Project: **1171**

Project title: **Impact of SOlar, Volcanic and Internal variability on Climate (ISOVIC)**

Principal investigator: **Ralf Koppmann**

Report period: **2021-05-01 to 2022-04-30**

In the reporting period we have completed the scheduled model simulations for this period and analyzed the simulation results. At present, we have one publication published (Fang et al., 2021) and one in preparation (Fang et al, in prep.) and further studies in progress.

One part of the ISOVIC projection is related to the simulation of the past two millennium (1-1850 CE) climate following the past2k PMIP4/CMIP6 protocol (Jungclaus et al., 2016). In these simulations we investigated the internal and external variability of the Atlantic multi-decadal variability (AMV) and their relationship with the Atlantic meridional overturning circulation (AMOC) (Fang et al., 2021). We found that the natural external forcing, including volcanic aerosols and solar radiation changes, accounts for ~25% of the multi-decadal North Atlantic temperature variations over the pre-industrial millennium from a multi-model ensemble of simulations (incl. MPI-ESM). By separating the AMV into the internally and externally driven components (Fig. 1), we show that the AMOC is mainly related to the internal component of AMV but external forcing can impact AMOC in a shorter timescale.

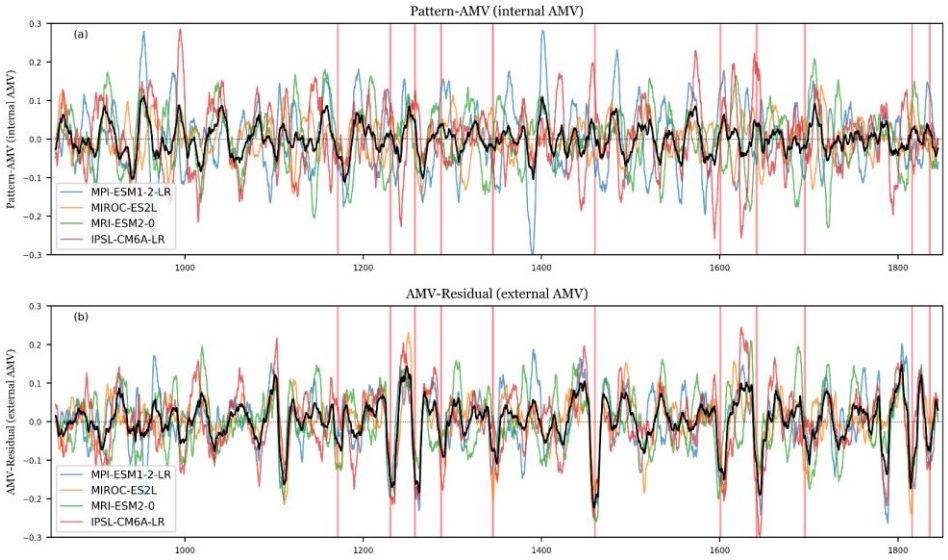

Figure 1: Times series of the pattern-AMV (internal AMV) and the AMV-Residual (external AMV) of the four models of the pre-industrial millennium simulations. The black think lines are the multi-model mean and the red bars are events of strong volcanic eruptions.

As ISOVIC focusing on the interactions between the internal variability and natural external forcing (such as solar irradiance and volcanic eruptions), our research focus is placed on the early 19th century when a solar minimum and multiple strong volcanic eruptions coincided. A set of ensemble simulations of the early 19th century (1791-1830) have been performed and analyzed during this reporting period with the MPI-ESM1.2 model targeting for understanding the responses from different naturel forcing agents and from different climate states.

At first, we aimed to understand the interplay of solar and volcanic forcing over the early 19th century with simulations including 20 ensemble member each and a combination of with/without volcanic eruptions and the two solar reconstructions (SATIRE and PMOD), which are suggested in the past2k protocol. We found that the climates responses from volcanic and solar forcing can in general be additive when they are separately or together simulated (Fig. 2). Several non-additive responses are found regionally, such as polar vortex, northward surface ocean heat transport, and El Niño-Southern Oscillation. In addition, the north extratropical surface ocean is emphasized for the contributions on the long-lasting post-volcanic cooling due to the interactions with Arctic sea-ice (Fang et al., in prep.).

