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Characteristics of Heatwaves in Africa: Morocco 2000 and South Africa 2015/16

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Abstract:

Heatwaves pose an ever increasing risk to African communities as exposure to heat extremes can have a drastic effect on individuals and in some cases can even result in death. This study presents new information about the characteristics of historical African heatwaves including a comprehensive synopsis of documented heatwave events from 1980 until 2020.Detailed research on heatwave case studies helps to inform the development of early warning systems and forecasting, which is an urgent priority. Here, the focus is on two reported heatwaves, Morocco 2000 and South Africa 2015/16. Both heatwaves feature in the EM-DAT database and include reported impacts, with the Morocco heat being the only hazard to be associated with an economic cost. In addition, these heatwaves reveal how the mechanisms behind them are closely influenced by synoptic systems and geography of their regions. Further, It is demonstrated there is some reporting by African Nations for heatwaves but that this needs significant improvement.

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1. Introduction

Africa is witnessing a rapid increase in dangerous weather extremes, including floods, drought and extreme heat (IPCC, 2013, Russo et al 2016). On a global scale heat extremes are known to be lethal, with more than 70,000 and 55,000 people dying globally in 2003 and 2010 (Schubert *et al* 2011, Robine *et al* 2008). However, there is surprisingly little evidence on heat extremes and their impacts across the African continent (Harrington and Otto, 2020; van der Walt and Fitchett , 2021).

Robust evidence is important for Africa for many reasons. It is a continent that is home to a rapidly increasing population, where these events represent a serious threat to local communities, and where many lack access to the resources needed to build resilience and adaptive capacity (Adger *et al* 2009, Russo *et al* 2016). The sparse evidence that exists demonstrates that heat in African nations can be deadly (Frimpong *et al* 2017, Codjoe *et al* 2020) and has many impacts for example reducing crop yields (Mubiru *et al* 2018, Mwaura and Okoboi 2014, Epule *et al* 2018, Abdulai *et al* 2018) and changing how communities migrate (Abass *et al* 2018, Gray and Wise 2016). Climate change projections show that heat could become so extreme in some regions of Africa that it will be uninhabitable unless there is urgent mitigation (Russo *et al* 2016, Rohat *et al* 2019, Schwingshackle *et at* 2021).

In addition there are calls by many for the international community to come to a consensus and face the risk posed by heat globally and in Africa (Harrington and Otto 2020, Russo *et al* 2016, Global Commission on Adaptation 2020, World Meteorological Organization 2018). This is a mandate for many working in the humanitarian sector who are on the frontline of climate emergency: *“An understanding of how temperatures have impacted people in Africa during past extreme heat events is critical to building public consensus on the issue and moving us toward action."* (Roop Singh, Climate Risk Adviser for the Red Cross Climate Centre, pers comm).

This study focuses on the extent to which heatwaves are recorded for the continent of Africa. It presents the first list of reported heatwaves in literature for the continent. Further, two heatwave case studies for Morocco July/August 2000 and South Africa 2015/16 and their characteristics are explored. This study sets a mandate for other reported heatwaves to be explored further and calls for more robust heat hazard reporting in African Nations.

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2. Methods

In this study a mixed method approach is used. Analysis of literature is employed to provide a synopsis of reported heatwaves, before the focus shifts to meteorological analysis of two heatwave case studies of Morocco 2000 and South Africa 2015/16. This approach was chosen as it allows for a more useful analysis of case studies directly from literature, than reviewing literature alone.

2.1 Synopsis of Africa historic heatwaves

A synopsis of historic heatwaves that occurred in Africa between 1980 and 2020 to date was compiled based on analysis of 21 academic papers, grey literature and EM-DAT. The chosen literature had to meet the criteria of having a focus on historic heatwaves in Africa and include either a physical characteristic of the heatwave or impact. Grey literature includes the World Meteorological Organization (WMO) Reports (e.g. World Meteorological Organisation, 2013) and the American Meteorological Society (AMS) State of the Climate publications (e.g. American Meteorological Society, 2004).

2.2 Defining a Heatwave

There is not a universal definition of heatwaves, as such we define a heatwave using an adaptation of the World Meteorological Organisation (WMO) definition for the Universal Thermal Climate Index (UTCI). According to the WMO heatwaves can be defined as *"A period of marked unusual hot weather (maximum, minimum and daily average temperature) over a region persisting at least three consecutive days during the warm period of the year based on local (station-based) climatological conditions, with thermal conditions recorded above given thresholds"* (World Meteorological Organization 2018a). Following that we define a heatwave in terms of heat stress when the mean UTCI is above the climate 90th percentile for the region. This is above 26.1°C UTCI (the 90th Percentile for December and January 1981 to 2019) for South Africa and 28.2°C UTCI (the 90th Percentile for July and August 1981 to 2010) for Morocco.

The UTCI is a thermal index which makes use of the meteorological parameters of 2m temperature, 2m dew point temperature, 10m wind speed and mean radiant temperature and a body model (Di Napoli *et al* 2021). It has been compared to many other thermal indices

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such as apparent temperature and heat index and captures well an average body response to the thermal environment (Zare *et al* 2018, Jendritzky *et al* 2012, Blazejczyk *et al* 2012). It has further been shown to be able to forecast heatwaves internationally (Pappenberger *et al* 2015) and accurately indicate extreme heat for Africa (Guigma *et al* 2020).

