Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2018-491-RC1, 2019

Biogeosciences Discussions
Open Access
EGU

Interactive comment on "Reciprocal bias compensation and ensuing uncertainties in model-based climate projections: pelagic biogeochemistry versus ocean mixing" *by* Ulrike Löptien and Heiner Dietze

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Received and published: 7 January 2019

General comments

A key problem in predicting the rate of carbon uptake by the oceans is that the uncertainty in the diapycnal diffusion. The authors show that this problem is not alleviated by optimizing an ocean model against the historical and current (biogeochemical) observations: the past and current state of the ocean can be described with very different parameter sets, which give dramatically different predictions for the future. Overall, this

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is a decent piece of work that I recommend for publication after minor revisions.

Specific comment

Although I think this is a decent piece of work, the Conclusions section leaves me rather dissatisfied. In particular, I find the conclusion "that an improved understanding of vertical diapycnal mixing in Earth System Models alleviates the risk of reciprocal bias compensation by (wrongly) tweaking biogeochemical modules to a deficient physics" weak. It is of course great to diagnose a problem, but it would be helpful to have some more specific pointers to how future research could work toward a possible solution. In other words: how can we get to an improved understanding of vertical diapycnal mixing?

Technical comments

throughout: "reziprocal" -> "reciprocal", "brakes" -> "breaks"

p. 1, l. 12: "Metrics like total..." -> "Metrics such as total..."

p. 2, l. 15/16: "...of biogeochemical relevance), are contain various sources for uncertainties." -> "...of biogeochemical relevance), contain various sources of uncertainties."

p. 2, l. 18: "The reason being that diapycnal..." -> "The reason is that diapycnal..."

p. 3, l. 3/4: "Thus, typically, diapycnal mixing of a specific ocean model must have a profound impact on the respective biogeochemical component and it's parameter settings." -> "Therefore, diapycnal mixing of a specific ocean model typically has a strong impact on the respective biogeochemical component and its parameter settings."

p. 4, l. 12: "...primitive-equation model Pacanowski (2010)." -> "...primitive-equation model (Pacanowski, 2010)."

p. 5, l. 4: "Both, phytoplankton..." -> "Both phytoplnakton..."

p. 5, l. 5: "...remineralization rate determines the..." -> "...remineralization rate, deter-

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mines the..."

p. 5, l. 8: "...mW denotes depth dependent detritus sinking speed..." -> "...mW is the derivative of wD with respect to depth..."

p. 6, l. 6: "...substantially different to the Genuine Truth." -> "...substantially different from the Genuine Truth."

p. 6, l. 28: "...they are representative for a pre-industrial world." -> "...they are representative of the pre-industrial world."

p. 7, l. 6: "In the following Section 3.1 we present..." -> "In the following Section 3.1, we present..."

p. 7, l. 7/8: "In Section 3.2 we present..." -> "In Section 3.2, we present..."

p. 8, l. 6: "...inline" -> "...in line..."

p. 8, l. 11-14: "The results under historical forcing are as follows: In terms of physical ocean circulation TUNE and MIX+ are almost identical (not shown). The main reason for this insensitivity is that the atmospheric CO2 concentrations are prescribed to the same preindustrial levels in both of the historical solutions. Hence the feedback from changed biogeochemistry via oceanic carbon uptake to atmospheric CO2 and associated changes in air-sea heat fluxes is excluded." -> "Under historical forcing, the physical ocean circulation is almost identical in TUNE and MIX+ (not shown). The main reason for this insensitivity is that the atmospheric CO2 concentrations are prescribed to the same preindustrial levels in both of the historical solutions, which means that the feedback from changed biogeochemistry via oceanic carbon uptake to atmospheric CO2 and associated changes in air-sea heat fluxes is excluded."

p. 9., l. 12: "...warms quicker than TUNE..." -> "...warms more quickly than TUNE..."

p. 9, l. 23: "Projections of phytoplankton are of interest also because phytoplankton forms..." -> "Projections of phytoplankton are of interest, because phytoplankton

forms..."

p. 9, l. 26: "...vertical mixing of nutrient replete waters..." -> "...vertical mixing of nutrient-replete waters..."

p. 10, l. 4: "Projections of phosphate are of interest also because it is an essential nutrient..." -> "Projections of phosphate are of interest, because phosphate is an essential nutrient..."

p. 10, l. 6: "...models phosphate..." -> "...models, phosphate..."

p. 10, l. 11" "...show alternating pattern of increasing..." -> "...show alternating patterns of increasing..."

p. 10, l. 18/19: "We speculate that, the absence of patches..." -> "We speculate that the absence of patches..."

p. 10, l. 28: "Projections of the oceanic carbon content are of interest, because the oceans currently take up..."

p. 10, l. 29: "To this end changes in..." -> "Therefore, changes in..."

