

Climate change made the deadly heatwaves that hit millions of highly vulnerable people across large parts of Asia more frequent and extreme

Authors

1. Mariam Zachariah, *Grantham Institute - Climate Change and the Environment, Imperial College London, UK*
2. Ben Clarke, *Grantham Institute - Climate Change and the Environment, Imperial College London, UK*
3. Maja Vahlberg, *Red Cross Red Crescent Climate Centre, the Hague, Netherlands (based in Umeå/Umeå, Sweden)*
4. Carolina Pereira Marghidan, *Red Cross Red Crescent Climate Centre, The Hague, The Netherlands; Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands; Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands*
5. Roop Singh, *Red Cross Red Crescent Climate Centre, the Hague, The Netherlands*
6. Sayanti Sengupta, *Red Cross Red Crescent Climate Centre, The Hague, The Netherlands*
7. Friederike E. L. Otto, *Grantham Institute - Climate Change and the Environment, Imperial College London, UK*

Review authors

1. Ben Clarke, *Grantham Institute - Climate Change and the Environment, Imperial College London, UK*
2. Izidine Pinto, *Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands*
3. Malcolm Mistry, *Red Cross Red Crescent Climate Centre, the Hague, The Netherlands; Environment & Health Modelling (EHM) Lab, Department of Public Health, Environments and Society, The London School of Hygiene & Tropical Medicine (LSHTM), London, UK*
4. Julie Arrighi, *Red Cross Red Crescent Climate Centre, the Hague, The Netherlands*
5. Sarah Gale, *Red Cross Red Crescent Climate Centre, the Hague, The Netherlands*
6. Luis Rodriguez, *International Federation of Red Cross and Red Crescent Societies (IFRC) Asia Pacific Regional Office, Kuala Lumpur, Malaysia*
7. Rana el Hajj, *Red Cross Red Crescent Climate Centre, the Hague, The Netherlands*

Main findings

- The heatwave exacerbated already precarious conditions faced by internally displaced people, migrants and those in refugee camps and conflict zones across West Asia. In Gaza, extreme heat worsened the living conditions of 1.7 million displaced people. The heatwave added pressure to the many challenges already faced by people in refugee camps and conflict zones, such as water shortages, difficulties to access medicines and poor living conditions for the large population that lives in makeshift tents that trap heat. With limited institutional support and options to adapt, the heat increases health risks and hardship.
- The extreme heat has forced thousands of schools to close down in South and Southeast Asia. These regions have previously also incurred school lockdowns during COVID-19, increasing the education gap faced by children from low-income families, enhancing the risk of dropouts, and negatively impacts the development of human capital.
- Heat impacts certain groups like construction workers, transport drivers, farmers, fishermen etc. disproportionately. It both impacts their livelihoods and causes a reduction in income, and results in personal health risks.
- In the current climate, warmed by 1.2°C since pre-industrial times due to human activities, this kind of extreme heat event is not very rare. In West Asia, the chance of it occurring in any given year is around 10% – or once every 10 years. In the Philippines, the chance of such an event happening in any given year is also around 10% – or once every 10 years under the current El Niño Southern Oscillation (ENSO) conditions, and a 1-in-20 year event, overall. In the larger South Asia region, an extremely warm April such as this one is a somewhat rarer event, with a 3% probability of happening in a given year – or once every 30 years.
- To estimate the influence that human-caused climate change has had on extreme heat in West Asia and the Philippines, we combine climate models with observations. Observations and models both show a strong increase in likelihood and intensity. In the Philippines, the change in likelihood is so large that the event would have been impossible without human-caused climate change. In West Asia, climate change increased the probability of the event by about a factor of 5.
- In terms of intensity, we estimate that a heatwave such as this one in West Asia is today about 1.7°C warmer than it would have been without the burning of fossil fuels. In the Philippines the intensity increase due to human-induced climate change is about 1.2°C.
- We also look at the role of the ENSO. In the Philippines, we find that the current El Niño made the heatwave about 0.2°C hotter. In West Asia, on the other hand, we do not find any influence of ENSO in the event, which is consistent with previous research.
- If the world warms to 2°C above pre-industrial global mean temperatures, in both regions the likelihood of the extreme heat would increase further, by a factor of 2 in West Asia and 5 over the Philippines, while the temperatures will become another 1°C hotter in West Asia and 0.7°C hotter in the Philippines.
- In South Asia, a region that we have studied twice in the last two years, our analysis was simpler and based only on observations. Similarly to what we found in previous studies, we observe a strong climate change signal in the 2024 April mean temperature. We find that these extreme temperatures are now about 45 times more likely and 0.85°C hotter. These results align with our previous studies, where we found that climate change made the extreme heat about 30 times more likely and 1°C hotter.
- Existing heatwave action plans and strategies are challenged by rapidly growing cities, increase in informal settlements and exposed populations, reduction in green spaces and rise in energy demands. While many cities have been implementing solutions like cool roofs,

