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

Project: bm1173

Project title: Climate, Climatic Change and Society

Principal investigator: Detlef Stammer

Allocation period: 01.01.2021 – 31.12.2021

Report on usage of the DKRZ Resources for the first 7 months

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Preface

The report summarizes the individual reports of projects of the Cluster of Excellence CLICCS (Climate, Climatic Change and Society). The reporting will cover the time period from 01. January 2021 to 31. December 2021. The numbers for used computation time and storage resources are taken mid-July, unless stated otherwise. The individual DKRZ project numbers are bm1183, bg1184, bg1186, mh1212, bu1213, bu1214, and bm1219. Please note that the current report covers not even 8 months.

1 Report project bm1219

Project title: CLICCS A1 - Carbon Dynamics in the Arctic

Project lead: Victor Brovkin

CLICCS project chairs: Victor Brovkin, Lars Kutzbach, Dirk Notz

Reporting Period: 01.01.-31.12.2021

	Allocated for 2021	Consumed (26.07.2021)	Projection of consumption to end of 2021
Computing time [node h]	21,600	14,259 (5135 expired)	21,600
Temporary storage / work [GB]	18,000	10,721	12,000
Storage / arch [GB]	24,000	0	10,000
Long term storage / doku [GB]	24,000	0	10,000

1.1 Experiments performed successfully at project account bm1219

A large fraction of the computing time was required for the improvement of the soil hydrology in the land surface model JSBACH. Here, it was the main objective to develop a model version that allows controlling the hydrological cycle in the permafrost-affected regions of the high northern latitudes. With this model version we could assess how the representation of the soil hydrology in the Arctic affects the simulated global climate and the high latitude carbon cycle. Three sets of simulations with the fully coupled MPI-ESM1.2 were performed covering the period 1800 -2100 and a 50-year period in which greenhouse gas emissions were prescribed to stabilize the global mean surface temperature at 1.5°C above pre-industrial levels. In one setup – the “Wet” setup – a high soil water retention and accessibility were simulated, while the second setup featured a comparatively “Dry” Arctic region – i.e. low water retention and accessibility. In the third setup the parametrization of the soil hydrology switches from “Wet” to “Dry” whenever the near-surface permafrost (within the top 3m of the soil column) is degraded in a given grid cell. In addition to the fully coupled simulations, we used the generated atmospheric conditions, to drive 24 sets of JSBACH-standalone simulations to assess the effects on the high-latitude carbon cycle.

1.2 Scientific results of project bm1219

Current generation Earth system models (ESMs) show large differences in the simulated climate of the high northern latitudes (Davy and Outten, 2020) At the same time, their land surface components exhibit a wide range of responses when forced with similar prescribed atmospheric conditions (Andresen et al., 2020). However, it is not clear whether the variations in the simulated climate of different ESMs originate in the differences in the representation of soil processes in the terrestrial Arctic, or whether the differences stem from differences in the atmospheric model component, differences in the latitudinal heat and moisture transport or other differences in simulated large scale climate patterns and remote effects.

By comparing simulations with the Wet and the Dry setups we found that, differences in the representation of the soil hydrology in the northern permafrost regions lead to variations in the simulated climate in the Arctic that are comparable to the spread in the CMIP6 ensemble (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). This is a strong indication that the terrestrial soil hydrology could indeed be responsible for the large spread in the simulated high latitude climate. Furthermore, it is often assumed that future methane emissions in the high latitude will be higher if the soils stay relatively moist after the near-surface permafrost disappeared (Lawrence et al., 2015). Here, it was found that the Dry setup actually produces methane emissions that are very similar to those of the Wet setup, because the effects of a smaller fraction of inundated soils (where organic matter is decomposed to CH_4 rather than CO_2) are compensated by a higher vegetation productivity, resulting from the higher near-surface temperatures.

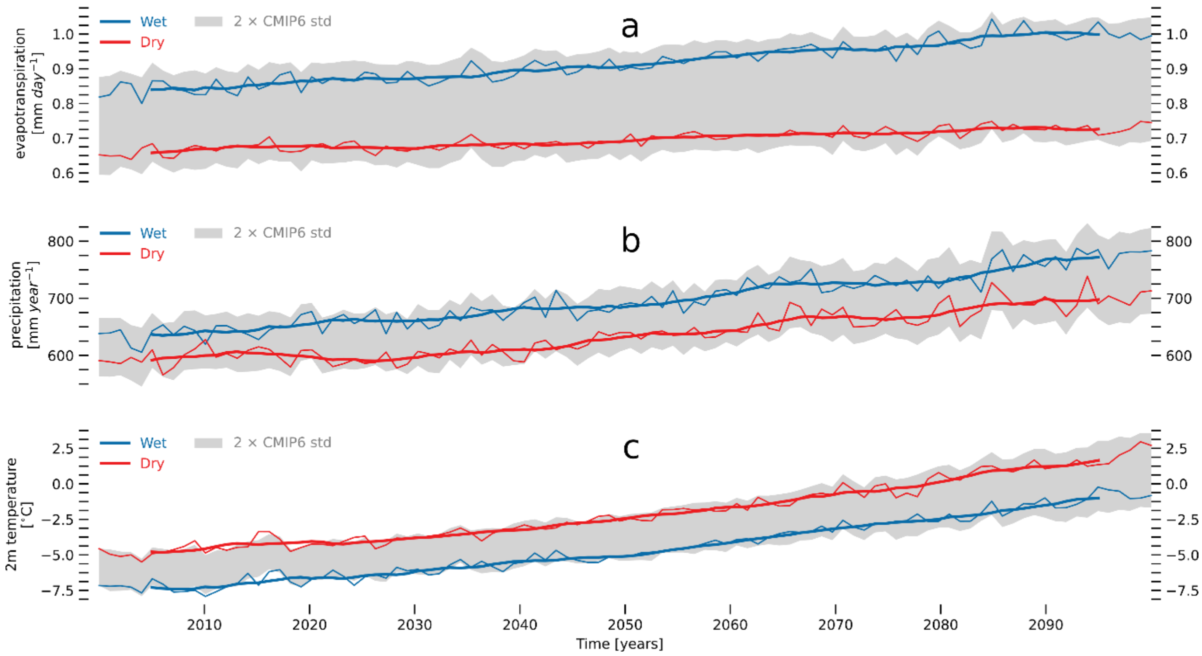

Figure 1: a) Simulated evapotranspiration rates averaged across the northern permafrost regions. Red lines refer to the MPI-ESM setup with a low soil water retention and availability (Dry), while blue lines refer to a high water retention and availability (Wet). The width of the shaded (grey) area indicates 2 x the CMIP6 ensemble standard deviation—note that it does not indicate the absolute value of the CMIP6 ensemble as the area is centered on the mean of the Wet and the Dry simulations. b) Same as a, but showing average precipitation rates. c) Same as a, but showing simulated 2m-temperature.

1.3 Publications in 2021 that use data of project bm1219

n.a.

1.4 Data Management of project bm1219

After the publications that use the primary data and are currently in preparation have been accepted, the data will be made available via the German Climate Computing Center's long-term archive for documentation data as a part of Good Scientific Practice at MPI-M.

1.5 References

Andresen, C.G., D.M. Lawrence, C.J. Wilson, A.D. McGuire, C. Koven, K. Schaefer, . . . I. Gouttevin, 2020: Soil moisture and hydrology projections of the permafrost region–a model intercomparison. The Cryosphere, 14(2), 445-459.

Davy, R. and S. Outten, 2020: The Arctic surface climate in CMIP6: status and developments since CMIP5. J Clim, 33(18), 8047-8068.

Lawrence, D.M., C.D. Koven, S.C. Swenson, W.J. Riley, and A. Slater, 2015: Permafrost thaw and resulting soil moisture changes regulate projected high-latitude CO2 and CH4 emissions. Environ Res Lett, 10(9), 094011.

2 Report project bm1183

Project title: CLICCS A2 - Clouds and Tropical Circulation
Project lead: Ann Kristin Naumann
CLICCS project chairs: Stefan Bühler, Bjorn Stevens
Reporting Period: 01.01.2021 - 12.7.2021

	Allocated for 2021	Consumed (16.07.2021)	Projection of consumption to end of 2021
Computing time [node h)]	44,800	33,302 (74%)	44,800
Temorary storage / work [GB]	161,040	157,541 (97%)	161,040
Storage / arch [GB]	110,400	0	106,000
Long term storage / doku (GB)	0	0	0

2.1 Experiments performed successfully at project account bm1183

For 2021, DKRZ provided us with resources to complement our ensemble of perturbed microphysics experiments (with a one- and a two-moment microphysics scheme) with two simulations at a higher resolution of R2B10 (i.e., ~2.5 km grid spacing) than the rest of the ensemble. Unfortunately, a major bug in the turbulence scheme in ICON-AES was identified in the beginning of 2021. While we know that a model as complex as ICON is probably never bug-free, this turbulence bug turned out to impact in particular the simulations with the two-moment microphysics scheme. Because the goal of the project is to compare the sensitivities of the one-moment and the two-moment scheme, the overly strong sensitivity of the two-moment scheme to an unrealistically moist atmosphere (due to the turbulence bug) hindered a fair comparison.

We therefore decided to use the provided resources to create a new ensemble of sensitivity experiments with a one- and a two-moment microphysics scheme. We could use our experience from the first ensemble for a more informed choice of perturbed parameters, which allowed us to reduce the overall number of ensemble members. This allowed us to stay at the original resolution of R2B09 (i.e., ~5 km grid spacing).

