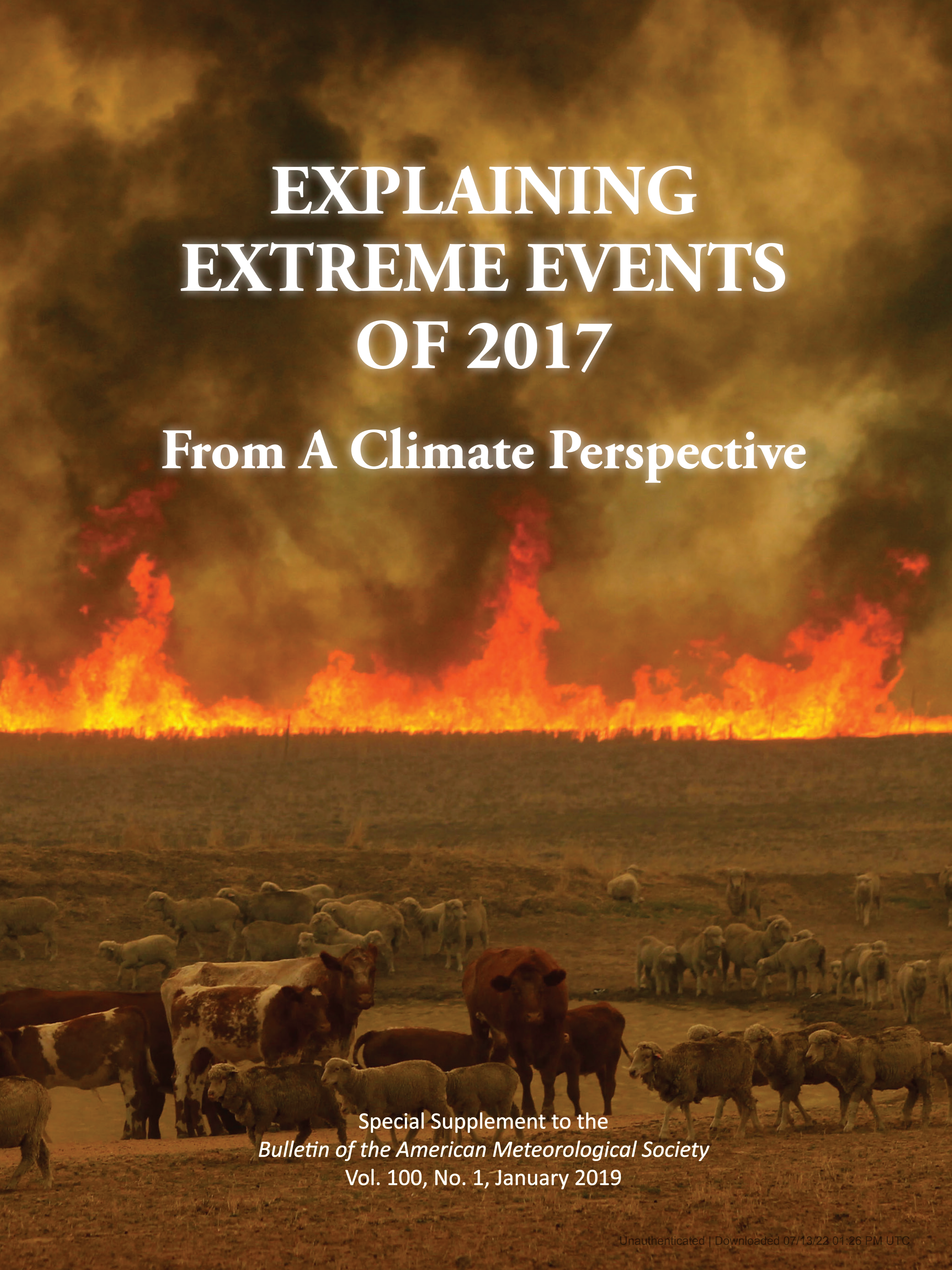
The Exceptional Summer Heat Wave in Southern Europe 2017

Sarah F. Kew, Sjoukje Y. Philip, Geert Jan van Oldenborgh, Gerard van der Schrier, Friederike E. L. Otto, Robert Vautard



EXPLAINING EXTREME EVENTS OF 2017

From A Climate Perspective

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EXPLAINING EXTREME EVENTS OF 2017 FROM A CLIMATE PERSPECTIVE

Editors

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COVER CREDIT:

—Sir Ivan Bushfire, February 2017. A bushfire that started near Leadvill, east of Duneedoo in the New South Wales (NSW) Central tablelands, ripped through bush and grasslands in a day that NSW fire authorities classified as catastrophic. Sheep and cattle maneuver around a dam to avoid a fast running bushfire as the fire front moved east. Photograph by Dean Sewell/Oculi.

