REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE: Denmark

Principal Investigator[1]**:** Chongyang Zhang

Affiliation: Department of Environmental Science, Aarhus University

Address:
Frederiksborgvej 399
4000 Roskilde
Denmark

Other researchers:
Peter Lang Langen (Aarhus University)

Shuting YANG (Danish Meteorological Institute)

Project Title: The anatomy of Arctic impact on European climate change

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ………….	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	18 M	12 M	-
Accumulated data storage (total archive volume)[2]	[GB]	31,200	62400	-

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 5,000,000 SBU should be more detailed (3-5 pages).

Summary

Recent reviews (Cohen et al. 2020; AMAP 2021) conclude that there is still no consensus on how and how much Arctic warming influences mid-latitude weather, due to the relatively low signal-to-noise ratio and a potential background state-dependence of the Arctic–midlatitude connection. The goal of this project is to identify the conditions under which Arctic–lower-latitude atmospheric interactions may drive climate extremes in Europe, and to assess the robustness of such interactions, by conducting several sensitivity experiments, based on EC-Earth3 climate model, a state-of-the-art, fully coupled Earth System Model. The requested high-performance computing (HPC) resources are essential for executing this ambitious modeling strategy.

Background state-dependent Arctic–midlatitude connections

The Arctic is warming three to four times faster than the global average (AMAP 2021; Rantanen et al. 2022), with far-reaching local and global impacts. On the one hand, it strongly affects the regional Arctic climate and the loss of ice masses contributing to global sea-level rise (IPCC 2021). On the other hand, Arctic warming is hypothesized to influence jet-stream behavior and weather patterns further south, thereby affecting temperature and precipitation extremes across North America, Europe, and Asia (e.g., Francis and Vavrus 2012). Multiple studies suggest that Arctic change—particularly sea ice loss—may influence mid-latitude weather (e.g., Yang and Christensen 2012; Sun et al. 2015; Screen 2017; Screen et al. 2018; Zhang et al. 2018; Ringgaard et al. 2020; Heo et al. 2022).

However, recent reviews (Cohen et al. 2020; AMAP 2021) highlight the absence of consensus on the pathway and magnitude of Arctic influence on mid-latitude weather. Moreover, Arctic–lower-latitude coupling appears to operate in both directions, with controversies arising partly from differences in statistical tools, modeling methodologies, and diagnostic frameworks (Screen and Simmonds 2013; Vihma 2014; Blackport and Kushner 2017; Cohen et al. 2020; Taylor et al. 2022).

The choice of metric or diagnostic framework has a substantial impact on whether a link is detected. The relatively low signal-to-noise ratio means that mid-latitude events or trends may spuriously appear to be caused by Arctic changes, due to random co-occurrence (McCusker et al. 2016; Siew et al. 2021) or due to large-scale circulation patterns that influence both regions simultaneously (Blackport et al. 2019). Internal climate variability modes—such as the Atlantic Multidecadal Oscillation (Osborne et al. 2017) and the Pacific Decadal Oscillation (Screen and Francis 2016)—also modulate Arctic–midlatitude communication. Blocking patterns, especially over the Urals, have been shown to affect the existence of these links (Siew et al. 2020), and strong seasonal dependence has been documented as well (e.g., Petrie et al. 2015).

Together, these findings suggest that specific mid-latitude atmospheric conditions and jet-stream configurations are required for southward communication of Arctic signals. Here, the conditioning should be seen as the background climate, in terms of the sea surface temperatures and large-scale atmospheric wind patterns. Only when these patterns align appropriately can Arctic changes establish atmospheric linkages. Whether such conditioning is a prerequisite, and how robust these relationships remain in a warming climate, remains poorly understood. Accordingly, we propose the guiding hypothesis that the strength of Arctic-to-lower-latitude connections depends on the short-term surface state.

Large-ensemble sensitivity experiments with EC-Earth3

We have previously demonstrated that the impact of Arctic sea ice on European winters is associated with the Arctic Oscillation (Yang and Christensen 2012), and analyses indicate that certain North Atlantic temperature patterns may favor Arctic–Europe communication. This is reminiscent of the findings of Osborne et al. (2017) and suggests that signal-to-noise-ratios are increased by mid-latitude conditioning.

Building on these preliminary analyses and previous research, this project will conduct a series of model experiments to investigate the causal relationship between Arctic change and mid-latitude weather—particularly over Europe—by analyzing atmospheric responses to Arctic sea ice loss or warming under different background atmospheric conditions. EC-Earth3 will be used in a suite of progressively complex experiments. The core design includes four sets of simulations combining two contrasting (in-phase) atmospheric background states with both high and low Arctic sea ice forcing. To maintain these background states, nudging will be applied primarily to the large-scale atmospheric structure (e.g., warmer climate, different NAO phase).