We successfully performed two control simulations (one with the one-moment scheme and one with a two-moment scheme) and six sensitivity experiments. The first control simulation with the one-moment scheme was done in cooperation with the DYAMOND-winter project (which suffered from the discovery of the same turbulence bug) and therefore did not weight on this project's computing budget. The following runs (2-8) were performed each for a 10-day period on a global domain with ~5 km grid spacing:

1. (Control run with one-moment microphysics schema and standard microphysics parameters)
2. Control run with two-moment microphysics schema and standard microphysics parameters
3. Like 1. but with a modified raindrop size distribution
4. Like 1. but with a higher ice fall speed
5. Like 1. but with modified snow properties
6. Like 2. but with a modified raindrop size distribution
7. Like 2. but with a higher ice fall speed
8. Like 2. but with modified snow properties

The perturbed microphysics ensemble is now complete, is currently analyzed and will be archived in the course of this year. We plan to use remaining computing resources in preparation of the next project within A2, which aims to untangle processes that lead to humidity differences in storm-resolving models (see A2 proposal for 2022; Theresa Lang).

2.2 Scientific results of project bm1183

Using the completed ensemble of perturbed microphysics simulations, the overall goal is to investigate how microphysical choices affect the albedo, radiative fluxes, and the tropical heat budget. First results indicate that microphysical sensitivities in global storm-resolving models are substantial.

The partitioning of liquid and frozen particles between the different hydrometeor categories differs strongly between the one- and the two-moment microphysics scheme (Figure 2 a-c). In particular, the conversion from ice to snow is much stronger in the one-moment scheme, which leads to a reduced ice water path compared to the two-moment scheme (Figure 2 b). Perturbing some of the parameters of the two microphysical schemes in their range of uncertainty leads to substantially smaller differences in the partitioning between ice and snow.

Because only cloud water and cloud ice interact with the radiation scheme in ICON, the differences in the partitioning of ice and snow affect the radiative fluxes. Less ice in the simulations with the one-moment scheme leads to less reflected shortwave radiation (Figure 2 d) and more outgoing longwave radiation (Figure 2 e) at the top of the atmosphere. Shortwave and longwave effects of ice clouds partly cancel so that differences in the top-of-the-atmosphere radiative balance are smaller but still reach up to 10 W m-2. Further analysis aims to better understand this offset.

2.3 Publications in 2021 that use data of project bm1183

None yet. Due to the discovery of a major bug in the turbulence scheme, the publication of scientific results will analyze the new perturbed microphysics ensemble described above. We plan to publish the scientific results of the simulations in a journal paper on the topic of "Sensitivities of the tropical heat budget to microphysical perturbations in a global SRM".

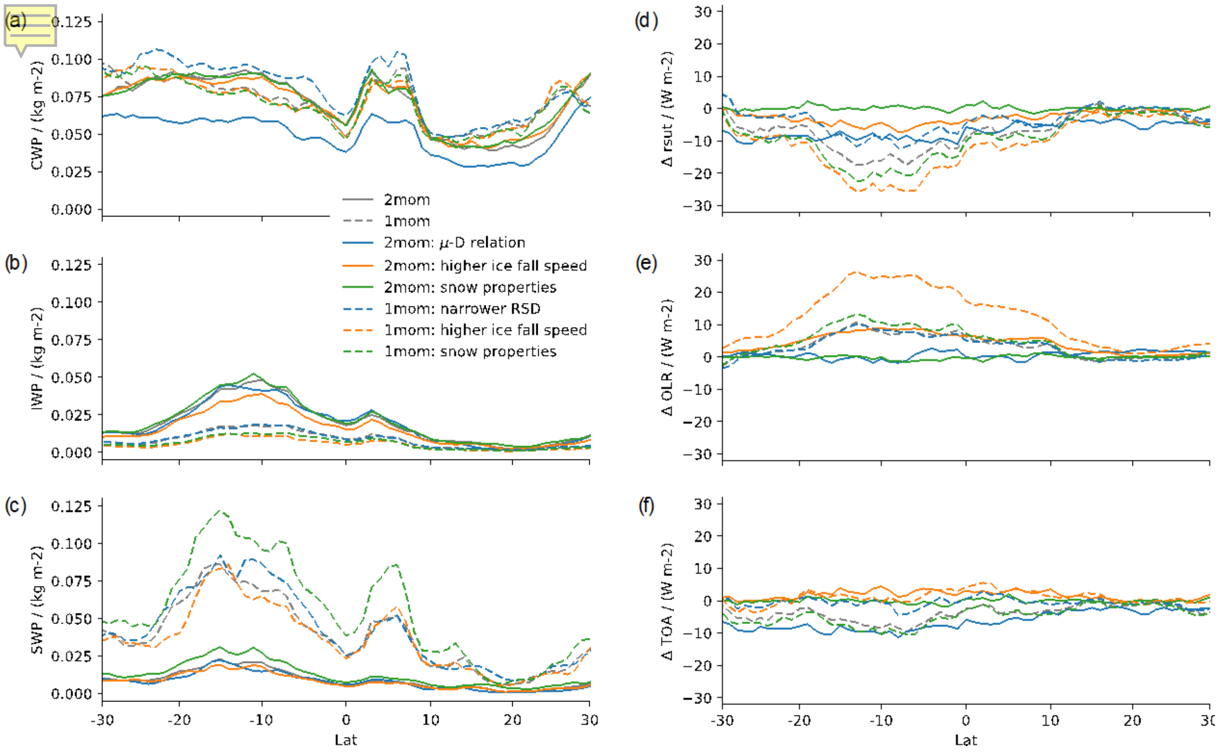

Figure 2: Latitudinal averages of (a) cloud water path (CWP), (b) ice water path (IWP), and (c) snow water path (SWP). Latitudinal average of the difference to the two-moment control run for top-of-the-atmosphere (d) upwelling shortwave radiation, (e) outgoing longwave radiation and (f) the radiative balance.

2.4 Data Management

There is an ongoing collaboration with the scientific data visualization group which is part of the HPC group in CLICCS. The group uses one of this project's simulations for a visual analysis of humidity transport.

In addition, a potential collaboration with a group from AWI has been identified, who possibly focuses on mid-latitude and polar aspects of this project's simulations.

If it becomes beneficial in the context of one of these collaborations, a separate publication of simulations results is planned in addition to the already foreseen publication of the scientific results of the simulations in a journal paper.

3 Report project mh1212

Project title: CLICCS A4 – African and Asian Monsoon Margins CLICCS
Project lead: Katharina D. Six (MPI-M), Shabeh ul Hasson(UHH)
CLICCS project chairs: Jürgen Böhner (UHH), Martin Claussen (MPI-M/UHH), Gerhard Schmiedl (UHH)
Reporting Period: 01.01.-31.12.2021

	Allocated for 2021	Consumed (06.08.2021)	Projection of consumption to end of 2021
Computing time [node h]	124,000	69,839	124,000
Temporary storage / work [GB]	36,000	20,814	36,000
Storage / arch [GB]	28,800	1,412	28,800
Long term storage / doku [GB]	4,800	0	4,800

The project aims at understanding the sensitivity and the variability of the tropical precipitation over the African and Asian monsoon margins, which the livelihood and well-being of a large part of the human population depend on. We will be able to assess the realism of state-of-the-art climate models in simulating monsoon dynamics and their changes, including the influence of internal climate variability. We will compare simulations, paleo-reconstructions, and observations. We focus on rapid climate changes such as the 8.2k-event and the termination of the African Humid Period some 5000 years ago, as well as the recent global warming with an outlook on possible future climate changes.

Of the four work packages (WP) within CLICCS A4 only WP 1) Marine sediment archives and ocean modelling and WP 2) Environmental process modelling applied for DKRZ resources. At the current stage, we report for each individual WP.

3.1 Experiments performed successfully at project account mh1212

WP1 Marine sediment archives and ocean modelling

Marine sediment archives of the eastern Mediterranean Sea over the last deglaciation (21,000 to present) show most prominent variations in the early Holocene which coincide with times of enhanced Nile river discharge. It is hypothesised that this freshwater input stabilizes the water column introducing circulation changes. Consequential changes in the biogeochemistry leave their imprint in the sediment records. However, previous studies showed that an enhanced Nile discharge is not sufficient to explain the observed sediment signals (Grimm et al., 2015).

To identify the drivers of the circulation variability of the Mediterranean Sea we set up a regional ocean model with biogeochemistry (MPIOM-MED). The model domain covers the entire Mediterranean Sea including the Black Sea and a small part of the North Atlantic. The model resolution is about 26 km in the horizontal with 30 unevenly spaced levels representing a realistic topography.

The forcing for the 21,000 years is provided by paleo simulations with the MPI-ESM (PALMOD version) which is based on ECHAM6 (T31 resolution). It is available as monthly mean values and comprises atmospheric drivers and river runoff as well as temperature and salinity for boundary conditions at the western model domain.

In preparation of long-term transient runs we, first, had to find a proper downscaling method for the atmospheric forcing in conjunction with a tuning of the physical model parameters to achieve a decent present day circulation. As sea level rise over the last deglaciation leads to significant bathymetry changes in the Mediterranean Sea with e.g. a dry northern Adria basin and a closed gateway to the Black Sea, we, second, implemented an automatic bathymetry adjustment which updates the bathymetry every 10 simulations years. Third, we had to tune the nutrient supply by river runoff as it is provided by the MPI-ESM simulation.

