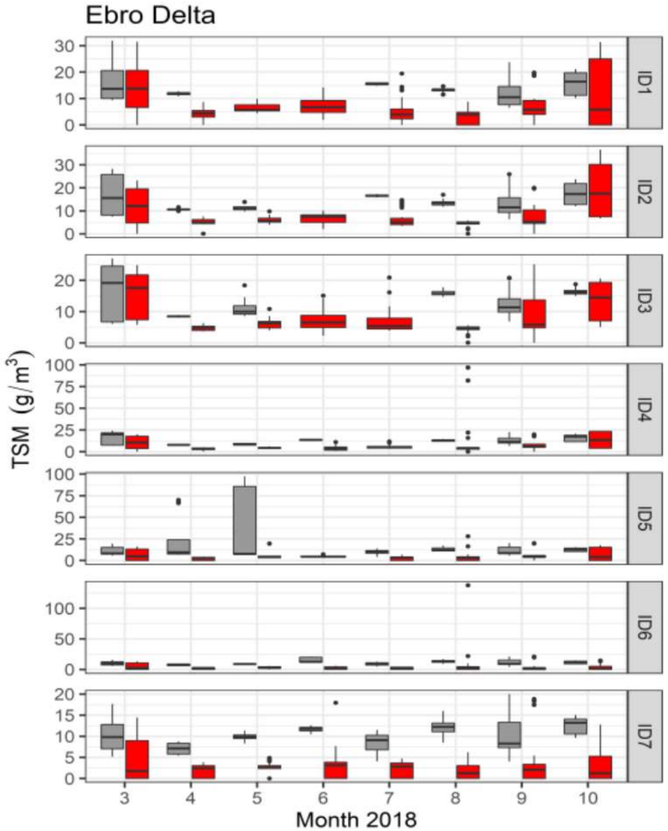
Data artefacts

- Relevance of bathymetric/shoreline updating for impact/risk analyses
- Coastal zone info: coastline, erosion rates, beach width, dominant land cover/use



Storm Gloria, January 2020

6.- Conclusions



- Robust agreement of metocean downscaled variables, providing a CMEMS coastal extension for structured/unstructured grids in 2 complementary sites.

- Density field controls hydro-morphodynamics, SSH and tidal asymmetry in the German Bight.

- In low energy (microtidal) cases, Eurlerian+Lagrangian validation required for SPM/ circulation fields

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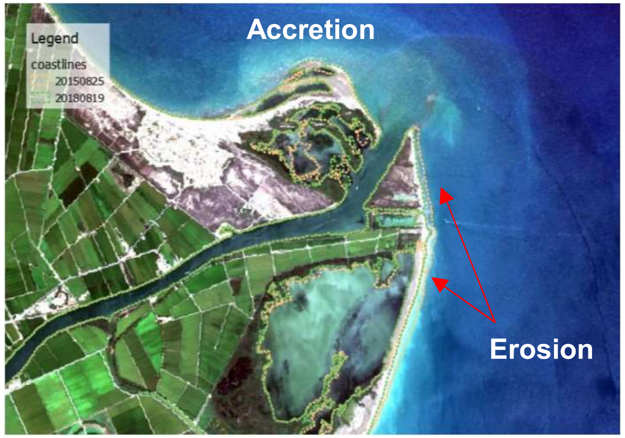
- Local CMEMS predictions may differ from observations due to local winds, land discharges, bed friction → **need** for adequate characterization (winds, bathymetry, granulometry, coastline, land solid/liquid discharges…)

- Combined in-situ and RS products for coastal models
  - … need for expertise on sensor/satellite
  - … SDB limited by physical processes (turbidity) and numerical issues (merging)



7.- Identified issues for CMEMS coastward evolution

1) Limited **compatibility/quality** of input data, BCs and SDB/shorelines

2) Inability to rank error contributions from

- **Land** river and distributed **discharges** (freshwater/sediment/nutrients) with a strong **seasonal** modulation

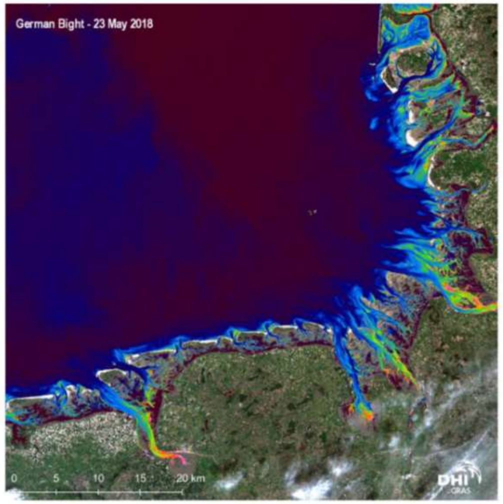
- **Short duration events** with operational forcing publicly available (ECMWF, 6 hours) insufficient for observed behaviour

3) Limited **multiple variable in-situ data** for ground truthing numerical and RS data

4) Calibration/validation for **low-energy hydrodynamics** (restricted domains) in Eulerian frame: Evolve to new metrics and approaches

5) **Artefacts and interpolation** coastal errors for SDB + in-situ data (sun glint/turbidity), reducing flexibility for capturing specific events

- Tidal flat areas (Wadden Sea) with tidal resuspension
- Chronic high turbidity in microtidal bays (Ebro delta)




CURAE – bridging the gap between regional CMEMS forecasts and coastal high-resolution applications

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