Characterization of heat waves: an example for La Plata Basin *

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Abstract

We propose a novel approach to study heat waves that focuses on characterizing key components of their definition: threshold temperature and persistence. Ambiguity about these criteria often arises from the lack of a specific impact of interest and results in questionable assumptions.

To present our idea we focus on summertime heat waves over the La Plata Basin (LPB) in South America and employ a high quality dataset of daily maximum temperature recently become available for the period 1961-2000. We start adopting the 90^{th} percentile of the maximum daily distribution as threshold temperature and a minimum persistence of two days to classify an event as a heat wave. The latter is chosen because 2–3 days is the typical persistence of these temperatures and longer persistence events are rare.

We show that two events occur on average every year; most years have 0–4 events, and only 15% of the years have at least 5. We identified only three ”hot” summers, which are defined as those in which a large number of events occurred across much of the region; they are: 1967/68, 1971/72, and 1988/89. Their limited number prevents any possible search for statistically significant large scale conditions associated with their occurrence.

The sensitivity of outcomes to the choice of threshold temperature is minimal: when the 80^{th} percentile is employed, heat waves are more frequent but persist as long as those characterizing the 90^{th} percentile, and only one additional hot summer is found: 1985/86. Results indicate the lack of a climatological circulation that sets the stage for heat waves in LPB; alternatively, this is too rare to be appreciated over a 40–year period.

1 Introduction

In recent years concern has grown about the possibility of global warming increasing the occurrence of heat waves, which can have important impacts on the environment, energy demand, and health. (Changnon et al. 1996) showed that the mean annual number of deaths in the United States caused by heat waves is much higher than that of other extreme weather events such as tornadoes, floods, hurricanes, and wind storms.

The variety of impacts related to the occurrence of heat waves precludes the possibility of defining them uniquely. When one focuses on human health, several very high nighttime minimum temperatures may be the most relevant factor to consider (Karl and Knight 1997). Together with temperature, humidity also plays a key role; and their combined effect is often measured by specific indices (Lee and Henschel 1966; Cerne et al. 2007).

Agriculture-oriented studies face the additional challenge of identifying when the heat waves occur at a finely resolved time scale, since their impact is closely bound to the developmental stage of the crop: even a single hot day during flowering could reduce the final crop yield (Wheeler et al. 2000). Fixed temperature thresholds are widely used in agricultural studies (Jagadish et al. 2007), which usually focus on a specific crop variety and geographical region. Within the climate community the use of percentiles is heavily preferred to the former approach because percentiles allow normalization on the local climate and facilitate comparison among different regions. Another issue one faces in defining heat waves comes from identifying and comparing the importance of isolated severe events as opposed to moderate but more frequent occurrences, both being further challenged by the practical need of having a sufficiently large sample to draw statistically significant conclusions (Tebaldi et al. 2006). The Intergovernmental Panel on Climate Change [IPCC, Houghton et al. 2001) sets the threshold at the 90^{th} percentile. Other definitions are the occurrence of a minimum of 3 days with Tmax above the 80^{th} daily percentile (Della Marta et al. 2007a), any number of days with Tmax above the 75^{th} percentile (Rusticucci et al. 2003); (Carril et al. 2008), a minimum of 6 consecutive days with temperature exceeding the 90^{th} percentile (Warm Spell Duration Index; Alexander et al. 2006), a minimum of 5 days exceeding the percentile 95^{th} (Feudale 2006), or more complex definitions requiring at least 3 days with very extreme temperatures preceded and followed by days with sustained but less extreme values; examples of adopted thresholds are $25-30\,^{\circ}\mathrm{C}$ (Huth et al. 2000) and the $81^{st}-97^{th}$ percentiles (Meehl and Tebaldi 2004). Some studies focused on the ”worst of the year (or season) heat event” defined as the maximum period of at least 5 days in which Tmax is $5\,^{\circ}\mathrm{C}$ larger than its mean value (Heat Wave

Duration Index; Frich et al. 2002, Klein Tank et al. 2003), and the maximum number of consecutive days where Tmax exceeds the 95^{th} percentile in summer (Della Marta et al. 2007b). Unfortunately, the reasons underlying these choices are often not disclosed. An alternative approach could be, for example, that followed by Curriero et al.(2002), who investigated meteorological variables some days prior to peaks in human mortality. Similarly, Robinson (2001) tested several thresholds for day and nighttime temperatures and identified those that corresponded to major epidemiological events. Further, in a study on the annual most intense heat waves in southern Canada, the stratification on duration disclosed the existence of negative trends for short events, as opposed to positive trends for longer-lasting events (Khaliq et al. 2005).

