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.

Results

Here we use a unique set of CMIP6 historical-like ensemble simulations based on three climate models EMAC (Joeckel et al., 2010[1]), FOCI (Matthes et al., 2020), and MPI-ESM-HR (Mauritsen et al., 2019) that participate in SOLCHECK. All members are driven by identical external anthropogenic forcings but differing solar forcing: 1) fixed to 1850 preindustrial conditions (named FIX, 23 members), 2) only long-term solar variability excluding the 11-year solar cycle (named LOWFREQ., 23 members), and 3) long-term solar variability + 11-year solar cycle (named FULL, 25 members). Large discrepancies between the modeling solar imprints in previous studies (Thiéblemont et al., 2015; Chiodo et al., 2019; Drews et al., 2022; Kuroda et al., 2022; Spiegl et al., 2023), diminish the robustness of the detected solar response and call into question the proposed mechanism. Considering the solar signals in the middle atmosphere work as a source of the so-called "top-down" mechanism, we first examined the solar responses of shortwave heating rate (SWHR), temperature, and ozone in SOLCHECK multiple-model ensemble. Figure 1a shows the composite differences between solar maxima and minima of the annual mean SWHR profiles averaged in the tropics (25S-25N). Compared to the FIX (dash lines), a significant and consistent solar response in the SWHR can be found in the FULL (solid lines) for both the FOCI and EMAC models. The temperature response (Figure 1b) following the SWHR, has the largest response around 1 hPa. The strongest ozone response (Figure 1c) exists in the ozone layer in the lower stratosphere around 10 hPa. These simulated initial solar imprints are consistent with the observation, suggesting a robust and significant impact of the solar UV radiation in the middle atmosphere temperature and constituents.

All three models used in SOLCHECK show a very consistent decadal solar imprint in the tropical stratopause temperature, which is phase-locked to the 11-year solar cycle. However, the uncertainty of the solar-related dynamical response is much larger than the thermal response. Therefore, it is not surprising that diverse results of the "top-down" mechanism show up among the models that a stratospheric poleward-downward propagation of the solar signal exists in all models but shows different timings (figure is not shown here). These results are not sensitive to the linear statistical methods (i.e. composite and multiple linear regression). One

[1] References are available from the authors upon request due to the strict two page limit

paper on this topic is in preparation for the *Atmospheric Chemistry and Physics* Journal (**Huo et al., 2023a).**

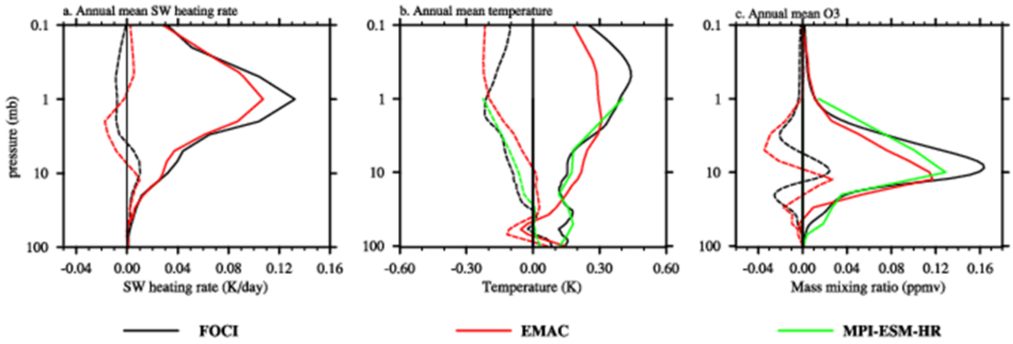

Figure 1. *Composite differences between solar maxima and minima of the annual tropical (averaged over 25S-25N) (a) shortwave heating rate anomalies in the FULLI (solid lines) and the FIX (dash lines) historical simulations ensemble mean with FOCI (black) and EMAC (red). (b) is the same as (a), but for air temperature anomalies from FOCI (black), EMAC (red), and MPI-ESM-HR (green). (c) is the same as (b), but for O3 volume mixing ratio anomalies.*

In addition, we implemented a two-way nested ocean model configuration (VIKING10) that consists of a high-resolution (1/10°) component and covers the northern North Atlantic in a 1/2°ocean grid as part of the FOCI. Our historical simulation (named Nest) based on this update version of FOCI (i.e. FOCI-VIKING10) demonstrated that the North Atlantic cold bias is reduced by half and the path of the North Atlantic current is more realistic, as shown in Figure 2 below. An improved representation of the North Atlantic Oscillation variability is achieved in FOCI-VIKING10 too (figure is not shown here). One paper on this topic is submitted to *Journal of Geophysical Research: Atmospheres* (Huo et al., 2023b).

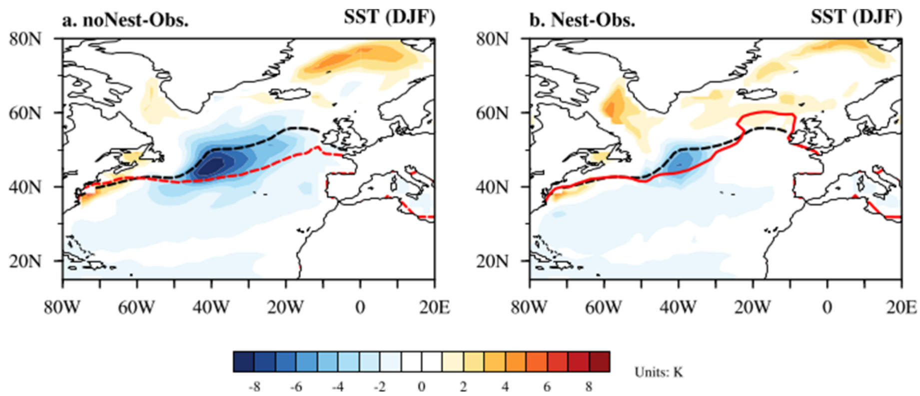

Figure 2. *Boreal winter (DJF-mean) SST bias (in K) in (a) the noNest historical simulation with FOCI and (b) the Nest simulation with FOCI-VIKING10, respecting ERSST climatology of 1950-2014. The black dash line is the 10◦C isotherm indicating the North Atlantic Current path in observation. The red dash and solid lines are the same as the black line, but for the noNest and the Nest runs.*

Publications in 2023 based on project 519

Huo, W. A. Drews, M. Torge, S. Wahl, 2023. Impacts of North Atlantic cold bias on local natural decadal climate variability. (submitted to JGR-A)

Huo, W. T. Spiegl, S. Wahl, K. Matthes, U. Langematz, H. Pohlmann, and J. Kröger, 2023. Assessment of the 11-year solar cycle signals in the middle atmosphere in multiple-model ensemble simulations. (in progress for ACP)