Global Temperature Responses to Large Tropical Volcanic Eruptions in Paleo Data Assimilation Products and Climate Model Simulations Over the Last Millennium

E. Tejedor, N. Steiger, J. E. Smerdon, R. Serrano-Notivoli and M. Vuille
Paleoceanography and Paleoclimatology, 2021

Mathurin Choblet
mchoblet@iup.uni-heidelberg.de

Team Variability meeting
April 25, 2022

Structure

1. Research questions
2. Data and methods
3. Results
4. Related/similar studies
5. Questions and discussion

Research questions

1. What are the **large-scale temperature responses** to volcanic events in **data assimilation** (DA) products and how do they compare to other **proxy-derived estimates**?
2. What do the DA products tell us about past **responses in ocean dynamics** to volcanism? (ENSO and AMO)
3. How do the estimated temperature and oceanic responses in the DA products compare to the **modeled volcanic responses**?

Data

Time from 1000 CE to 1850 CE

Volcanic events

- „Volv2k_v2“-Database
- eruptions happening within the tropics (25°N to 25 °S)
- magnitude larger than Mt. Pinatubo eruption (VSSI $>$ 8.78 Tg S)
- 19 eruptions (special treatment for double eruptions)

Climate sim. CESM Last Millennium Ensemble (10 members)

Proxy data

- Pages2k database (mostly tree rings and corals)
- Northern hemisphere tree-ring reconstructions based on TRW and MXD

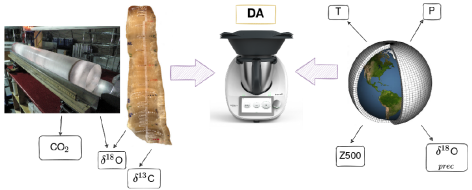
LM-DA products

- PHYDA (Steiger 2018, CESM prior)
- LMR (Hakim 2016, CCSM prior)

Paleoclimate Data Assimilation

Idea

Optimally combine proxy timeseries with a mean model climatology. *Fit* proxies to already simulated model data (Offline DA).



(In this study mainly tree rings from Pages2k-db are used)

Main ingredients

1. Annually/Seasonally resolved proxy data with uncertainties
2. Model prior: Ensemble of yearly/seasonal means from simulation.
   Static ensemble $\rightarrow$ Only proxies propagate time information in the reconstruction
3. Proxy System Model: Project model output into proxy space for comparability
4. Ensemble Kalman Filter: can be applied to all climatic variables of interest (also indices)

Analysis using Superposed Epoch Analysis (SEA)

- Common method to quantify climatic response to specific volcanic events
- Extract global temperature data from -5yrs prior until 20yrs after eruption
- Calculate temperature anomaly of post-eruption years wrt pre-eruption years
- Take mean over all studied eruptions

Metrics

Magnitude and persistence of cooling

Statistical significance testing

Monte Carlo bootstrapping using non-eruption years.

H_0: no significant difference in temperature cf non-eruption years.

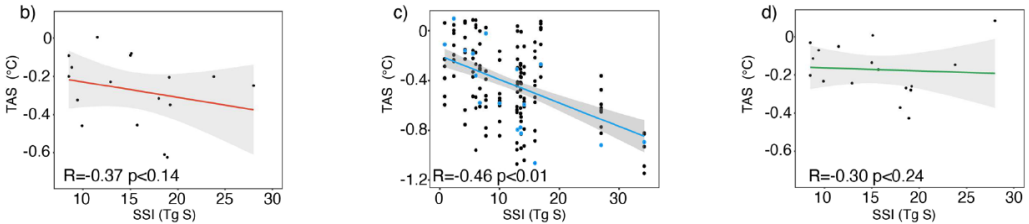


Figure 1: Global temperature response wrt pre-event mean for all 19 eruptions for PHYDA, CESM-LME and LMR. Correlation of mean TAS-annomaly and Stratospheric Sulfur Injection (b)-(d). Significant for models but not for DA products. Note different temperature scale for model ensemble (c).

Persistence of global cooling

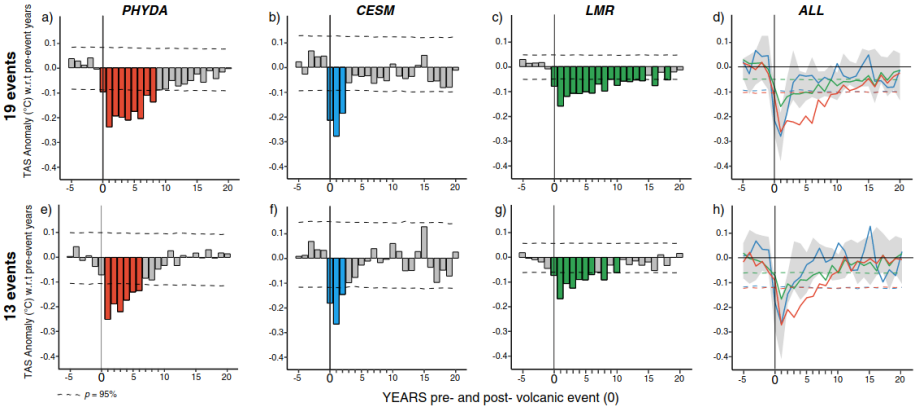


Figure 2: Superposed Epoch Analysis for DA products and CESM model ensemble member 10. CESM shows less persistent cooling. Grey envelope represents CESM-LME spread (not including member 10 (blue line)).