Three time slice simulations, each over one millennium and with a fixed bathymetry, have been performed for 21ka, 9ka and 0ka before present to test the model framework. Preliminary results are presented in 3.2.

Currently, we are performing a first transient simulation over 210,000 years including marine biogeochemistry, bathymetry adjustment, and transient river runoff. Only nutrient concentrations of river runoff are fixed to present day values.

WP2: Environmental process modelling

It is to mention that the WP2 computational resources are shared between the accounts uc0977 and mh1212.

First few sensitivity experiments are conducted at convection permitting scale over the whole Tibetan Plateau to see how the regional model performs in simulating the select extreme events. This is a single member contribution to the multi-physics ensemble being contributed by several groups under the 'Convection-Permitting Tibetan Plateau' CORDEX Flagship Pilot Study.

The main simulations under WP2 were on hold due to the delayed guidelines from the CORDEX community for downscaling CMIP6 experiments that are released this May. Hence, simulations under WP2.1 and WP2.3 will be kicked off in the latter half of the year and mainly from the mh1212 account.

3.2 Scientific results of project mh1212

WP1: Marine sediment archives and ocean modelling

We performed three time slice simulations with fixed bathymetry adjusted for 21ka, 9ka, and 0ka before present. 1000 years of forcing were downscaled from one MPI-ESM PALMOD run for the corresponding time slice. On this basis, we could investigate if applied forcing has the potential to create circulation variations in the same direction as deduced from proxy data. E.g., we expect colder sea surface temperatures (SST) at 21ka and a more sluggish circulation at 9ka than at present day.

A comparison of the SST anomaly deduced from planktonic foraminifera with model results shows a compelling agreement for both paleo time slice runs (Figure 3,c). The present day SST bias for the Mediterranean Sea is less than 0.5 K (Figure 3a) which is acceptable given the coarse spatial and temporal resolution of the forcing from the MPI-ESM. Water mass age is a good indicator for the ventilation of deep water. For present day, we find the youngest water masses in the Gulf of Lion being in line with observations on source regions of deep water formation (Figure 3d). Significant older water masses are found at 9ka as being hypothesized.   Thus, we conclude that the newly developed model framework seems to be suitable to run long-term transient simulations, which catch the observed circulation variations found in proxy data.

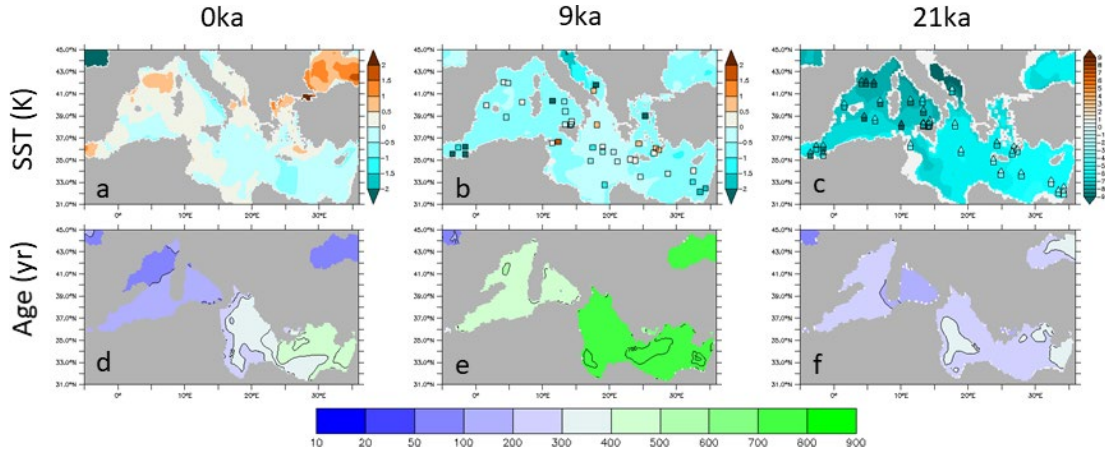

Figure 3: SST anomalies of model simulations minus observations (a: MEDATLAS, b,c: World Ocean Atlas (2018), unit: K) and water mass age at 1165m (d,e,f, unit: yr) for 0ka (a,d), 9ka (b,e), and 21ka (c,f) before present. Overlaid in b,c are reconstructions of SST anomalies from proxy data (symbols, data for 9ka from M. Kucera, pers. communication, and for 21ka from Hayes et al. 2005). Different colour scales are given for each panel in a,b,c. Note also the non-linear colour scale for d,e,f. Contour lines in d,e,f are given between 100 and 700 with an increment of 100 and at 750.

WP2: Environmental process modelling

For the planned sensitivity runs under WP2.2, we performed simulations of three selected extreme events over the whole Tibetan Plateau using the Weather Research and Forecasting Model driven by the ERA5 reanalysis at 4km resolution with explicitly resolved convection (Figure 4). These experiments include: 1) Mesoscale Convective System (MCS) event during 14-24 July 2008 (Figure 4, left), 2) a month-long simulation for the Monsoon season during July 27 and September 01, 2014 (Figure 4, middle), and 3) A heavy snowfall event during 4-9 October 2018 (Figure 4, right). The simulations are conducted mainly from the DKRZ account uc0977 (Dynamical Downscaling), which shares the resources with mh1212. Further simulations planned under WP2.1 and WP2.3 are due to run in the second half of the year and mainly from the DKRZ account mh1212. Initial assessment suggests that the experiments can imitate the extreme events well. However, in-depth evaluation of these runs against in-situ observations will be performed when in-situ observations will be quality-controlled and ready-to-use. The simulations are contributing to the CORDEX Flagship study project of “Convection-permitting Tibetan Plateau”.

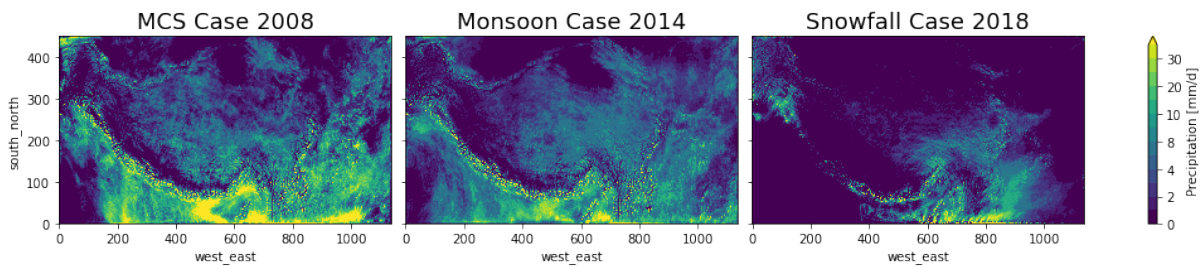

Figure 4: WRF-ERA5 downscaled mean precipitation (mm/day) at 4km resolution using explicitly resolved convection over the whole Tibetan Plateau for three extreme events.

3.3 Publications in 2021 that use data of project mh1212

WP1: The work has been presented at the EGU in Vienna 2021.

WP2: Publication of the scientific results is planned by the end of the year upon the completion of the simulations.

3.4 Data Management of project mh1212

WP1: At the current stage, we did not produce any data that are worth sharing. In general, data from long transient simulations will be available on /arch and /docu.

WP2: The WP2 project collaborates on the Convection-permitting Tibetan Plateau (CPTP) CORDEX Flagship study project. Experiments conducted so far are already shared with the project partners/collaborators and are placed on a Project's shared space other than /arch and /docu. The storages of /arc and /docu will be utilized in due course of time.

3.5 References

Boyer, T.P., O.K. Baranova, C. Coleman, H.E. Garcia, A. Grodsky, R.A. Locarnini, . . . D. Seidov, 2018: NOAA Atlas NESDIS 87. World Ocean Database.
Grimm, R., E. Maier-Reimer, U. Mikolajewicz, G. Schmiedl, K. Müller-Navarra, F. Adloff, . . . K.-C. Emeis, 2015: Late glacial initiation of Holocene eastern Mediterranean sapropel formation. Nat Comm, 6, 7099.
Hayes, A., M. Kucera, N. Kallel, L. Sbaffi, and E.J. Rohling, 2005: Glacial Mediterranean sea surface temperatures based on planktonic foraminiferal assemblages. Quaternary Science Reviews, 24(7-9), 999-1016.
Medatlas, 2002: MEDATLAS/2002 database. Mediterranean and Black Sea database of temperature salinity and bio-chemical parameters. Climatological Atlas, 520.

4 Report project bg1184

Project title: CLICCS A5 - The Land-Ocean Transition Zone
Project lead: Moritz Mathis
CLICCS project chairs: J. Hartmann (UHH), P. Korn (MPI-M), C. Schrum (Hereon)
Reporting Period: 01.01.2021- 31.12.2021

	Allocated for 2021	Consumed (23.07.2021)	Projection of consumption to end of 2021
Computing time [node h]	194,560	98,502	194,560
Temporary storage / work [GB]	52,000	50,379	52,000
Storage / arch [GB]	35,200	8,861	35,200
Long term storage / doku [GB]	16,800	0	16,800

4.1 Experiments performed successfully at project account bg1184

During reporting period 2021, our experiments were mainly related to the developments of 3 different model systems: the regional marine ecosystem model SCHISM-ECOSMO, the global ocean-biogeochemistry model ICON-Coast, and a new model system which for the first time couples the global ocean model ICON-O with the ecosystem component ECOSMO.