nature based infrastructure design, and adherence to climate risk informed building codes, there is limited focus on retrofitting and upgrading of existing buildings and settlements, with infrastructure deficits (e.g. asbestos roofs), to make them more liveable.

- Some countries such as India have comprehensive heat action plans in place, yet to protect some of the most vulnerable people, these must be expanded with mandatory regulations, such as workplace interventions for all workers to address heat stress, such as scheduled rest breaks, fixed work hours, and rest-shade-rehydrate programs (RSH) are necessary, but yet to become part of worker protection guidelines in the affected regions.
- The recurrent heat events and associated impacts every year in these regions in the past few years have enabled heatwaves to be recognised as a serious hazard of concern in most countries, with proper guidelines and action plans in place. At the same time, cross-sectoral collaborative strategies that focus on providing immediate relief during the hot days are needed.

1 Introduction

Globally averaged temperature for April in 2024 was the highest since 1940 as per the ECMWF-ERA5 reanalysis data. The temperature was 0.67°C above the 1991-2020 average for April ([Copernicus, 2024](#)). Throughout April extreme heat in large parts of Asia led to severe impacts across the continent with many new heat records being set. India's Kolkata grappled with its lengthiest April heatwave on record, as reported by the Times of India. The India Meteorological Department has issued a code red warning for excessive heat in Kolkata and its surrounding regions until May 2, as temperatures soared to as high as 46°C, marking a departure of 5 to 10°C above the seasonal average ([IMD, 2024](#)). In Myanmar and Laos, new national April temperature records were established when the mercury climbed to 48.2°C in Chauk and 43.2°C in Tha Ngon. In West Asia, high temperatures led to 3 days of heatwave conditions around 24-26, April 2024. In Tel-Aviv in Israel, temperatures hit 40.7°C breaking an 85-year April temperature record ([Times of Israel, 25 April 2024](#)). Syria experienced temperatures 8 to 10°C above the annual average during this period ([ARKNews, 25 April 2024](#)). Temperatures in Gaza in Palestine climbed to 100°F (approx 37.7°C) during the heatwave ([NPR, 27 April 2024](#)). In the Philippines, Manila experienced several significant heat records, with Sangley Point, situated on Manila Bay, observing a low of 30.2°C, the highest overnight minimum temperature in the country's history. Thailand is currently experiencing a barrage of record-breaking heat since March. Temperatures soared to as high as 44°C on Sunday, with numerous cities recording all-time record highs. According to the BBC, the Health Ministry has reported nearly as many heat stroke-related deaths in the year up to mid-April as were recorded throughout all of 2023, a year that ranked among the hottest on record. Vietnam registered its highest April temperature on record on Tuesday, with Tuong Duong reaching 44°C. ([WoPo, 2024](#))

While many heat-related health impacts will be unknown until weeks or months after the event and thus the full impact is severely underestimated at this point in time, a number of fatalities have already been recorded across the whole studied region ([CBS News, 2 May 2024](#)). In West Asia, in Palestine, at least two fatalities were reported ([Middle East Monitor, 28 April 2024](#)).

In South Asia, the impact of high temperatures was felt acutely in India, where heatwaves may have caused at least five suspected deaths in the state of Kerala ([Hindustan Times, 27 April 2024](#)). Classes up to grade 8 were suspended in Jharkhand, while the Meghalaya government advised schools against organising outdoor activities. The Odisha government announced summer vacations for school, to

combat adverse impacts. The low voter turnout in the first two phases of the ongoing general elections in the country (approx. 66%) relative to the previous general elections in 2019 is also thought to be due to the detrimental heat conditions, though other factors may have simultaneously played a role ([Election Commission of India, 03 May 2024](#)).

