Warm Arctic – Cold Continents: A reconsideration allowing for ozone feedbacks

Evaluation of the stratospheric pathway of the Arctic-midlatitude linkage with the Chemistry Climate Model EMAC

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In Short

- The Arctic region is undergoing an enhanced warming since two decades, but more cold weather extremes in winter occured over the continents.
- Does the Arctic warming can have a remote impact on the circulation in midlatitudes?
- We address this question with a Chemistry Climate Model and put emphasis on the role of the stratosphere and ozone feedbacks.

The continuously rising greenhouse gas (GHG) emissions are known to force a warming of the earth's atmosphere almost worldwide. In that respect, the Arctic region stands out because an accelerated warming has been observed accompanied by a dramatic sea ice decline. The average warming in the Arctic is about twice as high as for the rest of the globe. This phenomenon is known as Arctic Amplification (AA). On the contrary, the winter land temperatures in the Northern Hemisphere (NH), especially over eastern Eurasia, do not show a warming or even tend to have more cold weather extremes in winter [1]. These opposing trends since the 1990s raised the question whether the accelerated warming in the Arctic can have a remote impact on the circulation in the NH and the winter weather in midlatitudes.

Early studies focused on tropospheric processes regarding the changes in storm tracks mainly in the North Atlantic sector and changes in the characteristics in the jet stream. However, given the many still unresolved questions of the AA-midlatitude linkage, the role of the stratosphere recently attracted more and more attention [2]. A schematic of possible responses of AA is given in Figure [1]. Accounting for the stratospheric pathway in model studies we need a realistic presentation of the stratosphere. In particular, a model top at least in the mesosphere is required and stratospheric features such as the quasi-biennial oscillation (QBO) and ozone should be represented.

Ozone concentrations can be calculated by models with interactive chemistry but this is computationally demanding. On the other hand, a set of ensemble simulations is required to attribute a circulation anomaly to Arctic sea ice change, because the signal is very weak compared to the internal variability. A lively debate about the existence of the proposed connection is still ongoing in the scientific community. The question arises whether the diverging results of the numerous model studies in the past result from a missing or incorrect representation of physical processes in the models [3]. So far, a comprehensive study of the stratospheric pathway of the Arctic-midlatitude linkage has not been performed with a chemistry-climate model (CCM) including interactive chemistry. Against this background, this project is focused on the questions:

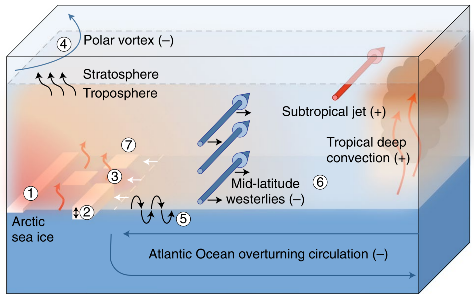

Figure 1: *Schematic representation of the potential climate response to Arctic sea-ice loss from [3]. An illustrative cross-section from the North Pole to the Equator. Major atmospheric and oceanic circulation features that are weakened by Arctic sea-ice loss are shown by blue arrows and labelled with minus signs, and those that are strengthened by Arctic sea-ice loss are shown by red arrows and labelled with plus signs. Red/orange shading indicates regions of greatest warming in response to sea-ice loss. Circled numbers indicate sources of disagreement in model experiments (see [3] for more details). Not drawn to scale.*

1. How important is the integration of ozone chemistry in model studies? May neglecting important stratospheric processes have led to the controversial results in the past?
2. Can the observed anomaly of the midlatitude circulation be considered as a significant response to the AA or just internal variability?

The aim of this project is to obtain an improved understanding of key stratospheric dynamical processes in the Arctic-midlatitude linkages. Emphasis will be put on the mechanisms underlying the stratospheric pathway and how interactive stratospheric ozone chemistry may impact the identified mechanisms.