In this study, we present a statistical characterization of the duration of heat waves and the sensitivity to thresholds in La Plata Basin (LPB) in South America, a region strongly dependent on agriculture and thus sensitive to the occurrence of heat waves. The majority of studies on extreme temperatures over the region have focused on the existence of trends, and few have investigated heat waves. The main difference among the two categories consists in the additional requirement of a persistence for the latter. Examples of the former are the studies by Vincent et al. (2005), Rusticucci and Barrucand (2004), Marengo and Camargo (2008), Rusticucci and Renom (2008), Rusticucci et al.(2010), Marengo et al.(2010), and Rusticucci (2012); Rusticucci et al. (2003) additionally provided some indications of associated meteorological conditions. Rusticucci and Vargas (1995, 2001) found northeasterly flow being associated with an increased number of heat spells (there defined as temperature anomalies of the same sign usually lasting no more than 2 days).

Specifically regarding heat waves in LPB, Cerne et al. (2007) reported about the heat wave occurred in Argentina on January-February 2003, which was characterized by 4 days of anomalies larger than one standard deviation and risky conditions for human health. Dry and clear sky conditions over Argentina, associated with an enhanced South Atlantic Convergence Zone, and an extratropical anticyclone preconditioned the environment prior to the development of the heat wave, which was then strengthened by the advection of heat and humidity through intense, northerly, low-level winds. Anticyclonic conditions and advection from the north characterized the event over northern Argentina in March 1980 (Campetella and Rusticucci 1998): the most persistent event during the period 1971-1990 in the region of Buenos Aires, and characterized by temperatures exceeding two standard deviations for 8 days.

In this study we present a characterization of heat waves in LPB and their spatial patterns during summer. Particular attention is given to those summers in which many events occurred in a substantial portion of LPB.

The dataset and methodology we employed are described in Section 2. Section 3 presents the results. Section 4 includes a summary and concluding remarks.

2 Data and Methodology

The present study is based on daily maximum surface temperature extracted from a new gridded dataset available for southeastern South America for 1961-2000. This product has at present the largest spatial ($20-40\,^{\circ}$S, $45-70\,^{\circ}$ W; see Fig. 1) and temporal extension, as well as the highest spatial resolution ($0.5\,^{\circ}$ latitude $\times$ $0.5\,^{\circ}$ longitude) over LPB (Tencer et al. 2011). We present an analysis of heat waves occurring during the austral summer (December-January-February).

The definition of heat waves we adopt is based on a threshold approach. This has the advantage of normalizing the results on the local climate, thus enabling comparisons among different climatic regimes; this is particularly relevant for LPB because the region encompasses coastal areas, plains, and steep mountains. We start by choosing the 90^{th} percentile as the threshold temperature. As discussed in the Introduction, not only this is the reference value recommended by the IPCC, but we believe it is a good compromise between defining an event as ”extreme” and obtaining a number of occurrences sufficient to draw some statistics. We also show results for the 80^{th} percentile, at the end of the next section.

In order to account for intraseasonal variations, the thresholds are derived from a distribution we formed for each day of the season at each location in LPB. In order to increase the significance of the resulting value, each of these distributions contains data for the target day as well as those of the 2 days prior to and following it. For example, the threshold for 15 January is based on observations collected between 13 January and 17 January of the entire period on record, resulting in 190 data. Next, we draw the number of events persisting any possible number of days from the subset of days in which the maximum temperature was higher than the threshold. This approach does not rely on subjective choices, allows a characterization of heat waves, and thus provides multiple pieces of information that can be used for different purposes.

3 Results

We begin by investigating the persistence of daily maximum temperatures with values higher than the 90^{th} percentile (Fig. 1a). We note that the vast majority of these hot days are isolated events.

Heat waves in LPB typically persist for 2 days, are on average 1-2 each year, and have little spatial variability: subregions in LPB differ by only $\pm$ 1/3 event per year, which corresponds to a difference of one heat wave every three years (Fig. 1b). The frequency of longer-persisting events decreases dramatically. For example, events lasting 5 days or more are very sporadic and consist of less than 10% of the total. In the remainder of the paper, we refer to as heat waves those events exceeding the 90^{th} percentile for *at least* 2 days; these account for approximately 20% of the total number (Fig. 1a).