Bangladesh recorded at least eight deaths, with an additional 20 fatalities occurring during an earlier heatwave in April ([The Express Tribune, 2024](#); [Rahaman, 2024](#)). At least 34 students and teachers were reported with heat-related illnesses, prompting the closure of all primary and secondary schools and madrasas in five districts, including Dhaka, affecting approximately 33 million children.

In Southeast Asia, Thailand documented a concerning rise in fatalities, with at least 38 deaths recorded between January 1st and April 17th, surpassing the total of 37 deaths reported for the entirety of 2023 ([The Nation, 2024](#)). Demand for energy surged to record levels.

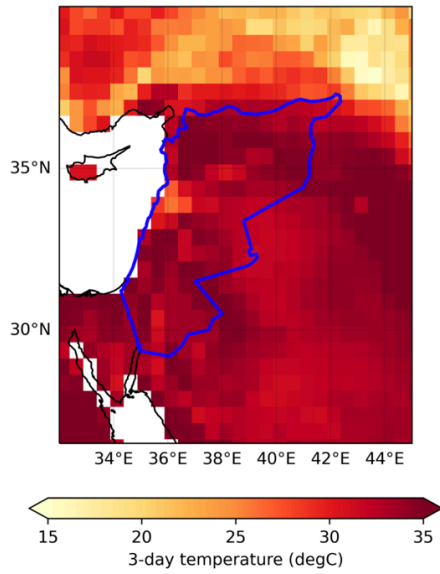
The Philippines reported at least six deaths attributed to the extreme heat in 2024, with additional casualties during earlier heatwave events ([Gomez, 2024](#)). At least 34 cases of heat-related illnesses were documented, and all public schools in Manila were closed. Power plants struggled with operational challenges ([Lopez, 2024](#); [Castro, 2024](#)).

1.1 Event definitions

Nearly all of Asia was extremely hot during April 2024, with different aspects of the large-scale event leading to some of the most severe humanitarian impacts. In the West, impacts were most severe around a period of three days, centred on the 25th of April, while in the East, the two weeks starting from April 15th saw the most widespread impacts. In South Asia, heat-related impacts occurred throughout April. To capture the varied spatial and temporal scale of the heat, we focus on three distinct event definitions.

1. For West Asia we consider the region encompassing Syria, Lebanon, Israel, Palestine and Jordan (blue outline in Figure 1; hereafter the WA region) and focus on maximum temperature averaged over 3 days. Figure 1 shows the absolute temperatures and anomalies during the hottest 3 days. While anomalies were also extremely high in southern Türkiye we exclude the country from this event definition as it has a much more temperate climate compared to the arid regions that we focus on here.

3-day maximum temperature: 24-26 April-2024



Anomaly in 3-day max temperature from 24-26 April-2024 wrt 1991-2020

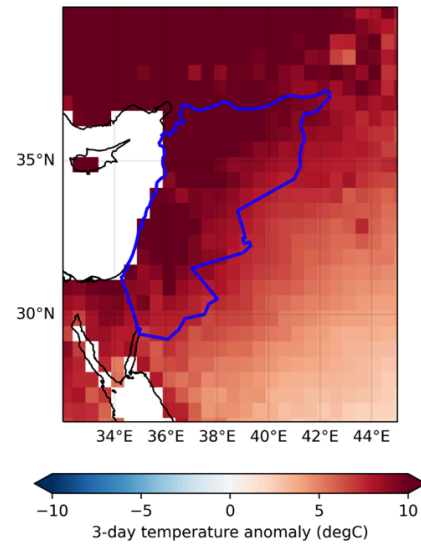
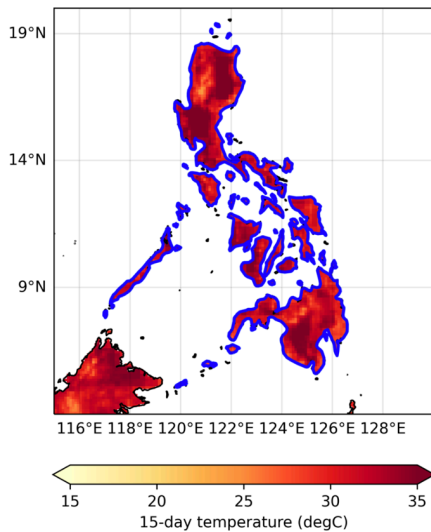


Figure 1: 3-day average daily maximum temperature for the period 24 - 26 April 2024 (a) and anomalies for the same period (b). The blue outline in a) and b) show the study region.

