Trends in severity of heat waves:
an added value of three-dimensional (3D) insight

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3D STRUCTURES OF HEAT WAVES

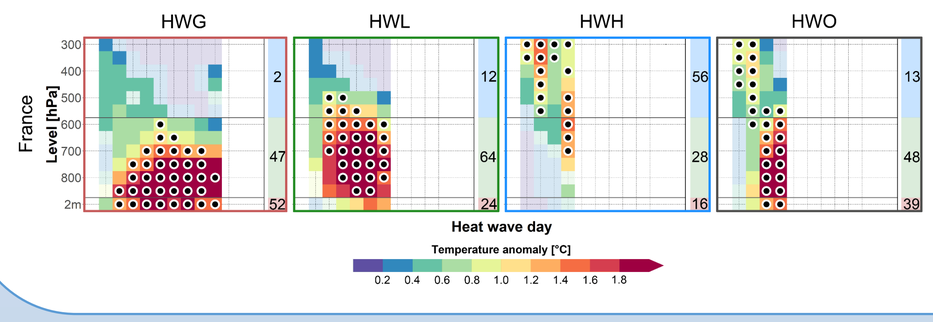
- Recently, we have analyzed heat waves based on their temperature anomaly, length, area and *vertical extent* in selected European regions

- In the current study, we analyze variability of heat waves worldwide (70°N–70°S), considering their 3D patterns

Lhotka, O., Kyselý, J. Three-dimensional analysis reveals diverse heat wave types in Europe. *Commun Earth Environ* **5**, 323 (2024, link).

HEAT WAVE TYPES

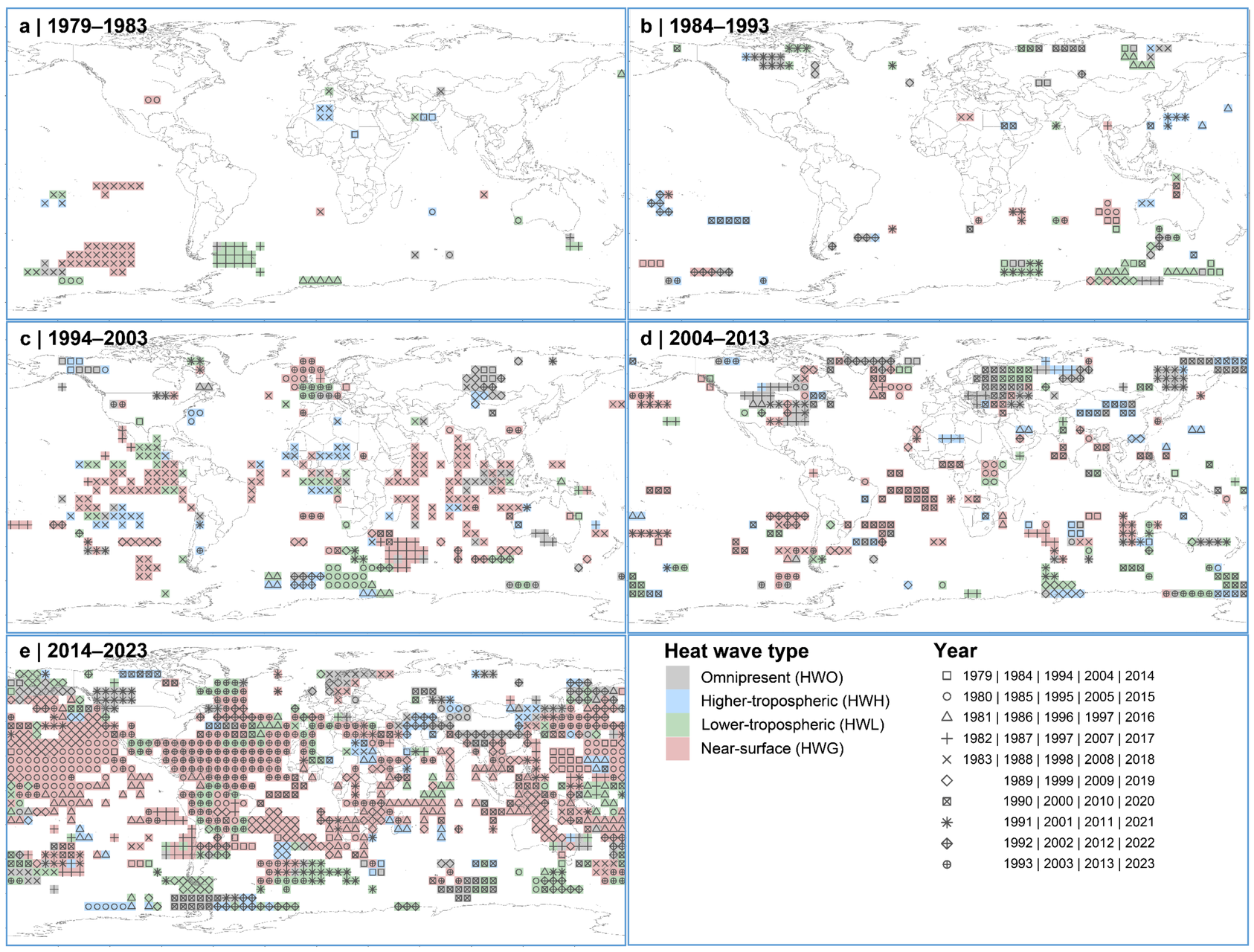
- Temperature at 2 meters and at 12 vertical levels (850–300 hPa) from the ERA5 reanalysis is used to define 4 heat wave types
- They are based on prevailing vertical location of positive temperature anomalies from the 95th percentile of their summertime distribution



