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CLUSTER OF EXCELLENCE
CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

Project: bm1173

Project title: Climate, Climatic Change and Society

Principal investigator: Johanna Baehr

Report period: 2023-01-01 to 2023-12-31

Report on usage of the DKRZ Resources for the first 9 months

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Preface

The report summarizes the individual reports of subprojects of the Cluster of Excellence CLICCS (Climate, Climatic Change and Society). The reporting will cover the time period from 01. January 2023 to 31. December 2023. The numbers for used computation time and storage resources are taken end of September. The individual DKRZ project numbers are bm1183, bg1184, bg1186, mh1212, bu1213, and bu1214. bm1219, which had previously been part of the bm1173, did not apply for ressources in 2023 and is therefore not listed here. Please note that the current report covers only 9 months.

Overall resource consumption in 2023

As of 13.10.23 the consumption is 71% (with 5% expiration) of allocated Levante CPU nodes for 2023. The expected consumption of all subprojects at the end of the year is 86%. (Linear extrapolation subprojects the end-of-year consumption to 90%.)

Report subproject bm1183

Subproject title: CLICCS A2, Clouds and tropical circulation; Subproject lead: Ann Kristin Naumann (MPI-M); Chairs: Stefan Bühler (UHH), Bjorn Stevens (MPI-M); Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante) [node h]	26850	34937	34937
Levante storage (TB)	142	70	120
Archive project (TB)	102	68	102
Archive long term (TB)	21	0	0
Swift Object Storage (GB)	10240	3	3

Experiments performed successfully at project account bm1183: For 2023, DKRZ provided us with the resources to perform two sets of simulations in two work packages (WP). For **WP1**, a sensitivity study with an idealized single-column model showed that the impact of uncertainty in water vapor continuum absorption was smaller than expected, thus we decided that testing these in global sensitivity simulations with ICON as planned is not promising. Instead, we used the resources of WP1 to study Stratocumulus cloud properties in a similar setup (global domain with 5 km grid spacing for a 45-day period) and applied a 2-moment cloud microphysics scheme (as in Lang et al., 2023) which treats the cloud droplet number concentration as a prognostic variable. An additional 12-day global simulation was carried out to investigate the response of the cloud properties to increased cloud condensation nuclei (CCN) concentrations. In **WP2**, we performed several tests for different climate change forcings in a limited area setup of the northern tropical Atlantic with the aim to study shallow cloud feedbacks. These tests are crucial in developing a suitable setup for a longer global warming scenario simulation.

Scientific results of subproject bm1183: WP1 Stratocumulus cloud properties simulated by the storm-resolving model differ greatly from satellite data, with increasing CCN having the opposite effect on the liquid water path in the model and in the observations. This was also reported for conventional climate models (e.g. Michibata et al., 2016). Investigations of this discrepancy with a causal approach (Fons et al., 2023) are ongoing. **WP2** Realistic high resolution regional LES with idealised climate change forcings are a new approach to investigate shallow cumulus cloud feedbacks. The development of a consistent climate change forcing signal is ongoing.

Publications in 2023 that use data of subproject bm1183: Two posters, one on each WP, were presented at the CFMIP conference in Paris, in July 2023 (Fons et al., Campos et al.). A paper draft that presents results from WP1 will be prepared by the end of 2023. Additionally, a paper discussing uncertainties in the tropical humidity structure in global storm-resolving models that is based on the subproject's simulations performed in 2022 was published (Lang et al., 2023). Another paper evaluating climate models at the gateway to the Arctic that is partially based on the subproject's simulations performed in 2021 was submitted (Pithan et al., in review).

Data Management of subproject bm1183: Analyses of both WPs are still ongoing; therefore, the relevant model output is currently kept in the subproject's directory on levante. Additional post-processed model output for analysis and part of the model output are saved in the mh1126 levante directory. Post-processed model output will be archived once the paper is accepted (estimated date: 1st half of 2024; WP1) or deleted once a consistent climate change forcing is developed (WP2). Additionally, (post-processed) model output from simulations performed with 2022's resources were archived as the corresponding paper has been accepted for publication (Lang et al., 2023).

