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Review

Of the *member* of the dissertation council for the dissertation of *Mikhail M. Latonin* on the topic: "Arctic amplification and meridional oceanic and atmospheric heat transports into the Arctic", submitted for the degree of *candidate* of geographical sciences in a scientific speciality 1.6.17. Oceanology

Latonin's thesis is well written and structured. It begins with a concise and clearly description of the motivation, background and key questions addressed. The results are presented in three chapters, with the first two chapters providing the bulk of findings. Key results have been published in three papers and a book chapter. Conclusion is well written and provides some suggestions for future research directions. Together the thesis provides a coherent study of climate change in the Arctic over the historical period and the role of meridional heat transports.

The thesis presents new insights into two key aspects of Arctic Amplification (AA) based on CMIP5 and CMIP experiments, and historical observations and reanalysis.

(1) It is shown that the pronounced warming of the Arctic during the early part of the 20th century (ETCW) is not reproduced by the models, while the most recent warming is. This suggests that internal climate variability contributed greatly to the ETCW. The CMIP6 models do not simulate the ETCW better than the CMIP5, and analysis of the "best" model shows poor agreement in terms of meridional heat transports into the Arctic.

(2) The importance of meridional heat transports into the Arctic through the Atlantic Gateway, on regional warming, and on interannual to decadal timescales is shown. Atmospheric meridional heat transport contributes more to the regional AA than the oceanic meridional heat transport, and it causes changes in the Arctic with around one year lag. The ocean heat transport is found have a limited direct effect on regional AA, despite being larger than atmospheric heat transports. However, the ocean meridional heat transport triggers the changes in atmospheric heat transport, via a Bjerknes Compensation mechanism. The changes occur three years later in atmospheric heat transport, and thus effect AA with a four-year delay in an opposite sense. These variations are found to occur on decadal timescales.

The novelty of the thesis is in the use of the most up to date climate simulations. I believe this is the first comprehensive assessment of historical changes in the Arctic using the CMIP6 experiments. However, in my opinion the most novel aspect of the thesis is to consider meridional heat transports to investigate regional AA, and to present evidence that the Bjerknes Compensation mechanisms is important for regional AA on decadal timescales.

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Although the thesis is of a high standard, I do have several specific concerns related to chapters 1 - 3. In Chapter 1, I agree that CMIP6 models represent further development in climate modelling, but I don't think it is accurate that these models are of higher solution the CMIP5 models. There seem to be subtilties in the computation of AA as shown in figures 1 and 2 and the warming patterns seen in figure 3, as in the former the ETCW seems stronger that the most recent warming, but the spatial map suggests the opposite. Is the low-latitude warming great during the recent period and this offsets changes in the Arctic? What does the negative bias in AA index of the historical experiments with respect to the observations represent? Does this basically reflects that the models fail to capture the ETCW (as anomalies are defined for the period 1960-1990)? I was not entirely convinced by that the comparison of 5 CMIP5 and CMIP6 models could reveal any significant difference, as the model ensemble is too small and internal variability is not supressed in the comparison.

In Chapter 3, there are details related to the computation of energy transports, mechanisms for the 10-15 year oscillation, and Bjerknes compensation that need clarifying. The computation of energy transports in the atmosphere from monthly data is unlikely to be accurate at these latitudes, as synoptic scales are important for energy transports. The computation and interpretation of heat transports computed through the restricted Atlantic Gateway also leads to some counter intuitive results. It gives the impression that the ocean transports much more heat poleward than the atmosphere (13 times, pg 56). However, it is well known that at this latitude the atmosphere transports more heat than the ocean (~2 versus 0.5 PW, e.g., Hartmann, textbook on physical climatology), when integrating around all longitudes. Do values of almost 10 PW in the ocean by the Norwegian current make sense? In my view the effective heating as determined by the temperature difference between incoming water and existing water is more important. How do these details in computing heat transports (using monthly data and regional atmospheric domain) effect the key findings?

Apart from this, the mechanisms for the 10-15 year oscillation are hard to follow. In particular, (section 2.5) why do you expect an index for the Arctic Ocean circulation to be related to the heat transport further south in the Norwegian seas? Are you implying an atmospheric response that drives the Arctic Ocean Circulation? Also, the relation between heat transport in the Norwegian Current and the AOO is not stationary? Why is this? Does it suggest there is little relation between the two? Furthermore, while the Bjerknes Compensation hypothesis is highly interesting, can we really expect localised compensation, and what determines the regions over which such a localised compensation would occur? In this thesis two different regions are chosen for atmosphere and ocean. The physical reasoning for this should be better explained. Also, is it expected that the ocean has fluctuations of much larger magnitude than the atmosphere? Why should there be a compensation at high-latitudes if the ocean heat is actually accumulated rather than released to the atmosphere as the Atlantic Water flows below the surface in the Arctic.

An important question is to what extent is the regional AA useful for understanding the entire AA? What is the relation between the two? Comparing Figure 20 with Figure 2 suggests that there is little relation. Chapter 3 provides further analysis to better understand meridional heat transport to the Arctic. They show key differences in eastern hemisphere and western hemisphere for sensible versus latent heat fluxes, but how these relate to AA (and previous chapters) is not made very clear. As a minor comment, I don't see the benefit

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of the EOF analysis, the definition for eastern and western hemispheres is easier to follow based on the meridional.

Despite these concerns, I am more than satisfied with that the thesis is of a high standard and introduces key new insights on climate change in the Arctic.

Dissertation of *Mikhail M. Latonin* on the topic: "Arctic amplification and meridional oceanic and atmospheric heat transports into the Arctic" *meets* the basic requirements established by Order No.11181/1 dd. 19.11.2021 "On the procedure for awarding academic degrees at St. Petersburg State University". The applicant *Mikhail M. Latonin deserves* to be awarded the academic degree of *candidate* of geographical sciences in a scientific speciality 1.6.17. Oceanology. Paragraphs 9 and 11 of the specified Order have not been violated.

Member of the Dissertation Council

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24.05.2022

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