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TABLE OF CONTENTS

1. Introduction to Explaining Extreme Events of 2017 from a Climate Perspective. S1
2. Actuaries are Paying Attention to Climate Data S5
3. Hydroclimatic Extremes as Challenges for the Water Management Community: Lessons from Oroville Dam and Hurricane Harvey S9
4. Observations of the Rate and Acceleration of Global Mean Sea Level Change S15
5. Anthropogenic Contributions to the Intensity of the 2017 United States Northern Great Plains Drought S19
6. Attribution of the 2017 Northern High Plains Drought S25
7. The Extremely Wet March of 2017 in Peru S31
8. Contribution of Anthropogenic Climate Change to April–May 2017 Heavy Precipitation over the Uruguay River Basin S37
9. December 2016: Linking the Lowest Arctic Sea-Ice Extent on Record with the Lowest European Precipitation Event on Record S43
10. The Exceptional Summer Heat Wave in Southern Europe 2017 . . . . S49
11. Examining the Potential Contributions of Extreme "Western V" Sea Surface Temperatures to the 2017 March–June East African Drought S55
12. Risks of Pre-Monsoon Extreme Rainfall Events of Bangladesh: Is Anthropogenic Climate Change Playing a Role? S61
13. The Effects of Natural Variability and Climate Change on the Record Low Sunshine over Japan during August 2017 . . . . S67
14. Anthropogenic Contribution to 2017 Earliest Summer Onset in South Korea S73
15. Anthropogenic Influence on the Heaviest June Precipitation in Southeastern China since 1961 . . . . S79
16. Attribution of the Persistent Spring–Summer Hot and Dry Extremes over Northeast China in 2017. . . . . S85
17. Anthropogenic Warming has Substantially Increased the Likelihood of July 2017–Like Heat Waves over Central Eastern China S91
18. Attribution of a Record-Breaking Heatwave Event in Summer 2017 over the Yangtze River Delta. S97
19. The Role of Natural Variability and Anthropogenic Climate Change in the 2017/18 Tasman Sea Marine Heatwave. S105
20. On Determining the Impact of Increasing Atmospheric CO_2 on the Record Fire Weather in Eastern Australia in February 2017 . . . . S111

chapter 10

THE EXCEPTIONAL SUMMER HEAT WAVE IN SOUTHERN EUROPE 2017

Sarah F. Kew, Sjoukje Y. Philip, Geert Jan van Oldenborgh, Friederike E. L. Otto, Robert Vautard, and Gerard van der Schrier

Across the Euro-Mediterranean the likelihood of a heat wave at least as hot as summer 2017 is now on the order of 10%. Anthropogenic climate change has increased the odds at least threefold since 1950.

INTRODUCTION. Summer 2017 in western Europe and the Euro-Mediterranean was remarkable in particular for its very hot heat waves. Following an exceptionally warm June (Otto et al. 2017) in western Europe, the heat returned to southern Spain in July and contributed to substantial forest fires. Madrid (Retiro) hit 40.6°C on July 13, equaling the 2012 record. Heat episodes continued into August, extending to many areas in southern Europe (see Fig. 1b).

Early August saw a particularly intense heat wave that was described as the "worst heat wave since 2003" (BBC 2017) in southern Europe and became dubbed as "Lucifer," with local maximum temperatures in Italy and the Balkans topping 40°C for several days. Several countries issued code red alerts (Fig. 1a). Records were broken in southern France (4 August, Nîmes-Courbessac, 41.6°C), for example, and in Corsica and Croatia, where nighttime temperatures exceeded 30°C. Widespread heat and lack of precipitation triggered a severe drought in many areas, persisting into fall.