2.3 Historical Heatwaves Anomalies

This study provides analysis of anomalies of mean values of variables that are indicative of heatwaves (Guigma *et al* 2020, Oueslati *et al* 2017) for 2m air temperature, the UTCI and geopotential height at 500hpa (z500) and 850hpa (z850) for two case studies: the 2015/2016 South Africa heatwave and the 2000 Morocco heatwave from the ERA5 reanalysis data set (Hersbach *et al* 2020; Di Napoli *et al* 2021). These heatwaves were chosen because they occur in different climate regions of the continent and exhibit different heat characteristics, notably area. In addition, they have reported impacts which are included in the EM-DAT international disaster database (CRED 2020).

Anomalies were calculated by using the mean of the period of the heatwave, minus the climatological values (1980 to 2010) of the months the heatwave is in, namely December and January for the 2015/2016 South Africa heatwave, and July and August for the 2000 Morocco heatwave. In addition, anomalies for the week before and the week after the heatwave are calculated to provide a picture of the meteorological characteristics that start and end the two heatwaves. All calculations were carried out using Rstudio.

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3. Results

3.1 Heatwaves are reported almost annually since 1980

Academic Literature and reports for Africa show that 39 heatwaves are reported for somewhere in Africa almost every year since 1980 (*Table 1*). Years where no reports could be found are 1984, 1985, 1991, 1993, 1994, 1991, 2001, 2006, 2007 and 2014. The synopsis also demonstrates where heatwaves are most commonly recorded. Specifically, it is seen that the Sahara region (17W, 36E, 17.5N, 30N) has the most reported heatwaves appearing 20 times whilst the Horn of Africa (39E, 50E, 5N, 12.5N) and Madagascar (30E, 50E, 30S, 10S) only appear once.

Characteristics of heatwaves are reported more than their impacts featuring for 26 of the heatwaves in comparison to 9 heatwaves respectively. The most reported characteristic for heatwaves is record temperatures (13), concurrence with El Niño-Southern Oscillation (ENSO) (12) and concurrence with drought (5). The most reported impact of heatwaves is mortality (6); other impacts include changes in social practices and agricultural impacts.

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Table 1: Synopsis of historic heatwaves compiled from news reports, academic literature and climate reports for the African continent from 1980 to 2020.

Year [Season]	Region (corresponding with Table 2)	Heatwave Impacts	Heatwave Characteristics	References
1982/3	Sahel, Sahel-Sudan and Guinea		Concurrent with the Sahel drought and an ENSO event	(Russo *et al* 2016)
1987 [MAM]	South Africa		Concurrent with a drought and an ENSO event	(Russo *et al* 2016)
1988	Sahara			(Russo *et al* 2016)
1989 [SON]	Sahel, Sahel-Sudan and Guinea		Locals reportedly remember high temperatures in Ghana	(Codjoe, *et al.*, 2020)
1990 [SON]	Mediterranean			(Russo *et al* 2016)
1992	Mediterranean, Sahara, Congo and South Africa		Concurrent with a drought	(Barbier *et al* 2018, Harrington and Otto 2020)
1995	Mediterranean and Sahara	32 reported deaths in Egypt		(CRED 2020)
1996	Mediterranean and Sahara	22 reported deaths in Egypt		(CRED 2020)
1997/98	Sahel-Sudan and Congo		Concurrent with an ENSO event	(Oueslati *et al* 2017, Ceccherini *et al* 2017, Russo *et al* 2016)
2000 [JJA]	Mediterranean and Sahara	News reports of 4 million chickens dying. Up to 809,000 USD of damage recorded in Morocco		(Panafrican News Agency 2000, CRED 2020)
2002 [JJA]	Sahara and Congo	60 reported deaths in Nigeria	In the Sahara temperatures as high as 50.6°C during June and July 2002	(World Meteorological Organisation 2013, CRED 2020)
2003 [JJA]	Mediterranean and Sahara	40 reported deaths in Algeria	Heatwave in Europe in the same season	(American Meteorological Society 2004, World Meteorological Organisation 2013, CRED 2020)
2004[JJA]	Mediterranean, Sahara, Sahel, Sahel-Sudan and Congo		ENSO event. Maximum temperature recorded on 29 June	(American Meteorological Society 2005, Russo

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			in Sidi-Slimane, Morocco of 47°C.	*et al* 2016, Oueslati *et al* 2017)
2004/5	Mediterranean, Sahara, Sahel, Sahel-Sudan and Congo		ENSO event	(Russo *et al* 2016)
2005 [JJA]	Mediterranean and Sahara		ENSO event	(World Meteorological Organisation 2013)
2008	Sahara and Congo			(Russo *et al* 2016)
2009/10	Sahara, Sahel, Sahel-Sudano and Guinea.		ENSO event	(Russo *et al* 2016)
2010 [JJA]	Mediterranean and Sahara but Morocco notable		Heatwave in Europe in the same season and an ENSO event.	(Fontaine *et al* 2013, Russo *et al* 2016, World Meteorological Organisation 2013, Oueslati *et al* 2017)
2011	Congo, Mid Africa and Madagascar			(Russo *et al* 2016)
2012	South Africa			(Russo *et al* 2016)
2012 [JJA, OND]	Mediterranean, Sahara, Sahel, Sahel-Sudano and Guinea		Ouarglon, southern Algeria reports 50°C on 2nd August. In October Morocco records temperatures up to 36°C	(Achberger *et al* 2013, Russo *et al* 2016, Ceccherini *et al* 2017)
2013 [MAM]	Sahara, Sahel, Sahel-Sudano, Guinea and South Africa.		Warmest temperature up until 2013 recorded on the 6th March of 43.0°C in Navrongo, Ghana. In South Africa the hottest African temperature up until 2013 is recorded of 47.3°C on 4 March. Temperatures above 40°C recorded in Nigeria	(World Meteorological Organization 2015, Oueslati *et al* 2017)
2013 [JJA]	Mediterranean and Sahara		Daily maximum temperature anomaly of over 10°C recorded.	(World Meteorological Organization 2015)