A relevant aspect to determine is whether spatially extended heat waves tend to occur uniformly or preferentially in specific years, thus suggesting a possible connection with the large-scale circulation. With an average of 2 heat waves per year and their yearly occurrence skewed toward few events, the latter analysis cannot be pursued: the majority of years (70%) have experienced 1 to 4 events, while years with at least 5 events account for only 15% of the total (Fig. 2a). The number of heat waves bears no evidence of trends (not shown). We thus focus on the events falling within the upper 15% of the distribution (i.e., at least 5 per year) in order to investigate their spatial extension and identify candidates for case studies; we refer to these as hot summers.

A concise visualization of these cases is given in Fig. 2b, where each marker represents a location and year in which there have been at least 5 heat waves. Data are organized such that longitudinal bands are piled from east to west to form a column representing LPB in each year. Thus, data at the bottom of Fig. 2b correspond to the Andes and eastern LPB, above which data describing central and then western LPB are stacked. Subregions in LPB have experienced a higher occurrence of heat waves in different periods, for example central LPB between the years 1963 and 1972 and the Andes in recent decades, although the latter may be sensitive to the scarcity of direct observations (Tencer et al. 2011). The extension of the area interested by at least 5 events suggests that heat waves in LPB are mainly local phenomena: in 70% of years such area is less than 15% of LPB and only in three years it is at least 25% (fig. 2c); the latter are shown in Fig. 3. The summers of 1967/68 and 1988/89 present a similar pattern over central LPB, whereas the summer in which both most events and larger spatial extension occurred (1971/72) is characterized by a meridionally oriented pattern. In the core of the latter, typical values are 10-11 events, which in temporal terms corresponds to the presence of heat waves for 1/4 - 1/3 of the summer.

We also investigated whether our results would change by setting the threshold temperature to the 80^{th} percentile. As expected, the number of heat waves increases (Table 1), but the increase in their persistence can barely be noticed (see Fig. 4a and Table 1). The additional events occurred primarily in those years that had few or no heat waves for the 90^{th} percentile, as illustrated by the diminished skewness of the distribution (Fig. 4b) compared with that of the 90^{th} percentile (Fig. 2). The summer of 1985/1986 is the only additional hot summer found; it presents a pattern located over the northeastern sector of LPB (not shown).

These findings may indicate the lack of a climatological circulation that sets the stage to the occurrence of heat waves in LPB; or, possibly, this is too rare an event to be relevant over a 40-year period. In either case, limitations about the long term predictability of such events follow.

4 Conclusions

In this study we present a novel and objective method to choose the threshold temperature and the minimum number of days above threshold that define a heat wave; this method consists in varying the threshold temperature and studying how the number and clustering of hot days vary accordingly. Investigations published on geophysical sciences journals typically either attempt to relate the occurrence of heat waves to atmospheric and oceanic conditions or to assess the rarity and gravity of specific events. In either case these studies are often not targeted to specific societal issues (like human health or agriculture) on which to measure the impact of these events and, as such, the criteria adopted to define heat waves are arbitrary. One potential negative consequence, for example, arises from choosing an *a priori* specific, typically long, duration because this does not reveal the existence of shorter events whose relevance may be important. Setting too low a threshold temperature may mix extreme and non-extreme cases. At the opposite end of the spectrum of proposed definitions, and motivated by the 22,000 to 35,000 deaths and the destruction of forests and ecosystems in Europe, the heat wave that hit Europe in the summer of 2003 received an enormous attention and has resulted in more than 170 published articles to date. We point out that such event, with anomalies as large as 4-5 standard deviations larger than the seasonal mean, is an extremely rare even in a warming climate (Schär et al.) 2004, see their Fig. 1) and that less extreme, but more likely, events also deserve closer attention.

The present study provides a characterization of heat waves in La Plata Basin (LPB) in South America during the years 1961-2000. We illustrate our methodology for the summer season and focus on daily maximum temperatures. We adopt a *percentile* approach to set the threshold temperature since it normalizes the results to the local climate and thus eases the comparison among different studies and climatic regions. We note, however, that a *fixed-value* threshold is often adopted for agricultural impacts, and thus fostering interdisciplinary discussions would be beneficial for assessing the atmospheric conditions leading to such extreme impacts for specific applications.