Zonal mean representation of cooling response

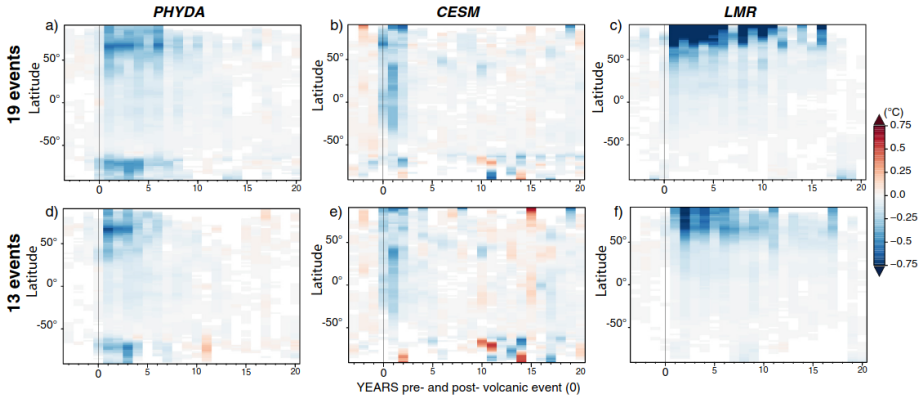


Figure 3: Hovmöller diagram showing weighted zonal-mean temperature. Pronounced cooling for high latitudes. DA products might be affected by lack of tropical proxies.

Comparison to proxy based reconstructions

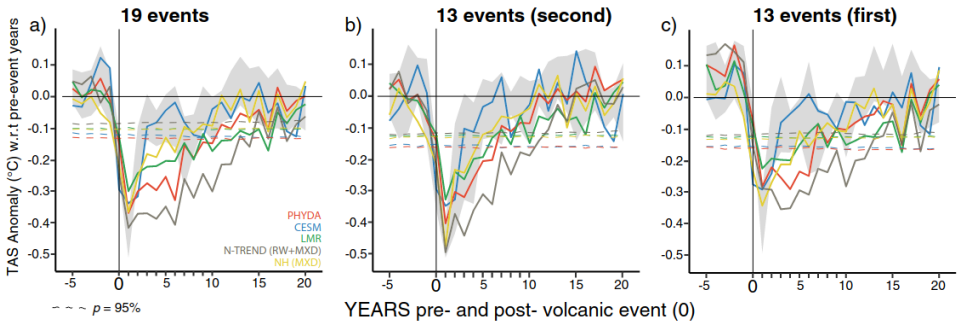


Figure 4: DA products in accordance with proxy based reconstructions. Highlights importance of proper selection of volcanic events in case of *double* events.

SEA for sea-surface temperature indices (El Niño and AMO)

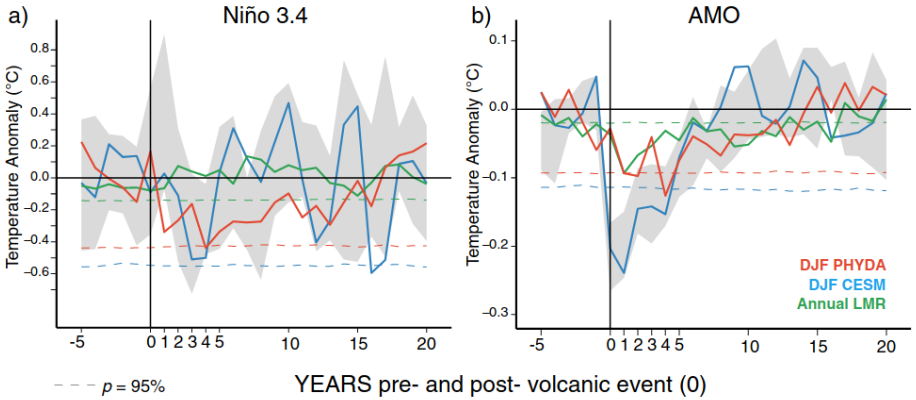


Figure 5: El Niño: Significant response only for single years. AMO: Significant response for LMR only.