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2015 [JJA]	Mediterranean and Sahara		Heatwave reported to be lasted up to 40 days	(Benzerga 2015)
2015 [MAM]	Mediterranean, Sahara, Sahel, Sahel-Sudano			(Russo *et al* 2016)
2015 [JJA]	Mediterranean, Sahara, Sahel, Sahel-Sudano Congo, Horn of Africa	110 death and 66 injuries reported in Egypt. 16 deaths reported in Sudan.		(Hafez and Almazroui 2016, Russo *et al* 2016, CRED 2020)
2015 [OND]	South Africa		Concurrent with a drought and an ENSO event	(World Meteorological Organization 2016, Russo *et al* 2016)
2016 [DJF]	Sahel, Sahel-Sudano, Guinea and South Africa	11 deaths and 20 injuries reported in South Africa	Concurrent with a drought and an ENSO event. Temperatures reached 42.7 °C in Pretoria and 38.9 °C in Johannesburg on 6th January.	(Russo *et al* 2016, CRED 2020, Codjoe *et al* 2020, World Meteorological Organization 2016)
2016 [MAM]	Sahel, Sahel-Sudano	Was the warmest April to date at the time in the Sahel.		(Batté *et al* 2018)
2016 [JJA]	Mediterranean, Sahara, Sahel, Sahel-Sudan and Guinea		ENSO event	(World Meteorological Organization 2016)
2016 [SON]	Mediterranean and Sahara		ENSO event	(World Meteorological Organization 2016)
2017 [MAM]	Mediterranean and Sahara		On 17 May reported record of 42.9°C Larach station, northern Morocco	(World Meteorological Organization 2017)
2018[JJA]	Mediterranean and Sahara		Algeria saw a peak of 51.3°C in July	(World Meteorological Organization 2018b)
2019 [DJF]	Southern Africa	Reduction in avocado crops in some regions		(Jansen 2019)
2019 [MAM]	Sahel-Sudan		In Nigeria 42.2°C recorded in Minna, 120km northwest of Abuja. Meanwhile, Kano, 345km north of the capital, has notched up highs in	(Al Jazeera 2019b)

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			excess of 40°C every day since the beginning of April	
2019 [JJA]	Mediterranean and Sahara		Temperatures up to 47 °C in Morocco	(Morocco World News 2019)
2019[SON]	Southern Africa	Court houses in Malawi allow for the wearing of wigs to be exempt. Increase in animal in particular elephant deaths in Botswana and Zimbabwe. One death reported in Botswana.	Temperatures up to 45°C in Malawi	(Sicetsha 2019, Al Jazeera 2019a, Tebele 2019)
2020[JJA]	Mediterranean and Sahara		Temperatures reached between 42 and 47°C in several provinces in southern Morocco	(Kasraoui 2020)

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3.2 South Africa 2015/16 Heatwave

The South Africa heatwave lasted from the 30th December 2015 to the 6th January 2016. It was chosen because it is one of the most widely reported heatwaves for the African continent (Table 1). In the 8 days (22nd to 29th December) leading up to the heatwave there are positive anomalies in the area and in much of the continent compared to the 1981 to 2010 climate for the mean of the UTCI, Z850 and Z500 (*figure 1,a)*. However, there is a large negative anomaly in z500 and z850 off the coast of South Africa during this period, and the temperature is anomalously cooler than the climate average by up to -6°C.

During the 8 days of the heatwave all variables have positive anomalies in the area (*figure 1,b)*.This indicates warmer than average temperatures and higher heat stress conditions coupled with anomalous high pressure. Much of the continent has positive anomalies in the UTCI, z850 and z500, whilst the temperature is slightly below average. In the 8 days (7th to 15th January) after the heatwave there is the return of the negative anomaly in the z500 and z800 off the coast of South Africa, extending onto the coast, and an area of low pressure (*figure 1,c)*. Considering the temperature and the UTCI it can be inferred that this low pressure cools temperatures and heat stress from the heatwaves warm anomalies.