References:

Fons, E., Runge, J., Neubauer, D. et al. Stratocumulus adjustments to aerosol perturbations disentangled with a causal approach. npj Clim Atmos Sci 6, 130 (2023). https://doi.org/10.1038/s41612-023-00452-w

Lang, T., Naumann, A. K., Buehler, S. A., Stevens, B., Schmidt, H., & Aemisegger, F. (2023). Sources of uncertainty in mid-tropospheric tropical humidity in global storm-resolving simulations. Journal of Advances in Modeling Earth Systems, 15, e2022MS003443. https://doi. org/10.1029/2022MS003443

Michibata, T., Suzuki, K., Sato, Y., & Takemura, T. (2016). The source of discrepancies in aerosol–cloud–precipitation interactions between GCM and A-Train retrievals. Atmospheric Chemistry and Physics, 16(23), 15413-15424.

Pithan, F., A. K. Naumann, and M. Maturilli: Too cold, too saturated? Evaluating climate models at the gateway to the Arctic, in review.

Report subproject mh1212

Subproject title: CLICCS A4 – African and Asian Monsoon Margins CLICCS; Subproject lead: Katharina D. Six (MPI-M), Shabeh ul Hasson(UHH); Chairs: Jürgen Böhner (UHH), Martin Claussen (MPI-M/UHH), Gerhard Schmiedl (UHH); Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante & Mistral) [node h]	190920	127907	190920
Levante storage (TB)	90	86	90
Archive project (TB)	190	40	60
Archive long term (TB)	45	0	10
Mistral Lustre work (GB)	-	-	-
Swift Object Storage (GB)	10240*	0	0

* was granted but not applied for

Experiments performed successfully at project account mh1212: WP1: Simulations with 3 different forcing (from 2 ice-sheet reconstructions and from one fully coupled ESM_ICE-SHEET_SOLID-EARTH model) over the entire last deglaciation (simulation length 22000 years); 3 sensitivity simulations with enhanced nutrient input of the Nile river (15000 years); 2 sensitivity simulations with additional freshwater input from the Black Sea (15000 years)

Scientific results of subproject mh1212: WP1: We produced a unique set of transient ocean biogeochemical simulations with a regional 3d model of the Mediterranean Sea (MedSea) over the entire Last Deglaciation which forms the basis for identifying the drivers of sapropel formation. Ocean stratification in the eastern MedSea, a precondition of sapropel formation, begins ~3000 years prior to the African Humid Period and, in conjunction with present-day river nutrient concentrations, results in strong drawdown of oxygen (by 120-160 mmol/m^3) in near bottom layers around 10 kyr BP (Fig. XXX).

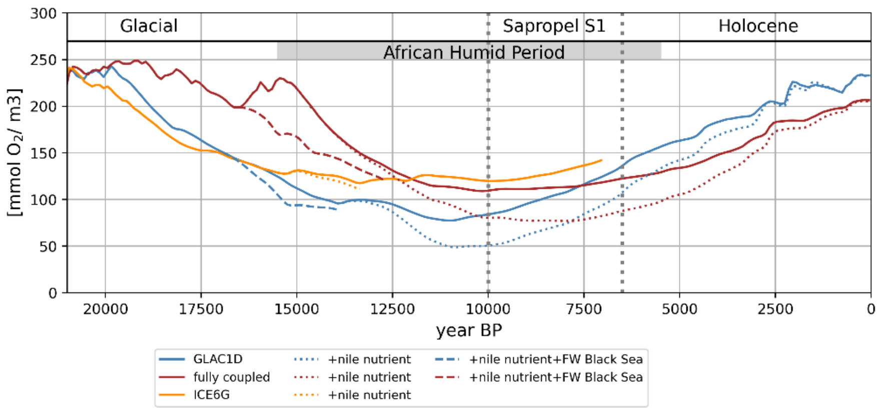

Fig.1: Oxygen concentration at 2300m depth in the eastern MedSea from the last glacial maximum to present-day for 8 different simulations (see legend)

Considering an enhanced nutrient input via the Nile river leads to an additional oxygen consumption of 30 mmol/m^3 in the eastern MedSea. Lowest oxygen concentrations are found in the fully coupled set-up in the period of sapropel formation as identified by proxy data (10-6kyr BP), while minima occur too early in the runs with ice-sheet reconstruction. Freshwater input from the Black Sea adds a minor signal of ~10 mmol/m^3 to the oxygen consumption. We do not find anoxic conditions in any of the runs, which could indicate still missing processes, such as the ballasting effects accelerating vertical organic matter fluxes. WP2: We produced a full analysis of 11 CMIP6 Models on land use and climate interactions over the South

Asia region. We looked at Climate information produced by these models' outputs as well as the land cover fraction available.