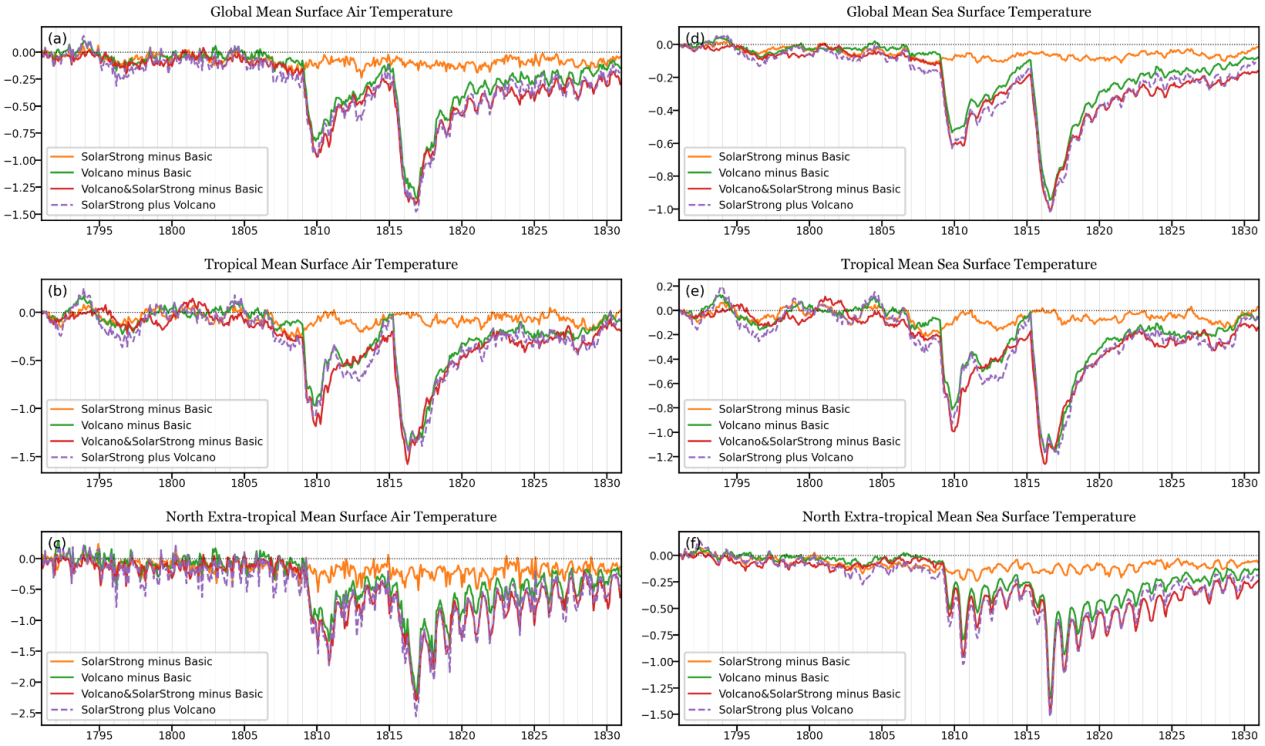

Figure 2: (a) The 20-ensemble mean of global mean surface air temperature difference between the SolarStrong (orange) and Basic experiment. Volcano is in green and Volcano&SolarStrong is in red. The dashed purple line is the addition of SolarStrong and Volcano experiment. (b) is for the tropical mean and (c) is the northern extratropical mean. (d)-(f) are for SST.

Furthermore, we have completed another 20-emsemble member simulation of the early 19th century with volcanic forcing that includes the small and moderate eruptions. These eruptions have not been considered in recent volcanic forcing reconstructions so far and may also have a similar contribution as for the solar forcing. These simulations are currently analyzed and compared with proxy-reconstructions.

Last, to study how the natural external forcing of solar and volcanic eruptions can contribute under present and future climate states, we have completed another 20-ensemble member simulation under 4xCO2 conditions using the solar and volcanic forcing in the early 19th century. In fact, to have a control simulation with near steady states under 4xCO2 forcing, we had to extend the CMIP6 abrupt 4xCO2 simulation beforehand for further 600 years. At present, the simulation for the present-day condition is on-going with 20-ensemble imposing the solar and volcanic forcing in the early 19th century onto the CMIP6 historical and ssp370. The control simulation of this present-day run is the new 30-member ensemble of the MPI-GE that was also run with the MPI-ESM1.2 model. As a result, when the simulations are done, we will have simulations to understand how solar and volcanic forcing can result in cooling under multiple climate conditions: the early 19th century, present-day, and under high-CO2 concentration. This comparison can shed lights on how climate states may impact the responses of natural external forcing, which also has limited understood.

All the simulations are stored on the Archive and can be reused for other applications.

References

Fang, S. W., Khodri, M., Timmreck, C., Zanchettin, D., & Jungclaus, J. (2021). Disentangling internal and external contributions to Atlantic multidecadal variability over the past millennium. *Geophysical Research Letters*, *48*(23), e2021GL095990.

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Jungclaus, J. H., Bard, E., Baroni, M., Braconnot, P., Cao, J., Chini, L. P., ... & Zorita, E. (2017). The PMIP4 contribution to CMIP6–Part 3: The last millennium, scientific objective, and experimental design for the PMIP4 past1000 simulations. *Geoscientific Model Development*, *10*(11), 4005-4033.