Heatwave occurrence worldwide: A comprehensive analysis integrating land properties, climate variables and groundwater depth

Anastasia Vogelbacher, Milad Aminzadeh, Mehdi H. Afshar, Nima Shokri

Institute of Geo-Hydroinformatics, Hamburg University of Technology,
Hamburg, Germany

Introduction

- Since 1950, heatwaves have risen in both frequency and intensity on a global scale, and this trend is projected to continue escalating in the future(1)
- The land surface properties, climatic parameters and their feedback mechanisms are significant factors influencing the occurrence of heatwaves(2,3).
- Shallow groundwater tables (Figure 1) may possess the ability to mitigate heatwave intensity(4) and play an important role on land-atmosphere processes(5)

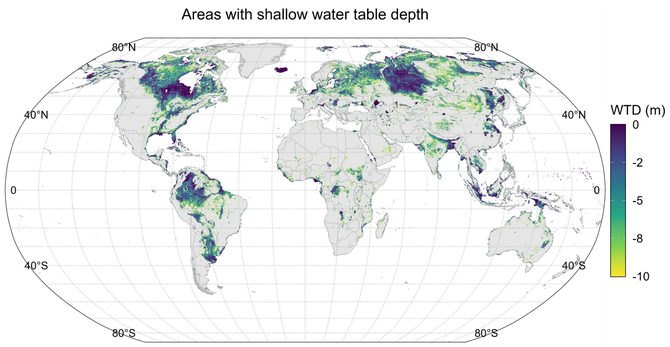


Figure 1: *Locations with shallow water table depth (<10m); data are resampled to 10 km² grid cells(6)*

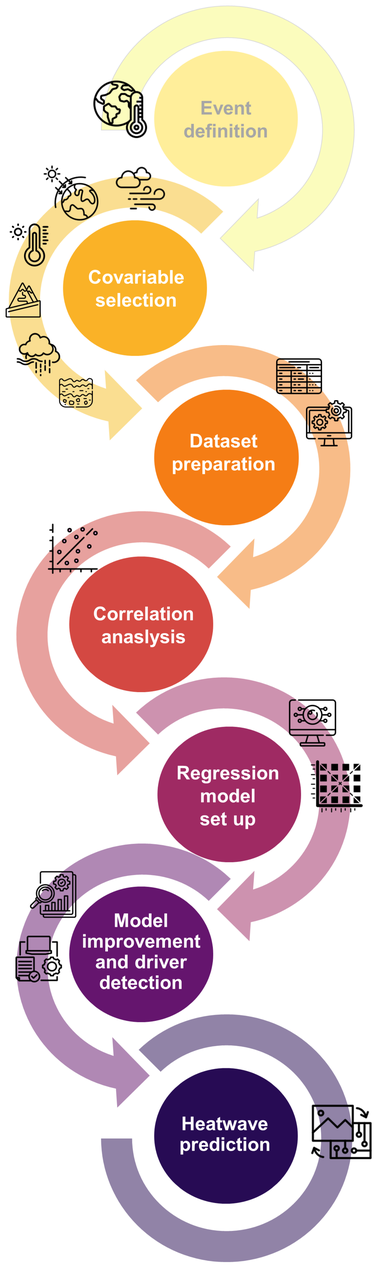
- The full extent of how various land and climatic variables impact the occurrence and intensity of heatwaves is not fully understood, especially regarding the influence of groundwater table depth on heatwave occurrence

Objectives

Using a comprehensive dataset of climatic, land, and hydrological information on a global scale, the specific objectives of this study are:

- **To identify the primary drivers affecting the occurrence of summer heatwaves**
- **To develop a predictive model capable of projecting future summer heatwaves**

