Remember, remember the fifth of November: was that thunder I heard or not?

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Remember, remember the fifth of November: Was that thunder I heard or not?

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Abstract

"Thunder days" are simple records of thunderstorm activity, logging whether a human observer heard thunder on a particular day or not. Despite their low dynamic range and inherent subjectivity, thunder days are invaluable as the only long-term observations of thunderstorm occurrence, with some records stretching back into the 19th century. Thunder days, however, are potentially susceptible to false positives, particularly from explosions. Thus one might expect UK thunder days to show anomalously high counts on New Year's Eve and days around 5 November, Bonfire Night, both of which are celebrated with large firework displays across the country. It is demonstrated that Met Office records of thunder days between 1980 and 2010 do not show any significant increase in thunder reporting around 5 November or 31 December. In fact, the days around 5 November exhibit the largest reduction in the amount of reported thunder relative to annual climatology. While meteorological variability cannot be completely ruled out, this result is suggestive of observer bias; It is speculated that human observers, armed with a priori knowledge of the likelihood of false positives, "second guess" themselves to a greater degree around 5 November than the rest of the year. In fact, the data suggest they should trust in their ability to correctly discriminate between thunder and fireworks.

Introduction

The only long-term observations of thunderstorm activity, extending back more than 100 years, are "thunder days," wherein an observer records 1 or a 0 depending on whether or not (they think) they have heard thunder that day [e.g., *Brooks*, 1925; *Changnon*, 1985; *Kitagawa*, 1989]. Despite the low dynamic range (e.g., a storms with 1 or 1000 lightning strokes will both simply register a 1 in thunder days) and the inherent subjectivity of such measurements, they're invaluable for long-term studies of thunderstorm occurrence, which could vary as a result of global warming [*Romps et al.*, 2014] or even changes in the space environment [*Stringfellow*, 1974; *Owens et al.*, 2014].

Thunder day observations are potentially susceptible to false positives, such as vehicle noise or natural/anthropogenic explosions being wrongly attributed to thunder [e.g., *Rampino*, 1989]. Thus increasing urbanisation and industrialisation may result in a long-term change in the noise level and hence bias in the data. On shorter timescales, "Bonfire" or "Guy Fawkes" night, as well as New Year's Eve, in the UK (5 November) are obvious candidates for false-positive thunder identification.

Data and analysis

Thunder day records produced by professional observers at UK Met Office meteorological stations are available from "Met Office Integrated Data Archiving System (MIDAS) land and marine surface stations (1853–current)," made available by the NCAS British Atmospheric Data Centre (http://badc.nerc.ac.uk). The measurement is a simple one: Met Office observers simply record a thunder day on any day they hear thunder [*Lewis*, 1991]. There is no formal training in discriminating between thunder and false positives, and there is no stipulation to use any additional instrumentation for verification [J. Wilkinson, personal communication]. In practice, however, on the suspected identification of thunder observers may, on occasion, also consult radar data or radio lightning observations (or "spherics") if/when available [P. Inness, personal communication]. Conversely, it is not possible for a thunder day to be recorded without the observer having heard thunder, thus distance bright fireworks confused with lightning flashes should not result in false positives in the thunder day record.

Prior to 1950, thunder days were recorded in the climatological returns of manned UK stations, with monthly totals available in the Monthly Weather Report. In the MIDAS daily dataset, thunder day records routinely began in 1950, with the number of manned UK stations making such observations was limited to fewer than 10 until 1957 and fewer than 100 until 1971. After this date, there were approximately 400 stations making thunder day observations, though it unfortunately slowly tapered off after 2000, to fewer than200 again at the end of 2010 [see also *Perry and Hollis*, 2005 and Figure 1a]. Due to the difficulty in discriminating between an observation of no thunder and no thunder observations, any station making a single observation of thunder in a given year is assumed to be actively observing and included in the analysis. *T*, the fraction of UK observing stations which recorded thunder on a given day, is constructed from individual station data.

