

REVIEWER 1

Review of manuscript: Coupled regional Earth system modelling in the Baltic Sea region by Gröger et al.

This paper provides a very complete and clear overview of the state-of-the art of the regional Earth system modeling in the Baltic Sea and stands out future challenges for the climate modeling community studying the region, such as the role of aerosols or hydrological model coupling. The paper is very well written and the structure and objective very clear. Thus, I recommend it for publication. In the text below you find a list of minor comments to improve the manuscript.

We gratefully thank the reviewer for a thorough review of the manuscript and appreciate the suggestions and recommendations that helped to improve the manuscript. The new version has been revised as followed.

General comments:

- **Please, avoid the use of back-to-back brackets along the text.**

We have removed all back-to-back brackets from the text.

- **Be consistent with the capitalization of the term “Earth System” all over the text, also in the title.**

The term earth system is now consistently written with lowercase letters. Only when used as nouns or titles it is capitalized in order to be consistent with the other papers of the BEAR special issue.

- **Write the word “modeling” with a single “L” in order to be consistent with the USA English style that is used in this manuscript.**

Done.

Specific comments:

L75 → You can consider adding Cabos et al. (2020).

Done.

L92 → A dot is missing by the end of the sentence.

Done.

L107 → What do you mean by process? Please, be more specific

We have changed the sentence now:

“Thus, the demand for modeling Europe’s climate includes high resolution, as well as a comprehensive process description by respective coupled model components.”

L125 → What do you mean by compartment behavior?

We have clarified this and removed the word compartment. The sentence reads now:

“Consequently, coupled models can drift from observed conditions which makes their tuning more difficult but allows a more realistic interaction between models.

L188 → Please cite in chronological order: Bonan 2008; Anderson et al. 2011...

Done.

L289 → I think this sentence belongs to the previous paragraph.

Yes, has been corrected now.

L295 → Please, specify the year of the references you provide.

Done.

L330 → Please, replace “summarise” with “summarize” to be consistent with the USA English style.

Done.

L348 → Please, replace “work has” by “works have”.

Done.

L375 → What is LAI?

It is leaf area index. This explanation is included in line 186 in the revised manuscript.

L377 → Please, replace “favour” with “favor” to be consistent with the USA English style.

Done.

L450 → What is PCO? Please, define it.

Passively coupled ocean model. The explanation is provided now.

L451 → Please, add model data to reanalysis data.

Done.

L459 → Please, add other relevant studies such as Cabos et al. (2020).

Is included now. We basically cite studies for the North Sea, Baltic Sea and Mediterranean as these Seas belong to the Euro-CORDEX domain.

L464-466 → Is this sentence referred to the Baltic Sea? If so, specify it since, to my knowledge, this is not the case in other regions of the world.

Yes. It applies basically to the Baltic Sea and North Sea. This information has been added now.

L509 → Please, add a comma after 70 hours.

Done.

L516 → I guess ERAI refers to ERA-Interim. Please, specify it for consistency.

Done.

L538 → An “A” is missing in “ERA40”.

Corrected now.

L552 → Remove the word “far”.

Thank you. Has been removed now.

L567 → Please, avoid repetition.

We removed the double “By contrast...”

L569 → Replace “behaviour” by “behavior”.

Done.

L590-592 → Could you please add more details about the development of this effect?

We provided some more details and made a reference to Gröger et al., (2015) for further details. The sentences read now:

“Enhanced mixing by winds brings cooler waters from depth to the surface. The cooler surface water likewise cool the air temperatures which imposes a stabilizing effect on the atmospheric boundary layer over sea thereby damping wind strength again (see Gröger et al., 2015 for details).”

L599 → You can also consider adding Cabos et al. (2020), in which a coupled model setup including the Mediterranean and the North Atlantic is used.

Done.

L758 → Please replace “parametrized” by “parameterized”.

Done.

L830-833 → Please rewrite the sentence to make it clearer

This has been reformulated now. The sentence now reads:

“Comparing coupled and uncoupled ocean model runs usually involves simulations that use different bulk formulae to calculate air sea fluxes in the atmospheric boundary layer in the coupled and uncoupled modes, respectively (e.g. Dieterich et al., 2019b).”

L928 and L944 → Change compared with by compared to.

Done.

L987-L990 → Isn’t the information presented contradictory?

It’s not contradictory. However, we put the second part of the sentence into brackets to improve readability. It now reads:

“On the one hand, the thermohaline circulation of the Baltic Sea is also influenced by inflows of highly saline water from the North Sea (that itself may be strongly impacted by precipitation and river runoff, Lehmann and Hinrichsen, 2000).

L1087 → I would say “Previous works have shown...”.

Done.

L1101-1104 → Please rephrase the sentence, it is hard to understand.

We have clarified this in the new version by including the sentence.

“When the atmosphere domain covers several seas as it does in Euro-CORDEX domain it might be feasible to coupled only a few of them to save computational costs (e.g. Tian et al., 2013; Gröger et al., 2015).”