Simulations with ICON-Coast were largely associated with tuning simulations for proper parameter settings. Simulation periods in the order of 10-20 years under present-day climatic conditions were generally performed with 2grid configurations of different horizontal resolutions: a coarse one with ~260k ocean surface cells, reaching a maximum resolution of 20 km at the coasts, and a fine one with ~850k surface cells and a maximum resolution of 10 km. The runs of both setups that compared best with observations have finally been used to prepare the first publication on ICON-Coast, introducing the conceptual approach of using a regional grid refinement for a better representation of the land-ocean transition zone in a global ocean-biogeochemistry model.

The high-resolution SCHISM-ECOSMO system was successfully employed in sensitivity experiments to investigate the ecosystem impact of internal tides on the Northwest European Shelf and the associated biological sequestration of atmospheric CO_2. The experiments included a 10-year spinup simulation, a hindcast simulation over the period 2010-2015 with enhanced horizontal resolution along the continental margin and a control simulation over the same period without tidal forcing.

4.2 Scientific results of project bg1184

In the current paper draft on the development of ICON-Coast (Mathis et al., in prep.), we present the first global ocean-biogeochemistry model that globally uses a telescoping high resolution for an improved representation of coastal carbon dynamics. Based on the unstructured triangular grid topology of the model, we apply a regional grid refinement in the land-ocean transition zone to better resolve the complex general circulation of shallow shelves and marginal seas as well as ocean-shelf exchange. In (Logemann et al., 2021),we have demonstrated a significant improvement of coastal tidal amplitudes simulated with ICON-O when such a regional refinement is used. Moreover, we extend the parameterizations of the global carbon cycle model HAMOCC to account more explicitly for key shelf-specific biogeochemical transformation processes. These comprise the incorporation of tidal currents including bottom drag effects, and the implementations of sediment resuspension, temperature-dependent remineralization, riverine matter fluxes from land, and aggregation of particulate matter. The combination of regional grid refinement and enhanced process representation enables for the first time a seamless incorporation of the global coastal ocean in model-based Earth system research. In particular, ICON-Coast unifies all coastal areas around the globe within a single, consistent ocean-biogeochemistry model, thus naturally accounting for two-way coupling of ocean-shelf feedback mechanisms at the global scale (Figure 5). The quality of the model results as well as the efficiency in computational cost and storage requirements qualifies this strategy a pioneering approach for global high-resolution modeling. We conclude that ICON-Coast represents a new tool ready to be used to deepen our mechanistic understanding of the role of the land-ocean transition zone in the global carbon cycle, and to narrow related uncertainties in global future projections.

The experiments with the high-resolution SCHISM-ECOSMO system highlights the impact of internal tides on marine primary production in the continental margins of the Northwest European Shelf. The model setup specifically developed for this study was successfully validated against observations. In the hindcast simulation, the model is able to reproduce relevant hydrographic and ecosystem features and resolve internal tides in the ocean-shelf transition zone. Vertical mixing induced by internal tides was found to regionally amplify biological productivity at the shelf break and at small scale bathymetric features on the shelf. A quantitative assessment of the role of internal tides for the shelf carbon cycle is part of ongoing work, planned to be published in 2022.

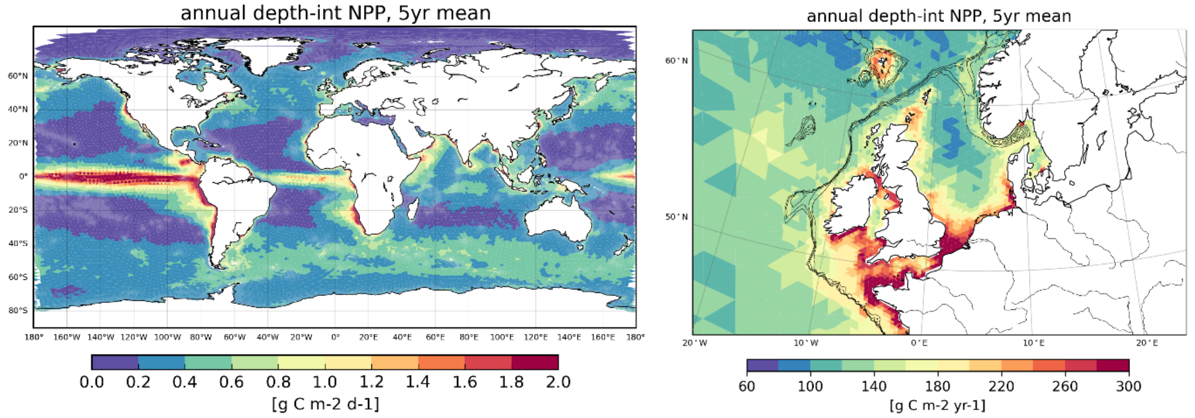

Figure 5: Annual net primary production for the period 2006-2010, simulated with the global ocean-biogeochemistry model ICON-Coast. Left: Global distribution. Right: Zoom on the Northwest European Shelf with isobaths of 200-500 m water depth illustrating the position of the shelf break. Note the different units.

Furthermore, general modifications of the code structure of the global ocean model ICON-O necessary to integrate the marine ecosystem model ECOSMO have been achieved. The coupling between ICON-O and ECOSMO is realized via the FABM framework and has been successfully tested for the dispersion of an idealized ecosystem tracer in the global ocean circulation.

4.3 Publications in 2021 that use data of project bg1184

Logemann, K., L. Linardakis, P. Korn, C. Schrum. Global tide simulations with ICON-O: testing the model performance on highly irregular meshes. *Ocean Dynamics* 71, 43–57 (2021). https://doi.org/10.1007/s10236-020-01428-7

4.4 Data Management of project bg1184

The data produced during the project so far are primarily related to model development and do not yet represent fully evaluated hindcast simulations that could be shared with the community e.g. for further analysis. Such simulations though are planned to be finished in the remaining time of 2021 (at least for the coarse-resolution configuration) and will be transferred to LTA Doku. Moreover, many of our early test simulations will be moved from currently /work to the archive, as they provide valuable information for ongoing and further development but we can dispense quick and direct access.

4.5 References

Logemann, K., L. Linardakis, P. Korn, and C. Schrum, 2021: Global tide simulations with ICON-O: testing the model performance on highly irregular meshes. Ocean Dyn, 71(1), 43-57.

Mathis, M., K. Logemann, J. März, F. Lacroix, S. Hagemann, F. Chegini, L. Ramme, T. Ilyina, P. Korn, C. Schrum. Towards a seamless connection of the open and coastal ocean in global biogeochemistry modeling. *Journal of Advances in Modeling Earth Systems* (in prep.)

5 Report project bu1213

Project title: CLICCS A6 - Earth System Variability and Predictability in a Changing Climate
Project lead: Johanna Baehr
CLICCS project chairs: J. Baehr (UHH), T. Ilyina (MPI-M), J.-S. von Storch (MPI-M), E. Zorita (HZG)
Reporting Period: 01.01.-x.x.2021

	Allocated for 2021	Consumed (Juli.2021)	Projection of consumption to end of 2021
Computing time [node h]	836,613	439,066	800,000
Temorary storage / work [GB]	145,938	65,156	145,000
Storage / arch [GB]	132,227	0	100,000
Long term storage / doku [GB]	0	0	0

Because the scope of CLICCS A6 covers a wide range, there are six work packages that work collaboratively to achieve the goals of A6. For 2021, only two work packages applied for computational resources, and thus their reports are summarized based on their work packages:

WP1: Scale interactions and their impact on variability in a transient climate

WP2: Decadal ensemble simulations within a coupled wave-ocean-atmosphere-compartment

5.1 Experiments performed successfully at project account bu1213

WP 1:

We performed experiments using ICON-A to study the effects of resolved atmospheric convection. Experiment **#2, #3 and #4** (listed below) were successfully performed on project account bu1213:

1) 1-year perpetual January run with R2B9 (control; present-day climatological January SST/SIC)
2) 10-years perpetual January run with R2B6 (control; present-day climatological January SST/SIC)
3) 1-year perpetual January run with R2B9 (January SST/SIC from a 4K warmer world)
4) 10-years perpetual January run with R2B6 (January SST/SIC from a 4K warmer world)

Reruns because of bug errors and changes to atmospheric boundary layer scheme accounts for a sizable portion of CPU usage. Additionally, we are configuring and testing the coupled R2B8 ICON-ESM, which also uses quite some resources. Furthermore, post processing and analysis of large data sets [MPI-ESM-ER, MPI-GE, ICON-A] further contribute to resource utilization.

WP 2:

The GCOAST setup configuration used for the present application consisting of three earth system compartments, ocean, wave and atmosphere, covert by the ocean GCOAST-NEMO, wave GCOAST-WAM and atmosphere GCOAST-CCLM models at regional scales (North Sea and the Baltic sea and downscaled for the German Bight)

- Ensemble runs have been performed with Geesthacht Coupled cOAstal model SysTem (GCOAST) in respect to lateral forcing and Model sensitivity to different river-run off forcing in respect to the river forcing data. Eight experiments were carried out with on different forcing taken from climatological data and hydrology models (HD). Analyses were focused on the extreme flood in German Bight in 2013. Then additional four experiments were conducted to investigate the impact of improving coastal ocean predictability of both lateral discharge and coupling of waves and circulation models and cross-scale interactions between high resolution estuary models and regional coupled models on.

