Global models show strong spatial variation in compound drought occurrence

Pihla Seppälä[1,2], Marko Kallio[1], Lauri Ahopelto[2], Amy Fallon[3,1], Pekka Kinnunen[4], Matias Heino[1], and Matti Kummu[1]
[1] Aalto University, School of Engineering, Espoo, Finland (pihla.seppala@aalto.fi)
[2] Finnish Environment Institute (Syke), Helsinki, Finland
[3] Gulbali Institute, Charles Sturt University, New South Wales, Australia
[4] Pellervo economic research PTT, Helsinki, Finland

Poster abstract:

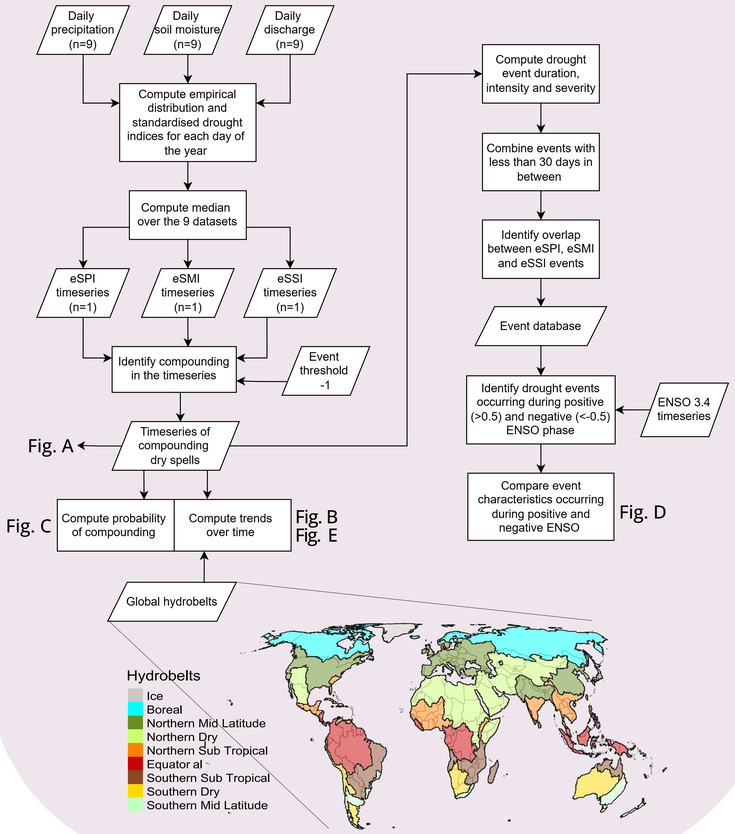
Introduction

Droughts are among the most severe natural hazards, impacting ecosystems, agriculture, and economies. When meteorological, hydrological, and soil moisture droughts co-occur, they form compound droughts, which amplify these effects. Despite their significance, global-scale research of compound droughts remain limited. This study analyzes their occurrence and different characteristics from 1961 to 2020 using multiple global hydrological model runs and three empirical drought indices. By examining spatial patterns and temporal trends, we identify areas most at risk and assess how different drought types interact.

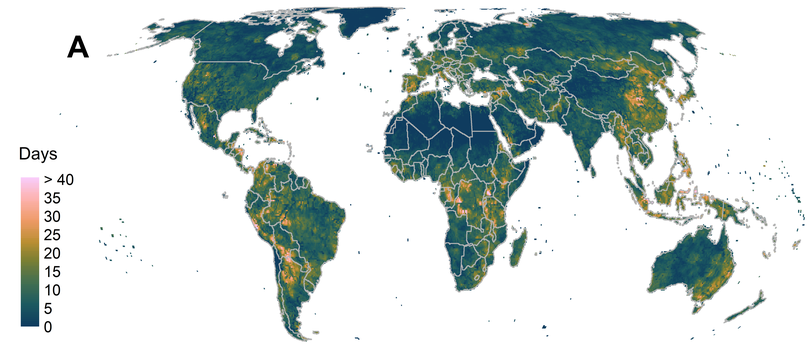
Methods

Our study is based on data from the ISIMIP 3a archive: 3 global hydrological models forced with 3 reanalysis forcing datasets. We used the daily discharge, soil moisture, and precipitation to compute standardised drought indices based on empirical distributions, which were fitted to years 1961-1990, and applied for the full analysis period 1961-2020. In the analysis, we use the median of the 9 estimates of each drought index.

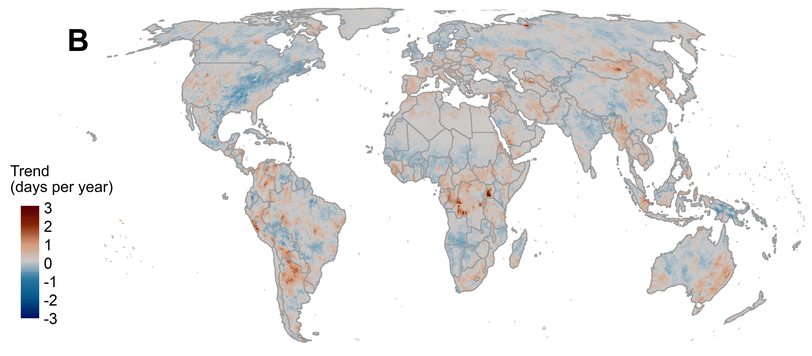
To identify drought events, we used run theory with a threshold of -1 (moderate drought), and analysed the co-occurrence of drought types.