Publications in 2023 that use data of subproject mh1212: WP1: K.D.Six, U.Mikolajewicz, G.Schmiedl, Modeling Mediterranean ocean biogeochemistry of the Last Glacial Maximum (in internal review, will be submitted in November) WP2: *Freitas Santos, Juliana, Udo Schickhoff, Shabeh ul Hasson and Jürgen Böhner: Biogeophysical Effects of Land-Use and Land-Cover Changes in South Asia: An Analysis of CMIP6 Models*

Data Management of subproject mh1212:
WP1: Output of all simulations is stored on /arch. We have not yet used the applied space on /docu.
WP2: Outputs of the analysis are stored in the running subproject folder due to the fact the outputs require low storage demand and easy accessibility.

Report subproject bg1184

Subproject title: CLICCS A5 - The Land-Ocean Transition Zone ; Subproject lead: Moritz Mathis (Hereon); Chairs: J. Hartmann (UHH), P. Korn (MPI-M), C. Schrum (Hereon); Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante & Mistral) [node h]	212,000	102,000	212,000
Levante storage (TB)	103	77	103
Archive project (TB)	44	15	44
Archive long term (TB)	0	0	0
Swift Object Storage (GB)	10,240	0	0

Experiments performed successfully at project account bg1184: Our experiments were mainly related to i) production runs of the global ocean-biogeochemistry model ICON-Coast and the regional ocean-ecosystem model SCHISM-ECOSMO, and ii) test simulations for further developments of model systems ICON-Coast, SCHISM-ECOSMO and ICON-ECOSMO. The latter for the first time couples the global ocean model ICON-O with the ecosystem component ECOSMO. We made ICON-Coast compatible with vertical z* coordinates and implemented carbon fluxes to the ocean due to coastal erosion. SCHISM-ECOSMO was developed further to account for the carbonate system of shelf seas. In ICON-ECOSMO, we included riverine volume and nutrient inputs.

A large portion of the CPU resources for 2023 were requested for novel high-resolution simulations with ICON-Coast. In the first half of the year, however, we had to focus on finishing a publication of existing results and therefore could not use all resources in time. The planned high-resolution runs, including new forcing data along the Arctic coast, were successfully set up in the second half and are now running under full consideration.

Scientific results of subproject bg1184: Our simulations with ICON-Coast (Mathis et al., under review) revealed that the coastal ocean is a more efficient CO2 sink than the open ocean, being the first model to show agreement with this conclusion first deducted from observational products (Laruelle et al., 2018; Roobaert et al., 2019). Moreover, we found that the increasing coastal CO2 sink is primarily driven by the biological response to climate-induced changes in the circulation and increasing riverine nutrient loads, exceeding the upper ocean-atmosphere equilibration lag. Our results imply that the future CO2 uptake of the coastal ocean is crucially influenced by the growth rates of atmospheric greenhouse gas concentrations and matter fluxes from land. From our SCHISM-ECOMSO simulations (Kossack et al., 2023), we find that 16% of annual primary production on the Northwest European Shelf is related to tidal forcing (Fig. 1). In stratified areas, tidal forcing enhances the vertical nutrient supply for phytoplankton growth above the thermocline, representing the largest contribution to the increase in biological productivity. In shelf areas with increasing distance to the shelf break, effects of internal tides become dominated by internal waves generated at local fine-scale bathymetric features, further underlining the relevance of high-resolution bathymetry data in ocean modeling.

