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Discussions

Interactive comment on "Short Commentary on Marine Productivity at Arctic Shelf Breaks: Upwelling, Advection and Vertical Mixing" *by* Achim Randelhoff and Arild Sundfjord

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[Below, please find: Your comments preceded by RC, "Reviewer Comment", and our replies preceded by AR, "Author Reply" and MC, "Manuscript Change"]

RC: This short commentary manuscript brings up a hot and important topic on how wind- driven upwelling, in conjunction with dramatic sea ice loss, may affect ocean productivity on the vast Arctic continental shelves. The authors argued that "shelf break up- welling is likely not a universal but rather a regional, albeit recurring feature of the new Arctic." I do agree with the authors that regional geographic, atmospheric, oceanographic, and sea ice conditions must be taken into account when assessing pan-arctic

upwelling phenomena and their impacts on upper ocean nutrient supply and primary production processes. Nonetheless, the authors can better justify their arguments and greatly improve the paper by providing more concrete data analysis and evidence, particularly in the northern Barents Sea shelf where the authors claim upwelling may function differently from other Arctic shelf systems.

AR: > We appreciate the reviewer's support for our key statement that a number of basic conditions, including geographical, together determine if and how upwelling and associated effects on the ecosystem are important in different parts of the Arctic. As you will see from our replies to the two first reviewers' comments we acknowledge that the purpose of the paper, and therefore also the reason for relying on general examples rather than comprehensive data analysis, should have been more clearly explained in the submitted manuscript. Namely, the goal of this paper is (partly) to show that just by general physical considerations, many conclusions can be reached already. These conclusions can help guide hypotheses and field measurements. In the revised version we have attempted to make the key points clearer; that these basic conditions can and should be assessed for different regions, and that snapshot data don't necessarily allow for underlying mechanisms to be deduced. We hope that our responses and suggested manuscript amendments detailed below are sufficient to clarify these key aspects.

> [Below, please find: Your comments preceded by RC, our replies preceded by AR, and our edits to the text preceded by MC.]

RC: Other comments: Figure 1: The illustrations are too vague and lack important geographic and hydro- graphic features. In the left panel, I would suggest the following changes: (1) add lati- tudinal circles and longitudinal lines, (2) use a better color map to illustrate bathymetry (or at least supplement a color bar for the grayscale), (3) draw general surface and bottom circulation patterns.

MC: > We have now added the broad patterns of surface and Atlantic layer circulation patterns as far as they are relevant to our manuscript; the bottom circulation, how-

ever, is not relevant to the manuscript and we did not illustrate it. > The following was added to the figure caption: “Arrows show selected patterns of the general circulation \citep[after][]{polyakov2012warming}. Blue arrows: Pacific-derived and other freshwater flowing along the shelf break, through the Transpolar Drift and in the Beaufort Gyre. Red arrows: Atlantic-derived water entering the Arctic Ocean through Fram Strait and the Barents Sea, flowing along the shelf break, submerging north of the Barents Sea and recirculating along the shelf break through the Arctic Ocean. Other major currents are not indicated here as they are of minor importance to this paper.” > We have also added a colorbar and the location of the transect shown later in the manuscript. AR: > We think longitude/latitude coordinates do not contribute significantly in this context, they would rather clutter the figure, which is why we refrain from adding them. If the reviewer has particular reasons for why they should be included we will be happy to reconsider.

RC: In section “Many interconnected phenomena”: The authors tried to explain different physical mechanisms that drive upwelling and other physical processes that interact with upwelling. I am uncomfortable that the authors did not attempt to put their discussion in the context of rich literature in upwelling. There is not a single citation in the section, which is unusual.

AR: > You are right, and this was also mentioned by reviewer #2. We have added a fair amount of citations throughout the text to be sure to make it clear to the reader that what we base our argument on is well-established in the literature and not our own speculation.

RC: In section “Drivers of marine productivity vary across the Arctic Ocean”: The authors should provide observational evidence when claiming Beaufort Gyre region is “one of most nutrient-depleted regions of the world ocean”.

AR: > Agreed; see also our reply immediately above. MC: > We have now inserted Codispoti et al., 2013, as a reference.

