Arctic Warming - A New Positive Feedback?

Arctic Amplification in the Barents Sea: Evaluation of an Ice-Ocean-Atmosphere Feedback in a Coupled Climate Model

T. Kanzow, F. Heukamp, C.Wekerle, Q. Wang, D. Sidorenko, *Alfred-Wegener-Institute: Helmholtz Center for Polar and Marine Research*

In Short

- A local atmosphere-ice-ocean feedback in the Barents Sea potentially affecting Arctic Amplification is investigated in a climate model
- Retreating sea-ice in the Barents Sea due to global warming modifies the heat exchange between ocean and atmosphere
- Observations and reanalysis show a decrease in air pressure accompanied with the ice retreat due to the enhanced ocean heat loss
- The resulting cyclonic wind anomaly could increase the warm Atlantic Water transport into the Barents Sea providing additional heat for further ice melt, closing the feedback

The ongoing warming of the Arctic during the last decades is unprecedented and approx. twice as strong as the global average, resulting in enormous changes in the ocean, atmo-/ cryo-/ and biosphere. Despite the large efforts being made in the scientific community, the strong warming known as 'Arctic Amplification' is not yet fully understood. It is assumed that undiscovered local, positive feedback mechanisms contribute to the strong warming of the Arctic.

One of the fastest changing environments in the Arctic is the Barents Sea (BS), located north of Norway between Svalbard, Franz Josef Land and Novaya Zemlja. Although covering only about 10% (1.4 million km^2) of the Arctic Ocean, the BS occupies a key position in the meridional ocean heat transport towards the Arctic Ocean as well as in the heat exchange between the atmosphere, ocean and sea-ice [1]. As part of the upper limb of the Atlantic Meridional Overturning Circulation (AMOC) warm and saline Atlantic Water (AW) enters the BS via the Norwegian Atlantic Current. In comparison to the second AW branch entering the Arctic Ocean via the deep Fram Strait, the shallow BS facilitates mixing, thus exposing the AW very efficiently to the icy atmosphere resulting in large ocean-atmosphere winter heat fluxes. Hence, on its pathway through the BS the AW releases almost all of its heat (76 TW [1]) before being insulated from atmosphere and ice interactions by the Cold Arctic Halocline (CAH), a layer of cold and fresh surface water below the ice. Due to its extraordinary role in the exchange of heat the BS is considered the 'cooling machine' of the Arctic [2]. Besides atmospheric variability the AW heat transport mainly controls the location of the BS sea-ice edge in winter which in turn is crucial for the ocean heat loss [3]. In accordance to the general warming of the oceans the BS has been experiencing a warming of the AW accompanied by a retreat in winter sea-ice cover of approx. 50% compared to pre-industrial conditions. The retreat of BS winter sea-ice is suggested to effect both, remote and local atmospheric circulation patterns. Focusing on local effects, a series of well established single cause and effects in the coupled ocean-atmosphere-ice system involving ocean heat transport, sea-ice cover, heat fluxes and atmospheric circulation changes may as a whole form a positive feedback mechanism. An initial positive perturbation in the AW heat transport towards the BS leads to a warmer BS, which requires more cooling before it reaches the freezing point, such that less winter sea-ice is formed, and there is a larger temperature contrast between the cold air and the warm ocean. As a consequence, there is increased net surface heat loss from the ocean to the atmosphere. The increased surface heat loss warms the lower atmosphere and leads to a local reduction in surface pressure [1]. The resulting cyclonic circulation anomaly produces strong westerly winds over the BSO that fosters additional AW transport into the BS, closing the positive feedback loop. Traces of this feedback mechanism are already found in recent changes in the BS winter mean state in various parameters. These changes are especially dominant when computing the difference in average winter (Dec - May) parameters (sea-ice concentration, surface air temperature, sea level pressure) from the 1979 to 1999 and 2000 to 2018 eras (Figure 1). The decreasing sea-ice concentration by up to 50% in the northern and especially north-eastern BS is accompanied by a strong increase in 2m air temperature, most pronounced just above the area where the ice loss is largest. We attribute the rise in 2m air temperature to the enhanced exposure of the warm AW to the atmosphere and increased heat loss in this area that was ice-covered and thus cold and well insulated before. Spatially consistent with

