Report

Project: **1398**

Project title: **OceanWeather**

Principal investigator: **Wolfgang Mueller**

Report period: **2025-11-01 to 2026-10-31**

Scientific background and experimental setup of the sensitivity experiment

The North Atlantic Ocean has been found to be a key factor for the development of European heat events (*e.g. Krüger et al. 2023, 2026)*. Further, it has been shown that particularly subdecadal variability (SDV) can modulate the downstream atmospheric development towards influencing the European summer climate (*Müller et al. 2020, Wallberg et al. 2024*). Therefore, we aim to investigate the role of the subdecadal variability in the Gulf Stream and extension region on the atmospheric circulation in more detail by performing a sensitivity study. One approach to evaluate how the atmospheric circulation responds to this enhanced SDV variability is the measure of Warm Conveyor Belt (WCB) activity as an outcome of a neural-network based diagnostic (Quinting and Grams, 2021). In addition to SDV, WCB activity has also been found to be a precursor of past European heat waves (*Rousi et al. 2023*). In this setup, we are now able to assess whether SDV and WCB activity synergistically influence the European summer climate by modifying the European blocking frequency and associated heat extremes.

We have conducted two historical ICON XPP atmosphere-only simulations with a 40km horizontal resolution from 1870 to 2014 using prescribed sea surface temperatures (SSTs). The *standard experiment (juk0015)* includes unchanged SST forcing, whereas the *forced experiment (juk0016)* includes SST forcing with enhanced SDV (5-10 year bandpass filter applied) by a factor of 4 confined to the subtropical North Atlantic (Fig. 1). The boundaries include a reduced amplification of factor 3 and 2 towards the surrounding regions in order to avoid introducing artificial gradients at the boundaries through this amplification method. The standard experiment has already been finished in the 2025 allocation period. The forced experiment has been finished in the current allocation period of 2026.

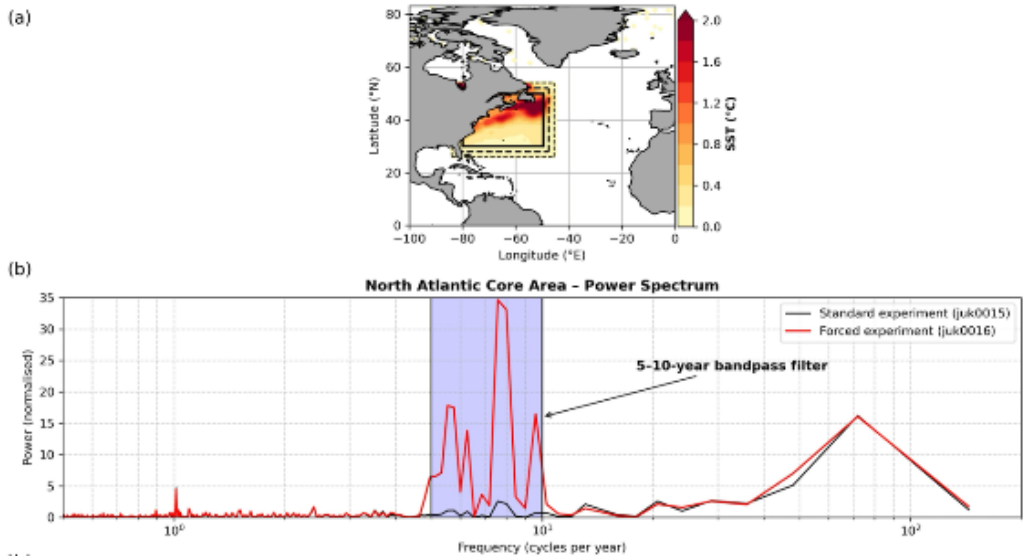


Fig. 1: *(a) Map, (b) power spectrum showing the difference of SST variability between standard experiment and forced experiment. The standard experiment uses historical CMIP prescribed SSTs. The forced experiment includes 4x amplified SDV in the North Atlantic (50-80°W, 30-50°N).*

Results

By performing a composite study of positive and negative SDV phases, we are able to detect differences in the SDV between both experiments. The forced experiment reveals enhanced surface temperature and specific humidity variability as response of enhanced SST variability (Fig. 2). The increase of the surface temperature and the supply of lower-tropospheric moisture enables intensified vertical lifting of warm and moist surface air masses, which promotes diabatic heating in the upper troposphere, and explains the enhanced WCB outflow. Further analysis has revealed that the SDV varies in amplitude throughout the period of 1871-2014. The SDV amplitude given by the SST anomaly averaged over the subtropical domain is stronger in the period of 1910 to 1970 (not shown). As a response, the

atmospheric variables as well as the WCB activity respond by indicating an enhanced variability in this period as well. Therefore, we will confine the analysis to this time frame. Since WCB outflow can induce downstream European blocking, we also analyzed the European blocking frequency differences between the two experiments. The European blocking frequency appears with a higher occurrence in the forced experiment, very likely as a response to the enhanced WCB outflow signal (not shown). The results are part of a manuscript that is currently in preparation for submission to the *Quarterly Journal of the Royal Meteorological Society*.