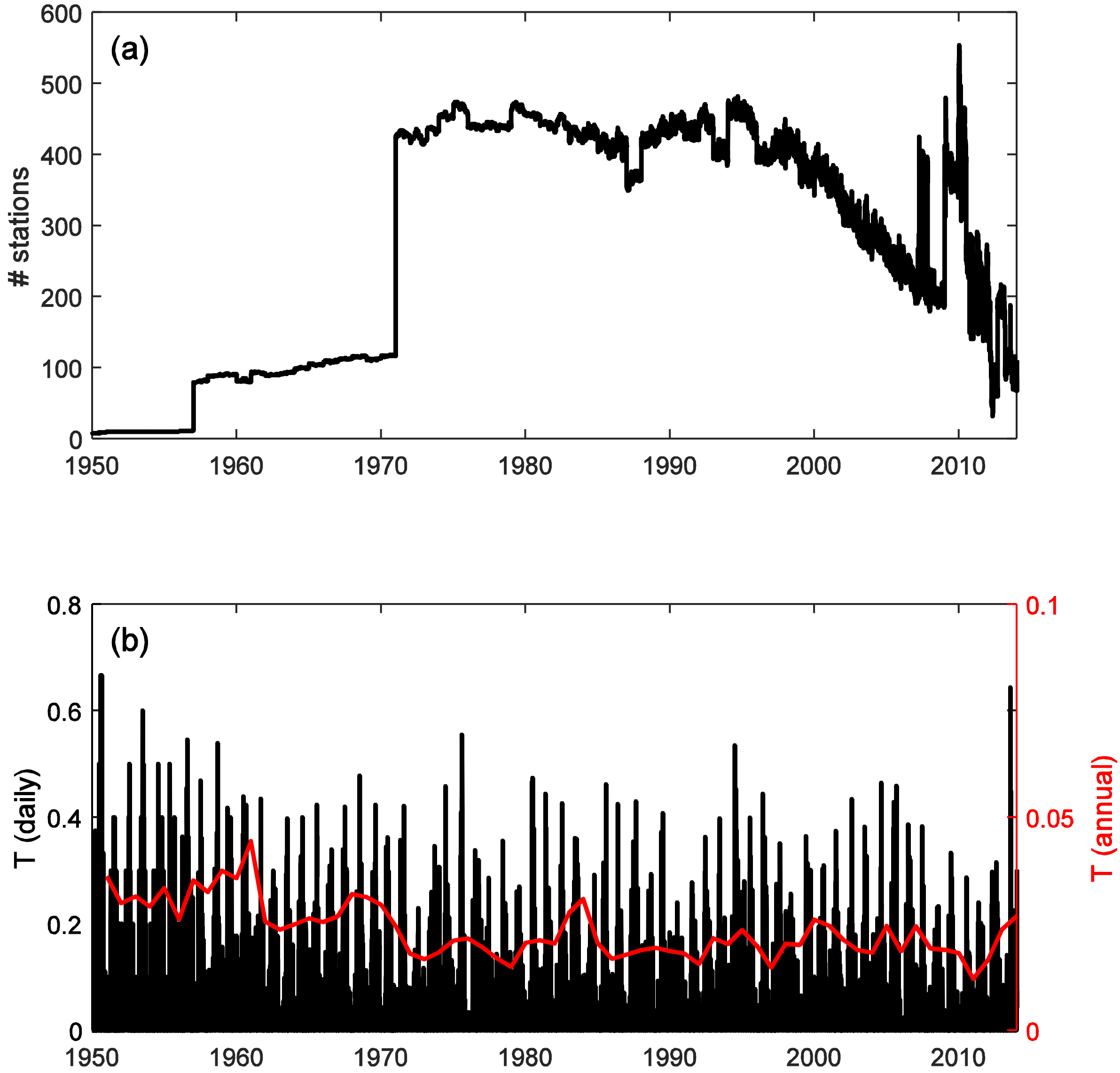

Figure 1: (a) The number of stations making thunder day observations. (b) The daily (black and left-hand axis) and annual (red and right-hand axis) values of *T*, the fraction of UK stations reporting thunder on a given day.

Multi-shell rockets and slow-burn composite fireworks are most likely to be mistaken for thunder (Pyrosociety.org.uk, personal communication). It is difficult to obtain data on the widespread use of such fireworks in the UK, but anecdotally at least, they appear to have been in wide-spread public use for UK Bonfire night celebrations since at least the early 1980s. Thus this study primarily considers the period 1980–2010. Changing the start year for this interval by ±10 years does not qualitatively change the results reported in this study, as discussed later. Figure 1b shows daily (black) and annual (red) *T*. As expected, there is a very strong seasonal variation in *T*. There is some evidence in a change in the annual mean *T* associated with the increase in number of stations from 1950 through to the early 1970s. After this time, there does not appear to be any immediate correspondence between changes in the number of stations and annual *T*, suggesting that the spatial distribution of reporting stations is not changing dramatically through the period of interest (1980–2010).

