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.

Model simulations in 2021

In 2021 we performed a total of 34 ensemble simulations that differ in the implementation of the solar forcing used. Note that not all of the simulations could be performed on MISTRAL due to the large queuing time during winter and spring 2021. As, at the same time, the Emmy system at HLRN4 in Göttingen, offered free-of-charge resources to us which allowed us to take load off the heavily used MISTRAL system. As we shifted some of the simulations to the Emmy system, we won't be able to use all CPU time granted in 2021.

Experiment ID	Years	Configuration
SW134 – SW140[1]	1850 - 2014	***Sol_full:*** Historical simulations (9 members) using full CMIP6 solar forcing
SW142 – SW150	1850 - 2014	***Sol_fixed.:*** Same as above but keeping the solar forcing constant at pre-industrial levels
SW152 – SW160	1850 - 2014	***Sol_lowfreq.:*** Same SW132 – SW140, but using a low-pass filtered version of the CMIP6 solar forcing.
SW172 – SW180	1940 - 2008	***Sol_Gmax:*** Simulations using a special solar max forcing (see text) branching off from SW132 – SW140 on January 1st, 1940

Table 1: Overview of simulations performed in 2021

[1] The first two simulations of this ensemble, SW132 and SW133 were already performed in 2020. See last years' report for details.

Results

As listed in Table 1, in addition to the planned historical-like ensemble simulations (SW134-SW160, 25 members in total), we performed a set of Sol_Gmax ensemble simulations (SW172-SW180) driven by a special solar maximum forcings to investigate the impact of the extreme solar forcings on decadal climate variability. These solar forcings are constructed by scaling the full CMIP6 solar forcings (works as a reference, 1940-2008) that keeps the solar minima same as the references and doubles the amplitude of each solar cycle. All other external forcings are same as the Sol_full.

Preliminary analysis based on the 27-member FOCI simulations (SW132-SW160) suggests that stronger solar cycle forcing can increase the detectability of solar signals in climate variables, especially the direct responses (like the stratopause temperature and ozone concentration in the mid-low stratosphere). The correlation coefficient between F10.7 and ensemble mean tropical stratopause temperature is 0.42 in the weak epoch (small solar cycle amplitude), increases into 0.67 in the strong epoch (with larger amplitude) and 0.85 in the historical-sol_Gmax ensemble mean. As shown in Figure 1, amplitudes of the decadal oscillations of the tropical stratopause temperature increase following the increased solar cycle amplitudes (black and blue lines in Figure. 1b) and the phases of individual members are more organized according to solar cycles (cadet-blue thin lines and gray thin lines in Figure 1a and b). However, the ensemble mean only can indicate the linear responses in the climate system, which occupies a very small fraction in the complicate dynamical responses (like the zonal wind anomalies or surface responses). So, the detectability of solar signals in the zonal wind or at surface is not linearly increased as the temperature. The analysis of the more complicated/non-linear/indirect effect of the solar signal onto e.g., the wind field or surface parameters is currently underway.

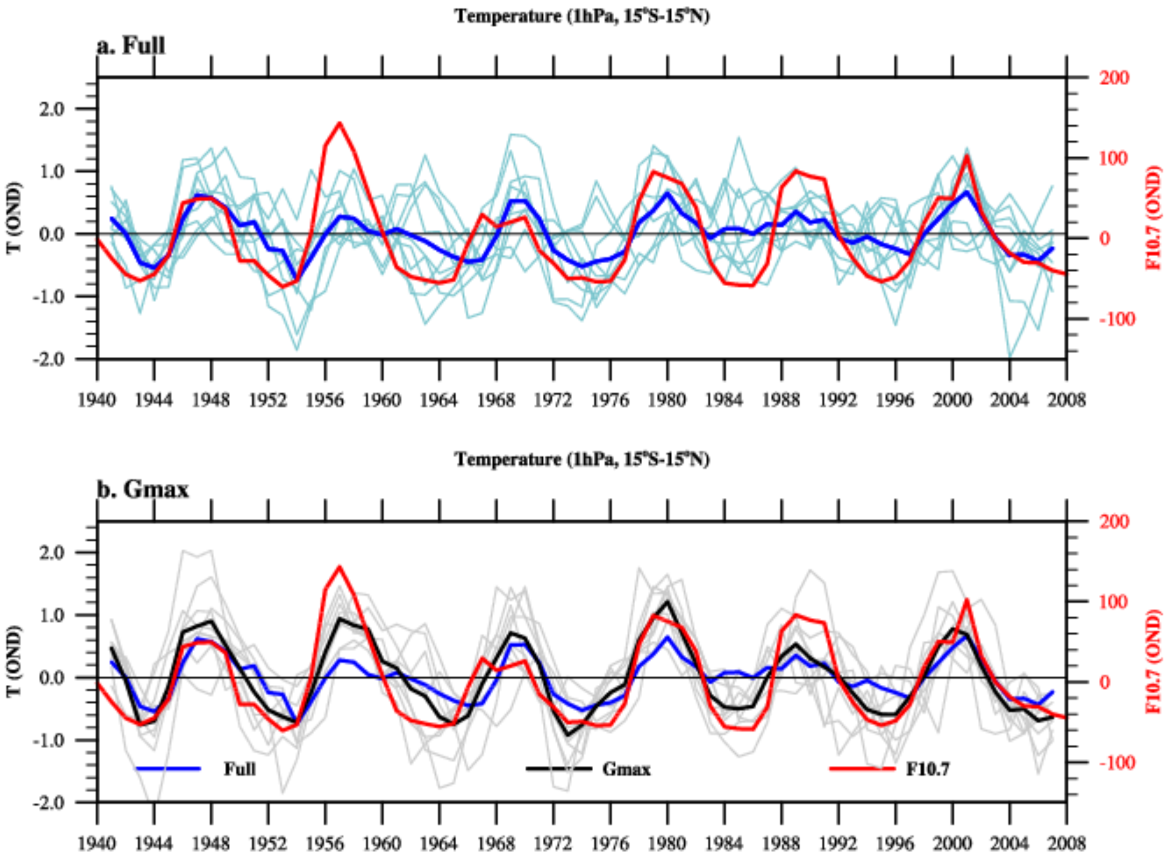

Figure 1. Time series of the tropical stratopause temperature (1hPa, 15°S-15°N) from FOCI historical runs averaged over the earlier winter season (Oct-Nov-Dec) for (a) Sol_full: the individual ensemble members (cadet-blue thin lines) and ensemble mean (blue thick line), (b) Sol_Gmax: the individual ensemble members (grey thin lines) and ensemble mean (black thick line). The red line represents the 11-year solar cycle index F10.7. Here all the time series are smoothed with a 3-year running mean and the ensemble mean of solar low-frequency (Sol_lowfreq.) was subtracted from all the members to obtain the 11-year solar cycle component.

References

Funke, B., Lopez-Puertas, M., Stiller, G. P., Versick, S., & Von Clarmann, T. (2016). A semi-empirical model for mesospheric and stratospheric NOy produced by energetic particle precipitation. *Atmospheric Chemistry and Physics*, *16*(13), 8667–8693. https://doi.org/10.5194/acp-16-8667-2016

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