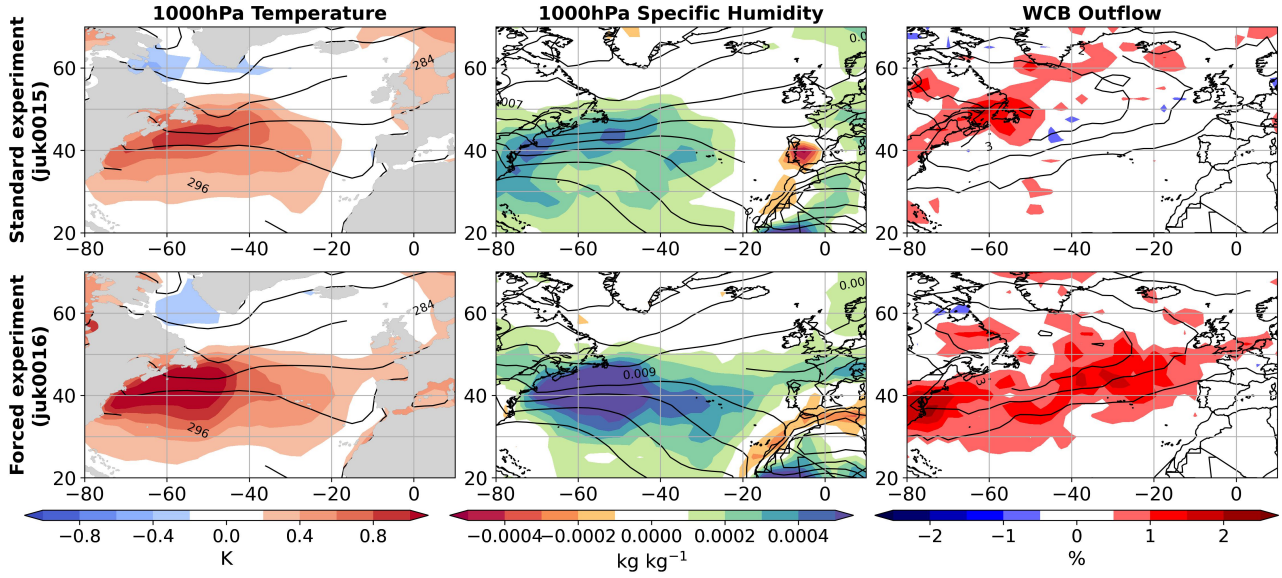


***Fig. 2**: Composite mean difference of daily summer (JJA) values between positive and negative SDV phases. 20 years of positive and 19 years of negative SDV phases are determined based on the standard deviation of the standard experiment, after removing 20-year running mean and the linear trend. Black contours denote the respective JJA mean climatologies.*

Current state (sensitivity experiment, higher atmosphere resolution)

While preparing this manuscript, a new experiment (*juk0017)* is underway. It mirrors the reference experiment, but with an increased atmospheric resolution (13 km, up from 40 km). In this way, we are able to diagnose the resolution dependence of the response of the atmospheric processes such as the Warm Conveyor Belt activity and European blocking to the underlying SST conditions. This approach is motivated by a previous study, which has shown that a higher horizontal resolution in the atmospheric model component allows for a strengthened vertical signal propagation across the atmospheric model levels (Wills et al. 2024). According to these findings, our working hypothesis is an enhanced communication between the SST signal and upper-tropospheric WCB outflow signal after increasing the atmospheric resolution from 40km to a weather-front resolving 13km resolution.

In the past months, we are experiencing quite long queue periods at Levante, which have led to some expired resources in the past quarters, unfortunately. The ongoing experiment (*juk0017)* has currently reached the year 1904 within its 1870–2014 simulation period, representing 24% completion. We allocate the remaining resources of the current allocation period of 2026 exclusively to this experiment.

References

- Krüger, J, Kjellsson, J, Kedzierski, RP and Claus, M. (2023). Connecting North Atlantic SST Variability to European Heat Events over the Past Decades. Tellus A: Dynamic Meteorology and Oceanography, 75(1): 358–374. doi.org/10.16993/tellusa.3235.
- Krüger, J., Kjellsson, J., Lohmann, K., , Matei, D., Kedzierski, RP (2026). Improved European heat event simulation in eddy-resolving climate models. Commun Earth Environ 7, 123. doi.org/10.1038/s43247-025-03145-9.
- Müller, W. A., Borchert, L., & Ghosh, R. (2020). Observed subdecadal variations of European summer temperatures. Geophysical Research Letters, 47, e2019GL086043. doi.org/10.1029/2019GL086043.
- Quinting, J. F. and Grams, C. M (2021): Toward a Systematic Evaluation of Warm Conveyor Belts in Numerical Weather Prediction and Climate Models. Part I: Predictor Selection and Logistic Regression Model. J. Atmos. Sci., 78, 1465–1485. doi.org/10.1175/JAS-D-20-0139.1.
- Rousi, E.,and Co-Authors (2023): The extremely hot and dry 2018 summer in central and northern Europe from a multi-faceted weather and climate perspective, Nat. Hazards Earth Syst. Sci., 23, 1699–1718. doi.org/10.5194/nhess-23-1699-2023.
- Wallberg, L., Suarez-Gutierrez, L., Matei, D., and Müller, W. A. (2024): Extremely warm European summers preceded by sub-decadal North Atlantic ocean heat accumulation, Earth Syst. Dynam., 15, 1–14. doi.org/10.5194/esd-15-1-2024.
- Wills, R. C. J., Herrington, A. R., Simpson, I. R., & Battisti, D. S. (2024). Resolving weather fronts increases the large-scale circulation response to Gulf Stream SST anomalies in variable-resolution CESM2 simulations. Journal of Advances in Modeling Earth Systems, 16, e2023MS004123. https://doi.org/10.1029/2023MS004123