RC: Figure 2: Please mark corresponding transect in Fig 1 left panel. Why not plotting temperature, salinity and density fields in this transect all together so that readers can better interpret Atlantic and Arctic water masses, vertical mixing, thermal or haline stratification? How many CTD profiles were casted along this transect? Please mark the CTD cast locations. What were the wind conditions during this transect sampling? I think wind diagnosis would be critical in answering whether or not vertical mixing was caused by upwelling.

AR: > Fig. 2 (Fig 2, right panel in revised version) is an illustration of what the density field looks like, generically, without consideration of special wind situations. Discussing the specifics of this transect would only distract from the general points we are trying to make: That a) these kinds of cross-slope hydrographical snapshot transects do not tell us anything about whether upwelling was happening or not (and so whether we plotted temperature and salinity should not change the reader’s judgement anyway), and b) that there is no physical reason to expect a dominant signal. Fig. 2, left panel (previously Fig 1 right panel), illustrates the geographical salinity and temperature patterns, thus indicates water masses present at the surface. MC: > We added a sentence to the figure caption to make clear that this is “just” a representative illustration. > The revised figure also includes station markers now and for completeness’ sake bottom bathymetry from IBCAO3 plotted into the transect.

RC: Figure 3: This is not an effective way to illustrate wind patterns. Did black dots repre- sent speeds of east wind component? So only those with 3 m/s or more were showed in the figure? How often were the wind measured? The author stated “only 2% of all summer days through the last 30 years can be considered upwelling-favorable”, but what’s the sample size in total? It didn’t look to me that 30-year wind measurements were included in the analysis given this few data points. To demonstrate seasonal differences in wind patterns and highlight the summer season, a plot of four wind roses that aggregate seasonal wind measurements might be more informative and illustrative.

AR: > Exactly, so the take-home message is that even taking 30 years of wind data only results in so few data points where wind could potentially be upwelling-favourable (*if* the shelf break was shallow enough, see the preceding arguments in our manuscript). A wind rose would not discriminate between short episodes of easterly wind (not sufficiently long to affect Ekman transport) and would hence tend to "overestimate" the occurrence of upwelling-favorable winds.

MC: > We added "[rather low a wind speed and makes for a generous criterion in this regard]; there is no universally accepted measure" to make it clearer to the readers that this methodology is more of a tentative thought experiment, assuming that the wind could drive upwelling in the first place even though the shelf is rather deep in the area in question. The figure caption now also says "assuming the local bathymetry facilitates such upwelling".

RC: In section "Summertime upwelling north of Svalbard?", the argument is unconvincing without showing results from mooring or ship-based hydrographic measurements. Per- sonal communication is not sufficient.

AR: > The argument rests entirely on general physical arguments. The personal communication is just an illustration. MC: > To get our point better across in the manuscript, we inserted "As we have seen, consideration of general physical and geographical patterns alone such as boundary layer physics and wind patterns already leads us to conclude that upwelling should not be expected to feature very prominently on the Barents side of the Arctic. This is not to say that upwelling events cannot ever happen (and indeed, in a system as complex as the Earth, it would be surprising if they would never happen), but no known physical mechanism would suggest a magnitude, frequency or importance similar to what has been found in the Pacific sector. To illustrate our point, let us just mention some upcoming work by A. Renner and collaborators [...]"

RC: In section "Climate Change and the Future of Arctic Marine Productivity", I think another relevant point is the changing phytoplankton abundance and species compo-

sition in response to changing hydrography and nutrients. I would suggest the authors to briefly touch on this point. Two examples are: 1) Li, W. K. W., F. A. McLaughlin, C. Lovejoy, and E. C. Carmack (2009), Smallest algae thrive as the Arctic Ocean freshens, Science, 326, 539; 2) Li, W. K. W., E. C. Carmack, F. A. McLaughlin, R. J. Nelson, and W. J. Williams (2013), Space-for-time substitution in predicting the state of picoplankton and nanoplankton in a changing Arctic Ocean, J. Geophys. Res. Ocean., 118(10), 5750–5759.

AR: > We did not originally include this story about plankton size spectra because our focus has been on the shelf breaks specifically, but we agree that this is important for the large-scale picture. MC: > We have now included them as you suggest; please see last paragraph in the "Climate Change and the Future. . ." section..

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