

Heat Waves

As a result of human-induced changes in climate, global mean surface air temperature shows a rising trend over the last 100 years¹. This has led to a worldwide increase in frequency, intensity and duration of extreme heat events or heatwaves² (noting these terms are often used interchangeably). Some of the most notable events are the heat waves of 2003 and 2005 in western Europe³, 2010 in Russia⁴, and 2011 and 2012 in Texas and the Midwest of the USA⁵.

The Intergovernmental Panel on Climate Change 5th Assessment Report (AR5) indicates an increase in frequency, length and intensity of heatwaves will be 'very likely over most land areas' well into the future¹. Heatwaves are a pervasive natural hazard. Generally, they should be periods of unusually hot and dry or hot and humid weather that have a subtle onset and cessation, a duration of at least two–three days, usually with a discernible impact on human and natural systems.

There is no universally accepted definition of heatwave. To determine a set of applicable heat wave definitions and methods, a wide range of heat wave and extreme temperature indices already defined in the scientific literature have been carried out within Climate Insights. In general, these methods could be put into two groups. The first one is to apply absolute or fixed temperature thresholds to define heatwaves (e.g., Fig.1). For example, Health Canada professionals used the thresholds of 22° and 25°C for night temperatures and 30° and 35°C for day temperatures following a temperature–mortality analysis to define heatwaves with a duration at least three days. These absolute temperature thresholds characterise the occurrence of hot weather events that can result in adverse health outcomes for Canadian communities. However, the thresholds would be 27.22 °C for daily minimum temperature, 39.44 °C for daily maximum temperature, while the heatwave duration period at least two days⁶.

1. Intergovernmental Panel on Climate Change (IPCC). 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change, edited by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley. Cambridge, UK, and New York, NY: Cambridge University Press. Online at <http://ipcc-wg2.gov/SREX/report/full-report/>, accessed on April 4, 2014.

2. Perkins, S. E. & Alexander, L. V. On the measurement of heat waves. *J. Climate* 156, 4500–4517 (2013).

3. Schär, C., Vidale, P. L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. A., & Appenzeller, C. (2004). The role of increasing temperature variability in European summer heatwaves. *Nature*, 427(6972), 332–336.

4. Barriopedro, D., Fischer, E. M., Luterbacher, J., Trigo, R. M., & García-Herrera, R. (2011). The hot summer of 2010: redrawing the temperature record map of Europe. *Science*, 332(6026), 220–224.

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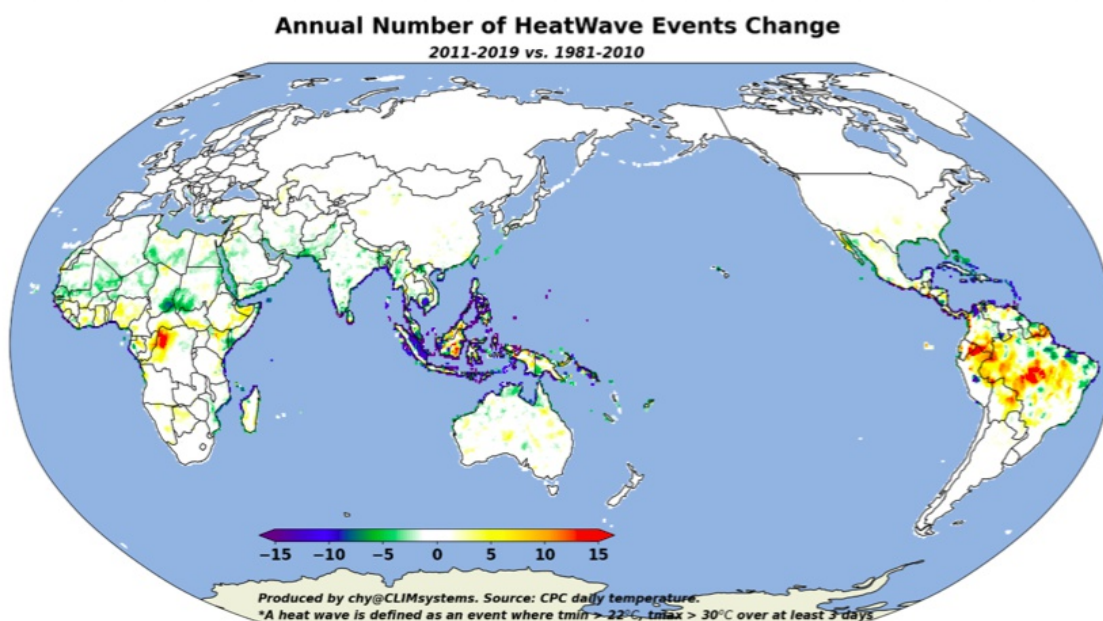