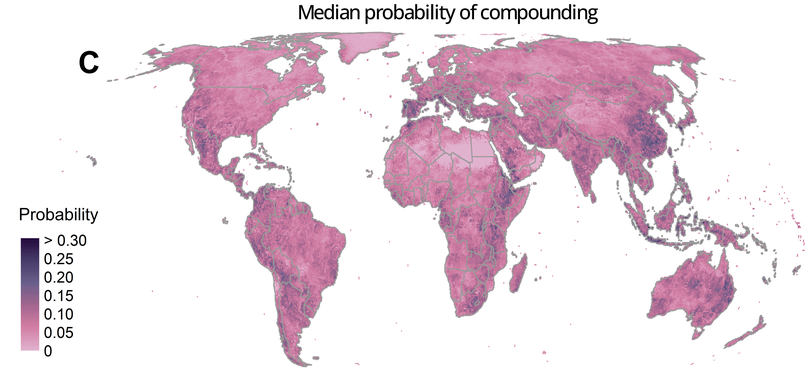
Mean number of days per year under compound drought over 1961-2020



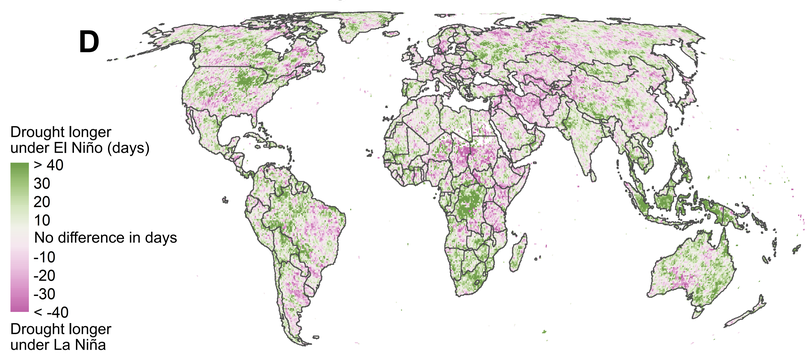
The trend of compound drought days per year over 1961-2020



Median probability of compounding



Difference in drought event duration under El Niño and La Niña



Results

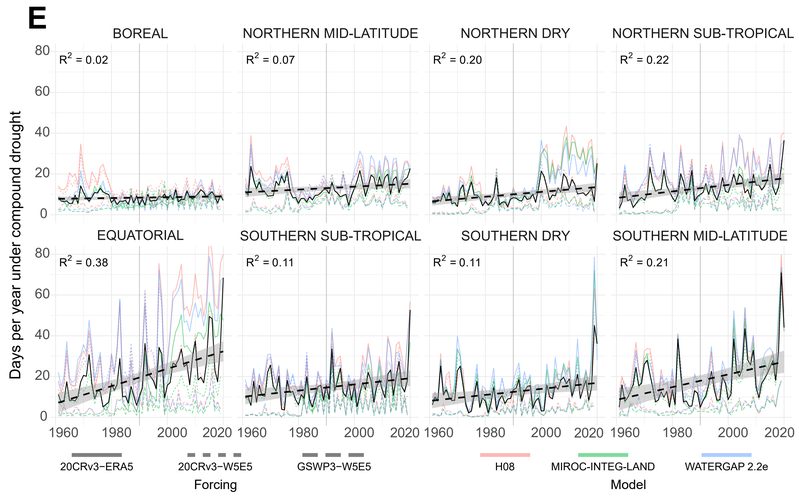
A Regions most prone to compound droughts include the equatorial belt, Southern Europe, the Middle East, Northern China, Myanmar's Central Dry Zone, Northern Argentina, and Western Australia. In contrast, the northern boreal zone and desert regions generally exhibit shorter compound drought durations.

B The areas experiencing most compound droughts largely coincide with areas showing increasing trends. Trends with decreasing compound droughts are evident in the central and northeastern United States, the Sahel region in Africa, the Kalahari Desert, and the Australian Outback.

C The highest probabilities of a drought event developing into a compound drought are found in Southern Europe, densely populated areas of China, the western United States, the Rift Valley in Eastern Africa, Northern Argentina, Southern Africa, and Western Australia. In comparison, boreal regions exhibit the lowest probabilities.

D The Equatorial Belt exhibit longer durations in compound droughts under El Niño conditions. Conversely, compound droughts under La Niña are longer in Eastern Africa, Middle East and Central Asia.

E Trends in compound droughts are increasing across all hydrobelts, but in particular in the equatorial and southern hydrobelts. The southern hydrobelts also exhibit the highest uncertainties within the ensemble.



Discussion and Conclusions

The Equatorial Belt stands out with more frequent compound droughts, a clear increasing trend, and higher probabilities of compounding. In contrast, the Boreal hydrobelt shows the fewest events, stable trends, and the lowest likelihood of compound droughts. El Niño conditions are associated with longer drought durations globally, except in East Africa, the Middle East, and Central Asia. These patterns highlight distinct spatial variability in compound drought behavior.

However, substantial uncertainties remain due to the wide spread among ensemble members, driven by differences in both hydrological models and forcing datasets. This underscores the urgent need for global hydrological models specifically designed to simulate drought processes.

Our findings enhance the understanding of compound drought dynamics and support improved drought risk management under a changing climate.

Aalto University School of Engineering
Suomen ympäristökeskus Finlands miljöcentral Finnish Environment Institute
Sven Hallinin tutkimussäätiö sr
MVTT
Research Council of Finland
erc European Research Council