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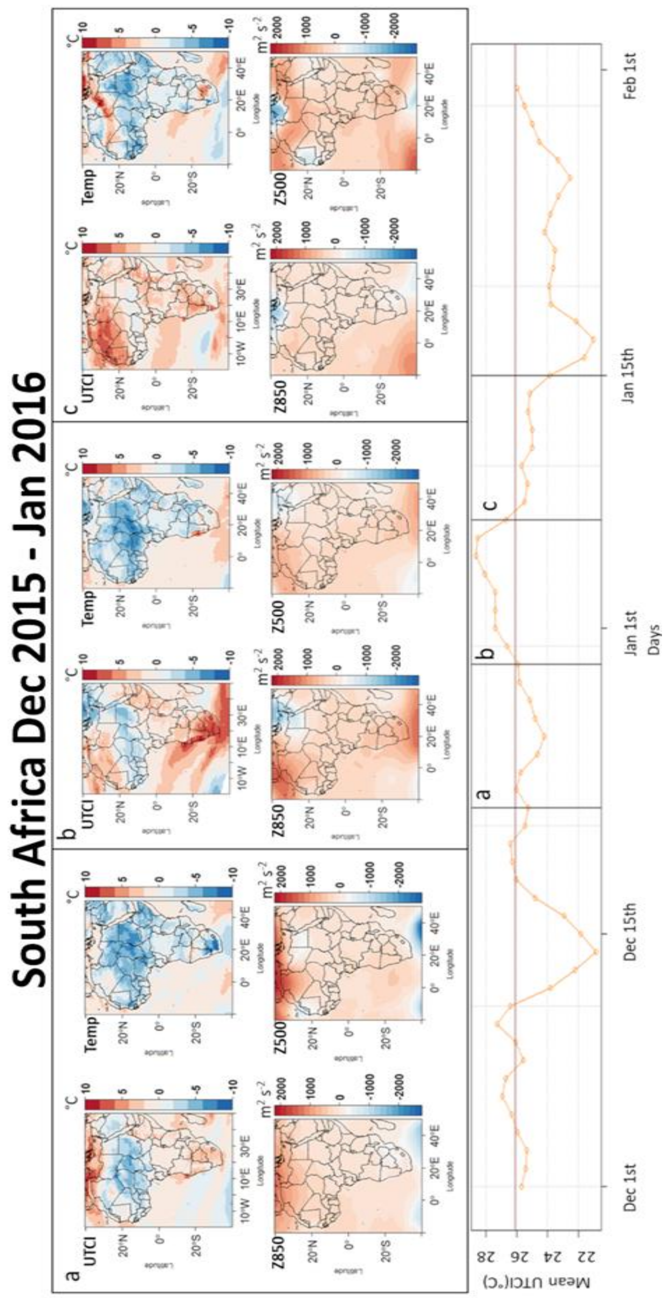

Figure 1: Before, during and after the South Africa heatwave (2015/16 a: 22nd to 29th, b: December, 30st to January 6th, c: 7th to 15th January), the Heatwave is indicated by when the mean UTCI trend (orange) is above the 90th percentile 1981-2010 climatology (in red).

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3.3 Morocco 2000 Heatwave

The 2000 Morocco heatwave lasted from the 30th July to the 3rd August. It was chosen because it was the only heatwave with a reported economic impact in Table 1. In the 5 days (25th to the 29th July) leading up to the heatwave there are slight warm anomalies in the area compared to the 1981 to 2010 climate for both temperature and the UTCI (*figure 2,a)*. There are also slight positive anomalies in geopotential at both z500 and z850. In comparison, the rest of the continent has slight cool anomalies in temperature and UTCI reaching -4*°C* and -6°C respectively.

During the 5 days of the heatwave there are significant warm anomalies in both the UTCI of up to 10°C and temperature of up to 6°C in Morocco (*figure 2, b).* In addition, within z500 and z850 there are positive anomalies in geopotential representative of the region being under the influence of high pressure. Interestingly the area of high warm anomalies is very small constrained to Morocco. In the 5 days (4th to the 9th July) after the heatwave the intensity of the warm anomaly for both temperature and UTCI dissipates and is at most 2°C and 1°C respectively (*figure 2, c)*. Within the z850 and z500 geopotential anomalies a negative anomaly can be seen to the east of Morocco, indicative of a low pressure system this could be in part having a cooling influence on Morocco.

Comparing the South Africa and Morocco heatwaves shows that the overall distribution of the peak in heat stress is similar with a rise in heat stress during the heatwaves of 2°C. However, this is where the similarities end, the Morocco Heatwave occurs over a shorter period (5 days) than that of the South African heatwave (8 days). In addition, the rise into the heatwave is steeper for Morocco increasing by 6°C in heat stress in 5 days than South Africa an increase of about 4°C in 8 days and this is mirrored at the end of the peak in heat stress. In addition, the area that a heatwave covers can be quite different, for example warm anomalies in the UTCI and temperature spread into neighbouring countries for South Africa, but are constrained to Morocco in July and August 2000. In both cases high pressure indicated by positive geopotential anomalies in the z500 and z850 dominates the area during the heatwave, with a low pressure system being in the vicinity as the heatwave dissipates.