- Several multi-year (1992-2017) coupled (NEMO-WAM) and stand-alone model simulations (North Sea and Baltic Sea) have been performed with GCOAST3D temperature and salinity obtained from these GCOAST runs were analyzed to investigate the uncertainty of the sea level predictions with focus on its thermosteric and halosteric components.

- Besides, long-term sea level reconstruction for the Baltic Sea during period 1993-2020 were performed using the Kalman filter, observations at tide gauges and the leading EOF modes of SSH.

- A series of sensitivity experiments with the GCOAST- NEMO coastal configuration (400 m horizontal resolution) were performed using changing bottom friction parametrizations and configurations of lateral boundary forcing from the 2nm regional GCOAST-NEMO setup. The aim of the experiments was to optimize the model performance of the coastal ocean predictions (incl. tides, storm surges and high waves).

5.2 Scientific results of project bu1213

WP 1:
Preliminary results from the aforementioned experiments recently completed within project bu1213 show some effects of resolved (r2b9) vs parameterized (r2b6) atmospheric deep convection on the Hadley cell and its response to warmer conditions. In Figure 6-a, the displacement of the southern edge of the Hadley cell is a little more obvious in r2b9 than in r2b6. Figure 6-b shows that the strength of the Hadley cell is weaker when deep convection is resolved, and has a slight tendency to weaken under global warming. This is however not the case when deep convection is not resolved. Further analysis are underway to see how heating profiles and precipitation distribution are affected from resolving deep convection, and how they might evolve in a warmer world.

WP 2:

Representing the lateral fluxes (e.g. freshwater river run off) is challenging for global and regional scale ocean modelling. Although rivers are well known to affect both the coastal and basin-wide circulation and dynamics, coarse resolution ocean models cannot resolve the estuarine dynamics and are usually forced at river outlets in a simplistic way, with climatological runoff and zero or constant salinity values. Within the CLICS A6 during the reporting period, simulations we provided a more realistic representation of the estuarine water inputs to our regional coupled model GCOAST, which is crucial for increasing model predictability. Ensemble simulations were carried out with the GCOAST system and analyses were focused on hydrometeorological extremes. The ensemble runs with different sources of river discharges have been validated against different in-situ observations (MARNET, FerryBox, Tide gauges). Figure 6-c & d show the comparisons between the calculated salinity and observations at the Nordsee Boje MARNET Station. The coastal salinity is sensitive with the fresh water discharges, especially during the flood event in the Elber River in July 2013. The ensemble mean salinity fits very well with the observations.

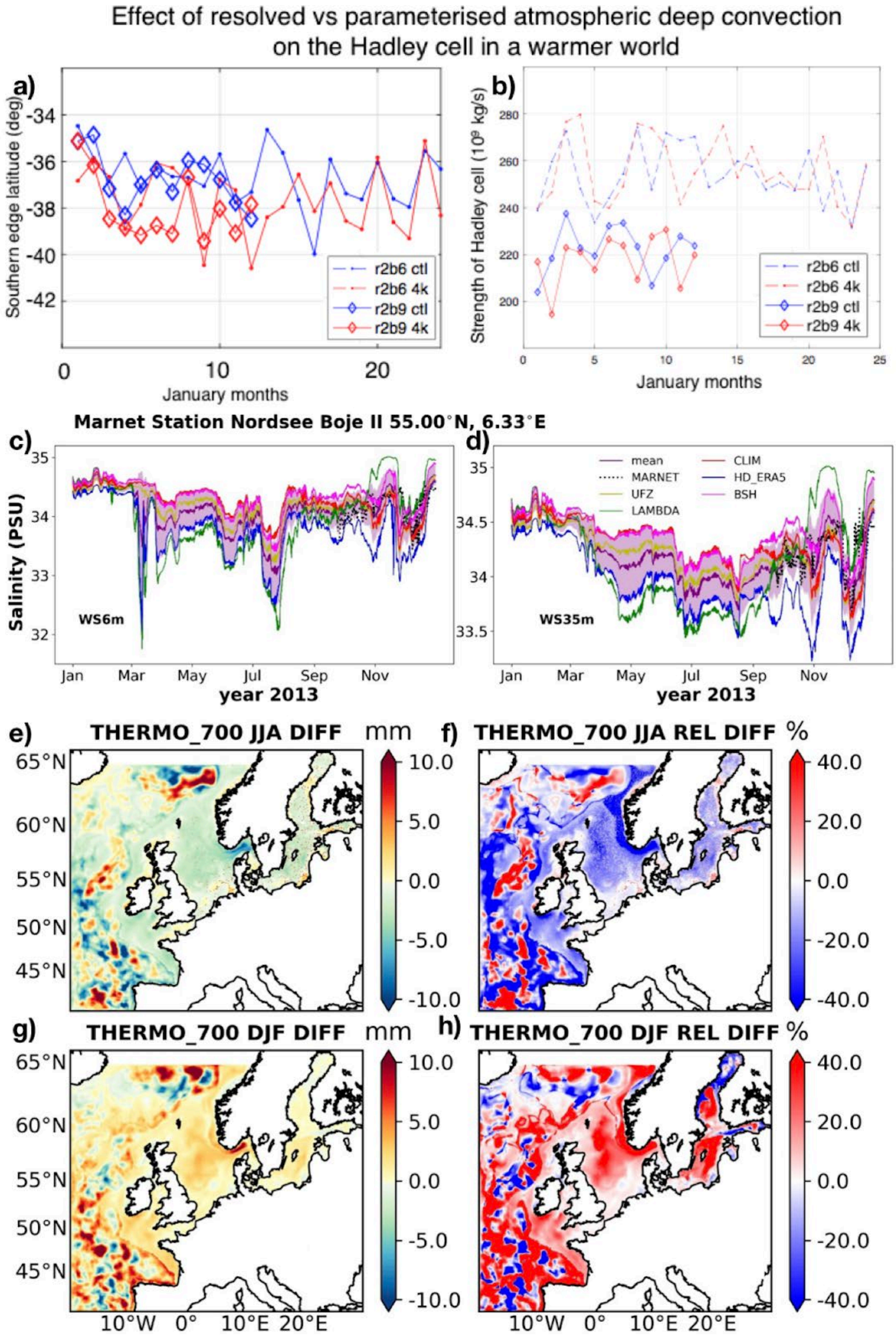

Figure 6: a & b) Latitude of southern edge and strength of Hadley cell based on ICON-A experiments; c & d) Simulated salinity and observations at Nordsee Boje MARNET station at water depth of 6 m (left) and 30 m (right). Dotted line for observation; shadow band for ensemble standard deviation; maroon, yellow, green, red and blue solid line correspond to REF (CLIM), BSH, UFZ, LAMBDA and HD_ERA5 experiments; e-h) Seasonal differences of thermosteric integrated in the vertical range 0 -700 m over period of 1992-2017.

- Sea level change and its impact on coastal zones have been attracting widespread interest from not only the natural, social scientific communities but also the media and policymakers. Efforts have been made to understand the source of uncertainties of sea-level projections looking at the surface flux anomalies between the atmosphere and the ocean Recent studies, emphasized the role of wave-induced processes the sea-state contributions to sea-level variability along the coasts of the global ocean were probably underestimated, underscoring the need of considering the changing non-linear interactions between the sea-level components of variability caused by sea-level rise. We demonstrated the ability of wave-ocean coupled simulations to disclose sea-state contributions to sea-level variability in the European Seas. The steric sea level changes in the European Seas due to thermo expansion/contraction of seawater were estimated based on the multi-decade 3D data of temperature and salinity. We investigated the sea state contributions in the ocean model (Stokes-Coriolis forcing, sea state dependent momentum and energy flux) and their impacts on the steric sea level. Figure 6-e, f, g & h illustrate the seasonal differences of thermosteric for the vertical range from 0-700 m for the GCOAST area, obtained by coupled models (with sea state contributions) and uncoupled model (without sea state contributions). In the winter season (DJF), the thermosteric by the coupled models are significant larger than by uncoupled models. The wind speed and waves are higher in the winter, leading the significant impact of wave coupling on the thermosteric level.

- The variability of sea level is one of the most important elements of the ocean dynamics and climate change. Basin-wide observations are due to satellite altimeters, observations in coastal stations are provided by tidal gauges. The first are not very accurate in the coastal areas, the second do not provide basin-wide coverage. The multiannual (1993-2020) variability of the Baltic Sea coastal sea level is reconstructed by Kalman filter approach, observations at tide gauges and the leading EOF modes of SSH simulated by the SMHI (CMEMS). We used observed data for both reconstructions and validations. The analyses (e.g. the correlation and Brier Score skill) showed that the reconstruction data are well-reproduced the observations.

- A fine resolution coastal model nest (a resolution of 400 m) has been successfully implemented into the GCOAST system. The coupled model simulations have been assessed against in-situ and satellite observations and the added-value of the downscaling approach demonstrated to improving coastal predictions

5.3 Publications in 2021 that use data of project bu1213

WP1:

- Publication on the effect of resolved vs parameterized deep convection on Hadley Cell is currently in preparation (von Storch et al.)
- Here are two publications not directly from data produced by project bu1213, but had used some computational resources for analysis with bu1213.