Southern Europe is familiar with very hot summer days. However, sustained extreme temperatures become hazardous, particularly for the very young and elderly and those suffering from heart conditions, high blood pressure, or asthma (IFRC 2017), or tourists unaccustomed to high temperatures. High energy and water consumption during prolonged heat waves also puts strain on supplies.

There were some reports of deaths associated with the August heat wave, but usually the full impact is only evident after analyzing and attributing the total mortality excesses (e.g., D'Ippoliti et al. 2010; Mitchell et al. 2016). Increased hospital admissions with people suffering from heat-related conditions were also reported. The agricultural industry bore the brunt of the hot and dry summer season, with Bosnia, Serbia, and Italy experiencing major losses (Zuvela and Vasovic 2017). In Italy, grape harvests (Horowitz 2017) were carried out weeks in advance to reduce risk of heat damage.

Here, we investigate the return period and changing risk of heat waves like those of summer 2017 in the Euro-Mediterranean, seeking a spatial and temporal event definition related to the impacts that society experienced (Otto et al. 2018). We analyze the annual maxima of 3-day-mean area-averaged daily maximum temperatures (TX3X) for a box over southeast Europe ("SE-box"; 8°–24°E, 36°–48°N; Fig. 1b), using the European daily high-resolution gridded dataset (E-OBS; 1950–present; Haylock et al. 2008). This spatial event definition is closely linked to impacts on the national scale, as the SE-box corresponds well with the early August 2017 Meteoalarm red-alert regions (Fig. 1a)—warnings issued by national weather services and therefore related to how weather is nationally perceived—for which there is good data homogeneity (up to 48°N). The 3-day temporal definition is representative of the period of time that sustained high temperatures became more hazardous (D'Ippoliti et al. 2010). Local station data are generally more homogeneous

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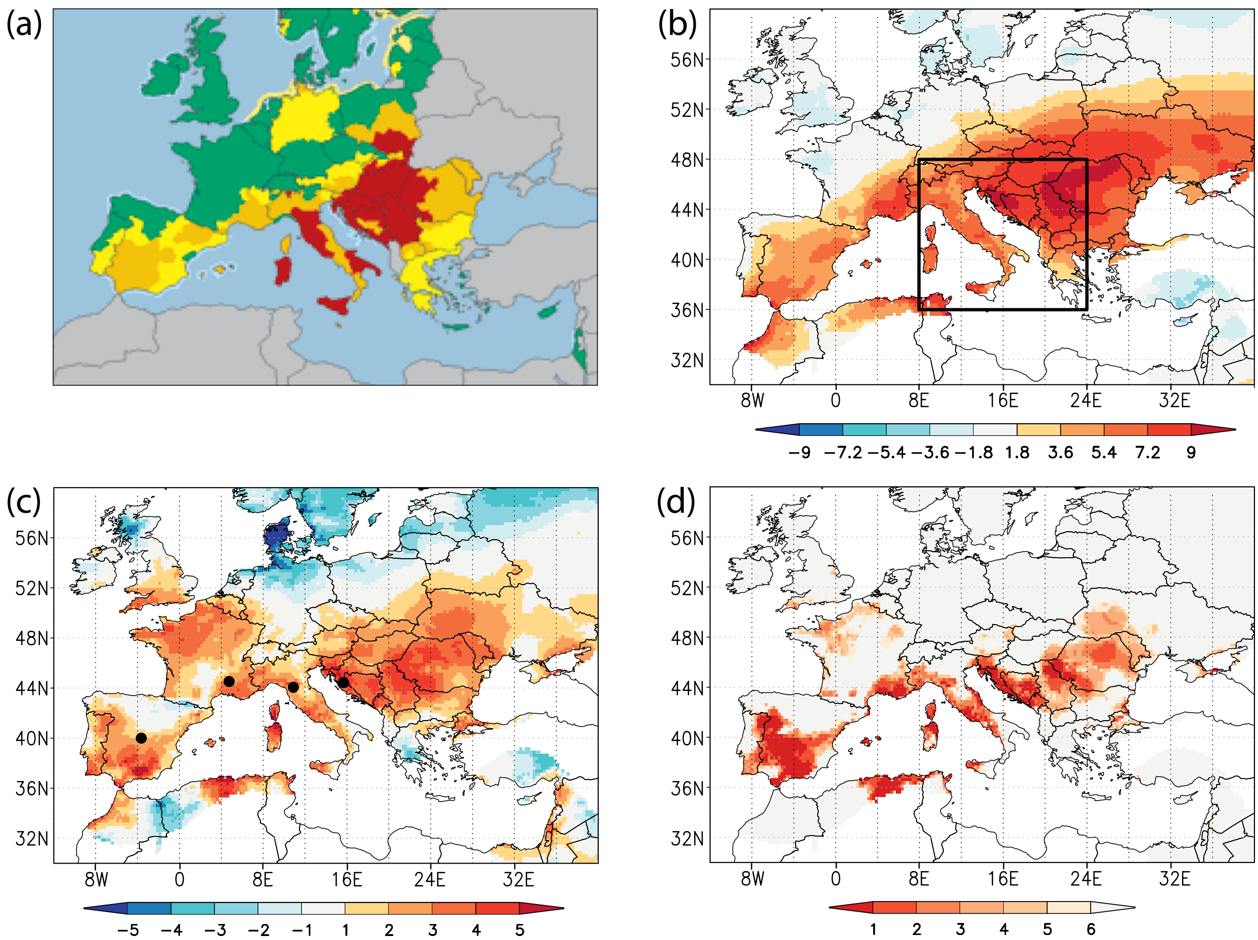