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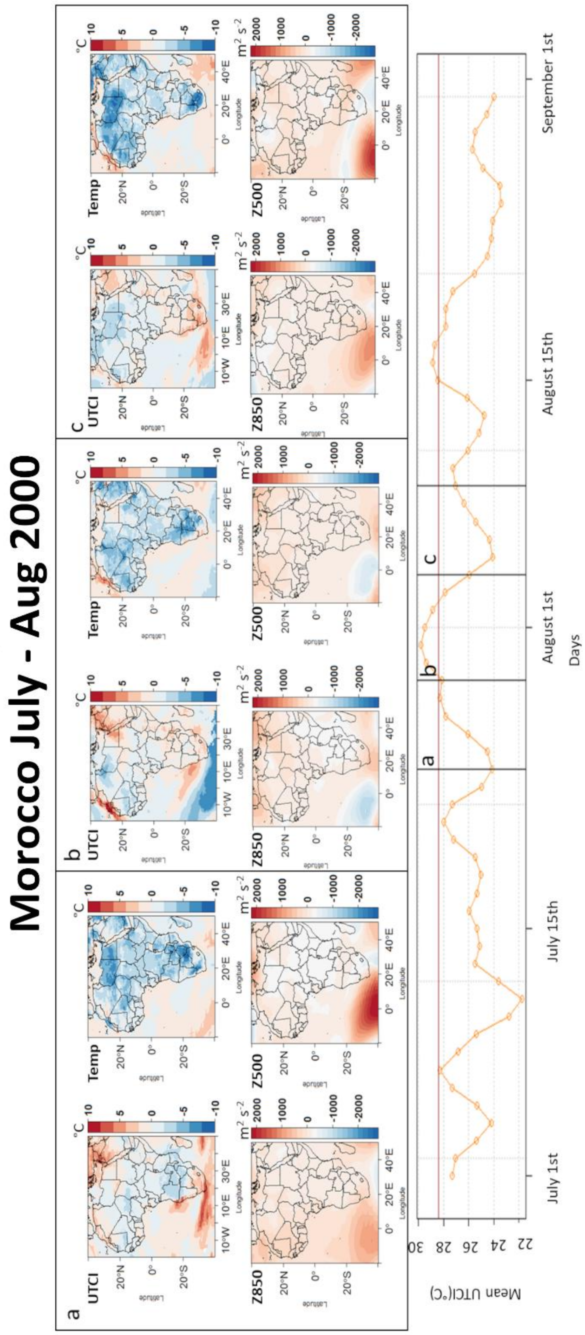

Figure 2: the Morocco (July-August 2000 a: 25th to 29th July, b: 30th July to 3rd August, c: 4th to 8th August). The heatwave is indicated by when the mean UTCI trend (orange) is above the 90th percentile 1981-2010 climatology (in red).

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4. Discussion

The purpose of this study was to provide a list of heatwave case studies from literature for Africa and then explore the characteristics of the pressure systems, temperature and biothermal conditions of two of the heatwaves reported, to demonstrate the usefulness of exploring past heatwaves. Further, our study supports others (i.e. Harrington and Otto, 2020; van der Walt and Fitchett , 2021) suggesting that international databases such as EM-DAT (CRED 2020) are not accurately recording heatwaves for Africa including sub-Saharan Africa only including 7 out of our 39 listed heatwaves in their records, which is less than 20%.

In addition, more heatwaves are found for Africa by this study than is reported by any one international meteorological organisation or disaster database (e.g. World Meteorological Organisation and EM-DAT). Which supports previous findings of an existing discrepancy in heatwaves reporting for Africa (Harrington and Otto 2020, van der Walt and Fitchett 2021). However, there are some heatwave warning systems (Hafez and Almazroui 2016, Boubaker 2010) and there is some reporting in place for African Nations that is not always captured at an international scale (Table 1).

With regards to the case studies, we show that anomalous levels of heat stress and temperature have different extents of coverage for the South of Africa and Morocco heatwaves. In addition, both heatwaves have positive geopotential anomalies at z500 and z850 which is an indicative pressure pattern of heatwaves (Guigma *et al* 2020, Suarez-Gutierrez *et al* 2020). This is the first time heatwaves from two different African regions have been presented and compared using both their physical characteristics and reported impacts and the results are as anticipated given that heatwaves drivers are closely linked to the climatology and synoptic systems in a region (Russo *et al* 2016, Hu *et al* 2019).

We suggest it would be beneficial to investigate other heatwave events to further expand this knowledge and reveal how heatwaves differ over the continent to inform the forecasting and identification of heatwaves in African Nations. Future detailed analysis can also shed light on the atmospheric dynamics of such extremes thus better aiding in-country forecasters in the predictability of and preparedness to heatwaves (see e.g. Guigma et al. 2021). Strengthening local meteorological services alongside health services has been identified as a key element for climate change preparedness plans and public health policies addressing

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temperature-related morbidity and mortality in Sub-Saharan Africa (Amegah *et al* 2016, Nunfam *et al* 2019, Hussey and Arku 2020,van Loenhout *et al* 2021).

The reported impacts of the South of Africa heatwave were 11 deaths and 20 injures (*table 1*). Previous literature reports a 1.64% increase in excess mortality rates in South Africa above an air temperature threshold of 19°C (Scovronick and Armstrong 2012). Considering that our analysis shows positive anomalies in heat stress indicated by the UTCI of up to 10°C, we hypothesise that impacts of the South Africa heatwaves have been underreported. For the Morocco heatwave the reported impacts are 4 million chickens dying leading to up to 809,000 USD of damages (*table 1*). Interestingly, this is the only heatwave with an economic loss associated with it. This reiterates the complexities of identify loss and damage due to heat extremes, especially for Africa where research on heat-related impacts is still limited (Campbell *et al* 2018).

Africa is exemplary in highlighting challenges that heatwave reporting faces globally. Whether this is lack of observations, under-reporting fuelling a lack of evidence or a patchy research field, these are intrinsic factors that has a growing mandate to be addressed globally (Harrington and Otto 2020, Vicedo-Cabrera *et al* 2021). Other studies show that heatwaves are increasing in frequency and intensity for Africa (Ceccherini *et al* 2017, Hu *et al* 2019, Russo *et al* 2016) and it therefore should be a priority that the whole continent has access to robust heat hazard forecasting.

5. Conclusion

Overall, this study presents a comprehensive list of reported heatwaves for Africa, which includes more reported heatwaves than any other one source. In addition, this study supports calls for more robust reporting of heatwaves in Africa. Further, characteristics including that of the UTCI are explored for two of the reported heatwaves Morocco 2000 and South Africa 2015/16, this demonstrates that as might be anticipated heatwaves are more complex than periods of high temperature and are linked to local synoptic systems and geography of a region. This study recommends that other studies focus on the reported heatwaves to provide evidence that heat is impacting African Nations. Finally, given the amount of reported heatwaves and the changing climate the whole continent should have access to robust heat hazard forecasting and resources for rigorous reporting.