Fig. 1. Heatwave frequency changes (times/year) in latest 9 years compared with the baseline period of 1981-2010.

The second group applies daily percentile climatology from a reference period (e.g., 1981-2010) as thresholds. For example, the threshold is the calendar day 90th percentile of T_{max} , based on a 5-day window (i.e., CTX90pct). That is, there is a different percentile value for each day of the year (thereby accounting for the seasonal cycle), where the window is centered on the day in question. Using a moving window accounts for temporal dependence while producing a reasonable sample size to calculate a realistic percentile value. The thresholds are calculated for each time period and grid box separately. The threshold also could be the calendar day 90th percentile of T_{min} (CTN90pct), as described for T_{max} . These two thresholds are already applied to identify hot days (TX90p) and hot nights (TN90p) by Climate Insights. As a heat wave is considered to be an event of at least three consecutive days^{7 8}, single (1 day) threshold exceedances defined by ETCCDI indices (such as TX90p and TN90p) are not used here to define heatwaves.

5. Hoerling, M. P., Dettinger, M., Wolter, K., Lukas, J., Eischeid, J., Nemani, R., ... & Kumar, A. (2013). Present weather and climate: Evolving conditions. In *Assessment of climate change in the Southwest United States* (pp. 74-100). Island Press, Washington, DC. Hoerling, M. P., Dettinger, M., Wolter, K., Lukas, J., Eischeid, J., Nemani, R., ... & Kumar, A. (2013). Present weather and climate: Evolving conditions. In *Assessment of climate change in the Southwest United States* (pp. 74-100). Island Press, Washington, DC.

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Some research employed only one threshold to identify heatwaves. For instance, the maximum temperature (Tmax) heatwave definition is applied in Perkins and Alexander (2013)⁹. That is, daily Tmax must exceed the calendar-day 90th percentile for at least three consecutive days for a heatwave to be declared. In addition, Nairn et al. (2009)¹⁰ applied the 95th percentile of daily mean temperature (Tmean) for the time period in question as the thresholds to define the Excess Heat Factor (EHF), one of the heatwave components in their research. On the other hand, some research applied both CTN90pct and CTN90pct thresholds to defined heatwaves.

In Climate Insights, we adopt the idea from the second group, namely using percentile thresholds to define heatwaves, as this kind of method is more robust and applicable across different climatic zones than the first group of methods that uses fixed thresholds. A given temperature that defines what is extreme heat, heatwaves are relative to a location's climate: the same meteorological conditions can constitute a heatwave in one place but not in another (e.g., Fig.1). Moreover, it is thought that day and night-time conditions are equally important for understanding the health effects of heatwaves, which may range from heat rash to heat cramps, heat exhaustion, heatstroke, and death. At the individual level, poor thermoregulation, or the inability to balance heat gains to, and heat losses from, the body are responsible for heat-related health outcomes. As a result, CTN90pct and CTN90pct thresholds are both applied to defined heatwaves. That is, daily Tmax and Tmin must simultaneously exceed the calendar-day 90th percentile (CTN90pct and CTN90pct) for at least three consecutive days for a heatwave to be declared (Fig.2).