Putrasahan, D.A., O. Gutjahr, H. Haak, J.H. Jungclaus, K. Lohmann, M.J. Roberts, and J.S. von Storch, 2021: Effect of Resolving Ocean Eddies on the Transient Response of Global Mean Surface Temperature to Abrupt 4xCO2 Forcing. *Geophys Res Lett*, **48**(8), e2020GL092049.

Putrasahan, D.A. and J.S. von Storch, 2021: Piecewise Evolutionary Spectra: A Practical Approach to Understanding Projected Changes in Spectral Relationships Between Circulation Modes and Regional Climate Under Global Warming. *Geophys Res Lett*, **48**(14), e2021GL093898.

WP2:

- Two publications with results obtained from ensemble experiments based on lateral forcing and coupling are under preparation (A6 PhD Student Thoa Ngyen as a leading author) and soon will be submitted to the journals NHESS (Copernicus) and Regional Studies in Marine Science (Elsevier)
- The results on steric sea level will be published in the Frontiers in Earth Science (Bonaduche et al., 2021)

- The results   on sea level trends are still under preparations and are planned to be published in JGR –Ocean
- Attached are 4 published manuscripts that pertain to this work package and have acknowledged CLICCS.

Benetazzo, A., F. Barbariol, P. Pezzutto, J. Staneva, A. Behrens, S. Davison, . . . L. Cavaleri, 2021: Towards a unified framework for extreme sea waves from spectral models: Rationale and applications. *Ocean Engineering*, **219**, 108263.

Li, D., J. Staneva, J.-R. Bidlot, S. Grayek, Y. Zhu, and B. Yin, 2021: Improving regional model skills during typhoon events: A case study for super Typhoon Lingling over the northwest Pacific Ocean. *Frontiers in Marine Science*.

Staneva, J., S. Grayek, A. Behrens, and H. Günther. GCOAST: Skill assessments of coupling wave and circulation models (NEMO-WAM). in *Journal of Physics: Conference Series*. 2021a. IOP Publishing.

Staneva, J., M. Ricker, R. Carrasco Alvarez, Ø. Breivik, and C. Schrum, 2021b: Effects of wave-induced processes in a coupled Wave–Ocean model on particle transport simulations. *Water*, **13**(4), 415.

5.4 Data Management of project bu1213

WP1

Data generated for the study of the role of vertical resolution and ocean eddies are century-long experiments with mainly monthly ocean and atmosphere outputs, higher temporal outputs that follow DyamondWinter style. This study is conducted in conjunction with MPI-M Ruby-Thin project. Data from these experiments can/will be used outside of CLICCS, such as comparative climate studies by CLICCS project partners and other MPI-M/UHH users. This data also provides model comparison possibilities with MPI-ESM simulations that were produced through the PRIMAVERA project and the MPI-Grand Ensemble (data that is also available at DKRZ and we intend to analyze them together).

Data generated for the study of the effects of resolved convection are 1-year R2B9 and 10-years R2B6 experiments with mainly daily outputs and some hourly outputs for 2D variables and a few 3D variables. These simulations are now complete but occupy storage space for analysis, hence they are italicized in the table. This study was conducted in conjunction with MPI-M Dyamond-Circulation project, and hence data is also used by MPI-M scientists.

<u>Storage space in work</u>

For the requested 100-year coupled R2B8 ICON-ESM simulation, it requires storage of 40TB per simulation year, resulting in **4000 TB** for the simulation alone **on '/work'**. ICON-A (R2B6/R2B9) simulations were recently completed, however, storage space for them is still required as ongoing analyses are in progress. We therefore request **62TB** of storage space on '/work' for these simulations (two R2B6 simulations and one R2B9 simulation). The other R2B9 simulation is stored on mh0256.

In summary, for A6-WP1, we ask a total of ***<u>4062 TB</u>*** for work storage space the upcoming year.

<u>Storage space in HPSS archive</u>

We intend to archive raw outputs from the production runs so that data is available for usage to project partners and for extended analysis. We assume a compression factor of 0.5 (50% of original size) and would like to archive all the experiments under CLICCS for easier data management, rather than distributing the archiving to separate projects. Therefore, we request ***4062 TB*** for storage on the tape archive.

Storage space in HPSS Doku
Because of how expensive these runs are and how useful they would be for future studies, we would like to ensure long-term storage and accessibility of these runs. Also, this is in consideration to ensure compliance of data availability for journal publication. We intend to store on Doku ***62 TB*** in 2022 for ICON-A simulations and much more in 2023 for ICON-ESM simulations.

Data volume for simulations under CLICCS:

Experiment	Raw output generated per integration year	Total storage requirements		
		Lustre Work [TB] for 2022	HPSS Arch [TB] for 2022	HPSS Doku [TB] for 2022
ICON-AES (R2B6) 10-year perpetual January (PI-control)	*0.34 TB/year*	*3.4 TB*	*3 TB*	*3 TB*
ICON-AES (R2B9) 1-year perpetual January (PI-control)	*55 TB/year*	*0 TB (stored on mh0256)*	*28 TB*	*28 TB*
ICON-AES (R2B6) 10-year perpetual January (4K warmer world)	*0.34 TB/year*	*3.4 TB*	*3 TB*	*3 TB*
ICON-AES (R2B9) 1-year perpetual January (4K warmer world)	*55 TB/year*	*55 TB*	*28 TB*	*28 TB*
ICON-ESM (R2B8/R2B8) 100-years PI control (classical 128 ocean levels)	40 TB/year	0 TB (to be stored on mh0287)	2000 TB	0 TB (2000 TB for 2023)

ICON-ESM (R2B8/R2B8) historical & SSP5-85 [1950-2099] (classical 128 ocean levels)	40 TB/year	4000 TB (+2000 TB for 2023)	2000 TB (+1000 TB for 2023)	0 TB (2000 TB for 2023)
TOTAL for WP1 (in 2022)		**4062 TB**	**4062 TB**	**62 TB**

This project requires enormous amount of computational resource as well as data storage. Therefore, we are applying for resources from both CLICCS and MPI, not as duplication but rather to complement one another. Resources applied from MPI under project Sapphire/Ruby are for model setup, tuning and preindustrial control ICON-ESM runs to address basic-science type of research. Resources applied for CLICCS are more for the climate change ICON-ESM runs.

WP2

The model simulations data have been archived. Data used for analyses are currently stored on '/work' in order to accessible for forcing other on-going models setups (e.g. downscaling CLICCS C3) and parallel analysis for the manuscripts' works. For upcoming simulations, experiment A6-2 will have 6 ensemble members, each 75-year long integration, which would need a total of 224TB storage space on '/work'. Since parallel analysis is needed from these experiments, archiving them would be inefficient. Experiment A6-3 are shorter (only 5 years each), but at much higher resolution, which would result in a total of 194 TB, of which only one simulation needs to be stored on '/work' (which is 39TB), while all of these runs will be archived on tape. Experiment A6-4 is complementary to A6-2 but only 15-year long. They would only need to be on '/work' and require 41 TB.

In summary, A6-WP2 would need **304 TB on '/work' and 194 TB on tape archive**.

5.5 References

Benetazzo, A., F. Barbariol, P. Pezzutto, J. Staneva, A. Behrens, S. Davison, . . . L. Cavaleri, 2021: Towards a unified framework for extreme sea waves from spectral models: Rationale and applications. *Ocean Engineering*, **219**, 108263.

Li, D., J. Staneva, J.-R. Bidlot, S. Grayek, Y. Zhu, and B. Yin, 2021: Improving regional model skills during typhoon events: A case study for super Typhoon Lingling over the northwest Pacific Ocean. *Frontiers in Marine Science*.

Putrasahan, D.A., O. Gutjahr, H. Haak, J.H. Jungclaus, K. Lohmann, M.J. Roberts, and J.S. von Storch, 2021: Effect of Resolving Ocean Eddies on the Transient Response of Global Mean Surface Temperature to Abrupt 4xCO2 Forcing. *Geophys Res Lett*, **48**(8), e2020GL092049.

Putrasahan, D.A. and J.S. von Storch, 2021: Piecewise Evolutionary Spectra: A Practical Approach to Understanding Projected Changes in Spectral Relationships Between Circulation Modes and Regional Climate Under Global Warming. *Geophys Res Lett*, **48**(14), e2021GL093898.

Staneva, J., S. Grayek, A. Behrens, and H. Günther. GCOAST: Skill assessments of coupling wave and circulation models (NEMO-WAM). in *Journal of Physics: Conference Series*. 2021a. IOP Publishing.

Staneva, J., M. Ricker, R. Carrasco Alvarez, Ø. Breivik, and C. Schrum, 2021b: Effects of wave-induced processes in a coupled Wave–Ocean model on particle transport simulations. *Water*, **13**(4), 415.

6 Report project bu1214

Project title: CLICCS C1 - Sustainable Adaptation Scenarios for Urban Areas – Water from 4 Sides
Project lead: Franziska Hanf
CLICCS project chairs: Jörg Knieling (HCU), Jürgen Oßenbrügge (UHH), Heinke Schlünzen (UHH), (Bernd Leitl (UHH))
Reporting Period: 01.01.-31.12.2021

	Allocated for 2021	Consumed (16.07.2021)	Projection of consumption to end of 2021
Computing time [node h]	7,400	Used: 1,272 Expired: 2,651	7,400
Temorary storage / work [GB]	24,000	411	24,000
Storage / arch [GB]	48,000	0	
Long term storage / doku [GB]	5,600	0	

6.1 Experiments performed successfully at project account bu1214

For the purpose of this project, we firstly implemented the model setup COSMO-DCEP-MUSCAT on Mistral. The MUSCAT model was provided by its developers from the Leibniz Institute for Tropospheric Research (TROPOS). During the implementation of the model setup on Mistral a few technical problems occurred, which delayed the start of the scientific experiments.