We initially set the threshold temperature to the 90^{th} percentile because it is a common choice, and therefore eases comparison among studies, and the criterion indicated by the IPCC. More precisely, we determined the threshold for each day during summer, an approach that allows us to account for intraseasonal variability. We found the vast majority of these hot days to be isolated events, which emphasizes the different statistics one obtains by requiring or not persistence to the definition of heat waves.

Heat waves in LPB typically last 2-3 days (Fig. 1), which represents 35% of the total number of cases, and average to 2 per year. The temporal distribution of all events lasting a minimum of 2 days is positively skewed toward few heat waves each year; only 15% of the years studied have 5 or more of such events (Fig. 2). We found only three summers in which at least 1/4 of LPB was interested by the latter number of occurrences: 1967/68, 1971/72, and 1988/89 (Fig. 3); among these 1971/72 was characterized by heat waves for a remarkably large fraction of time: 1/3 - 1/4 of the days.

We found the sensitivity of the results to the choice of the threshold temperature to be minimal. When the 80^{th} percentile is used, heat waves are more frequent (as expected) and average to 3-4 per year; but they persist as long as those characterizing the 90^{th} percentile (Figs. 1 and 4). Interestingly, the temporal distribution of the number of events per year is more symmetric and therefore indicates that a significant portion of the additional events occurred in years in which no events or few occurred for the 90^{th} percentile (Figs. 2 and 4). The right tail of the distribution is similar for the two percentiles: few years presented a large number of events, and indeed only one additional hot summer results for the 80^{th} percentile: 1985/86.

The limited number of hot summers may indicate the lack of a climatological circulation that sets the stage for the occurrence of heat waves in LPB and it represents a limit in the long term predictability of such events. Individual case studies can be conducted for the hot summers we identified to investigate the associated synoptic conditions.

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Tables

Table 1. Comparison between the 90^{th} and 80^{th} percentile as thresholds

	Mean number of hw	Total number	duration (days)	Number of hot summers
90^{th}	2	70	2-3	3
80^{th}	3	122	2-3	4

Figure Captions

Fig. 1. Persistence of high maximum temperature above the 90^{th} percentile (a) and average number of events persisting 2 days (b).

Fig. 2. Frequency of heat waves (a), spatio-temporal distribution of hot summers (b, see text for details), and percentange of LPB hit by at least 5 events (c) for the 90^{th} percentile.

Fig. 3. Patterns of the number of heat waves during hot summers.

Fig. 4. Persistence of high maximum temperature (a) and frequency of events (b) for the 80^{th} percentile.

Figures

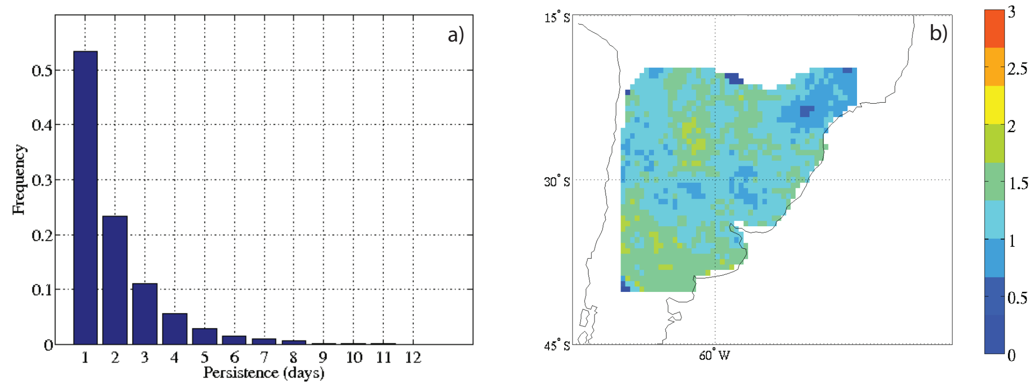
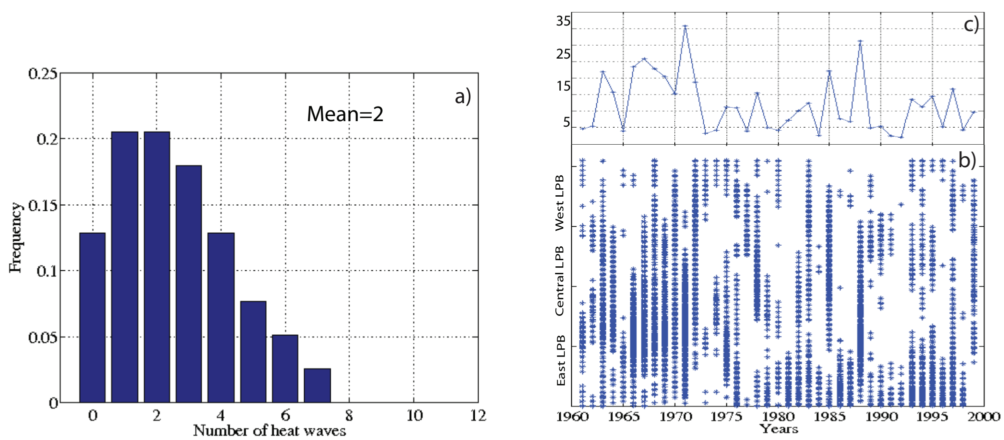