6. Robinson, P.J., 2001: On the Definition of a Heat Wave. J. Appl. Meteor., 40, 762–775, [https://doi.org/10.1175/1520-0450\(2001\)040<0762:OTDOAH>2.0.CO;2](https://doi.org/10.1175/1520-0450(2001)040<0762:OTDOAH>2.0.CO;2)

7. Collins, D. A., P. M. Della-Marta, N. Plummer, and B. C. Trewin, 2000: Trends in annual frequencies of extremes temperature events in Australia. Aust. Meteor. Mag., 49, 277–292.

8. Pezza, A. B., P. van Rensch, and W. Cai, 2012: Severe heat waves in southern Australia: Synoptic climatology and large scale connections. Climate Dyn., 38, 209–224, doi:10.1007/s00382-011-10169. Perkins, S. E. & Alexander, L. V. On the measurement of heat waves. J. Climate 156, 4500–4517 (2013).

9. Perkins-Kirkpatrick S, Gibson P. Changes in regional heatwave characteristics as a function of increasing global temperature. Sci. Reports. 2017;7:12256.

10. Nairn, J., R. Fawcett, and D. Ray, 2009: Defining and predicting excessive heat events: A national system. CAWCR Tech. Rep. 017, 83–86.

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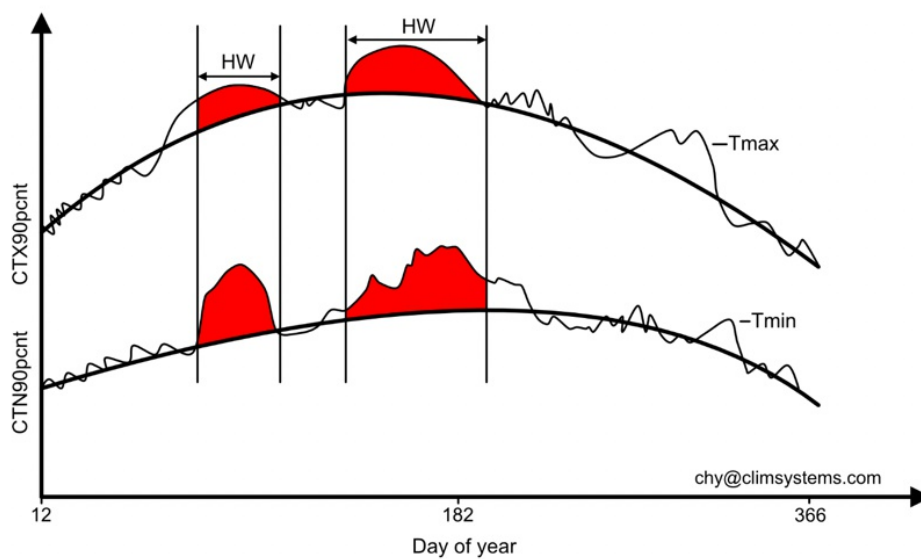


Fig.2 Illustration of defining heatwaves in Climate Insights. A heatwave is an event that daily Tmax and Tmin must simultaneously exceed the calendar-day 90th percentile (CTX90pct and CTN90pct) for at least three consecutive days.

Annual heatwave frequency (HWF, times/year) and heatwave total days or length (HWD, days/year) are presented in Climate Insights (e.g., Fig. 3 and 4). It is recommended that these two layers are used together. Due to climate change, a decrease in the heatwave frequency might occur concurrently with an increase in the length. That is, heatwave days could become more consecutive in the future.