Fig. 1. Context of the event in maps. (a) Meteoalarm weather alerts for 1420 CET 4 Aug 2017. Note that maps are issued every 20 min; regions experiencing an alarm varied slightly during the hea twave of 3–5 August. All red warnings, and also the orange and yellow warnings in southern Europe, are for extreme high temperature. (b) 3-day averaged Tmax anomalies (w.r.t 1981–2010) for 3–5 Aug 2017, with box illustrating the area selected for analysis. Also shown are annual maxima of 3-day averaged Tmax as (c) anomalies w.r.t 1981–2010 and (d) rank of the year 2017 in the 1950–2017 series. Locations of the stations used in Spain, France, Italy, and Croatia (black markers) are given in (c). Source: E-OBS data.

in their time series than gridded observations, which can suffer from varying variability (heteroscedasticity) due to varying numbers of input stations per grid box over time: more stations can average out some of the noise, and no stations gives climatology. A resulting artificial change in variability over time could be incorrectly interpreted as a change in the frequency of extremes due to global warming. We therefore additionally analyze homogenized station series of TX3X, based on the European Climate Assessment and Dataset (ECA&D; Klein Tank et al. 2002), for four stations (see dots in Fig. 1c): Madrid-Cuatro Vientos Airport (Spain), Montélimar (France), Monte Cimone (Italy), and Gospić (Croatia). The record heat wave conditions were to the south of the stations analyzed here in Spain and France (see ranking of 2017 TX3X in Fig. 2d), but we could not find (by visual inspection of the TX3X time series) non-coastal stations without discontinuities in those regions and the models we use cannot resolve the required coastal effects.

To determine the return periods of TX3X, we fit the temperature observations to a generalized extreme value (GEV) distribution, with μ being the position parameter, σ the scale parameter, and ξ the shape parameter. Global warming is factored in by allowing the GEV fit to shift with the (low-pass filtered) global mean surface temperature (T_{global}), that is, $\mu = \mu_0 + \alpha T_{global}$, with α being the fitted trend in K K^{-1} and with σ and ξ fixed. This assumption, that global warming influences only the mean of the distribution and not the variability or shape, is checked in climate models with enough data to analyze the distributions of the past and present climate in independent time