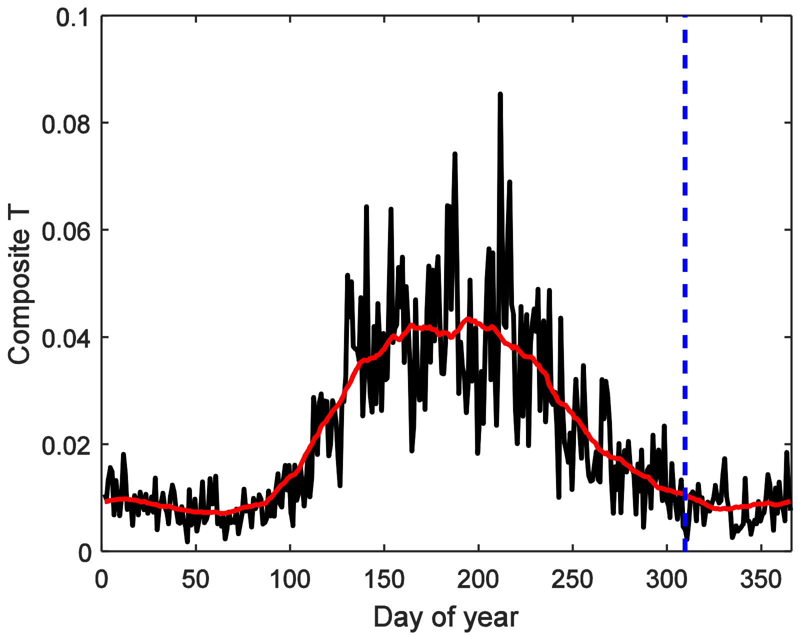

Figure 2: A composite of the annual mean variation in *T* for the period 1980–2010. Black lines show the daily values, red lines show 50-day running means. The blue dashed line shows 5 November (for non-leap years).

In order to compare the reporting of thunder on 5 November with the rest of the year, it is necessary to subtract the strong annual variation which dominates thunderstorm occurrence. Mean *T* for each day of year is computed over the whole 1980–2010 period (the black lines in Figure 2). In order to make an annual climatology, a 50-day running mean of the annual composite is computed (the red line in Figure 2), denoted *T50*. The size of this smoothing window does not qualitatively affect the results presented here, as long as it is greater than ~10 days and shorter than ~6 months. The climatological deviation is then taken to be the difference between the smoothed and unsmoothed value (i.e., *T - T50*). As the magnitude of the climatological deviation will be much greater during times of higher average *T* (summer) than lower average *T* (winter), the fractional climatological deviations, *ΔT*, are computed (i.e., *ΔT = [T-T50]/T50*).

Organised firework displays and private firework use may occur a number of days around 5 November, particularly in years when it falls during the middle of the week and the celebrations are shifted either forward or backward to the weekend. If it assumed that fireworks use is focussed on the Friday or Saturday closest to 5 November, then on average this will mean fireworks use is within ± 1.3 days on fireworks night. To capture this, a 3-day running mean is applied to *ΔT*, yielding *ΔT3*. This may miss some activity in years when fireworks celebrations are split between the weekends before/after 5 November, but this is preferable to over-smoothing the whole data set and removing the possible signal.

An annual composite of *ΔT3*, centred on 5 November so as to allow for leap days, is shown for the 1980–2010 period in Figure 3b. In this annual composite, there is clearly no evidence for an increase in the false positive reporting of thunder due to fireworks. In fact, 5 November is the lowest mean *ΔT3* value.

The most basic estimate of the probability of the lowest *ΔT3* value falling on 5 November purely by chance is that it is 1/N, in this case approximately 1 in 365 (or closer to 1 in 100 if the 3-day smoothing window is considered). But it is more important to quantify the probability that such a value (*<ΔT3>* = -0.67) falls within the natural meteorological variability present in the data. The following "Monte Carlo" approach is taken. Instead of using 5 November in each year as the t=0 time for the composite to produce *<ΔT3>*, random times throughout each year are selected and a new *<ΔT3>* computed. This is done 10,000 times. The grey-shaded panels on Figure 3 show the bands which contain 90, 95 and 99% of the *<ΔT3>* values about these randomly selected times. It can be seen that 5 November is below the 99% band, also suggesting approximately a 1 in 100 probability of the low value occurring purely by chance. (Note, however, that this test implicitly assumes the annual variation has been adequately removed by the climatology.) Figure 4b shows the probability density function of *<ΔT3>* for the 1980–2010 period, using a kernel density estimate. It can be seen that while 5 November is the lowest *<ΔT3>* value, it sits at the edge of the overall variability, rather than being an extreme outlier. Finally, as a simple test of the robustness of this signal, individual decades of data within this period are considered. For the years 1980–1989, 1991-–2000 and 2001–2010, *<ΔT3>* = -0.64, -0.51 and -0.86, and the rank within the distribution is 15, 53 and 2 of 365, respectively. So in all cases, 5 November is well below climatology (though the climatology itself will be poorly described for such short intervals).