Methodology and preliminary results



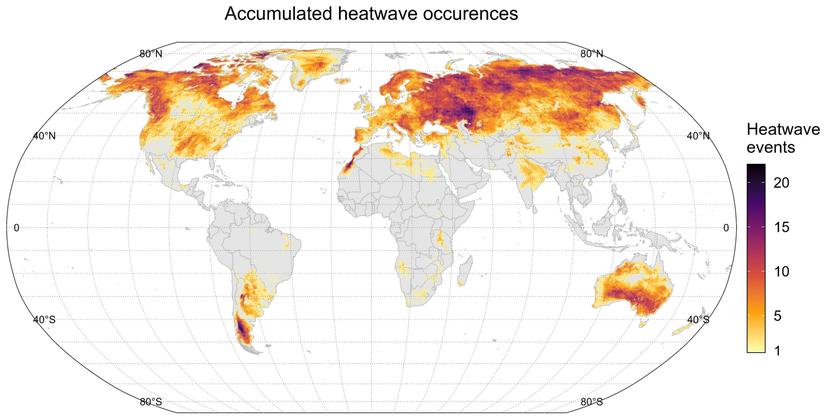


Figure 2: *Determination of summer heatwaves between 2004-2014 in reference to 1980-2022, based on Era-5 Land dataset, following WMO definition of heatwaves (7)*

- Based on a comprehensive literature review, the main surface drivers for heatwave events have been identified (Table 1)

Table 1: *Overview of selected drivers of summer heatwaves*

Covariables		
Atmospheric variables		Wind Speed (m/s)
		Cloud cover (% fraction)
Surface fluxes		Net Solar Radiation (SolRad in W/m²)
		Sensible heat flux (SHF in W/m²)
		Total Evaporation (ET in mm)
		Surface Temperature (T in°C)
Inherent land characteristics		Elevation (m), Slope (°)
		Average soil and sedimentary deposit thickness (Soil thickness in m)
Hydrological variables		Precipitation (mm)
		Surface soil moisture (% Volume fraction)
		Water table depth (WTD in m)

- At each cell center of an identified heatwave, the covariables have been extracted, considering summer seasons for northern and southern hemisphere (months JJA and DJF, respectively)
- A correlation analysis between the covariates and heatwave frequency (Figure 2) has revealed varying levels of significance, depending on the land cover and climatic zones (Figure 3)

Figure 3: *The correlation between the number of heatwaves and selected covariables across various land cover and climatic zones in regions with shallow water tables. Note; WTD in absolute values.*

Next steps

- Developing a model to correlate the occurrence of heatwave to the variables listed in Table 1
- Validating the model based on calculated heatwave occurrences presented in Figure 2
- Identifying the heatwave hotspots in future under different climate scenarios

Institute of Geo-Hydroinformatics,
Hamburg University of Technology,
Hamburg, Germany
anastasia.vogelbacher@tuhh.de

References:
1. Intergovernmental Panel on Climate Change (2023). Climate Change 2021 – The Physical Science Basis. Cambridge University Press; 2023:1513-1766.
2. Seneviratne, S. I. et al. (2021). Climate Change 2021: The Physical Science Basis (IPCC, Cambridge Univ. Press).
3. Domeisen, D. I. V., Eltahir, E. A. B., Fischer, E. M., Knutti, R., Perkins-Kirkpatrick, S. E., Schär, C., Seneviratne, S. I., Weisheimer, A., & Wernli, H. (2023). Nature Reviews Earth & Environment, 4(1), 36–50.
4. Keune, J., F. Gasper, K. Goergen,A. Hense, P. Shrestha, M. Sulis, andS. Kollet (2016). J. Geophys. Res. Atmos.,121,13,301–13,325.
5. Vogelbacher, A., Aminzadeh, M., Madani,K., & Shokri, N. (2024). Water Resources Research, 60, e2023WR036643.
6. Fan, Y., Li, H., & Miguez-Macho, G. (2013). Science 339, 940–943.
7. Frich, P., Alexander, L., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A., & Peterson, T. (2002). Climate Research, 19, 193–212.

Acknowledgments :
We greatly acknowledge financial support from the German Research Foundation (DFG) under Germany's Excellence Strategy – EXC 2037 'CLICCS - Climate, Climatic Change, and Society' – Project Number: 390683824, as well as from the Institute of Geo-Hydroinformatics at TUHH.

OSPP

Sharing is encouraged