As a first step we began with implementing the setup without the chemistry model in order to test the urban parametrization DCEP. And a first problem occurred with finding the right compiler setting for the model. With corrected and updated compiler settings we were able to successfully compile COSMO-DCEP on mistral and started with first test-runs. We run test-simulations for each domain, starting with a Europe domain nested via two steps to the domain with the highest resolution, which covers grid cells with 500 m grid spacing. This domain is centered over the metropolitan area of Leipzig covering an area of 100 km x 100 km with 65 vertical levels. Comparing model runs with and without DCEP showed, that with the parametrization a clear urban heat island signal arises at night and a strong influence in the vertical mixing by the city is seen. This illustrates the importance of using the DCEP parametrization for our research.

As a next step we included the chemistry model MUSCAT and were able to start simulations with the coarsest domain. For those simulations we noted, that some chemistry process caused problems while integrating, leading to a slowdown of the model. The simulations needed the triple amount of Wall-Clock-Time for one COSMO-MUSCAT cycle compared to simulations performed with the same setup at TROPOS. Therefore, the setup was moved back to TROPOS and checked for errors. At TROPOS the problem could be identified and solved.

While working on the above an update to the newest model version has become necessary. One advantage of the new version will be that the integration time of one chemical cycle is reduced. First test-runs have been performed, however without the DCEP parametrization. The new version with DCEP will be implemented on mistral soon.

Facing all those hurdles, which were not predictable before, it was not possible to start with productive experiments yet. It is planned to start with the experiments in the next months.

6.2 Scientific results of project bu1214

Using the model setup COSMO-DCEP-MUSCAT we aim to investigate the interactions between atmospheric aerosol particles, emitted in the traffic sector in urban environments, and the formation of clouds and precipitation in the vicinity of large urban agglomerations. To simulate convection in urban areas, it is important to capture the dynamic and thermodynamic effects of the city. Therefore, we compared test simulations with and without the urban parametrization.

Preliminary results of the first test simulations show the formation of an urban heat island (UHI) signal at night with the urban parametrization (see figure 7). The temperatures are 2 K higher in the city center compared to the simulations without DCEP, and an urban heat plume has formed downwind the city center. The higher temperatures can encourage low-level convergence and uplift by shifting the thermal structure of the boundary layer towards neutrality and instability. The resulting uplift can lead to precipitation initiation and/or enhancement if atmospheric moisture conditions are suitable (Ok et al., 2017). Further analysis of the UHI and resulting changes in convergence is currently underway.

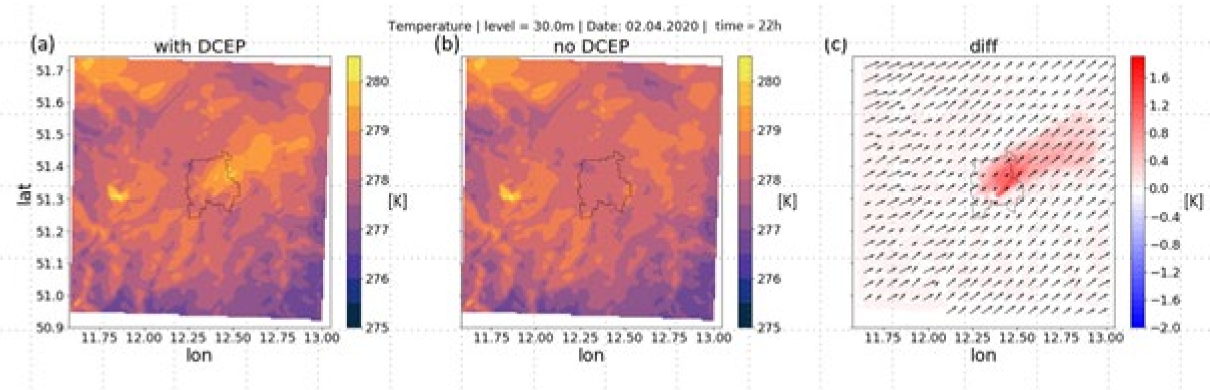

Figure 7: Horizontal temperature field at height of 30m for the 22 simulated hour, (a) with DCEP parametrization, (b) without DCEP. (c) Differences of the horizontal temperature fields, the black arrows correspond to the wind direction. The black line in the center indicates the contours of Leipzig. Publications in 2021 that use data of project bu1214

None.

6.3 Data Management of project bu1214

Currently 411 GB storage on work are used. This includes the model setup, the input data and first finished test-runs.

6.4 References

Oke, T., Mills, G., Christen, A., & Voogt, J. (2017). Urban Climates. Cambridge: Cambridge University Press. doi:10.1017/9781139016476

7 Report project bg1186

Project title: CLICCS C3 - Sustainable Adaptation Scenarios for Coastal Systems
Project lead: Johannes Pein
CLICCS project chairs: K. Emeis (UHH/HZG), P. Fröhle (TUHH), C. Möllmann (UHH), B. Ratter (UHH/HZG)
Reporting Period: 01.01.2021-02.07.2021

	Allocated for 2021	Consumed (19.07.2021)	Projection of consumption to end of 2021
Computing time (node h)	349569	176146	349569
Temporary storage / work (GB)	327338	257386	69952
Storage / arch (GB)	67180	0	67180
Long term storage / doku (GB)	?	?	?

7.1 Experiments performed successfully at project account bg1186

7.1.1 NEMO-ECOSMO

During the first months of the project, we successfully setup automated workflows for the GCOAST-NEMO+ECOSMO (3.5km) and GCOAST-NEMO-ECOSMO-CCLM (3.5km) simulations. The coupling with ECOSMO has been done within the Framework for Aquatic Biogeochemical Model (FABM). The surface and lateral forcing for the regional model has been prepared by using climatology WOA climate data, as well as the North Atlantic ECOSMO model. During the implementation phase it appear that additional model NEMO-ECOSMO –code modifications and adjustments are necessary. This includes an enhanced parametrization approaches for the penetrating short wave radiation (visible light), nutrient input from rivers and seabed deposition/remineralisation of nutrients. Several sensitivity simulations in respect to biogeochemical model parameterisation have been performed. Subsequent tests and validations simulation revealed open issues within the memory management of the coupling between NEMO and ECOSMO. These issues have been successfully solved and long-term integrations will be soon initiated.

3.1.2 SCHISM-ECOSMO

The coupled physical-biogeochemical model of the Elbe estuary has been physically nested into regional climate projections of global RCP8.5 scenarios. During this implementation phase, it appeared that the relatively coarse temporal resolution of the regional climate projections for the area of the North-Western shelf is not optimal to transfer the full physical dynamics from the regional model to the estuarine model. In particular, the horizontal velocities that convey the momentum generated by tides and wind would need at least an hourly temporal resolution when applied to an estuarine model with open boundaries in the shallow waters of the German Bight. For this reason, the nesting strategy has been adapted. Taking advantage of the availability of the modelling data, coupled MPIOM-REMO ensemble simulations from the ClimExtreme A9 project, the new approach is to enlarge the high resolution mesh of the larger Elbe area by the region of the southern North Sea, whereas the latter is coarsely resolved in the order of the resolution of the parent model (MPIOM ~ 5 km). At the boundaries of the enlarged model we apply vertical and horizontal tides from a tidal model (FES 2014). Daily sea level and monthly mean horizontal currents from the regional MPIOM are added to tidal seal level and currents, respectively. Also monthly salinity and temperature from the regional projection are prescribed at the open boundaries. Furthermore, the dynamics of the unstructured model area nudged to the salinity and temperature fields of the MPIOM regionalization on a monthly time scale in the coarsely resolved region. The hourly atmospheric data represented by the REMO are applied to the total unstructured mesh area, that is the coarsely resolved southern North Sea and the highly resolved Elbe estuary area.

7.1.3 SCHISM (German-Bight)

At Hereon, the hydrodynamic SCHISM-German-Bight model was set up as pre-operational model accompanied by scientific studies on tidal inlet secondary circulation, which further verified the models capabilities of replicating observed coastal dynamics: A hindcast for 2011 was performed enhancing the model resolution in the inlet Otzumer Balle to 50m. The modeled dynamics of the lateral circulation in the inlet cross-section have been studied together with transects sampled in the inlet with a research vessel to identify the driving mechanisms and spring-neap tidal variation.
The mid-term goal for the German Bight model is to enhance this setup with wave and morphodynamics coupled to represent combined effects of these dynamics
(e.g. with respect to ocean state during extreme weather and development of coastal morphology). As step into this direction the coupling with the WWM III spectral wave model and the generation of wave boundary data running Wave Watch III have been successfully implemented making use of Hereon and DKRZ computational facilities. The model coupled with wave is currently in the state of tuning and optimization. It is intended for future use in C3 after successful implementation of the three way coupling with morphodynamics.

7.2 Scientific results of project bg1186

The different computational activities this project aim at highly resolved climate projections of hydrodynamics and biogeochemical dynamics. The latter are closely related to wind waves, sediment and morpho-dynamics. The coupled hydrodynamics and biogeochemistry are tackled by a structured approach, represented by the NEMO-ECOSMO framework, and by unstructured approach, represented by the SCHISM-ECOSMO framework. The former covers a larger spatial region (i.e. the North-Western shelf of the Atlantic Ocean) and shall provide boundary conditions for the estuarine unstructured modelling in the future.

