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 will run until 2023.

Model simulations in 2022

In 2022, we focused on the analysis of both our simulations (see last year's report) performed in 2021 and those provided by our project partners and FU Berlin and MPI Hamburg. In addition, we performed simulations that are part of SOLCHECK's work package (WP) 2.2[1], and are listed in the table below.
Unfortunately, some of the simulations could not be used due to errors in the model setup or changes in the setup of the simulations requested by our project partners based on new results. Namely, it was shown during the 2022 SOLARIS-HEPPA working group meeting (https://solarisheppa.geomar.de/bergen2022) that the solar forcings initially planned for SOLCHECK's WP 2.2 simulations are too small to impose significant imprints onto the climate system compared to internal variability and anthropogenic forcings. Therefore, our project partners at FU Berlin who lead the WP2.2 provided several alternative solar forcings. After rigorous discussions with our project partners, we decided to perform a set of "grand solar minimums" experiments for WP2.2 (Table 1) based on the grand solar minimum reconstruction of McCracken and Beer from 2017 (see Egorova et al., 2018 for details) using the remaining CPU time before the end of 2022.

ID	Machine	Years	Configuration
SW183	mistral	1850 - 2014	piControl time slice experiment using perpetual solar cycle 19 – 23 conditions, deleted because photolysis rates used piControls solar forcing (bug in source code)
SW184	mistral	1850 – 2009*	Same as SW183 but using the solar extreme forcing as defined by SOLARIS-HEPPA consortium for CMIP6[2]

[1] For details on work package 2.2 see https://romic2.iap-kborn.de/projekte/solcheck
[2] See https://solarisheppa.geomar.de/cmip6

SW185	levante	1850 – 2001*	Repetition of SW183, stopped due to changes requested by project partner FU Berlin (for details see text).
SW186	levante (planned)	not started	Repetition of SW184, never started due changes requested by project partner FU Berlin (for details see text).
SW187	levante (planned)	not started	Same as SW183 but perpetual year 2100 background conditions instead of piControl background conditions.
SW188	levante (planned)	not started	Same as SW184 but perpetual year 2100 background conditions instead of piControl background conditions.

*Table 1: Overview of simulations performed in 2022. Experiments marked with * have been stopped at the given year due to the reasons given in the last column.*

Results

The experiments performed in 2022 were either misconfigured or have not yet been performed. Hence no results can be presented from those experiments. As indicated in the previous section, we focused on the analysis of the ensemble data available from the simulations performed in 2021.
Here we use a total of 25 ensemble members of historical-like simulations (named SOL-FULL) based on three climate models EMAC (Joeckel et al., 2010), FOCI (Matthes et al., 2020), and MPI-ESM (Mauritsen et al., 2019) that participate in SOLCHECK. To illustrate one of the most direct impacts of the 11-year solar signal onto the climate system, the tropical stratopause temperature (Figure 1a) and zonal mean zonal wind in the polar vortex region (Figure 1b) based on the ensemble runs from EMAC, FOCI and MPI-ESM are shown below. A significant and robust 11-year solar signal can be found in the tropical stratopause temperature in the ensemble mean of each model and the multiple model ensemble mean (black). The air temperature at 1hPa oscillates in phase with the 11-year solar cycle. Compared to the solar minimum, more intense heating and ozone production during the solar maximum conditions can increase the tropical stratopause temperature and hence the meridional temperature gradient between low and high latitudes. Based on the thermal wind balance, we expect a stronger wintertime stratospheric polar vortex during the solar maximum years than the solar minimum, However, as shown in Figure 1b, zonal wind averaged over 55°N-65°N does not show a phase-locking oscillation to the 11-year solar cycle either in the ensemble mean of each model or multiple models mean. These diverse responses in the zonal wind suggest the dynamical response to the 11-year solar cycle forcing is not a linear response that can be directly identified by the ensemble mean. The large internal variability in the polar vortex region and its entanglement with the solar signal reduces the detection of 11-year solar signals in the dynamical processes. Besides, the simulated response to the external forcings and internal decadal variability might be different across the models.
The initial solar signals in the upper stratosphere and their downward propagations play a key role in explaining the possible solar impacts in the troposphere and surface that have been

postulated in literature. Massive analysis of various ocean (e.g., AMOC), surface (e.g., ENSO, NAO) or upper atmosphere (e.g., polar vortex strength) climate indices have not yet led to a consistent conclusion based on the data from the climate models participating in SOLCHECK. We will do further analysis extending into 2023 (see this year's application) by considering the impact of the internal variability and assessing the solar signal in each model separately in more detail.