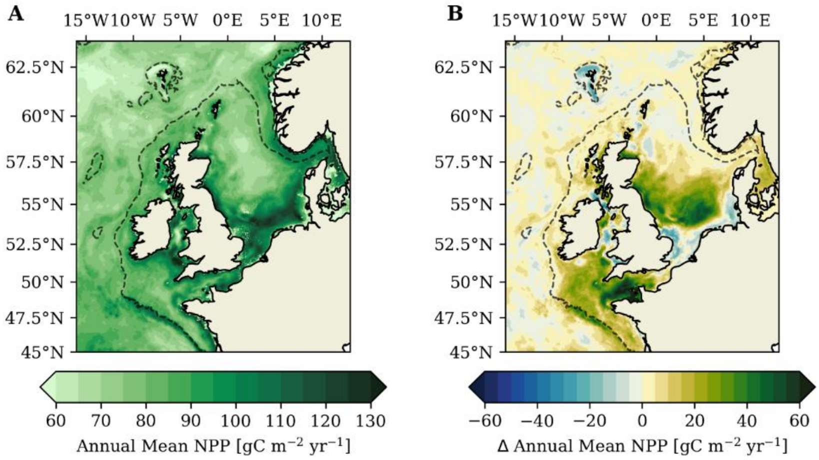

Figure 2: (A) Simulated annual primary production (2011–2015) in the SCHISM-ECOSMO experiment including tidal forcing and (B) difference between the experiment with and without tidal forcing. Dashed black contour shows the 200 m isobath.

Publications in 2023 that use data of subproject bg1184:

Mathis, M., F. Lacroix, S. Hagemann, D. Nielsen, T. Ilyina, C. Schrum. Enhanced CO2 uptake of the coastal ocean is dominated by biological carbon fixation, 23 May 2023, preprint (version 1) available at Research Square, https://doi.org/10.21203/rs.3.rs-2928105/v1

Kossack, J., Mathis, M., Daewel, U., Zhang, Y. J., Schrum, C (2023). Barotropic and baroclinic tides increase primary production on the Northwest European Shelf. Frontiers in Marine Science, 10, https://doi.org/10.3389/fmars.2023.1206062

Data Management of subproject bg1184: The simulations with SCHISM-ECOSMO will be transferred to LTA Doku early next year to be shared with the community for further analysis. The ICON-Coast simulations are currently under review and will be added to LTA Doku as soon as they are published. Moreover, many of our test simulations for model development will be moved from currently /work to the DKRZ archive, as they provide valuable information for ongoing and further development but we can dispense quick and direct access.

References:

Laruelle, G. G., Cai, W. J., Hu, X. et al. (2018). Continental shelves as a variable but increasing global sink for atmospheric carbon dioxide. Nat Commun 9, 454. https://doi.org/10.1038/s41467-017-02738-z

Roobaert, A., G. G. Laruelle, P. Landschützer, N. Gruber, L. Chou, P. Regnier (2019). The spatiotemporal dynamics of the sources and sinks of CO2 in the global coastal ocean. Glob Biogeochem Cycles, 33, 1693-1714. doi: 10.1029/2019GB006239

Report subproject bu1213

Subproject title: CLICCS A6 - Earth System Variability and Predictability in a Changing Climate ; Subproject lead: Dian Putrasahan; Chairs: J. Baehr (UHH), T. Ilyina (MPI-M), J.-S. von Storch (MPI-M), E. Zorita (Hereon) ; Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante) [node h]	516,321	410,781	516,321
Levante storage (TB)	1175	1109	1175
Archive project (TB)	645	107	645
Archive long term (TB)	-	-	-
Mistral Lustre work (GB)	-	-	-
Swift Object Storage (GB)	1	0.004	.004

Experiments performed successfully at project account bu1213: WP1: Completed 30-years thick counterpart for coupled ICON-ESM (R2B8L128/R2B8L90). Some changes to coupled ICON-ESM configuration made for the centennial simulations because we wanted to resolve mesoscale eddies up to polar regions, thus having a new R2B9L75 ocean coupled to R2B8L90 atm, which is also adopted by EERIE. Test runs for new setup amounting to 20 years. **WP2:** Several five-year simulations (2010-2014) with the coupled GCOAST-NEMO-WAM (3.5 km) setup. Additional multiple 9-year simulations (2010-2018) with the coupled GCOAST-NEMO-WAM-CCLM (3.5 km) and four 2-year simulations (2017-2018) with the high-resolution coupled GCOAST-NEMO-WAM (400 m) setup. **WP3:** Two 30-year (with and without phytoplankton feedback) with ICON-O-HAMOCC R2B8L128, and 3-years of ICON-O-HAMOCC R2B9L72