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Code and Data Availability

ERA-5 Data is available freely from the Copernicus Data Store Website: DOI: 10.24381/cds.f17050d7

Author contribution

Chloe Brimicombe: Conceptualization, Formal analysis, Investigation, Resources, Writing - original draft, Visualization.. **Claudia Di Napoli**: Conceptualization, Resources, Writing - review & editing. **Rosalind Cornforth:** Conceptualization, Writing - review & editing. **Florian Pappenberger:** Writing - review & editing. **Celia Petty**: Writing - review & editing. **Hannah L. Cloke**: Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abass R, Mensah A and Fosu-Mensah B 2018 The role of formal and informal institutions in smallholder agricultural adaptation: The case of lawra and nandom districts, Ghana *West African J. Appl. Ecol.* **26** 56–72

Abdulai I, Vaast P, Hoffmann M P, Asare R, Jassogne L, Asten P Van, Rötter R P and Graefe S 2018 Cocoa agroforestry is less resilient to suboptimal and extreme climate than cocoa in full sun: Reply to Norgrove (2017) *Glob. Chang. Biol.* **24** e733–40

Achberger C, Ackerman S A, Albanil A, Alexander P, Alfaro E J, Allan R, Alves L M, Amador J A, Ambenje P, Andrianjafinirina S, Antonov J, Aravequia J A, Arendt A, Arévalo J, Arndt D S, Ashik I, Atheru Z, Banzon V, Baringer M O, Barreira S, Barriopedro D E, Beard G, Becker A, Behrenfeld M J, Bell G D, Benedetti A, Bernhard G, Berrisford P, Berry D I, Bhatt U, Bidegain M, Bindoff N, Bissolli P, Blake E S, Blunden J, Booneeady R, Bosilovich M, Box J E, Boyer T, Braathen G O, Bromwich D H, Brown R, Brown L, Bruhwiler L, Bulygina O N, Burgess D, Burrows J, Calderón B, Camargo S J, Campbell J, Cao Y, Cappelen J, Carrasco G, Chambers D P, Chang'A L, Chappell P, Chehade W, Cheliah M, Christiansen H H, Christy J R, Ciais P, Coelho C A S, Cogley J G, Colwell S, Cross J N,

https://doi.org/10.5194/nhess-2021-242
Preprint. Discussion started: 2 September 2021

Crouch J, Cunningham S A, Dacic M, De Jeu R A M, Dekaa F S, Demircan M, Derksen C, Diamond H J, Dlugokencky E J, Dohan K, Dolman A J, Domingues C M, Dong S, Dorigo W A, Drozdov D S, Duguay C R, Dunn R J H, Dúran-Quesada A M, Dutton G S, Ehmann C, Elkins J W, Euscátegui C, Famiglietti J S, Fang F, Fauchereau N, Feely R A, Fekete B M, Fenimore C, Fioletov V E, Fogarty C T, Fogt R L, Folland C K, Foster M J, et al 2013 State of the climate in 2012 *Bull. Am. Meteorol. Soc.* **94** S1–258

Adger W N, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson D R, Naess L O, Wolf J and Wreford A 2009 Are there social limits to adaptation to climate change? *Clim. Change* **93** 335–54 Online: http://link.springer.com/10.1007/s10584-008-9520-z

Al Jazeera 2019a Malawi court suspends wearing of wigs, gowns as temperatures rise *Clim. Chang. News* Online: https://www.aljazeera.com/news/2019/11/2/malawi-court-suspends-wearing-of-wigs-gowns-as-temperatures-rise

Al Jazeera 2019b Nigeria suffers severe heatwave with no relief in sight *Clim. Chang. News* Online: https://www.aljazeera.com/news/2019/4/6/nigeria-suffers-severe-heatwave-with-no-relief-in-sight

Amegah A K, Rezza G and Jaakkola J J K 2016 Temperature-related morbidity and mortality in Sub-Saharan Africa: A systematic review of the empirical evidence *Environ. Int.* **91** 133–49

American Meteorological Society 2004 State of the Climate in 2003 *Bull. Am. Meteorol. Soc.* **85** S1–72 Online: https://doi.org/10.1175/1520-0477-85.6s.S1

American Meteorological Society 2005 State of the Climate in 2004 *Bull. Am. Meteorol. Soc.* **86** 1–86 Online: https://journals.ametsoc.org/bams/article/86/6s/1/58191/STATE-OF-THE-CLIMATE-IN-2004

Barbier J, Guichard F, Bouniol D, Couvreux F and Roehrig R 2018 Detection of intraseasonal large-scale heat waves: Characteristics and historical trends during the Sahelian spring *J. Clim.* **31** 61–80

Batté L, Ardilouze C and Déqué M 2018 Forecasting West African heat waves at subseasonal and seasonal time scales *Mon. Weather Rev.*

https://doi.org/10.5194/nhess-2021-242
Preprint. Discussion started: 2 September 2021

Benzerga M 2015 Heatwaves are on the rise in Algeria due to climate change, says specialist | Environment | The Guardian *Clim. Publ. Network, Guard.* Online: https://www.theguardian.com/environment/2015/aug/24/algeria-to-experience-more-heat-waves-due-to-climate-change-says-specialist