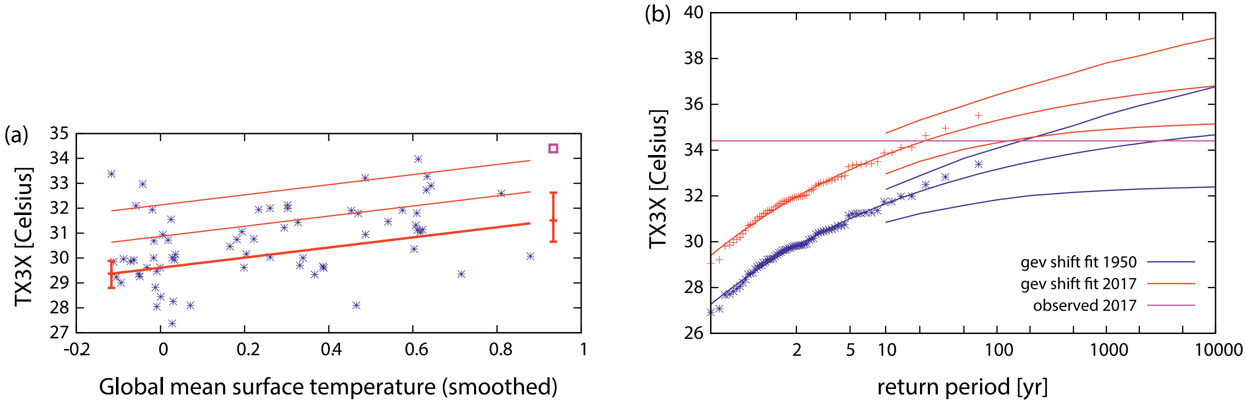

Fig. 2. An example of the results for the observed TX3X for the SE-box. (a) The fit applied to observations, where asterisks mark the observations, the thick line denotes the time-varying mean (fitted position parameter), the thin lines mark 1σ and 2σ (with σ the fitted scale parameter) above the mean, and the two vertical red whiskers show the 95% confidence interval of the fitted position parameter for the climates of 1950 (leftmost) and 2017 (rightmost). (b) Return period distributions shifted to the climates of 2017 (red lines and crosses) and the past (1950; blue lines and asterisks), including error margins (red and blue bounding curves). The purple square in (a) and horizontal line in (b) indicate the 2017 value (not included in the fits).

slices/experiments. Confidence intervals are estimated using a 1000-member non-parametric bootstrap.

After validations on several model ensembles (weather@home, the European Consortium Earth System Model (EC-Earth), the Hadley Centre Global Environment Model, version 3a, (HadGEM-3A), and the European branch of the Coordinated Regional Downscaling Experiment (EURO-CORDEX)] we perform a standard analysis to attribute changes in the return period to climate change, and synthesize the results. Similar methods, including the GEV approach described above, have been applied in van Oldenborgh et al. (2015), Uhe et al. (2016), Philip et al. (2018), and van Oldenborgh et al. (2018).

RESULTS. Our observational analysis shows that the 2017 SE-box TX3X peaked for 3–5 August at 34.4°C (3.4°C higher than the average 3-day heat wave in 1981–2010) in the E-OBS dataset. The return period in 2017 is about 20 years [95% confidence interval (CI): 7–130 yr], whereas in 1950 the (extrapolated) return period is about 3000 years (97.5% CI: at least 160 yr); see Fig. 2. The ratio of these return periods gives a best estimate of the risk ratio (RR) between 1950 and 2017 of roughly 140 (97.5% CI: at least 5), and a change in magnitude of about 2.1°C (95% CI: 0.9°–3.7°C).

In this particular study, model validation (see the online supplemental information) revealed that the models overestimate the variability found in the SE-box-averaged TX3X observations. Therefore we cannot provide RRs for models or a synthesis combining observations and models for the SE-box. It is nevertheless clear that there is an increase in the occurrence of heat waves like those of summer 2017. Observations revealed that, since 1950, the risk at least quintupled, but probably increased much more. We emphasize communication of the conservative lower limit of "at least 5" to avoid results dependent on large extrapolations. A formal attribution to anthropogenic climate change is therefore not possible but is very plausible given the attributed rise in seasonal mean temperatures (Stott et al. 2004).

The results for the station analysis are listed in Table 1. As expected, the return periods for Madrid-Cuatro Vientos and Montélimar are not extreme, but in Monte Cimone and Gospić the 2017 heat wave was the highest on record. All stations show a significant trend toward more frequent extremes ($p < 0.025$). We also include model results (Table 1) for models evaluated (see the supplement) to perform adequately at the individual station locations. Three out of the four stations are located outside of the SE-box, which explains part of the different outcome in the models' performance. Note that the signal-to-noise ratio of the observations will be smaller for individual stations than for an area average. Model systematic errors may therefore fall within uncertainty ranges of the observations more easily at single locations. A synthesized (weighted average) result for each station combining observed and available validated model results is given in the final column of Table 1. This provides estimates of the lower and upper bounds (95% CI) of the risk ratio between 1950 and 2017. In general, the