L1118 → add “to assess whether”.

Done.

L1157 → Please, keep the word “This”.

Done.

L1201 → What do you mean by realized?

We replaced “realized” by “implemented”.

References:

Cabos, W., de la Vara, A., Álvarez-García, F.J. et al. Impact of ocean-atmosphere coupling on regional climate: the Iberian Peninsula case. *Clim Dyn* 54, 4441–4467 (2020). <https://doi.org/10.1007/s00382-020-05238-x>.

REVIEWER 2

Coupled regional Earth system modelling in the Baltic Sea region

By Gröger et al.

The paper gives a comprehensive overview of coupled modelling systems applied over the Baltic Sea region. It covers a wide variety of coupling options between different parts of the earth system for example biosphere, atmosphere, cryosphere and ocean – and gaps and challenges which lies therein. The article has a good structure and is well written, I thus recommend it for publication.

We gratefully thank the reviewer for a thorough review of the manuscript and appreciate the suggestions and recommendations that helped to improve the manuscript. The new version has been revised as followed.

General comments:

1) Though the article emphasizes its focus on the Baltic Sea region I still feel that other coupled models could be briefly mentioned. Amongst others the dynamical vegetation model FATES and the coupled system COAWST are state of the art model systems worth mentioning briefly in a review article as this.

We thank the reviewer for this excellent suggestion. We have now made a number of changes to Section 2.1, especially between lines 325-331 and 339-360 of the new version. In particular, we have added a number of references to other DGVMs and LSMs that take vegetation demography into account, including FATES, and have even added a reference to the study by Kumkar et al. (2020) who applied CLM4.5 to a Fennoscandian domain at high resolution

We also agree and mentioned COAWST now in the Introduction. See first sentence, last paragraph:

“In the past decades several advancements in coupled modeling have led to a growing number of different regional climate models on the way to a fully comprehensive description of the earth system for many regions of the world e.g. the east coast of the U.S. (COAWST – Coastal Ocean-atmosphere-wave-sediment transport model, Warner et al., 2008; 2020).”

Warner et al., 2008; 2020 have been added to the reference list.

2) Regional coupled models at high spatial resolution are still very computational demanding and therefore sacrifices must often be made. I miss a section towards the end where this is discussed. In my opinion a setup that fits most purposes aren't still computationally feasible, therefore one must consider whether the coupling is at all worth the computationally cost for the particular problem addressed. What is the authors opinion on such challenges?

Thank you for mentioning this important topic! We have included the following paragraph to the concluding remarks.

“Coupled models can be computationally highly demanding especially when multiple components are included. For hindcast simulations of the historical climate the more economic standalone models are a good tool provided that forcing and boundary data is of good quality. For future climate simulations where this is not the case, rather coupled models will be the first choice. The higher costs of coupled climate simulations will require to reduce the size of individual ensemble simulations which hampers a robust assessment uncertainties due to global models and scenarios. However, advanced techniques for reducing the ensemble size by by conserving the model ensemble spread are currently under development (e.g. Wilcke and Barring, 2016).

Specific comments:

L32; double word “models”

Has been corrected

L464+475+539; which data were used as initial and boundary conditions in the ocean? This must have effect on the results, i.e. also on how these then can be interpreted I assume?

We have added the information on the lateral boundary condition in the revised manuscript at lines: 475, 487, 552.

We could not add all information on initial fields since this was not always properly described in the literature. However since all runs were longterm i.e. multidecadal climate runs (>60 years) the discussed main findings are robust against initial fields. This is also prominently discussed in the section 3 “Uncertainties and gaps”.

L475+539; Missing A in ERA40

This has been corrected now.

L605–610; Perhaps mention ERA5 which has a much higher resolution, both spatially and temporal.

We agree and thus added the sentence

“More recent products like e.g. ERA5 may improve the situation by providing a higher spatial and temporal resolution.”

L736; double word “also”

This been corrected now.

L837; The fact that the driving data in a stand-alone model may be at a coarser resolution compared to the interface in a coupled model can be mentioned here too.

Very good idea! We have included this now.

The sentence reads now:

However, a general statement about model performance of coupled versus standalone models can not be drawn as many studies showed added value of coupling especially in those cases the uncoupled model was driven by low quality forcing data (Tian et al., 2013; Gröger et al., 2015; Ho-Hagemann, 2017) and often had a low resolution at the air sea boundary.

L1144; Sentence is hard to read, consider to reformulate for better understanding

We now made 2 sentences out of this. It now reads:

So far, only a few hydrological models include nutrient cycling to provide explicit estimates of nutrient inputs to the sea (Hundecha et al., 2016). This needs to be addressed in more detail in future model development.

L1168; Typo in “statistics”

Has been corrected.

L1255–1260; Several typos in the author contribution paragraph

We carefully corrected the typos in this paragraph in the revised manuscript.