Note that Figure 3b also shows a large positive peak in *<ΔT3>* at t = 55 days, i.e., 30 December. It is only significant relevant to the meteorological variation at the 95% level and only present in the 1990–1999 data, not in the 1980s or 2000s. Its possible relation to fireworks displays associated with New Year's Eve celebrations is discussed later.

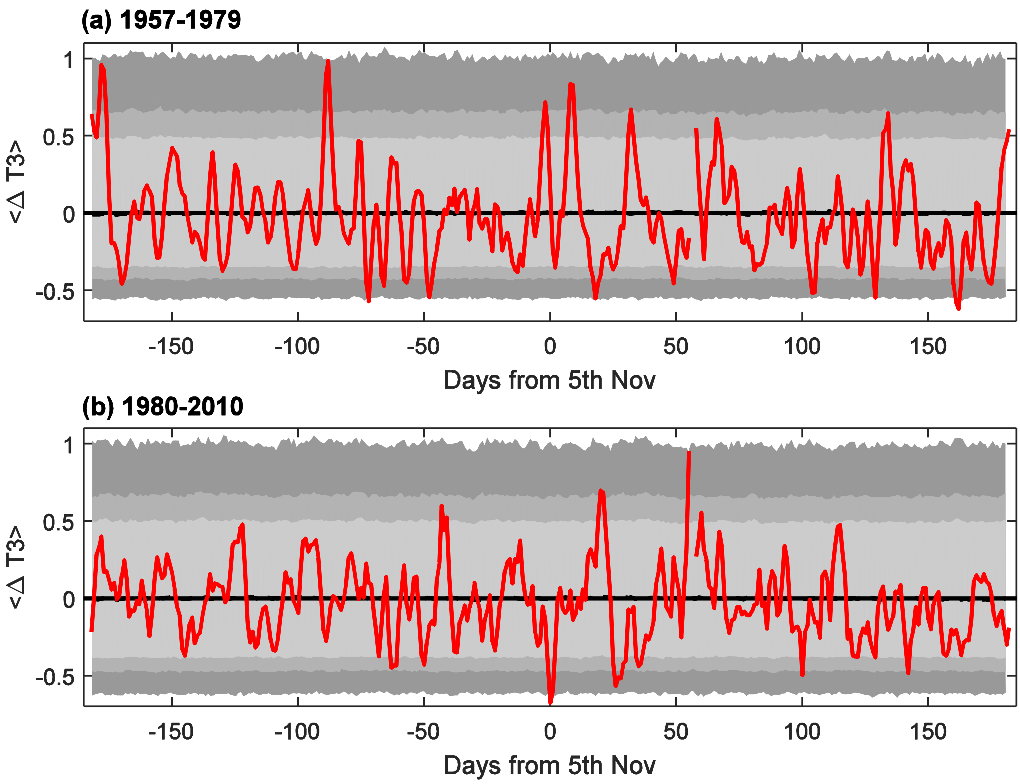

Figure 3: Mean fractional climatological deviation of thunder days, ΔT3, about 5 November. Panel (a) shows the period 1957–1979. Panel (b) shows the period 1980–2010. The grey-shaded areas shows the intervals containing 90, 95 and 99% of the variations from a Monte Carlo sampling of ΔT3 in the given period. Note that in panel (b) there is no evidence for an enhanced false positive rate around 5 November. In fact, ΔT3 on 5 November is the lowest observed, suggesting a systematic under-reporting of thunder.