p. 11, l. 1-3: "...oceanic carbon content: Historically, the ocean simulated carbon content of the ocean between the simulations varies by less then 0.5% between the simulations." -> "...oceanic carbon content. In the Historical Model Solutions, the simulated carbon content of the ocean varies by less than 0.5% between the simulations."

p. 11, l. 7/8: "Projections of suboxic volume are of interest also because suboxia trigger denitrification and thus reduce the global availability of fixed nitrogen which is an essential nutrient for all phytoplankton other than diazotrophs." -> "Projections of suboxic volume are of interest, because suboxia triggers denitrification and thus reduces the global availability of fixed nitrogen, an essential nutrient for all phytoplankton other than diazotrophs."

p. 11, l. 31 - p. 12, l. 1: "...that since, EMICs and...." -> "...that since EMICs and..."

p. 12, l. 2: "...kernels, that our..." -> "...kernels, our..."

p. 12, l. 3/4: "... are inline with our results. Still we have to stress that our mixing parameter settings can presumably be regarded..." -> "...are consistent with our results. Even so, we wish to stress that our mixing parameter settings should be regarded..."

p. 12, l. 20-24: "Hence, using a diffusivity that is averaged over time and space (as is inevitable in the current generation of models that apply a finite-differences discretization) but, at the same time, is fraught with high uncertainties. An additional source of uncertainty is implicit diffusion. As opposed to explicitly prescribed diffusion implicit diffusion is a spurious and hard-to-quantify artifact (cf., Getzlaff et al. (2012)) of the underlying numerical advection algorithm." -> "Thus, using a diffusivity that is averaged over time and space (as is inevitable in the current generation of models that apply a finite-differences discretization) is fraught with uncertainties. An additional source of uncertainty is implicit diffusion, a spurious and hard-to-quantify artifact (cf., Getzlaff et al. (2012)) of the underlying numerical advection algorithm."

p. 12, l. 28-31: "The visible effects on physical tracers when using ad-hoc measures, based on temperature and salinity, are rather weak. In terms of global sea surface temperature differences only 0.03K. In terms of meridional averaged heat fluxes the differences are below 5W/m2 form 50âŰęS to 50âŰęN. At high latitudes differences reach 25W/m2." -> "Using ad-hoc measures, based on temperature and salinity, has a rather weak impact on physical tracers: only 0.03K in terms of global sea surface temperature differences and in terms of meridional averaged heat fluxes, the differences are below 5W/m2 from 50âŰęS to 50âŰęN, reaching 25W/m2 at high latitudes."

p. 12, l. 33/34: "To rate this numbers, we put them into perspective with IPCC models:" -> "These numbers are broadly consistent with IPCC models:"

p. 13, l. 2-5: "The spread among models in the late twentieth century is with 21 Sv huge, and even exceeds the spread of the simulated max. meridional overturning in CMIP3 models. Thus, the difference between the lowest and highest projected max

overturning in CMIP5 models is even higher as the present day observational estimate..." -> "The spread among models in the late twentieth century is with 21 Sv huge, even exceeding the present day observational estimate..."

p. 13, l. 7: "...both, changed..." -> "...both changed..."

p. 13, l. 10: "E.g. Kriest et al. (2017) assumes..." -> "For example, Kriest et al. (2017) assume..."

p. 13, l. 11: "...Illyina..." -> "...Ilyina..."

p. 13, l. 11: "Also,..." -> "Furthermore,..."

p. 13, l. 29: "...inline..." -> "...in line..."

p. 14, l. 1: "...wind forcing and Bryan (1987) stresses the importance for the simulated large-scale meridional overturning..." -> "...wind forcing and thus the simulated large-scale meridional overturning..."

p. 14, l. 6: "The results for suboxic volume is consistent with findings..." -> "The results for suboxic volume are consistent with findings..."

p. 14, l. 14/15: "With this our results are inline with earlier findings..." -> "Our results are consistent with earlier findings..."

p. 14, l. 23/24: "Also, dating ranges of CFCs are not suitable to resolve the dynamics of the deep ocean which recently lead to the suggestion to introduce additionally 39Ar (Ebser et al, 2018). The latter, promising approach is currently under investigation." -> "Furthermore, dating ranges of CFCs are not suitable to resolve the dynamics of the deep ocean which recently led to an investigation of the use of 39Ar as an additional tracer (Ebser et al, 2018)."

p. 14, l. 25: "...an pressing..." -> "...a pressing..."

p. 15, l. 10: "For carbon the projections..." -> "For carbon, the projections..."

p .16, l. 9: "These results are inline with earlier findings..." -> "These results are consistent with earlier findings..."

p. 16, l. 17/18: "With these findings our study reminds on the need..." -> "With these findings, our study emphasizes the need..."

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