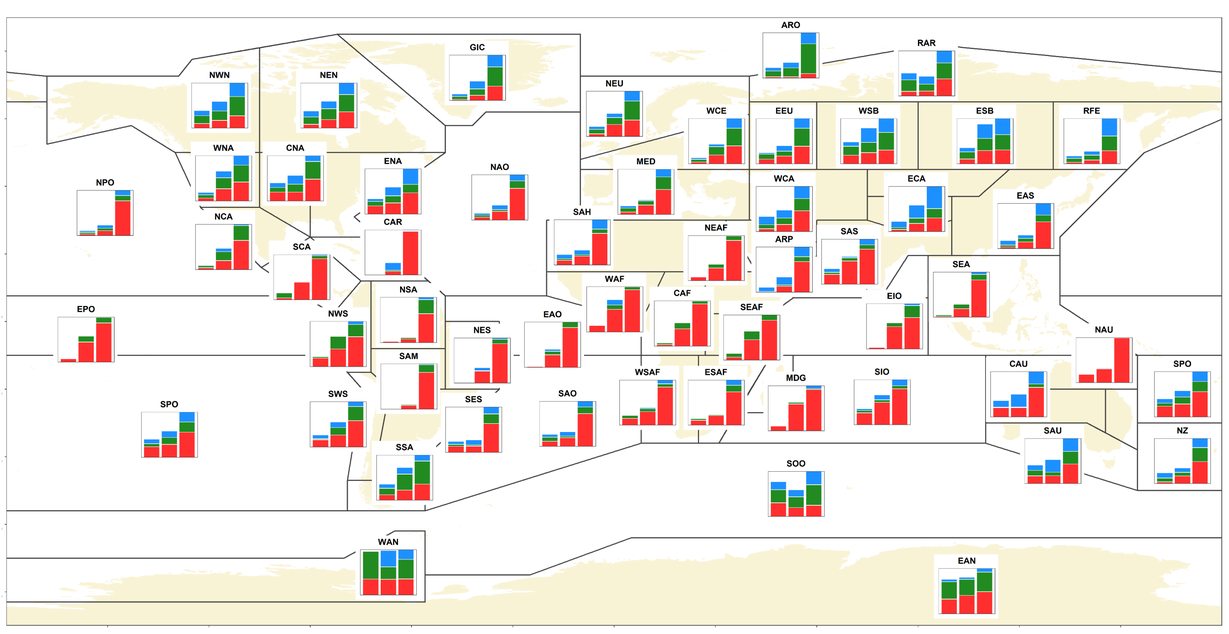
Mean cross sections showing temporal evolution of temperature anomalies for individual heat wave types: near-surface (HWG), lower-tropospheric (HWL), higher-tropospheric (HWH), and omnipresent (HWO). An example for France region.

MOST SEVERE HEAT WAVES

- Severity of heat wave is determined through its length and standardized temperature anomalies (divided by a standard deviation of daily temperatures) at near-surface (2m), lower-tropospheric (850–600 hPa), and higher-tropospheric (550–300 hPa) layers
- Analysis performed for each grid box (5×5°) separately
- Each heat wave is classified into one of the 4 types
- Over continental mid-latitudes, the majority of the most severe heat waves (2003, 2007, 2010, 2011, 2018, 2021, and 2022) is classified as omnipresent (or lower-tropospheric)
- Near-surface heat waves are dominant over water bodies (1998, 2015, 2019 and 2023) but also prevail in continental tropics (2016, 2019, 2022)
- 52% of grid boxes experience the most severe heat wave in the most recent 2014–2023 decade.



Most severe heat waves in the 1979–2023 period between 70°N and 70°S. Colours distinguish between heat wave types, while symbols denote year of occurrence. The time period is divided into five slices: a) 1979–1983, b) 1984–1993, c) 1994–2003, d) 2004–2013, and e) 2014–2023.



Regionally averaged severity of heat waves in 1979–1993 (left column), 1994–2008 (middle column), and 2009–2023 (right column) time slices. Red colour represents share of standardized temperature anomalies at the near-surface layer, while green (blue) colour indicate proportions of lower-tropospheric (higher-tropospheric) anomalies.

TEMPORAL VARIABILITY OF HEAT WAVES

- Severity of heat waves is increasing in all IPCC AR6 regions (generally larger increment in tropics compared to extratropical regions)
- Relative contributions of standardized temperature anomalies in near-surface, lower-tropospheric, and higher tropospheric layers to heat waves' severity are relatively stable over the three time slices
- But in the majority of African regions and the Middle East, the increases of heat waves' severity are primarily linked to higher share of anomalies at near-surface layer
- By contrast, increased severity of heat waves is not linked to higher shares of lower- and higher-tropospheric anomalies