Project: **1171**

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

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Report period: **2022-05-01 to 2023-04-30**

In the reporting period we have completed the scheduled MPI-ESM simulations for this period and analyzed the simulation results. At present, we have one more publication published (Fang et al., 2022) and one in preparation (Fang et al, in prep.) and further studies in progress.

The focus of the ISOVIC projection is related to the interaction between the responses from solar and volcanic forcing over the early 19th century (1791-1830). By using the MPI-ESM1.2 model with two different solar forcing data sets and one volcanic forcing data set, we have simulated four ensemble experiments with 20 members each to not only examine the forced responses but also understand the internal variability (Fang et al., 2022). We found that the volcanic forcing (Volcano) mainly contributed to the early 19th-century cooling, while the strong solar forcing (SolarStrong) may help explain part of the cooling (Fig. 1). When combining the two forcings (Volcano&SolarStrong), the cooling after the 1815 Tambora eruption is more consistent with the reconstructions, indicating the potential of solar contribution in the period.

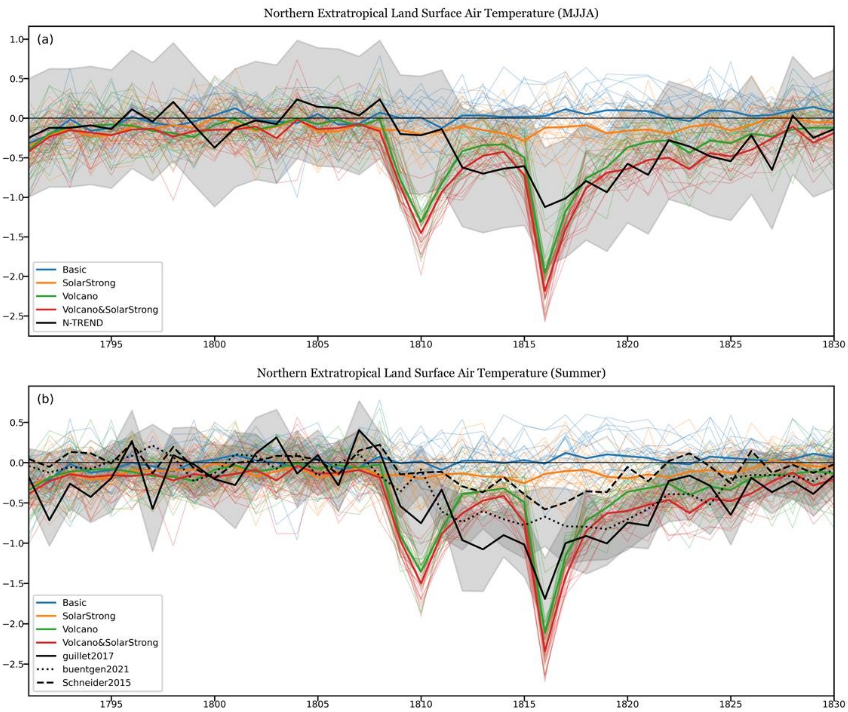

Figure 1: (a) Northern extratropical (30° N to 90° N) May to August land surface air temperature anomalies Basic (blue), SolarStrong (orange), Volcano (green), and Volcano&SolarStrong (red) experiments, (b) for northern extratropical summer land surface air temperature. The black lines are for the anomalies from different reconstructions and the gray shadings are their uncertainties. In (a), the uncertainty of the N-TREND (Wilson et al., 2016) is provided in the dataset. In (b), the uncertainty of guillet2017 (solid; Guillet et al., 2017) is provided in the dataset; the uncertainty for the buentgen2021 is calculated by the one standard deviation of the 15 ensemble members (R1 to R15; dotted; Büntgen et al, 2021); and no uncertainty for Schneider2015 (Schneider et al., 2015).

As ISOVIC also focuses on the interactions between internal variability and natural external forcing, we have investigated the dynamic interactions between solar and volcanic forcing. We found that the responses from volcanic and solar forcing can, in general, be additive when they are separately or together simulated. In the northern extratropical oceans, the temperature slowly recovered at a constant rate until 1830, which is related to the reduction of seasonality and the concurrent changes in Arctic sea-ice extent. Several non-additive responses are found regionally, such as for the polar vortex, the northward surface ocean heat transport, and El Niño-Southern Oscillation. In addition, we also investigate how different feedbacks contribute to the stronger Arctic cooling compared to the tropic (often called Arctic amplification). We found that the albedo feedback of Arctic sea ice contributes mainly to the long-lasting Arctic cooling, resulting in the slower recovery in the Arctic region.

Over the past two years of ISOVIC project, we have simulated several experiments to disentangle the possible cooling source for the early 19^{th} century. This includes different solar forcing, distinct background states, and additional small-to-moderate volcanos not generally simulated (Table 1). We have investigated the contribution of small-to-moderate eruptions to early 19^{th}-century cooling (Fang et al. in prep.). We found that the small eruptions cannot have a noticeable climate impact individually but can contribute to the early 19th-century cooling as they occurred as a cluster. Twelve small-to-moderate eruptions have been included in the calculation from higher resolved new ice core, and they can contribute to the long-lasting cooling after the 1815 Tambora eruption. For the dynamical responses, we found that the northward propagation of the additional cooling from the small eruptions is slowed by the circulation changes caused by the strong 1815 Tambora eruption, indicating potential dynamical interactions between the clustered small eruptions and the large Tambora eruption.

Experiment	Solar forcing	Volcanic forcing	Members	Period	Reference
Basic (climatology)	SATIRE	-	20	1791-1850 (x10) 1791-1830 (x10)	Fang et al., 2022
Volcano	SATIRE	evolv2k			
Volcano&SolarStrong	PMOD	evolv2k			
SolarStrong	PMOD	-			
VolcanoSmall	SATIRE	evolv2k+Di	20	1791-1830	Fang et al. in prep
PresentDay	SATIRE	evolv2k	20	2000-2039	-
4xCO2 (climatology)	climatology	-	1	600 years more	-
4xCO2	SATIRE	evolv2k	20	40 years	-

Table 1: List of experiments done by the ISOVIC project.

We have also completed 20-ensemble member simulations with distinct background states (early 19^{th} century, present-day, 4xCO2). The preliminary analysis shows that no apparent difference can be found between distinct background conditions, though detailed analysis should be made in the future. All simulations are stored on the Archive and can be reused for other applications.

Last, besides using the MPI-ESM model, we start investigating the volcanic climate impacts with a high-resolution storm-resolving model. However, technical difficulties are faced when conducting the planned volcano-forced experiments, such as configuration issues, missing restart files, and having a realistic mean state atmosphere. We have now followed the ICON (ICOsahedral Nonhydrostatic) model with R2B8 configuration for coupled atmosphere and ocean (~10 km), which is designed for studying long-term climates (Putrasahan et al., in prep), and successfully ran a test experiment. As no restart files are available anymore, we have started running our own control run. We also investigated the mean climate and slightly modified the configuration to obtain a more realistic atmosphere for studying the atmospheric responses to volcanic eruptions. As a result, we are planning to conduct volcano-forced experiments with 10 ensemble members, which gives us a general idea of how the state-of-art storm-resolving model can have different atmospheric responses compared to other earth system models.

References

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