Project: 519

Project title: Evaluation of the effects of extreme solar/volcanic activities in past and future climates

Principal investigators: Sebastian Wahl (PI), Wenjuan Huo

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Preface

The work of the former Helmholtz-University Young Investigators Group NATHAN (2009-2015) has been continued within the national BMBF-ROMIC SOLIC project (Quantification of Uncertainties of SOLar Induced Climate variability) until 2017, the BMBF project “Solar contribution to climate change on decadal to centennial timescales (SOLCHECK) until 2023, and since 2025 via the externally reviewed Helmholtz Innopool project: SOLar and Volcanic Fingerprints in Past and Future Climates (SOLVe, 2025-2027).

Results

In our previous report, we described a sea ice bias in the CMIP6 historical-like simulations performed with our FOCI model, characterized by an underestimation of Antarctic sea ice cover relative to observations (black dashed and blue line in Figure 1). This bias is of particular concern for the simulations planned within our SOLVe project because of the important role of sea ice climate feedbacks, especially in shaping the regional climate response. We therefore devoted substantial effort to reducing the bias. Following extensive debugging and diagnostic analyses, we found that increasing the atmosphere-ocean coupling frequency to one hour can substantially reduce the sea ice bias. After conducting a spin-up simulation with the updated model version (FOCI3.0 hereafter), we performed a CMIP6 historical simulation to assess the model’s stability and its ability to represent key climate processes. Although FOCI3.0 still exhibits a negative bias in total Antarctic sea ice cover (Figure 1), its seasonal cycle is comparable to the multi-model mean of CMIP6 models reported by Roach et al. (2020).

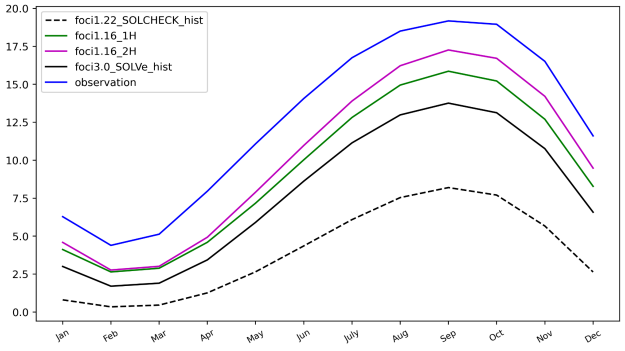


Figure 1. *Seasonal cycle of sea ice cover (10^{12} m²) averaged over the Southern Hemisphere, based on different FOCI versions and simulations.*

Two sets of time-slice simulations — reference (REF) and Grand Solar Minimum (GSM)-forced simulations — were performed with FOCI3.0 to investigate the effects of extreme solar forcing under past (1850), present-day (2020), and future (2100) climate conditions. As shown in the top panel of Figure 2, the annual-mean Antarctic sea ice fraction increases by about 10% in the GSM simulations relative to REF under the 1850 and 2020 conditions, particularly in the West Antarctic sector and the Ross, Amundsen, and Bellingshausen Seas. This response is not evident under the 2100 condition, when Antarctic sea ice is strongly reduced. The sea ice

response is even larger in austral winter, reaching up to 30% in the West Antarctic sector and Ross Sea (figure not shown). A significant cooling response in the middle atmosphere is found in all time-slice simulations (bottom panel of Figure 2), while the surface response differs — Antarctic cooling occurs under the 1850 condition, whereas warming is found under the 2020 and 2100 conditions. Further analysis shows that the 2020 and 2100 simulations have not yet reached equilibrium, as the ocean is still warming. This transient adjustment may contribute to the different responses to GSM forcing. Therefore, the reference simulations for 2020 and 2100 need to be extended to obtain more equilibrated climate states. Further analyses and collaborative work based on these simulations are ongoing.