Scientific results of subproject bu1213: WP1: *Effect of surface ocean layer thickness (2m vs 10m) on climate variability:* We completed the 30-years thick counterpart for the coupled ICON-ESM (R2B8/R2B8), and compared it to 30-years thin run. Preliminary results show that thick run captures strong 3-year ENSO oscillation while thin run had no interannual variability for ENSO (Fig. 1a). Manuscript in preparation (Putrasahan et al.) to detail results. **WP2:** Using the completed A6-WP2 simulations, we optimized the model parameterization and deepen understanding of nonlinear interaction processes between the covered compartments of the Earth System. For a detailed description of the scientific results, we refer the reader to the publications of Grayek et al. (2023) and Nguyen et al. (submitted 2023). **WP3:** *Eddy effects on carbon vertical transport:* To derive accurate eddy-flux values, we implemented online calculations in our ICON-O-HAMOCC runs similar to von Storch et al 2016. Using these calculations, we compare the mechanisms governing oxygen, heat, and carbon dynamics, in the higher R2B8 resolution to the coarser R2B6. The analysis gives insight into eddy-induced carbon vertical transport in different regions, with particulate organic carbon (POC) fluxes for the Southern Ocean dominated eddy (Fig. 1b)

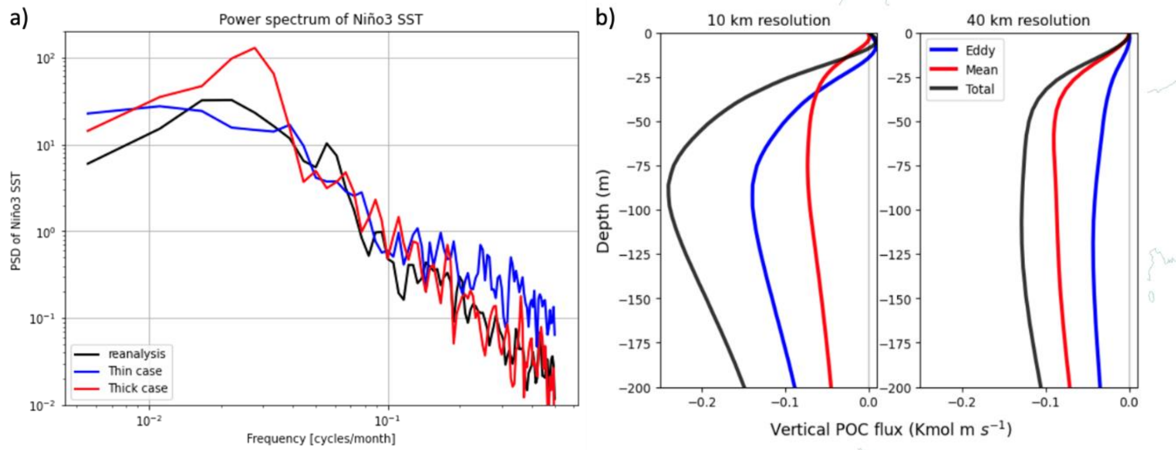

Figure 3: a) Power spectrum of Nino3 index. b) Comparison of total, mean and eddy POC flux in the Southern Ocean between the 10km and 40km res. setups

Publications in 2023 that use data of subproject bu1213:

- Casaroli et al. 2023, Effects of mesoscale processes on biogeochemistry, EGU2023.
- Chegini et al. 2023, Spin-up strategy for ocean biogoechemistry in a high resolution Earth System Model, EGU2023.
- Grayek, S., Wiese, A., Ho-Hagemann, H. T. M., Staneva, J. (2023). Added value of including waves into a coupled atmosphere–ocean model system within the North Sea area. *Frontiers in Marine Science*, *10*, 1104027.
- Nguyen, T. T., Staneva, J., Grayek, S., Bonaduce, A., Hagemann, S., Pham, N., Kumar, R., Rakovec, O. (submitted). Impacts of extreme river discharge on coastal dynamics and environment: Insights from high-resolution modeling in the German Bight. *Regional Studies in Marine Science*, Manuscript Number: RSMA-D-23-01240
- Putrasahan et al. (2023): Geographical distribution and spatio-temporal scale dependency of air-sea coupling via the vertical mixing mechanism, EGU2023 and AOGS2023
- Putrasahan et al. (2023): Impact of ocean layer thickness in Storm-and-eddy-rich Global Coupled Simulations on ENSO variability, AOGS2023
- Putrasahan, D. A., von Storch, J.-S. (2023): Temporal and spatial scale dependency of air-sea interactions via the vertical mixing mechanism (submitted to Geophysical Research Letters)