Table 1. Summary of observational and validated model results in TX3X for the station locations.					
Station	**Observed 2017 TX3X and anomaly w.r.t. 1981–2010**	**Return period in current climate (95% CI)**	**Year of comparison for risk ratio**	**Risk ratio (95% CI)**	**Synthesized results: Risk ratio for 2017/1950**
Spain: Madrid-Cuatro Vientos (1945–now)	39.5°C, 6.3°C	6 yr (3 … 19 yr)	1950	13 (2 … 1300)	6 … 50
EURO-CORDEX			1971–2000	5 (3 … 7)	
France: Montélimar (1921–2017)	37.9°C, 8.0°C	6 yr (3 … 20 yr)	1950	3.3 (1.1 … 9.5)	3 … 8
EC-Earth			1950	4.9 (3.8 … 6.3)	
EURO-CORDEX			1971–2000	4.2 (2.5 … 5.8)	
Italy: Monte Cimone (1951–2017 with gap)	23.5°C, 14.7°C	20 yr (6 … 500 yr)	1950	220 (1.9 … ∞)	3.5 … 8
EC-Earth			1950	4.7 (3.6 … 5.8)	
EURO-CORDEX			1971–2000	3.5 (2.5 … 7.5)	
Croatia: Gospić (1906–2017 with gaps)	37.5°C, 10.4°C	40 yr (4 … ∞ yr)	1950	60 (4 … ∞)	3 … 7
EC-Earth			1950	4.4 (3.3 … 5.4)	

lower bounds of the observations and model results are of the same order of magnitude but the upper bounds and best estimates differ with large differences in sample sizes and higher variability in the models. Besides providing a formal attribution, the effect of the model results in the synthesis is to confine the large uncertainty range on the upper bound.

In general, observations and models agree on a tendency toward more frequent 3-day summer temperature extremes like in summer 2017, at the selected individual station locations. Accounting also for the observed increase in risk in the SE-box, we estimate that probabilities in 2017 are at least 3.5 times higher compared to 1950 (and at least 4 times higher compared to 1900).

DISCUSSION. Our impact-based approach to attribution for last summer's Euro-Mediterranean heat waves yielded a return time in the current climate of around 20 years for southeastern Europe, the region suffering the greatest impacts. This is similar to King (2017), indicative that results are insensitive to minor differences in event definition. Significant trends in the likelihood of 3-day heat waves can be seen not only in area-averaged observations but also in individual station series. Foundational attribution work on European *seasonal* temperature extremes (e.g., Stott et al. 2004; Schär et al. 2004; Christidis et al. 2015) has led to a general view that the "heat wave attribution problem" is largely solved. On the *daily* time scale however, this is not the case: Models confirm an increase in likelihood with global warming but fail to reproduce some key features of the observed distribution of heat waves [variability in southeastern Europe (this study) and trends and variability in northern Europe (Sippel et al. 2016; Min et al. 2013)]. Future research is necessary to reveal the mechanisms. Possible hypotheses are over-efficient model moisture recycling leading to spatial, and over time, temporal, temperature heterogeneity, insufficient moisture transport, or an incorrect variability in boundary layer height.

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REFERENCES

BBC, 2017: Europe heatwave sparks health warnings as temperatures soar. BBC, 4 August 2017, www.bbc.com/news/world-europe-40825668.

Christidis, N., G. S. Jones, and P. A. Stott, 2015: Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nat. Climate Change*, **5**, 46–50, https://doi.org/10.1038/nclimate2468.

D'Ippoliti, D., P. Michelozzi, C. Marino, and Coauthors, 2010: The impact of heat waves on mortality in 9