Blazejczyk K, Epstein Y, Jendritzky G, Staiger H and Tinz B 2012 Comparison of UTCI to selected thermal indices *Int. J. Biometeorol.* **56** 515–35

Boubaker H Ben 2010 Les paroxysmes climato-thermiques en Tunisie : approche méthodologique et étude de cas *Climatologie*

Campbell S, Remenyi T A, White C J and Johnston F H 2018 Heatwave and health impact research: A global review *Heal. Place* **53** 210–8

Ceccherini G, Russo S, Ameztoy I, Francesco Marchese A and Carmona-Moreno C 2017 Heat waves in Africa 1981-2015, observations and reanalysis *Nat. Hazards Earth Syst. Sci.* **17** 115–25

Codjoe S N A, Gough K V., Wilby R L, Kasei R, Yankson P W K, Amankwaa E F, Abarike M A, Atiglo D Y, Kayaga S, Mensah P, Nabilse C K and Griffiths P L 2020 Impact of extreme weather conditions on healthcare provision in urban Ghana *Soc. Sci. Med.* **258** 113072

CRED 2020 EM-DAT | The international disasters database *EM-DAT* Online: https://www.emdat.be/

Di Napoli C, Barnard C, Prudhomme C, Cloke H L and Pappenberger F 2021 ERA5-HEAT: A global gridded historical dataset of human thermal comfort indices from climate reanalysis *Geosci. Data J.* **8** 2–10

Epule T E, Ford J D, Lwasa S, Nabaasa B and Buyinza A 2018 The determinants of crop yields in Uganda: What is the role of climatic and non-climatic factors? *Agric. Food Secur.* **7** 1–17 Online: https://doi.org/10.1186/s40066-018-0159-3

Fontaine B, Janicot S and Monerie P A 2013 Recent changes in air temperature, heat waves occurrences, and atmospheric circulation in Northern Africa *J. Geophys. Res. Atmos.* **118** 8536–52

Frimpong K, Eddie Van Etten E J, Oosthuzien J and Fannam Nunfam V 2017 Heat exposure

https://doi.org/10.5194/nhess-2021-242
Preprint. Discussion started: 2 September 2021

Natural Hazards and Earth System Sciences
Open Access
Discussions

on farmers in northeast Ghana *Int. J. Biometeorol.* **61** 397–406

Global Commisson on Adaptation 2020 *Adapt Now: A Global Call for leadership on Climate Resilience*

Gray C and Wise E 2016 Country-specific effects of climate variability on human migration *Clim. Change* **135** 555–68

Guigma K H, Todd M and Wang Y 2020 Characteristics and thermodynamics of Sahelian heatwaves analysed using various thermal indices *Clim. Dyn.* **1** 3 Online: https://doi.org/10.1007/s00382-020-05438-5

Hafez Y Y and Almazroui M 2016 Study of the relationship between African ITCZ variability and an extreme heat wave on Egypt in summer 2015 *Arab. J. Geosci.* **9**

Harrington L J and Otto F E L 2020 Reconciling theory with the reality of African heatwaves *Nat. Clim. Chang.* 1–3 Online: http://www.nature.com/articles/s41558-020-0851-8

Hersbach, H, Bell, B, Berrisford, P, et al. The ERA5 global reanalysis. *Q J R Meteorol Soc*. 2020; 146: 1999– 2049. https://doi.org/10.1002/qj.3803

Hu L, Luo J-J, Huang G and Wheeler M C 2019 Synoptic features responsible for Heat waves in Central-Africa, a region with strong multi-decadal trend *J. Clim.*

Hussey L K and Arku G 2020 Are we ready for it? Health systems preparedness and capacity towards climate change-induced health risks: perspectives of health professionals in Ghana *Clim. Dev.* **12** 170–82

IPCC 2013 *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press) Online: www.climatechange2013.org

Jansen C 2019 South Africa: Heatwave reduces Hass, but avo crop could still surprise *Fresh Plaza* Online: https://www.freshplaza.com/article/9080389/south-africa-heatwave-reduces-hass-but-avo-crop-could-still-surprise/

Jendritzky G, de Dear R and Havenith G 2012 UTCI-Why another thermal index? *Int. J. Biometeorol.* **56** 421–8

Kasraoui S 2020 High Temperatures to Persist Throughout Morocco Until Thursday *Morocco World News* Online: https://www.moroccoworldnews.com/2020/08/316381/high-temperatures-to-persist-throughout-morocco-until-thursday/

Morocco World News 2019 Heat Wave Hits Morocco, Temperatures Reach up to 47 Degrees Online: https://www.moroccoworldnews.com/2019/08/281004/heat-wave-morocco-temperatures-47-degrees/

Mubiru D N, Radeny M, Kyazze F B, Zziwa A, Lwasa J, Kinyangi J and Mungai C 2018 Climate trends, risks and coping strategies in smallholder farming systems in Uganda *Clim. Risk Manag.* **22** 4–21 Online: https://doi.org/10.1016/j.crm.2018.08.004

Mwaura F M and Okoboi G 2014 Climate variability and crop production in Uganda *J. Sustain. Dev.* **7** 159–72

Nunfam V F, Van Etten E J, Oosthuizen J, Adusei-Asante K and Frimpong K 2019 Climate change and occupational heat stress risks and adaptation strategies of mining workers: Perspectives of supervisors and other stakeholders in Ghana *Environ. Res.* **169** 147–55 Online: https://doi.org/10.1016/j.envres.2018.11.004