Data Management of subproject bu1213:

Present data storage (completed runs for present analyses) on work/, and to be archived on tape. After publication of manuscript, data will be in long-term archive:

- WP1: 320TiB for studying effects of surface ocean layer thickness (2m vs 10m) on climate variability
- WP2: 270TiB for studying impacts of extreme river discharge (Nguyen et al., 2023) and 130TiB from coupled GCOAST-NEMO-WAM (400 m) for extreme events impact analyses.
- WP3: 277TiB for studying eddy effects on carbon vertical transport

Data storage request for 2024 (TiB):
WP1: 966 (work), 323 (archive) **WP2:** 180 (work), 90 (archive) **WP3:** 972 (work), 277 (archive)

Report subproject bu1214

Subproject title: CLICCS C1 - Sustainable Adaptation Scenarios for Urban Areas – Water from 4 Sides; Subproject lead: Franziska S. Hanf (UHH); Chairs: Jörg Knieling (HCU), Bernd Leitl (UHH), Jana Sillmann (UHH); Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante & Mistral) [node h]	5349	0	2600
Levante storage (TB)	20	9	20
Archive project (TB)	23	0	
Archive long term (TB)	4	0	
Mistral Lustre work (GB)		0	
Swift Object Storage (GB)	10240	0	

Experiments performed successfully at project account bu1214:
Work on the subproject was on hold due to parental leave (11.09.22-20.10.23). The subproject activities will resume in mid-October. We plan to run simulations for a sensitivity study in November and December. As part of the study, we intend to run an ensemble of simulations that includes two or more different precipitation events and a variance of different emission sources and emission rates. We therefore estimate that we will need about half (~2600 node hours) of our allocated computing time.

Scientific results of subproject bu1214: There are no new scientific results so far since the last report in 2022 due to parental leave.

Publications in 2023 that use data of subproject bu1214: No publications that use data of subproject bu1214.

Data Management of subproject bu1214: Currently 9 TiB storage on work are used. This includes the model setup, the input data and first finished model-runs from last year.

Report subproject bg1186

Subproject title: CLICCS C3 – Climate change adaptation scenarios
Subproject lead: Johannes Pein, Joanna Staneva
CLICCS subproject chairs: K. Dähnke (UHH/Hereon), P. Fröhle (TUHH), C. Möllmann (UHH), B. Ratter (UHH/Hereon)
Reporting Period: 01.01.-29.09.2023

	Allocated for 2023	Consumed (29.09.2023)	Projection of consumption to end of 2023
Computing time (Levante & Mistral) [node h]	82000	109528	137056
Levante storage (TB)	470	257	470
Archive project (TB)	148		148 470
Archive long term (TB)	60		60
Mistral Lustre work (GB)	-	-	-
Swift Object Storage (GB)	10240		-