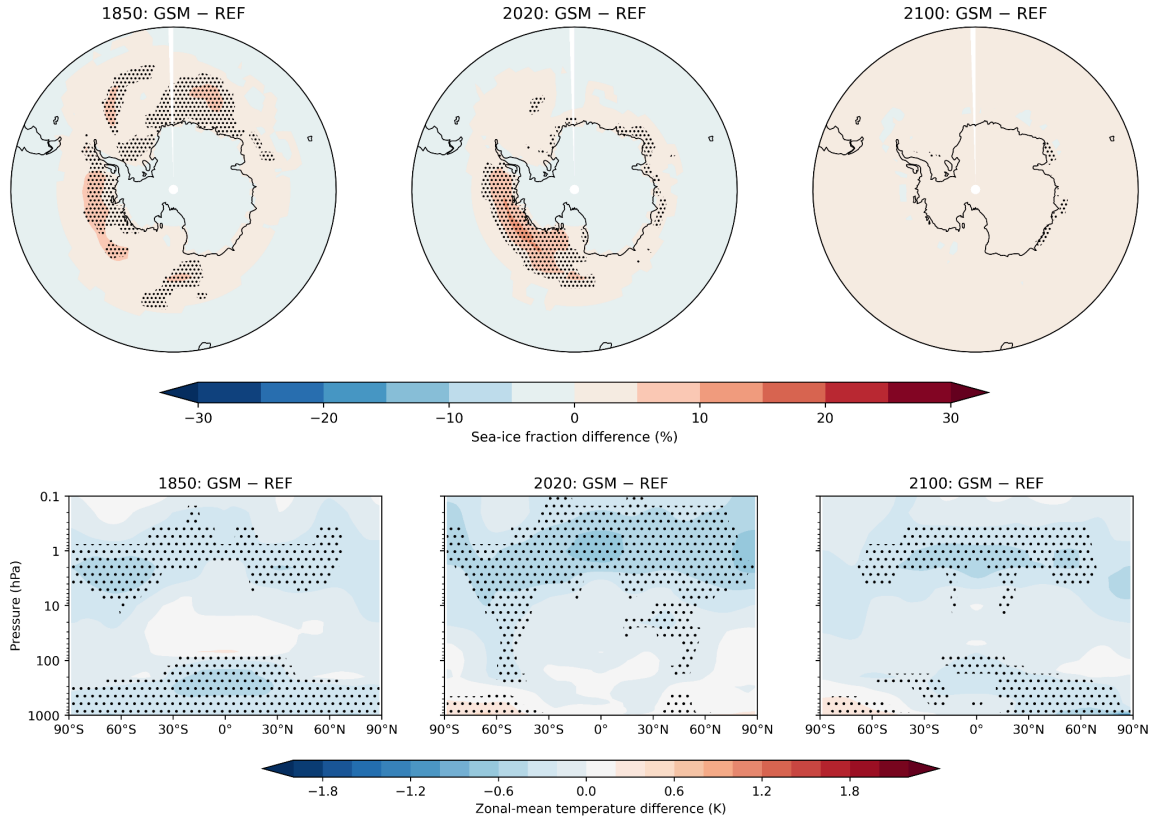


Figure 2. *Differences in annual sea ice fraction (top) and annual zonal mean temperature (bottom) between GSM-forced simulations and the reference simulations for the 1850, 2020, and 2100 conditions.*

Publications based on project 519:

Spiegl, T., Langematz, U., **Huo, W**., Kröger, J., Reddmann, T., Kappenberger, F., **Wahl, S**., Ramezani Ziarani, M., Pohlmann, H., and Sinnhuber, M.: The SOLCHECK Project: A State-of-the-Art Investigation into the Imprints of Solar Variability Across Multiple Timescales, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-126, 2026.

Spiegl, T., Rimbu, N., Kappenberger, F., Hao, X., **Huo, W**., Thober, S., Langematz, U., and Lohmann, G.: Anthropogenic control on solar-induced hydro-meteorological summer extremes, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-3630, 2026.

Garfinkel, C. I., Avisar, D., **Huo, W.**, Kuchar, A., Minobe, S., Osprey, S., Perny, K., and Wright, J. S.: Isolating the boreal winter response to the Pinatubo and Krakatoa eruptions using large-ensemble single-forcing simulations, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-3738, 2026.

References

Roach, L. A., Dörr, J., Holmes, C. R., Massonnet, F., Blockley, E. W., Notz, D., et al. (2020). Antarctic sea ice area in CMIP6. Geophysical Research Letters, 47, e2019GL086729. https://doi.org/10.1029/2019GL086729