Oueslati B, Pohl B, Moron V, Rome S and Janicot S 2017 Characterization of heat waves in the Sahel and associated physical mechanisms *J. Clim.* **30** 3095–115

Panafrican News Agency 2000 Morocco: Heat Wave Kills Four Million Chickens in Morocco - allAfrica.com Online: https://allafrica.com/stories/200008070719.html

Pappenberger F, Jendritzky G, Staiger H, Dutra E, Di Giuseppe F, Richardson D S and Cloke H L 2015 Global forecasting of thermal health hazards: the skill of probabilistic predictions of the Universal Thermal Climate Index (UTCI) *Int. J. Biometeorol.* **59** 311–23 Online: http://link.springer.com/10.1007/s00484-014-0843-3

Robine J M, Cheung S L K, Le Roy S, Van Oyen H, Griffiths C, Michel J P and Herrmann F R 2008 Death toll exceeded 70,000 in Europe during the summer of 2003 *Comptes Rendus - Biol.* **331** 171–8

Russo S, Marchese A F, Sillmann J and Immé G 2016 When will unusual heat waves become normal in a warming Africa? *Environ. Res. Lett.* **11**

https://doi.org/10.5194/nhess-2021-242
Preprint. Discussion started: 2 September 2021

Natural Hazards and Earth System Sciences Discussions

Schubert S, Wang H and Suarez M 2011 Warm season subseasonal variability and climate extremes in the northern hemisphere: The role of stationary Rossby waves *J. Clim.* **24** 4773–92 Online: http://journals.ametsoc.org/jcli/article-pdf/24/18/4773/3981781/jcli-d-10-05035_1.pdf

Scovronick N and Armstrong B 2012 The impact of housing type on temperature-related mortality in South Africa, 1996-2015 *Environ. Res.* **113** 46–51

Sicetsha A 2019 SA weather: Four-day heatwave expected in these provinces *The South African* Online: https://www.thesouthafrican.com/news/weather/sa-weather-four-day-heatwave-expected-which-provinces/

Suarez-Gutierrez L, Müller W A, Li C and Marotzke J 2020 Dynamical and thermodynamical drivers of variability in European summer heat extremes *Clim. Dyn.* 1–16 Online: http://link.springer.com/10.1007/s00382-020-05233-2

Tebele M 2019 Deadly heatwave hits SADC states *South. Times Africa* Online: https://southerntimesafrica.com/site/news/deadly-heatwave-hits-sadc-states

Vicedo-Cabrera A M, Scovronick N, Sera F, Royé D, Schneider R, Tobias A, Astrom C, Guo Y, Honda Y, Hondula D M, Abrutzky R, Tong S, Coelho M de S Z S, Saldiva P H N, Lavigne E, Correa P M, Ortega N V, Kan H, Osorio S, Kyselý J, Urban A, Orru H, Indermitte E, Jaakkola J J K, Ryti N, Pascal M, Schneider A, Katsouyanni K, Samoli E, Mayvaneh F, Entezari A, Goodman P, Zeka A, Michelozzi P, de'Donato F, Hashizume M, Alahmad B, Diaz M H, Valencia C D L C, Overcenco A, Houthuijs D, Ameling C, Rao S, Di Ruscio F, Carrasco-Escobar G, Seposo X, Silva S, Madureira J, Holobaca I H, Fratianni S, Acquaotta F, Kim H, Lee W, Iniguez C, Forsberg B, Ragettli M S, Guo Y L L, Chen B Y, Li S, Armstrong B, Aleman A, Zanobetti A, Schwartz J, Dang T N, Dung D V., Gillett N, Haines A, Mengel M, Huber V and Gasparrini A 2021 The burden of heat-related mortality attributable to recent human-induced climate change *Nat. Clim. Chang. 2021 116* **11** 492–500 Online: https://www.nature.com/articles/s41558-021-01058-x

van der Walt A J and Fitchett J M 2021 Exploring extreme warm temperature trends in South Africa: 1960–2016 *Theor. Appl. Climatol.* 1–20 Online: http://link.springer.com/10.1007/s00704-020-03479-8

https://doi.org/10.5194/nhess-2021-242
Preprint. Discussion started: 2 September 2021

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

World Meteorological Organisation 2013 *The Global Climate 2001–2010: A Decade of Climate Extremes Summary Report*

World Meteorological Organization 2015 *Climate in Africa: 2013.* (Geneva: WMO)

World Meteorological Organization 2018a Guidelines on the Defintion and Monitoring of Extreme Weather and Climate Events *Task Team Defin. Extrem. Weather Clim. Events*

World Meteorological Organization 2017 High temperatures and heatwaves take hold - World | ReliefWeb *WMO Press Release* Online: https://reliefweb.int/report/world/high-temperatures-and-heatwaves-take-hold

World Meteorological Organization 2018b WMO climate statement: past 4 years warmest on record | World Meteorological Organization *WMO Press Release* Online: https://public.wmo.int/en/media/press-release/wmo-climate-statement-past-4-years-warmest-record

World Meteorological Organization 2016 WMO Statement on the Status of the Global Climate in 2016

Zare S, Hasheminejad N, Shirvan H E, Hemmatjo R, Sarebanzadeh K and Ahmadi S 2018 Comparing Universal Thermal Climate Index (UTCI) with selected thermal indices/environmental parameters during 12 months of the year *Weather Clim. Extrem.* **19** 49–57