European cities: Results from the EuroHEAT project. *Environ. Health*, **9**, 37, https://doi.org/10.1186/1476-069X-9-37.
Haylock, M. R., N. Hofstra, A. M. G. Klein Tank, E. J. Klok, P. D. Jones, and M. New, 2008: A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. *J. Geophys. Res.*, **113**, D20119, https://doi.org/10.1029/2008JD010201.
Horowitz, J., 2017: In Italy's drought-hit vineyards, the harvest of a changing climate. 22 August 2017, *New York Times*, www.nytimes.com/2017/08/22/world/europe/barolo-italy-wine-climate-change.html?mcubz=0&_r=0.
IFRC, 2017: IFRC warns of serious health risks as extreme heatwave sweeps across Europe. 4 August 2017, International Federation of Red Cross and Red Crescent Societies, http://media.ifrc.org/ifrc/press-release/ifrc-warns-serious-health-risks-extreme-heatwave-sweeps-across-europe/.
King, A., 2017: Southeast Europe swelters through another heatwave with a human fingerprint. *The Conversation*, accessed 19 March 2018, https://theconversation.com/southeast-europe-swelters-through-another-heatwave-with-a-human-fingerprint-82139.
Klein Tank, A. M. G., and Coauthors, 2002: Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *Int. J. Climatol.*, **22**, 1441–1453, https://doi.org/10.1002/joc.773.
Min, E., W. Hazeleger, G. J. van Oldenborgh, and A. Sterl, 2013: Evaluation of trends in high temperature extremes in north-western Europe in regional climate models. *Environ. Res. Lett.*, **8**, 014011, https://doi.org/10.1088/1748-9326/8/1/014011.
Mitchell, D., and Coauthors, 2016: Attributing human mortality during extreme heat waves to anthropogenic climate change. *Environ. Res. Lett.*, **11**, 074006, https://doi.org/10.1088/1748-9326/11/7/074006.
Otto, F. E. L., and G. J. van Oldenborgh, R. Vautard, and C. Schwierz, 2017: Record June temperatures in western Europe. World Weather Attribution, accessed 30 March 2018, www.worldweatherattribution.org/analyses/european-heat-june-2017/.
——, S. Philip, S. Kew, S. Li, A. King, and H. Cullen, 2018: Attributing high-impact extreme events across timescales—A case study of four different types of events. *Climatic Change*, **149**, 399–412. https://doi.org/10.1007/s10584-018-2258-3.
Philip, S. Y., S. F. Kew, M. Hauser, B. P. Guillod, A. J. Teuling, K. Whan, P. Uhe, and G. J. van Oldenborgh, 2018: Western US high June 2015 temperatures and their relation to global warming and soil moisture. *Climate Dyn.*, **50**, 2587–2601, https://doi.org/10.1007/s00382-017-3759-x.
Schär, C., P. L. Vidale, D. Lüthi, C. Frei, C. Häberli, M. A. Liniger, and C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. *Nature*, **427**, 332–336, https://doi.org/10.1038/nature02300.
Sippel, S., F. E. L. Otto, M. Flach, and G. J. van Oldenborgh, 2016: The role of anthropogenic warming in 2015 central European heat waves [in "Explaining Extreme Events of 2015]. *Bull. Amer. Meteor. Soc.*, 97, S51–S56, https://doi.org/10.1175/BAMS-D-16-0150.1.
Stott, P. A., D. A. Stone, and M. R. Allen, 2004: Human contribution to the European heatwave of 2003. *Nature*, **432**, 610–614, https://doi.org/10.1038/nature03089.
Uhe, P., F. E. L. Otto, K. Haustein, G. J. van Oldenborgh, A. D. King, D. C. H. Wallom, M. R. Allen, and H. Cullen, 2016: Comparison of methods: Attributing the 2014 record European temperatures to human influences. *Geophys. Res. Lett.*, **43**, 8685–8693, https://doi.org/10.1002/2016GL069568.
van Oldenborgh, G. J., R. Haarsma, H. de Vries, and M. R. Allen, 2015: Cold extremes in North America vs. mild weather in Europe: The winter of 2013–14 in the context of a warming world. *Bull. Amer. Meteor. Soc.*, **96**, 707–714, https://doi.org/10.1175/BAMS-D-14-00036.1.
——, and Coauthors, 2018: Extreme heat in India and anthropogenic climate change. *Nat. Hazards Earth Syst. Sci.*, **18**, 365–381, https://doi.org/10.5194/nhess-18-365-2018.
Zuvela, M., and A. Vasovic, 2017: 'Lucifer' heat wave holds Italy, eastern Europe in fiery grip. 4 August 2017, Reuters, www.reuters.com/article/us-europe-weather-heatwave/lucifer-heat-wave-holds-italy-eastern-europe-in-fiery-grip-idUSKBN1AK1I8.