Experiments performed successfully at project account bg1188: 1) SCHISM-(SED)-WWM: (a) Utilizing the resources of bg1186, simulations on levante were conducted to investigate what-if scenarios addressing the suitability of coastal vegetation for coastal protection in the German Wadden Sea. The model for the German Bight domain is based on the semi-implicit cross-scale hydroscience integrated system (SCHISM) running in coupled mode with the included wind Wave model (WWM), both incorporating a parameterization for vegetation drag. The model area consists of 476 k nodes and 932 k triangular and quadrangular elements. The horizontal resolution varies between a maximum of 1.5km at the open boundary and a minimum of 50m in the estuaries. The vertical dimension is resolved using 21 terrain-following sigma coordinates. The study period covers the year 2017, for which five different vegetation scenarios were conducted, including realistic observation based seagrass coverage (E1: Ref) , no vegetation (E2: Blank), and seagrass recovery scenarios, which introduced vegetation in the entire Wadden Sea (E3: Veg_{max}), as well as only in its shallower (E3: Veg_{LE}) and deeper areas (E3: Veg_{HE}). (**b)** Hindcast wave simulations for the western Black Sea were performed using the resources of the CLICCS C3 subproject (bg1186). Different runs based on the WAM model for the period 2020-2023 were performed to investigate the sensitive physics and calibrated parameters. The model output was validated against in-situ and satellite data. **2) SCHISM-SED3D-ECOSMO:** Using regional climate simulations from Extremeness subproject (A9), time-slice ensemble simulations including three ensemble members have been performed for the period 2000-2019 and 2080-2099 producing 120 years of data in total, whereas time resolution of output was 1h and spatial resolution was 5 km in southern North Sea and 30-300 m in Elbe estuary including port of Hamburg (details of set-up see Pein et al., 2023). An additional short run (1 year) was performed to test the use of a bathymetric filter to mimic morphodynamic adjustment under sea level rise between time slices. A smaller set-up (Pein et al., 2021a) was used to test and assess bundles of adaptation scenarios according to the CLICCS research plan. A reference case and eight geometric adaptation scenarios including four active weir control cases were run for a historic reference period (2 month in 2012) and a simplistic climate change scenario following RCP8.5. This coupled runs accounted for hydrodynamics and morphodynamics. Finally the larger set-up (Pein et al., 2023) was run in fully coupled mode SCHISM-SED3D-ECOSMO for one historic year and for future simplistic scenario (RCP8.5). **3)** NEMO-WAM coupled model and NEMO ocean model as part of

GCOAST domain covers 40˚N to 65˚N and −19˚W to 30˚E; including the Northern part of Atlantic, the North Sea and the Baltic Sea. The horizontal resolution is ~ 3.5 km.

Scientific results of subproject bg1186: 1) SCHISM-(SED)-WWM: (a) The results comparing the different scenarios based on monthly average and quantiles for different variables related to hydro and sediment dynamics, suggest that the introduction of seagrass meadows locally can reduce both current velocities and significant wave heights in the order of up to 30% in the deeper areas and above 90% in the shallow areas. Seagrass can effectively affect hydro-morphodynamic conditions favouring sediment accumulation. Therefore, seagrass expansion could potentially help tidal flats height growths to keep up with SLR and to maintain the bathymetry-induced tidal dampening helping to lower risks of flooding and erosion. **(b)** The validation showed that with the physics ST4 and $\beta max = 1.5$, the computed significant wave height is in good agreement with the observed data (Fig. 1). The wave model has also been used to simulate the wave climate (2070-2100) for the entire Black Sea under different projection scenarios based on the wind forcing provided by the CMIP6 and CORDEX EU-11 data. **2) SCHISM-SED3D-ECOSMO:** The sea level projections revealed dominance of mean sea level rise with regard to estuarine mean water levels, whereas ensemble spread showed high relevance of internal climate variability for extreme water levels (Pein et al., 2023). Time slice experiments demonstrated necessity to account for morphodynamic adjustment and using a bathymetric filter a simple solution was found. With the smaller model, morphydynamics runs covering the Elbe estuary were feasible and they reproduced observed trends of erosion and accumulation. All proposed adaptation pilots reduced turbidity locally, proving that geometric adaptation measures potentially mitigate the ecologic and economic challenges with estuarine management. The fully coupled physical-biogeochemical runs revealed the major climate change impacts on the coupled systems, such as enhanced mixing and turbidity in port area, increased oxygen depletion and shift of biological frontal system upstream. **3)** NEMO-WAM simulations revealed decadal dynamics of salinity and temperature in the southern North Sea. They showed that continental freshwater run-off is the main driver of coastal freshening.

Publications in 2023 that use data of subproject bg1186:

Chen, W., Staneva, J., Jacob, B., Sanchez-Artus, X., & Wurpts, A. What-If Nature-Based Storm Buffers on Mitigating Coastal Erosion. *Available at SSRN 4463184*.

Pein, J., Staneva, J., Mayer, B., Palmer, M. D., & Schrum, C. (2023). A framework for estuarine future sea-level scenarios: Response of the industrialised Elbe estuary to projected mean sea level rise and internal variability. *Frontiers in Marine Science*, *10*, 1102485.

Data Management of subproject bg1186: The raw outputs have been processed and relevant information such as tidal parameters, daily and monthly averages have been compiled for long-term storage.