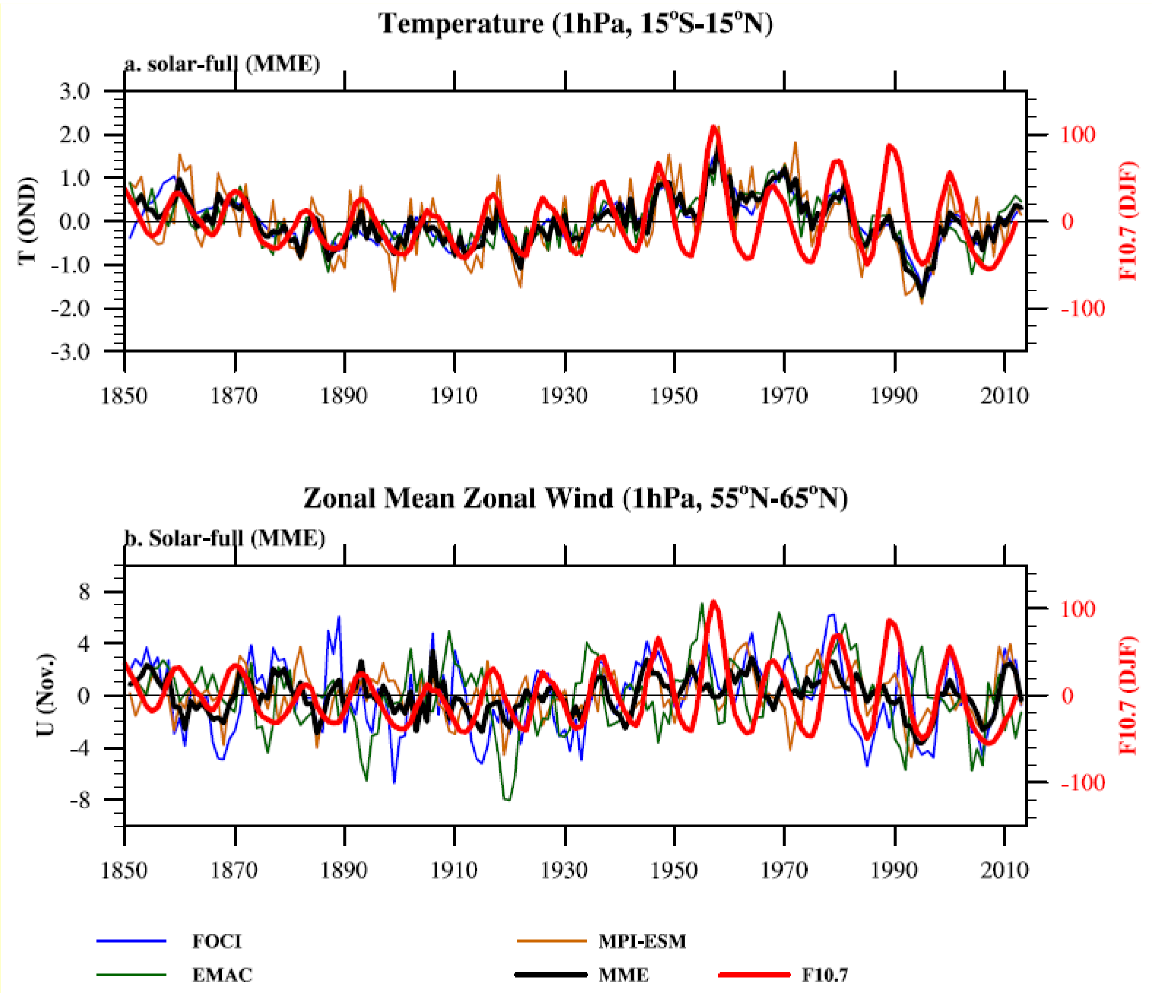

Figure 1. (a) Time series of the Oct-Nov-Dec mean tropical stratopause temperature (1hPa, 15°S-15°N) for the ensemble means of FOC (blue), EMAC (green), MPI-ESM (brown), and multiple models ensemble mean (black). The red line represents the 11-year solar cycle index F10.7. (b) Same as (a), but for November zonal mean zonal wind at 1hPa averaged over 55°N-65°N.

References

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