Because of the controversial nature of Arctic–midlatitude linkages and the inherently low signal-to-noise ratio, a large ensemble is required to detect robust signals. In each group of sensitivity experiment, multiple realizations will be necessary to isolate the causal effects of Arctic forcing from internal variability. Each ensemble member will be integrated 6-month control simulation (November–April), using different initial conditions taken from a freely integrated control simulation.

The difference between composite responses under high vs. low sea ice forcing for a given atmospheric background will isolate the atmospheric response to sea ice forcing under that particular regime (e.g., warmer climate, different NAO phase). Comparing these contrasts across two opposite background states will reveal how the background modulates the atmospheric response to sea ice forcing.

The requested HPC resources are crucial for executing this modeling strategy. EC-Earth3 (Döscher et al. 2022)—a fully coupled model including atmosphere (IFS cycle 36r4 or later), ocean (NEMO3.6), sea ice (LIM3), and land surface (LPJ-GUESS, HTESSEL)—is central to this project. A key technical component is the exploitation of EC-Earth3's nudging capability to relax simulated atmospheric state toward observed or predefined patterns in a specific region, allowing isolation of atmospheric responses to targeted sea ice boundary conditions—an innovation in this context.

Computationally demanding project design

1. A 300-year free control run under fixed forcing with a seasonal cycle, to assess the model's ability to simulate climate variability modes and to supply initial conditions for sensitivity experiments.

2. High and low Arctic sea ice forcing experiments to evaluate atmospheric responses and compare with observations, identifying surface temperature and SLP patterns influencing atmospheric sensitivity to Arctic changes.

3. Four groups of sensitivity experiments under two contrasting atmospheric background states (e.g., warmer climate, different NAO phase), with nudging to guide the atmosphere toward target states that either favor or suppress Arctic–midlatitude linkages, combining high/low Arctic sea ice forcing.

4. Experiments with nudged climatological atmospheric backgrounds, applying the same high/low sea ice forcing. Comparison with the above sensitivity experiments allows isolation of the atmospheric response under specific background conditions, independent of nudging methodology itself.

Additionally, sensitivity tests assessing linkage robustness under (i) different background climates and (ii) various model physics parameterizations may also be conducted.

The specific numbers are summarized in Table 1 below.

Year	Experiment	SBU/year	Total years	Total SBU
2026	300-year free control run; high and low Arctic ice forcing experiments (300 ensemble members each); High and low Arctic ice forcing with climatological background nudging experiments (300 ensemble members each)	20000	900 (300 continuous years for the control run; 0.5 years for each ensemble in the sensitivity run)	18M
2027	High and low Arctic ice forcing under two distinct background-state conditions/ forcings (e.g., warmer world, different NAO phase), 300 ensemble members each	20000	600 (0.5 years for each ensemble member)	12M
Total SBU				30M
Total storage GB (with clean up underway)				62400

Table 1: Estimated resources needed for our experiments.

Success Criteria

The project will be successful upon the characterization of the non-Arctic conditioning required for Arctic impacts on European climate and an assessment of its robustness under future climate change and across model configurations, culminating in a peer-reviewed publication.

References

AMAP, 2021: Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policymakers. Arctic Monitoring and Assessment Programme (AMAP), Troms, Norway. 16 pp.

Blackport, R., and P. J. Kushner, 2017: Isolating the Atmospheric Circulation Response to Arctic Sea Ice Loss in the Coupled Climate System. J. Clim., 30, 2163–2185, https://doi.org/10.1175/JCLI-D-16-0257.1.

Blackport, R., J. A. Screen, K. van der Wiel, and R. Bintanja, 2019: Minimal influence of reduced Arctic sea ice on coincident cold winters in mid-latitudes. Nat. Clim. Change, 9, 697–704, https://doi.org/10.1038/s41558-019-0551-4.

Cohen, J., and Coauthors, 2020: Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. Nat. Clim. Change, 10, 20–29, https://doi.org/10.1038/s41558-019-0662-y.

Döcher, R., and Coauthors, 2022: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6. Geosci. Model Dev., 15, 2973–3020, https://doi.org/10.5194/gmd- 15-2973-2022.

Francis, J. A., and S. J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophys. Res. Lett., 39, https://doi.org/10.1029/2012GL051000.