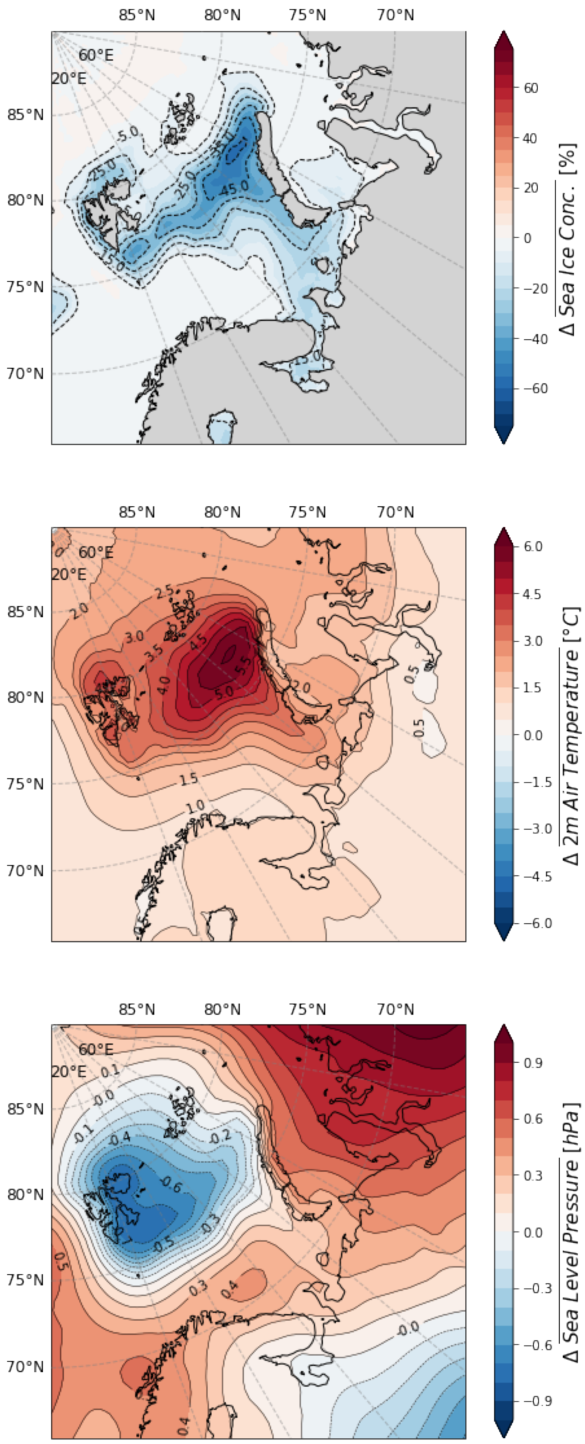

Figure 1: Differences in sea-ice concentration (top), 2m air temperature (center) and sea level pressure (bottom) for the mean Dec-May fields between 2000 â 2018 and 1979 to 1999; sea-ice data from NSIDC, temperature and sea level pressure from JRA55-do-v1.4.0 reanalysis; negative values indicate a decrease of the parameter in the 2000 to 2018 era.

the sea-ice and temperature anomalies a negative sea level pressure anomaly is found in various reanalysis data-sets (JRA55, ERAint, ERA5, NCEP) which is consistent with the proposed feedback. The shape and location of the sea level pressure anomaly results in an anomalous cyclonic wind field over the BS and results in a meridional air pressure gradient across the BS Opening (BSO) from Norway to Spitsbergen leading to an increase in westerly winds. We consider these changes in the mean state of the BS as strong evidence for the existence of the positive feedback mechanism which motivates further research.

In this project we plan to investigate this specific feedback mechanism in the coupled climate system of the Arctic, in particular the BS, to asses its impact on Arctic Amplification. In order to achieve this, we plan to perform global simulations of the coupled climate system with the latest release of the 'Alfred-Wegener-Institute Climate Model' (AWI-CM3), a state-of-the-art full blown climate model. The simulations will include (**I**) spinup and tuning experiments to prepare the coupled model configurations for the planned experiments, (**II**) reference simulations and fully coupled perturbation experiments in which local anomalous cyclonic wind fields are added to assess the impact of local winds on the BS heat budget and atmosphere-ice-ocean interactions as well as (**III**) partially coupled simulations with prescribed climatological wind stress and cyclonic wind anomalies over the BS following the 'Modini-method' [4]. In this way, cause and effect chains can even be identified in feedback loops.

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More Information

[1] L. Smedsrud et al. *Reviews of Geophysics* **51 (3)**, 415-449 (2013).

[2] O. Skagseth et al. *Nature Climate Change* **10 (7)**, 661-666 (2020).

[3] V. Lien et al. *Journal of Climate* **30 (2)**, 803-812 (2017).

[4] M. Thoma et al. *Geoscientific Model Development* **8 (1)**, 51-68 (2015).

Project Partners

AWI Bremerhaven: Physical Oceanography of the Polar Seas, Climate Dynamics, Sea-Ice Physics

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