2. For Southeast Asia we focus this analysis on the Philippines, as impacts were particularly severe in the country. April is generally the hottest time of the year in the Philippines, we use the annual 15-day maximum temperatures (Figure 2) to capture the event that caused the most severe impacts that was reported over the last two weeks of April.

15-day maximum temperature: 15-29 April-2024: MSWX



Anomaly in 15-day max temperature from 15-29 April-2024 wrt 1991-2020 :MSWX

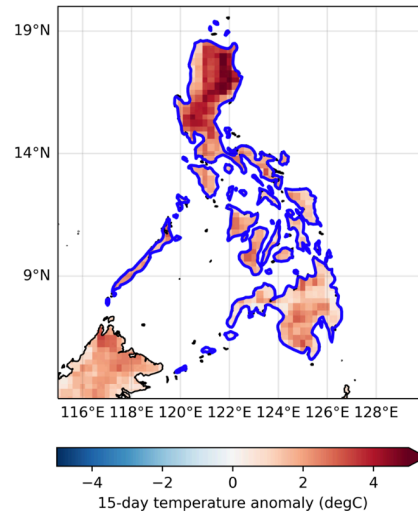


Figure 2: 15-day average daily maximum temperature for the period 15 - 29 April 2024 (a) and anomalies for the same period (b). The blue outline in a) and b) show the study region.

3. The region affected by extreme heat in South Asia is very large, encompassing India, Bangladesh, Myanmar, Lao PDR, Vietnam, Thailand and Cambodia. The blue outline in figure 3 shows the most affected area which includes all the countries listed, apart from

mountainous areas. This larger affected tropical region is climatologically homogeneous and influenced by the same weather systems; it also encompasses the regions assessed in previous World Weather Attribution studies in [2023](#) and [2022](#). We therefore do not undertake another attribution study for this region, but only calculate the return times for this year's April average temperatures and assess any potential role of El Niño.

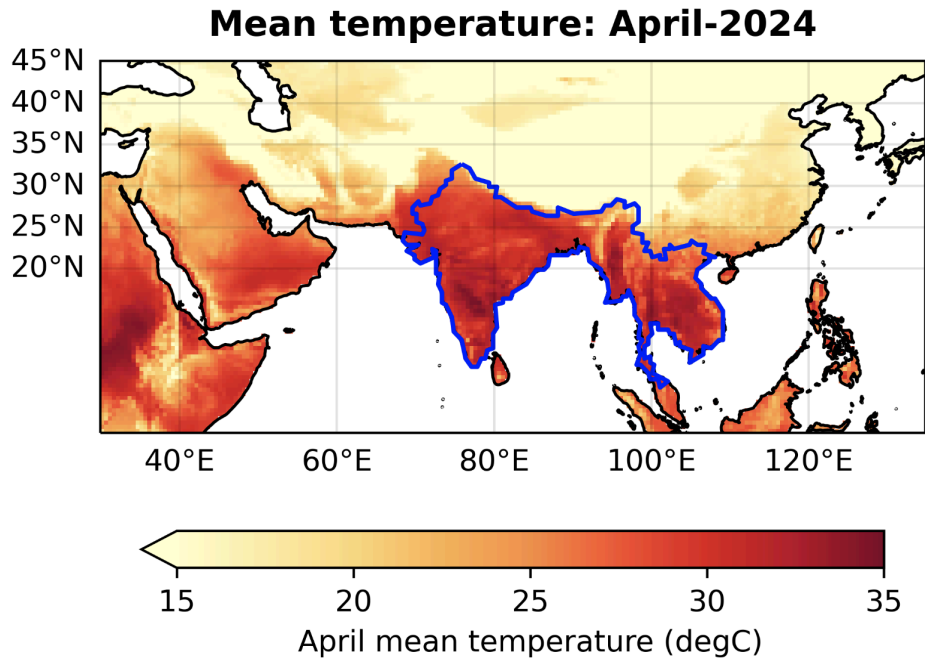


Figure 3: April mean temperature 2024. The blue outline shows the study region.