Fig. 1. Persistence of high maximum temperature above the 90^{th} percentile (a) and average number of events persisting 2 days (b).



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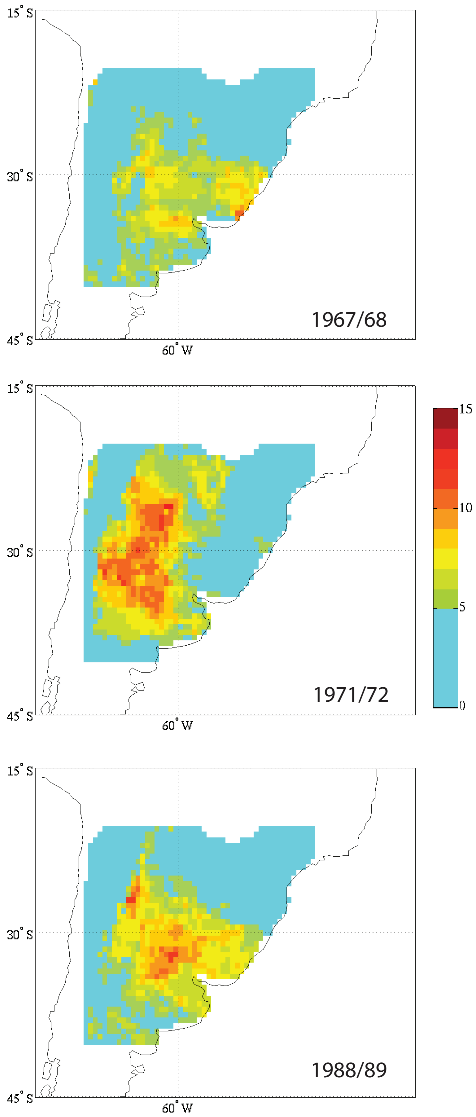

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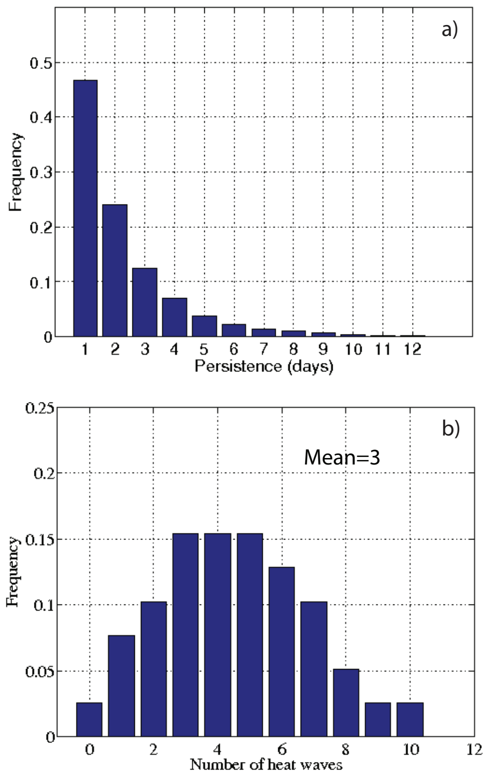

Fig. 4. Persistence of high maximum temperature (a) and frequency of events (b) for the 80^{th} percentile.