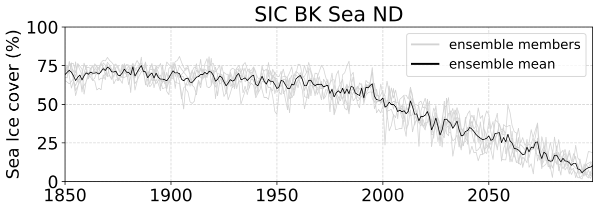

Figure 2: Seasonal mean (November, December) of the Sea Ice Cover in the Barents-Kara sea from 1850 to 2099 . Grey lines show the six individual ensemble members and the black line the ensemble mean.

A set of six ensemble simulations from 1850 to 2100 with a more compact interactive chemistry configuration have been performed with EMAC. This enables us to assess the evolution of Arctic sea ice, cold winter extremes and circulation anomalies in the stratosphere. As illustrated in Figure [2], the sea ice cover (SIC) in the Barents-Kara sea (BKS) is slowly declining since the middle of the 20th century with an acceleration of the sea ice reduction since 2000. On average, the SIC in the Barents-Kara sea is 70% in the pre-industrial period compared to 10% at the end of the 21th century. For the observational period, the values are in good agreement and we therefore assume that the simulation of the sea ice loss is adequate in EMAC.

The next step of our model evaluation was to examine the simulated conditions in the stratosphere. A strong low pressure regime in the winter polar stratosphere, namely the polar vortex, and its disturbances are the central point of the stratospheric pathway (see Figure [1]). These disturbances or sudden stratospheric warmings (SSWs) are driven by an enhanced planetary wave activity possibly strengthened by the Arctic Amplification. We calculate the occurrence of SSWs following the WMO classification for every winter (November to March) for all ensemble simulations. Figures [3] shows an overview of all transient simulations. The averaged occurrence of SSWs per decade is approximately 0.5 which fits very well with observations. In some ensemble runs the SSW frequency increases towards the end of the century. This would be expected, if we assume an intensification of wave activity through the Arctic Amplification. However, the AA is just one factor potentially influencing the circulation in the stratosphere among others. We are planning to further analyse this topic and extend our research with time slice simulations to gain statistical insights.

A potential source of planetary waves are large-scale blocking highs over the Ural region. There are divergent opinions regarding the cause and effect of the interaction between Arctic sea ice, Ural Blocking and SSWs. One part of the community supports the thesis that the AA can trigger Ural blocking events and others suggest that the Ural blocking itself causes the melting of the sea ice. We could find a significant increase in Ural Blocking Events in autumn in our transient simulations (not shown). In that respect, we are planning further time slice simulations for the past, the present and the future. The repetitive simulation of certain years should be applied to untangle a possible effect of sea ice from interannual variability.

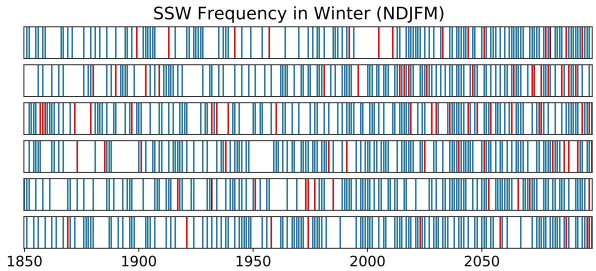

Figure 3: Frequency of SSWs in winter (from November to March) in six transient ensemble EMAC simulations. Blue lines indicate one SSW per winter, red lines indicate two and dark red lines three SSWs per winter.

There is much controversy about the relation of the AA and midlatitude weather and we intend to contribute with more insights specifically regarding the ozone feedback.

WWW

https://www.geo.fu-berlin.de/met/

More Information

[1] Cohen, J., Screen, J., Furtado, J. et al. (2014). Recent Arctic amplification and extreme mid-latitude weather. *Nature Geoscience* **7**, 627–637. doi:10.1038/ngeo2234

[2] Cohen, J., Zhang, X., Francis, J. et al. (2020). Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10**, 20–29. doi: 10.1038/s41558-019-0662-y

[3] Screen, J.A., Deser, C., Smith, D.M. et al. (2018). Consistency and discrepancy in the atmospheric response to Arctic sea-ice loss across climate models. *Nature Geosciience* **11**, 155–163. doi:10.1038/s41561-018-0059-y

Project Partners

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