1.2 Literature

Heat extremes are becoming more frequent and intense across the world. According to the sixth assessment report of the IPCC, at present levels of warming, heat extremes that occurred once every 50 years now occur once every 10 years, or equivalently have become around 1.2 °C hotter. As in most land regions of the world, in West, South and Southeast Asia this can be directly attributed with high confidence to human influence on the climate, with further changes projected commensurate with further warming. For instance, at 2 °C of global temperature rise, the formerly 1 in 50-year event will occur once every 3.5 years and be 2 °C hotter.

South Asia

In South Asia, there has been a succession of hot spring periods in recent years including multiple direct attribution studies. In 2022, the hot March-April over northwest India and southern Pakistan was made 30 times more likely and 1 °C hotter ([Zachariah et al., 2022](#)). In April 2023, two weeks of humid heat in parts of India, Bangladesh, Thailand and Lao PDR were shown to have been amplified by climate change; in India and Bangladesh it had increased in likelihood by 30 times and intensity by around 2 °C, and in Thailand and Lao PDR it was all but impossible without climate change and became 2.3 °C hotter ([Zachariah et al., 2023](#)). These studies are commensurate with an extensive literature documenting observed and projected increases in heat extremes in the region due to anthropogenic influence (e.g. [Ullah et al., 2022](#); [Im et al., 2017](#); [Panda et al., 2017](#); [Kishore et al.,](#)

[2022](#)). April 2024 represents another manifestation of this changing likelihood of extremes and the same results apply. While there is evidence that El Niño events increase the likelihood and intensity of heatwaves over India ([Murari et al., 2016](#); [Neethu et al., 2023](#); [Rohini et al., 2019](#)), this does not diminish the role of global mean surface temperature (GMST) in making the event hotter than it would have been. This is based on multiple prior studies undertaken for events occurring at different phases of ENSO finding consistent results.

West Asia

The largely hot and arid region of West Asia has warmed significantly more rapidly than many other land regions, at around 0.45 °C per decade since 1981 ([Zittis et al., 2022](#)). This has led to a rapid rise in heatwave duration and frequency, and cumulative heat over each season in the region ([Perkins-Kirkpatrick & Lewis, 2020](#)). In a business-as-usual scenario, the region is likely to experience growing risks from extreme heat ([El-Samra et al., 2018](#); [Wedler et al., 2023](#)), facing extended and life-threatening heatwaves on an annual basis from the middle of the 21st century ([Zittis et al., 2021](#)). This has direct implications for rapid rises in mortality ([Wedler et al., 2023](#)), especially in vulnerable older populations ([Ahmadalipour & Moradkhani, 2018](#)). There is some evidence that ENSO plays a role in heat extremes in boreal winter, but otherwise the correlation is likely to be weak ([Donat et al., 2014](#)).

Southeast Asia

Over the whole region of Southeast Asia, increasing trends are detected in the frequency and duration of heatwaves, though their amplitude has changed significantly ([Dong et al., 2021](#)). With further warming, the amplitude of heatwaves increases linearly with warming, while duration and frequency will increase at a greater than linear rate. The same study finds that to date over the Philippines specifically, trends in heatwave amplitude, frequency and duration are very small, but that they are expected to increase in scenarios of further warming. The complex picture to date in the Philippines is reinforced by other work using both observational and reanalysis data, suggesting that in the northern part of the nation heatwave frequency may be decreasing, though these changes are not statistically significant and may be associated with complex topography ([Li et al., 2022](#)).

Heat extremes in the southeast Asia region, especially in spring, are strongly modulated by the state of the El Niño Southern Oscillation (ENSO) ([Dong et al., 2021](#); [Lin et al., 2018](#)). Over the Indochina peninsula, virtually all recent temperature extremes in April coincided with El Niño years. For the extreme temperatures in April 2016, 49% of the observed anomaly was estimated to be due to El Niño and 26% due to global warming ([Thirumalai et al., 2017](#)). In the spring following strong winter El Niño events, atmospheric circulation is characterised by weakened Walker circulation with subsidence over the western North Pacific (WNP), resulting in an enhanced WNP anticyclone, in turn leading to reduced precipitation and elevated temperatures ([Lin et al., 2018](#)). However, the specific influence of El Niño on temperatures in the Philippines is not as clear as the Indochina peninsula, partly due to the dependence on the type of El Niño ([Eggeling et al., 2024](#); [Thirumalai et al., 2017](#)), and further work is required to elucidate this connection, thus indicating the value of an explicit study.

