Response to reviewers: *Modeling the marine chromium cycle: New constraints on global-scale processes*

We highly appreciate the comments and suggestions provided by Ed Boyle, and we want to thank him for his time evaluating our work. As such, we have tried to fully incorporate the suggested changes and remarks as detailed blow in our point-by-point response.

In order to efficiently refer to our replies to comments by other reviewers, we here continue the numbering of our replies.

The original reviewer comments are in black and our responses are colored blue. Line references correspond to the revised manuscript without tracked changes.

Reviewer#4 (Edward Boyle)

Review of “Modeling the marine chromium cycle: New constraints on global scale Processes” by Pöppelmeier, Janssen, Jaccard, and Stocker (bg2021-0106)

The paper serves a useful purpose as a first-stab model for Cr in the global ocean. The model itself is well documented, and for many purposes, of sufficient complexity that many processes can be included. It makes estimates of things that are poorly known (most notably, the benthic flux of Cr), which gives observationalists targets to aim at. And if anyone disagrees with some of the model assumptions, then they are free to make their own model. Hence I recommend publication of a revised version of the manuscript.

Reply#34: We thank the reviewer for the positive assessment of our work and for sharing his insight in the geochemical cycling of Cr.

That said, there are many things in here that I wouldn’t have done if I were the one constructing the Cr assumptions. My major unhappiness is in the assumption of a (relatively large) globally uniform seafloor flux for Cr, although I would also have handled the OMZ assumptions differently. I think the manuscript bears some confusion on the ocean residence time of Cr. If the benthic flux of Cr comes from regenerated biogenic matter that removed it from the upper ocean, it doesn't shorten the residence time in the entire ocean-surface sediment system. I think that the river flux is the main constraint on that number, unless Cr release from aluminosilicates in sediments is significant. And there is no data upon which to know whether this happens.

Reply#35: We acknowledge that we had to make a number of (simplifying) assumptions in our implementation of the Cr cycle in the Bern3D model, largely due to missing observational constraints. However, we here want to seize the opportunity and further elaborate on the aspects mentioned by the reviewer. First, we consider a globally uniform benthic flux the only sensible parameterization with the current state of knowledge. For now, only a handful of pore-water profiles exist that characterize the nature of the benthic Cr flux and very little is known about the driving processes leading to the sedimentary release of Cr. As such, we feel that an implementation of a regionally variable benthic flux is premature at this point and could in fact create a false sense

of precision that is not supported by the data. Further, we here want to emphasize that the strength of this benthic flux is a free parameter in our implementation that was tuned for the best model-data agreement. Indeed, our tuning ensemble also included runs with no benthic flux, which however produced worse model-data agreements than a moderate benthic flux of 0.1-0.2 nmol cm^{-2} yr^{-1}. The reviewer further mentions that our calculation of the ocean residence time bears some confusion, since it remains unclear whether the Cr associated with the benthic flux is recycled or new. We have already addressed this issue in response to a similar comment by reviewer#3 in reply#22. As such, we now clearly state in the manuscript that the model cannot distinguish between recycled and new benthic Cr and that the ocean residence time may hence be larger dependent on the fraction of recycled Cr contributing to the benthic flux (see section 3.1).

As the authors note, the model's handling of oxygen deficient zones (ODZs, which should be distinguished from oxygen minimum zones (OMZs) is inadequate to represent them very well – even for simpler properties such as oxygen. Is there a companion paper on the nitrogen system in ODZs? I bet that it is similarly problematical. Probably someone needs to make a regional model that can do a decent job at representing ODZs before trying to include them in a global model.
Reply#36: We agree that the representation of OMZs (here defined as $[O_2] < 5$ µmol/kg) is somewhat limited in the Bern3D model, which is primarily related to the coarse spatial resolution (see also line 376). Yet, we want to note that the representation of ODZs (5 µmol/kg < $[O_2]$ < 80 µmol/kg) is substantially better as characterized by Battaglia & Joos (2018) who investigated the impact of (de)nitrification in OMZs and ODZs on the nitrogen cycle in the Bern3D model. These authors further parameterized subgrid-scale processes that partly alleviated the issue of the somewhat poor representation of OMZs on the nitrogen system. With a better understanding of the processes driving the Cr redox behavior in OMZs, this may also be a possibility for the Cr implementation in the future. We discuss these model shortcomings and their potential alleviations in section 4.2.

The paper misses out on some significant references:

Lines 110-120: Shiller (1991) GCA 55:3241
Lines 120-129: Brumsack (1983) Mar.Chem. 14:89 and Shaw (1990) GCA 54:1233
Lines 180-185: Elderfield (1970) EPSL 9:10 and Shiller (1987) GCA 51:3273
Line 275: Sherrell (1988) DSR 35:1319
Reply#37: All suggested references are now added to the main text, except the last one (Sherrel & Boyle, 1988), which measured Cr in the Mediterranean Sea, a basin that we explicitly excluded from our interpretation, because it is only very poorly spatially resolved in the Bern3D model (please see also reply#19).

And I would also add for lines 285-290, Arctic surface Cr is influenced by Fe(II) oxidation by reduced Fe released from organic-rich Arctic shelf sediments, with Cr(III) formation and Fe oxide scavenging.
Reply#38: We now added the process suggested by the reviewer as an alternative/additional explanation for the low Cr(III) surface concentrations in the Arctic.

References

Battaglia, G. and Joos, F.: Marine N_2O Emissions From Nitrification and Denitrification Constrained by Modern Observations and Projected in Multimillennial Global Warming Simulations, Global Biogeochem. Cycles, 32(1), 92–121, doi:10.1002/2017GB005671, 2018.

Sherrell, R. M., and Boyle, E. A.: Zinc, chromium, vanadium and iron in the Mediterranean Sea, Deep Sea Research Part A, 35(8), 1319-1334, doi:10.1016/0198-0149(88)90085-4, 1988.