Project: 519

Project title: NATHAN - Quantification of Natural Climate Variability in the Atmosphere-Hydrosphere System with Data Constrained Simulations

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Preface

The work of the former Helmholtz-University Young Investigators Group NATHAN (funding finished end of 2015) has been continued within the national BMBF-ROMIC SOLIC project (Quantification of Uncertainties of SOLar Induced Climate variability) until 2017. In 2018/2019 we continued to address questions related to the overall topic of solar-induced natural climate variability financed through GEOMAR base funding. After a massive delay the BMBF project "Solar contribution to climate change on decadal to centennial timescales (SOLCHECK)" finally started in December 2019 and ran until June 2023. Since then funding has been secured by GEOMAR internal money.

Results

Significant influences of solar variability on climate and in particular on natural climate variability modes have been found in many observational as well as model studies in recent decades. However, the understanding of the underlying mechanism as well as the quantification of solar contributions to global and regional climate change remains a challenge due to an inescapable entanglement of the solar signal with internal climate variability in observations. In our SOLCHECK project, we performed large ensemble simulations with state-of-the-art chemistry-climate models together with our project partners (FOCI, EMAC and MPI-ESM-HR) to quantify the solar contribution to decadal and centennial climate variability. In addition to the CMIP6 historical-like ensemble simulations (please see our previous reports), two pairs of dedicated centennial simulations with the preindustrial (the year 1850) and future (the year 2100) background conditions as well as a Grand Solar Minima forcing were performed with FOCI to assess the solar effects on climate and the impact of climate background on its imprint. Databases from SOLCHECK project are open to the public (Wahl, et al., 2023; Spiegl et al., 2023).

Using the CMIP6 historical-like ensemble simulations based on three climate models EMAC, FOCI, and MPI-ESM-HR that participate in SOLCHECK, we found during our analysis in 2024 that the 11-year solar cycle signals in the short wave heating rate (SWHR) and ozone anomalies are robust and statistically significant in all three models (figures can be found in the previous report), which is consistent with previous work. A follow-on study found that these initial solar cycle signals in SWHR, ozone and temperature anomalies are sensitive to the strength of the solar forcing (Figure. 1). But the reliance becomes more complex when the solar cycle amplitude exceeds a certain threshold, i.e., the solar cycle amplitudes — measured by standard deviations of the DJF-mean F10.7 index in the 45-year running windows — are larger than 40 in our study.

Analysis done in 2024 suggests that the cold bias in the tropical stratopause of EMAC dampens the subsequent results of the initial solar signal. The warm North pole bias in MPI-ESM-HR leads to a weak polar night jet (PNJ), which may limit the top-down propagation of the initial solar signal. Although FOCI simulated a so-called top-down response as revealed in previous studies in a period with large solar cycle amplitudes, its warm bias in the tropical upper stratosphere results in a positive bias in PNJ and can lead to a "reversed" response in some extreme cases. Therefore, we suggest a careful interpretation of the single model result and further re-examination of the solar signal based on more climate models, a topic is being discussed in Huo et al., 2024 (preprint in *Atmospheric Chemistry and Physics*).

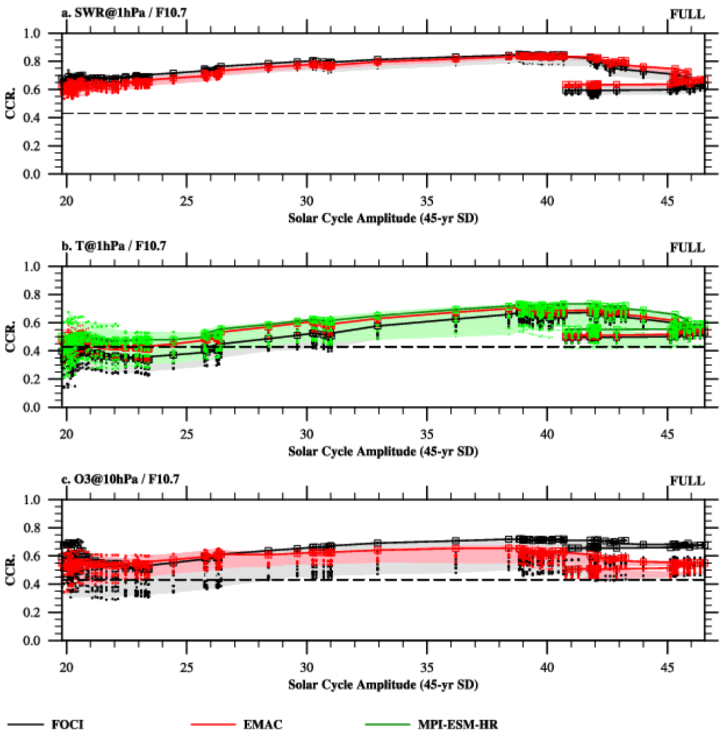

Figure 1. *(a) Scatterplot of correlation coefficients between the annual shortwave heating rate anomalies in the tropical stratopause (averaged over 25S – 25N at 1 hPa) and the F10.7 index in all 45-year running windows vs. the solar cycle amplitude (standard deviations of the F10.7 index in all 45-year windows) for FOCI (black) and EMAC (red) in the FULL experiment. Dots indicate the correlation coefficients of individual members and squares (marker lines) represent the ensemble mean for each model. The shadow regions indicate the spread of correlation coefficients among individual members. The black dashed line indicates the 95% significance level. (b) is the same as (a), but for the temperature anomalies from FOCI (black), EMAC (red), and MPI-ESM-HR (green). (c) is the same as (a), but for the O3 volume mixing ratio anomalies at 10 hPa from FOCI (black) and EMAC (red).*

Publications in 2024 based on project 519

Huo, W., Drews, A., Martin, T., & Wahl, S. (2024). Impacts of North Atlantic model biases on natural decadal climate variability. Journal of Geophysical Research: Atmospheres, 129, e2023JD039778. https://doi.org/10.1029/2023JD039778

Huo, W., Spiegl, T., Wahl, S., Matthes, K., Langematz, U., Pohlmann, H., and Kröger, J.: Assessment of the 11-year solar cycle signals in the middle atmosphere in multiple-model ensemble simulations, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-1288, 2024.

Spiegl, Tobias; Wahl, Sebastian; Huo, Wenjuan; Schmidt, Franziska; Langematz, Ulrike (2023). ROMIC-II-SOLCHECK joint database part II - Grand Solar Minimum sensitivity experiments under different climatic background. DOKU at DKRZ.

Wahl, Sebastian; Huo, Wenjuan; Spiegl, Tobias; Schmidt, Franziska; Langematz, Ulrike (2023). ROMIC-II-SOLCHECK joint database part I - CMIP6-like ensemble experiments with various solar forcings. DOKU at DKRZ.