2 Data and methods

2.1 Observational data

To characterise the heat extremes analysed in this study, we use three gridded observational and reanalysis datasets.

- The European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) begins in the year 1940 ([Hersbach et al., 2020](#)), and available at 0.25° spatial resolution. It should be noted that the variables from ERA5 are not directly assimilated, but these are generated by atmospheric components of the Integrated Forecast System (IFS) modelling system. Daily maximum and minimum daily temperature data from this product starting from the year 1950, is available at $0.5^\circ \times 0.5^\circ$ from the [Climate Explorer](#). The re-analysis is available until the end of the preceding month (31 March 2024). We extend the re-analysis data with the ECMWF analysis (1-29 April) and the ECMWF forecast (30 April -7May) to cover the days of the event in the selected study domains.
- The second dataset used in this study is the Climate Prediction Centre (CPC) gridded climate data. This product from NOAA PSL, Boulder, Colorado, USA known as the CPC Global Unified Daily Gridded data, is available from [NOAA](#) at 0.5° spatial resolution covering the period 1979-present.
- The Multi-Source Weather (MSWX) v2.8 dataset (updated from [Beck et al., 2019](#)) is fully global, available at 3-hourly intervals and at 0.1° spatial resolution, available from 1979 to ~3 hours from real-time. This product combines gauge-, satellite-, and reanalysis-based data.

As a proxy for anthropogenic climate change we use the (low-pass filtered) GMST taken from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Science (GISS) surface temperature analysis (GISTEMP, [Hansen et al., 2010](#) and [Lenssen et al., 2019](#)).

The detrended Niño3.4 index is computed from [NOAA's ERSST v.5](#) sea surface temperatures, by subtracting the mean tropical SST (20S-20N) from the mean SST over the Niño3.4 region (5S-5N, 170W-120W).

2.2 Model and experiment descriptions

We use 3 multi-model ensembles from climate modelling experiments using very different framings ([Philip et al., 2020](#)): coupled global circulation models (GCMs) and regional climate models (RCMs).

1. Coordinated Regional Climate Downscaling Experiment- Middle East and North Africa (CORDEX-MENA) with 0.22° resolution (MENA-22) and 0.44° resolution (MENA-44) ([Bucchignani et al., 2018](#)). The ensemble consists of 1 RCM that is driven by 3 GCMs. These simulations are composed of historical simulations up to 2005, and extended to the year 2100 using the RCP8.5 scenario.

2. Coordinated Regional Climate Downscaling Experiment-Southeast Asia (CORDEX-SEA) (0.22° resolution, SEA-22) multi-model ensemble ([Tangang et al., 2020](#)), consisting of simulations resulting from pairings of 5 GCMs and 3 RCMs. These simulations are composed of historical simulations up to 2005, and extended to the year 2100 using the RCP8.5 scenario.

3. CMIP6. This consists of simulations from 12 participating GCMs with varying resolutions. For more details on CMIP6, please see [Eyring et al., \(2016\)](#). For all simulations, the period 1850 to 2014 is based on historical simulations, while the SSP5-8.5 scenario is used for the remainder of the 21st century.

2.3 Statistical methods

In this analysis we analyse the three sets of time series below, that correspond to the three events identified for this attribution study (as described in Section 1.1), from the gridded reanalysis and gauge-based datasets discussed in Section 2.1.

- Maximum of 3-day averaged daily maximum temperatures in March-April in a region including Jordan, Syria, Israel, Palestine and Lebanon in West Asia
- Maximum of 15-day averaged daily maximum temperatures annually in the Philippines
- Average April temperatures over South Asia covering India, Bangladesh, Myanmar, Thailand, Lao PDR, Vietnam and Cambodia.