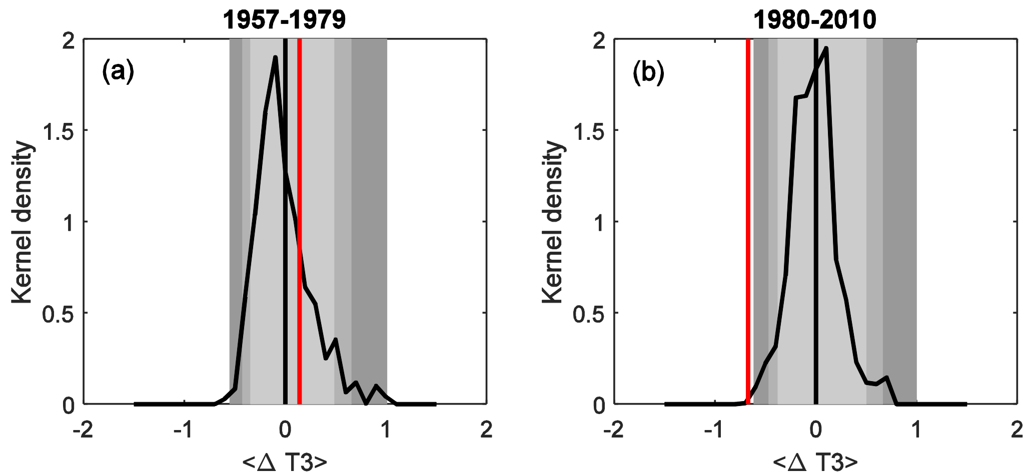

Figure 4: Probability density functions, computed from kernel density, of ΔT3 for the (a) 1957–1979 and (b) 1980–2010 periods. The grey-shaded areas shows the intervals containing 90, 95 and 99% of the variations from a Monte Carlo sampling of ΔT in the given period. The red lines show the 5 November.

As a comparison to the 1980–2010 period, wherein UK fireworks use around 5 November is expected to be widespread, the earlier period, 1957-1979, is considered here. 1957 is taken as the start date as the number of stations rises to approximately 100 (see Figure 1a). Unfortunately, there is a large jump in the number of stations in the early 1970s, but limiting the period to 1973–1979 reduces the meaningfulness of the climatology required to compute *ΔT3*, which is even less desirable. With this limitation in mind, Figures 3a and 4a show the analysis for 1957–1979. From the asymmetric probability distribution function, it is clear the change in number of stations is having an effect. Nevertheless, it can be seen that 5 November for this periods lies somewhere within the middle of the $\langle \Delta T3 \rangle$ variability. Also of note is that there is one point below the 99% lower bound ($\langle \Delta T3 \rangle = -0.62$ at +162 days from 5 November, i.e., 25 or 26 April). This is to be expected as part of the normal meteorological variability (i.e., by definition, 1 point in 100 should be outside the 99% band on average).

Discussion and conclusions

Audible thunder records, or "thunder days," are expected to be susceptible to false positives, particularly from explosions. Thus in the UK, one might reasonably expect an over-reporting of thunder on and around 5 November. Fireworks experts were spilt on the issue, with some expressing doubt that shells and rockets would be mistaken for thunder, while others argued that fireworks are, on occasion, mistaken for thunder, particularly multi-shell fireworks and slow-burning compositions *[Pyrosociety.org.uk, personal communication].* In fact, no increase in thunder, relative to climatology, is found for the 1980–2010 period when the signal is expected to be most pronounced. Similarly, there is not strong evidence for an enhancement in thunder reporting on New Year's Eve, as the peak is on 30 December and celebrations are not traditionally spread around that time. Furthermore, the peak is only present in the 1990–1999 interval and not 1980–1989 or 2000–2009. Thus there is no direct evidence for false positives in the thunder day data as a result of fireworks.

In fact, around 5 November for 1980–2010, there has been a dearth of thunder reported (relative to the climatological variation). A similar drop in reported thunder is not found for 31 December, but New Year's Eve firework displays are a more recent phenomenon and personal firework use remains more limited. The apparent lack of thunder for 5 November is at the edge of the observed variability in the data, so chance or simple meteorological variation cannot be completely ruled out. But an alternative explanation of observer bias seems more plausible. Audible thunder records are not compiled by an unthinking listening device or computer algorithm. They are put together by human observers, which come bundled with "a priori" knowledge that around 5 November there are a lot of loud noises which, they believe, can be mistaken for thunder. Thus they will be more likely to "second guess" [*Pliske et al.*, 2004] any potential thunder observation as a false positive resulting from loud fireworks. The results presented here suggest observers are actually playing it too safe. The actual probability of an observer mistaking fireworks for thunder is much lower than the observer assumes. Thus observers should trust more in their ability to discriminate between thunder and fireworks.

Acknowledgements

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