7.2.1 NEMO-ECOSMO

The full implementation of ECOSMO in the GCOAST (Geesthacht Coupled cOAstal model SysTem) will enable to investigate the response of the North-Baltic Sea regional climate system and the German coast to the natural and anthropogenic changes in respect to coupled wave-ocean processes and changing hydrological forcing.

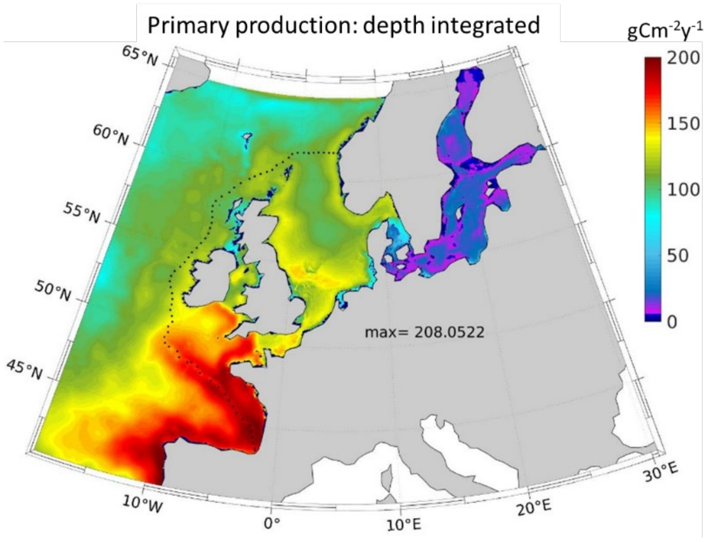

Figure 7: Depth integrated Primary production with NEMO-ECOSMO set-up for the Northwest European shelf - Baltic region model domain.

7.2.2 SCHISM-ECOSMO

By means of the coupled physical-biogeochemical model the hydrodynamics and biogeochemistry of the Elbe estuary and comparable systems was studied and results presented in two papers. In (Pein et al., 2021) it is demonstrated that temperature-induced density gradients lead to seasonal stratification, increased particle trapping and oxygen consumption in the upper Elbe estuary and specifically in the port area. In Pein et al., 2021b (under revision) it is shown that channel meanders potentially mitigate the effect of eutrophication on oxygen levels in the deepened navigational channel and port area. The studies involved a warming scenario demonstrating that such a solution would be ecologically sustainable even under a moderate warming of 2°C globally in comparison with the reference run.

Furthermore, we present a seamless downscaling of climatic variability for the Elbe estuary, which can be easily transferred to any other estuary of the area covered by the parent model (in this case the regional MPIOM simulation from ClimExtreme project). The missing tidal variability in the thermohaline and velocity fields of the regional climate projection is generated internally by the child model. To the best of our knowledge this is a novel approach. It does not require to repeat the resource expensive regional projections in order to provide tidally resolved currents, temperature and salinity at the mouth of the estuary that are usually needed to generate realistic estuarine dynamics. The new modelling approach scales comparable to the coupled estuarine model because only mesh cells coarser than the ones in the estuary have been added. The use of the nudging option which comes as a standard with SCHISM allows to transfer monthly physical and biogeochemical fields to the unstructured model in combination with the tidal forcing simulate monthly climatic variability plus tidal variability at the border of the region of interest, i.e. at the mouth of the estuary.

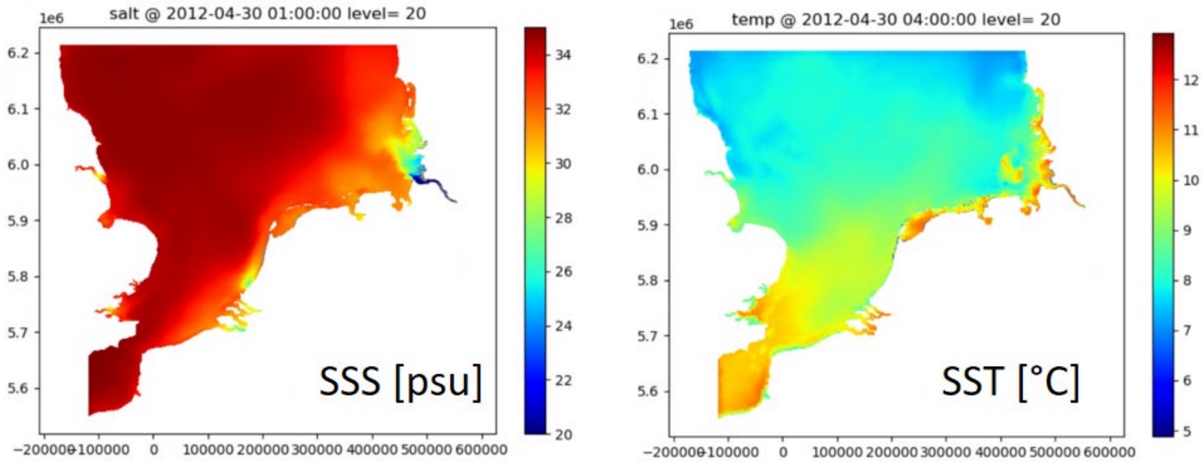

Figure 8: Snapshots of the surface salinity and temperature fields of a nest of the unstructured SCHISM-ECOSMO set-up to a regional downscaling of the RCP8.5 scenario.

7.2.3 SCHISM-German-Bight

The study of inlet dynamics during the spring-neap tidal cycle showed that simulated tide averaged lateral flows are in line with observed ones: Advection plays the dominant role in the lateral momentum budget; in case of spring tide, the eddy viscosity and tidal shear covariance (ESCO) become similarly important. Changes in the structure of the ESCO forcing reverse the secondary circulation from an anti-clockwise rotating cell in neap tide to a single clock-wise rotating cell in spring.
The workflows developed in the operationalization of the German-Bight-Setup allow for an easy implementation CMEMS forced SCHISM setups with different regional foci on the European Northwestern Shelf.

The simulations with the coupled hydrodynamic-wave model give first promising results in comparison with observations demonstrated in Figure 9. At the example of significant wave height at Helgoland buoy. The peaks show still an underestimation of observed local maxima, which is being fixed during the currently ongoing works on further optimization of the coupled setup.

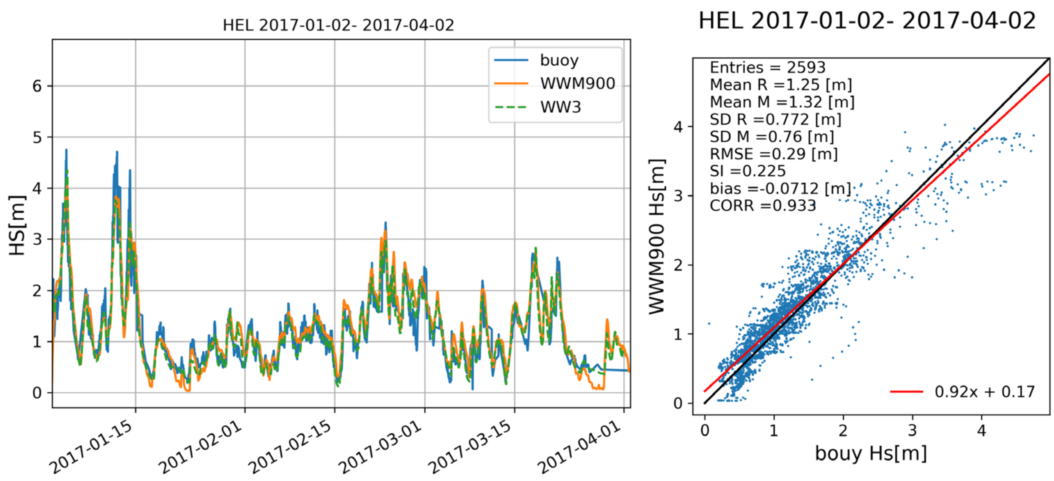

Figure 9: Time Series (left) and scatter plot (right) of significant wave height (Hs) simulated by SCHISM-WWM coupled wave model in comparison with buoy data near Helgoland.

7.3 Publications in 2021 that use data of project bg1186

Published:

Pein, J., A. Eisele, T. Sanders, U. Daewel, E.V. Stanev, J.E. van Beusekom, et inter C. Schrum, 2021a: Seasonal stratification and biogeochemical turnover in the freshwater reach of a partially mixed dredged estuary. Frontiers in Marine Science, 8, 624.

Submitted:

Pein, J., Staneva J., Daewel U., Schrum C., 2021b: Channel curvature improves water quality and nutrient filtering in an artificially deepened meso-tidal idealised estuary. Under revision at Continental Shelf Research.

In preparation:

Pradhan H, Grayek S., Daewel U., Staneva and Schrum C. GCOAST (NEMO—ECOSMO), 2021: A model set-up for Ecosystem Scenario Simulations in North West European Shelf, Earth System Model Development

Jacob B, Stanev E., Pein J. Staneva J., 2021: On the impact of wave-induced processes of the Wadden Sea dynamics. Regional Studies in Marine Science.

Chen W, Jacob B, Stanev E. Badewien T. Valle-Levinson A, Staneva J., 2021: Secondary circulation in the Otzumer bay. Continental Shelf Research.

7.4 References

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