Main conclusions

- Robust agreement between DA products and proxy-based reconstructions in:
  - magnitude of cooling
  - persistence of cooling
- In contrast to the models, DA products don't consistently show significant
  - El Niño and AMO response
  - Cooling - magnitude of eruption correlation
- Call for further investigation of differences between PHYDA and LMR (no systematic comparison in this study)

Related/similar studies

RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES | OPEN ACCESS

Global hydroclimatic response to tropical volcanic eruptions over the last millennium

Ernesto Tejedor, Nathan J. Steiger, Jason E. Smerdon, +1, and Mathias Vuille Authors Info & Affiliations

March 8, 2021 | 118 (12) e2019145118 | https://doi.org/10.1073/pnas.2019145118

Research Article

ENSO's Response to Volcanism in a Data Assimilation-Based Paleoclimate Reconstruction Over the Common Era

Sylvia G. Dee, Nathan J. Steiger

First published: 14 February 2022 | **https://doi.org/10.1029/2021PA004290**

Research Letter | Free Access

Resolving the Differences in the Simulated and Reconstructed Temperature Response to Volcanism

Feng Zhu, Julien Emile-Geay, Gregory J. Hakim, Jonathan King, Kevin J. Anchukaitis

First published: 28 March 2020 | **https://doi.org/10.1029/2019GL086908** | Citations: 11

Article | Open Access | Published: 08 February 2022

A re-appraisal of the ENSO response to volcanism with paleoclimate data assimilation

Feng Zhu, Julien Emile-Geay, Kevin J. Anchukaitis, Gregory J. Hakim, Andrew T. Wittenberg, Mariano S. Morales, Matthew Toohey & Jonathan King

Nature Communications **13**, Article number: 747 (2022) | Cite this article

From the Tejedor hydroclimatic response paper

- Same experimental setup (only PHYDA and CESM-LME)
- Focus on *Palmer Drought Severity Index (PDSI)* for different regions in SEA after a volcanic eruption
- Show significant drying over tropical Africa, Central Asia, Middle East, wetter conditions over Oceania and South America

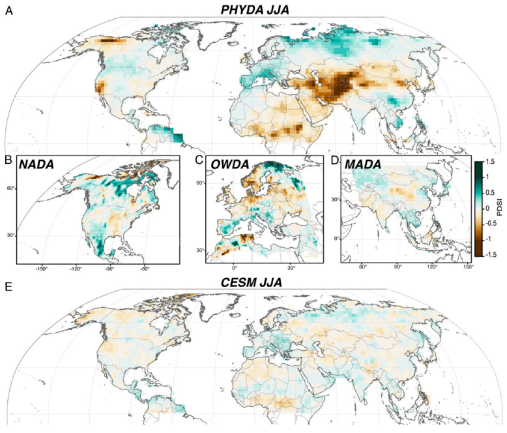


Figure 6: Comparison of PHYDA post-eruption SEA to proxy-based drought atlases.

Questions and discussion

S

Topics discussed during the Journal Club

- Low temporal variability/significance threshold of LMR
- Low latitudes in the Hovmöller diagram, comparison to HadCM3 (Beas paper)
- Missing uncertainties in the SEA plots
- Discrepancies of PHYDA and drought atlases
- Significance of eruption magnitude - cooling correlation in CESM models excluding largest eruptions

S. G. Dee and N. J. Steiger. Enso's response to volcanism in a data assimilation-based paleoclimate reconstruction over the common era. *Paleoceanography and Paleoclimatology*, 37(3):e2021PA004290, 2022.

G. J. Hakim, J. Emile-Geay, E. J. Steig, D. Noone, D. M. Anderson, R. Tardif, N. Steiger, and W. A. Perkins. The last millennium climate reanalysis project: Framework and first results. *Journal of Geophysical Research: Atmospheres*, 121 (12):6745–6764, 2016.

N. J. Steiger, J. E. Smerdon, E. R. Cook, and B. I. Cook. A reconstruction of global hydroclimate and dynamical variables over the common era. *Scientific data*, 5(1): 1–15, 2018.

E. Tejedor, N. Steiger, J. Smerdon, R. Serrano-Notivoli, and M. Vuille. Global temperature responses to large tropical volcanic eruptions in paleo data assimilation products and climate model simulations over the last millennium. *Paleoceanography and Paleoclimatology*, 36(4):e2020 PA004128, 2021a.

E. Tejedor, N. J. Steiger, J. E. Smerdon, R. Serrano-Notivoli, and M. Vuille. Global hydroclimatic response to tropical volcanic eruptions over the last millennium. *Proceedings of the National Academy of Sciences*, 118(12), 2021b.

F. Zhu, J. Emile-Geay, G. J. Hakim, J. King, and K. J. Anchukaitis. Resolving the differences in the simulated and reconstructed temperature response to volcanism. *Geophysical Research Letters*, 47(8):e2019GL086908, 2020.

F. Zhu, J. Emile-Geay, K. J. Anchukaitis, G. J. Hakim, A. T. Wittenberg, M. S. Morales, M. Toohey, and J. King. A re-appraisal of the enso response to volcanism with paleoclimate data assimilation. *Nature communications*, 13(1):1–9, 2022.