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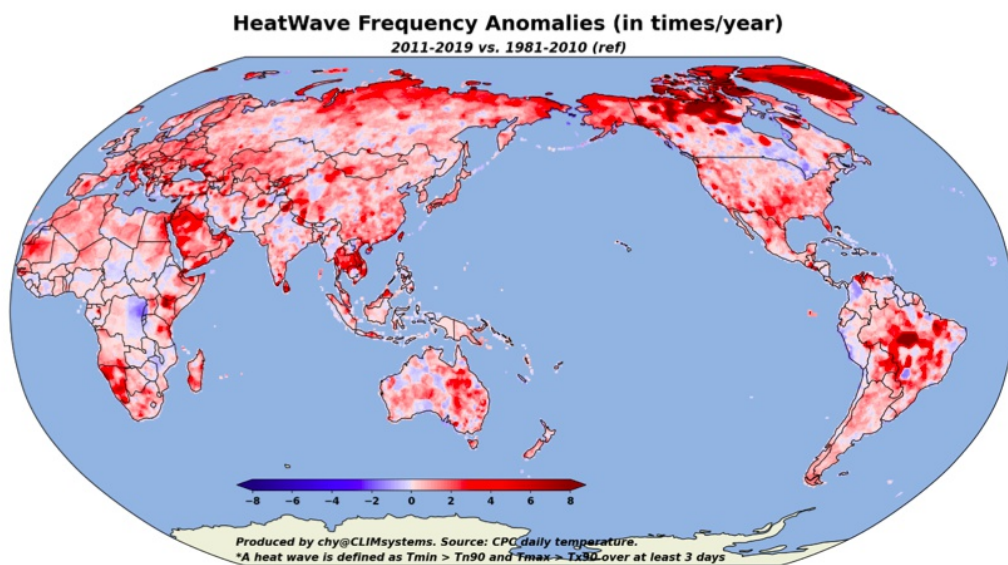


Fig. 3. Heatwave frequency changes (times/year) in latest 9 years compared with the baseline period of 1981-2010.

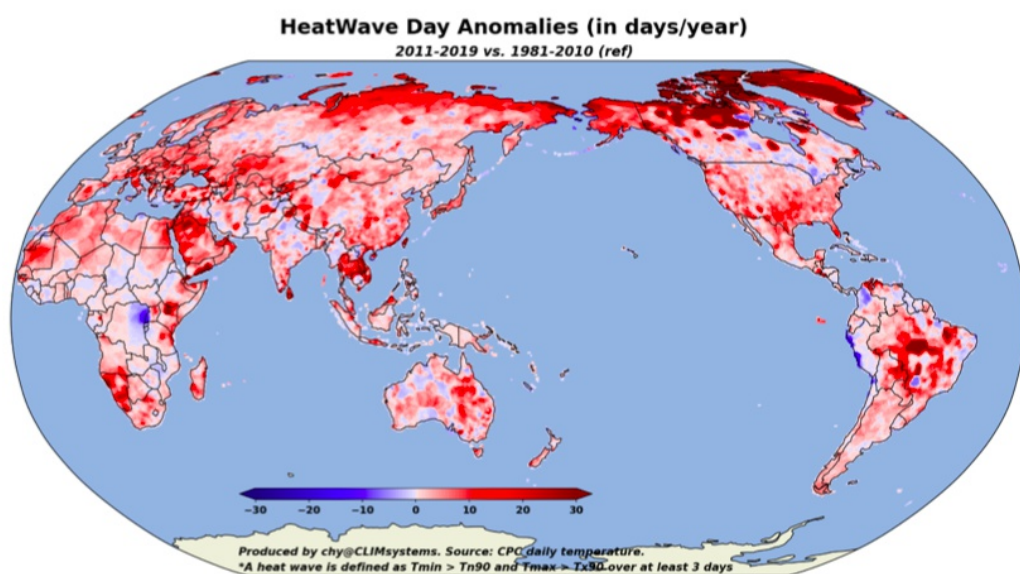


Fig. 4. Heatwave length changes (days/year) in latest 9 years compared with the baseline period of 1981-2010.