Heo, E.-S., S.-I. An, I. M. Ringgaard, S. Yang, J. H. Christensen, and M.-K. Sung, 2022: Influence of retreating Barents–Kara sea ice on the periodicity of El Nino–Southern Oscillation. Int. J. Climatol., 42, 4881–4892, https://doi.org/10.1002/joc.7509.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson- Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekci, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

McCusker, K. E., J. C. Fyfe, and M. Sigmond, 2016: Twenty-five winters of unexpected Eurasian cooling unlikely due to Arctic sea-ice loss. Nat. Geosci., 9, 838–842, https://doi.org/10.1038/ngeo2820.

Osborne, J. M., J. A. Screen, and M. Collins, 2017: Ocean–Atmosphere State Dependence of the Atmospheric Response to Arctic Sea Ice Loss. J. Clim., 30, 1537–1552, https://doi.org/10.1175/JCLI-D-16-0531.1.

Petrie, R. E., L. C. Shaffrey, and R. T. Sutton, 2015: Atmospheric Impact of Arctic Sea Ice Loss in a Coupled Ocean–Atmosphere Simulation. J. Clim., 28, 9606–9622, https://doi.org/10.1175/JCLI-D-15-0316.1.

Rantanen, M., A. Yu. Karpechko, A. Lipponen, K. Nordling, O. Hyvarinen, K. Ruosteenoja, T. Vihma, and A. Laaksonen, 2022: The Arctic has warmed nearly four times faster than the globe since 1979. Commun. Earth Environ., 3, 168, https://doi.org/10.1038/s43247-022- 00498-3.

Ringgaard, I., S. Yang, E. Kaas, and J. Christensen, 2020: Barents-Kara sea ice and European winters in EC-Earth. Clim. Dyn., https://doi.org/10.1007/s00382-020-05174-w.

Screen, J., and J. Francis, 2016: Contribution of sea-ice loss to Arctic amplification is regulated by Pacific Ocean decadal variability. Nat. Clim. Change, 6, https://doi.org/10.1038/nclimate3011.

Screen, J. A., 2017: Simulated Atmospheric Response to Regional and Pan-Arctic Sea Ice Loss. J. Clim., 30, 3945–3962, https://doi.org/10.1175/JCLI-D-16-0197.1.

Screen, J. A., and I. Simmonds, 2013: Exploring links between Arctic amplification and midlatitude weather. Geophys. Res. Lett., 40, 959–964, https://doi.org/10.1002/grl.50174.

Screen, J. A., and Coauthors, 2018: Consistency and discrepancy in the atmospheric response to Arctic sea-ice loss across climate models. Nat. Geosci., 11, 155–163, https://doi.org/10.1038/s41561-018-0059-y.

Siew, P. Y. F., C. Li, M. Ting, S. P. Sobolowski, Y. Wu, and X. Chen, 2021: North Atlantic Oscillation in winter is largely insensitive to autumn Barents-Kara sea ice variability. Sci. Adv., 7, eabg4893, https://doi.org/10.1126/sciadv.abg4893

Siew, P. Y. F., C. Li, S. P. Sobolowski, and M. P. King, 2020: Intermittency of Arctic–mid-latitude teleconnections: stratospheric pathway between autumn sea ice and the winter North Atlantic Oscillation. Weather Clim Dynam, 1, 261–275, https://doi.org/10.5194/wcd-1-261-2020.

Sun, L., C. Deser, and R. A. Tomas, 2015: Mechanisms of Stratospheric and Tropospheric Circulation Response to Projected Arctic Sea Ice Loss*. J. Clim., 28, 7824–7845, https://doi.org/10.1175/JCLI-D-15-0169.1.

Taylor, P. C., and Coauthors, 2022: Process Drivers, Inter-Model Spread, and the Path Forward: A Review of Amplified Arctic Warming. Front. Earth Sci., 9.

Vihma, T., 2014: Effects of Arctic Sea Ice Decline on Weather and Climate: A Review. Surv. Geophys., 35, 1175–1214, https://doi.org/10.1007/s10712-014-9284-0.

Yang, S., and J. H. Christensen, 2012: Arctic sea ice reduction and European cold winters in CMIP5 climate change experiments. Geophys. Res. Lett., 39, https://doi.org/10.1029/2012GL053338.

Zhang, P., Y. Wu, and K. L. Smith, 2018: Prolonged effect of the stratospheric pathway in linking Barents–Kara Sea sea ice variability to the midlatitude circulation in a simplified model. Clim. Dyn., 50, 527–539, https://doi.org/10.1007/s00382-017-3624-y.