Methods for the observational and model analysis, the model evaluation and the synthesis employed in this study follow the World Weather Attribution Protocol, as described in [Philip et al. \(2020\)](#), with supporting details in van [Oldenborgh et al. \(2021\)](#), [Ciavarella et al. \(2021\)](#) and [here](#).

The analysis steps include: (i) trend calculation from observations; (ii) model evaluation; (iii) multi-method multi-model attribution and (iv) synthesis of the attribution statement.

We calculate the return periods, Probability Ratio (PR; the factor-change in the event's probability) and change in intensity of the event under study in order to compare the climate of now and the climate of the past, defined respectively by the GMST values of now and of the preindustrial past (1850-1900, based on the [Global Warming Index](#)). To statistically model the events under study, we use a GEV distribution that shifts with GMST for the n-day annual (and seasonal) maximum temperature and Gaussian (or Normal) distribution that shifts with GMST for the monthly average temperature. Next, results from observations and models that pass the evaluation tests are synthesised into a single attribution statement.

2.3.1 Statistical modelling of the combined effect of GMST and ENSO

As discussed in Section 1, inter-annual variability in extreme temperature events and the April temperature in South and Southeast Asia is known to be influenced by the ENSO. Therefore for improving the fit and the performance of the model in describing the variable distribution, we extend the non-stationary model to include ENSO as an additional covariate, as follows:

$$X \sim GEV(\mu, \sigma, \xi | \mu_0, \sigma_0, \xi_0, \alpha, \beta, T, I), \text{ and } Y \sim Norm(\mu, \sigma | \mu_0, \sigma_0, \alpha, \beta, T, I)$$

where X and Y denote the variables of interest, the annual (or seasonal) max of n-day temperature and the seasonal average temperature, respectively; T is the smoothed GMST, I is the detrended Niño3.4 index, μ_0 , σ_0 and ξ_0 are the location, scale and (where applicable) shape parameters of the nonstationary distribution and α , β are the trends due to GMST and ENSO, respectively. As a result, the location parameter of the distribution will have a different value in each year, determined by both the GMST and Niño3.4 states. In keeping with the fundamental expectation that for temperature

events the trend shifts linearly with GMST, it is reasonable to assume that such events will also shift linearly with the strength of the detrended Niño3.4 index, so that

$$\mu = \mu_0 + \alpha T + \beta I.$$

Maximum likelihood estimation is used to estimate the model parameters. Under this model, the effects of GMST and the detrended Niño3.4 index are assumed to be independent of one another, so that the change in intensity due to GMST is unaffected by the change in intensity due to the ENSO phase. We note that this may not be the case in the real world, as the intensity and frequency of El Niño events may have been influenced by climate change ([Cai et al., 2021](#)); therefore, to minimise any potential correlation between GMST and ENSO, we use the detrended Niño3.4 index ([Barnes et al., 2024](#)).

2.3.2 Defining the ENSO state in climate models

Where the ENSO phase is included in the statistical model, the factual climate is defined by the 2024 GMST and by the mean of the detrended Niño3.4 index during the 2023-24 DJF season. During the attribution step, the detrended Niño3.4 index derived from each climate model is standardised so that the subset from 1979-2023 has mean 0 and variance 1; the ‘factual’ climate is then defined as having the model’s 2023 GMST and the 2023-24 observed value of the detrended Niño3.4 index, standardised in the same way. This removes any potential biases in the results due to differences between the amplitude of the modelled Niño3.4 index and that observed ([Barnes et al., 2024](#)).

3 Observational analysis: return period and trend

For quantifying the role of climate change in this on-going extreme heat episode over Asia, it is important to factor in the influence of ENSO that has established links with extreme weather events in the regions examined in this study. Therefore, for determining a statistical model that best describes the probability distributions of the variables under study, we assess the model fits for two cases: (1) GEV (or Gaussian where applicable) distribution that shifts only with GMST, and (2) GEV(or Gaussian where applicable) distribution that shifts with both GMST and ENSO as covariates (these models are described in detail in Section 2.3).

3.1 Analysis of gridded data

3.1.1 West Asia

Figure 4 shows the time series of March-April Tx3day area-averaged over the WA study region overlaid with the estimates from the fitted models, for the three gridded datasets. The left panels show the model estimates from fitted GEV models that shift with GMST only and the right panels show the respective estimates from fitted GEV models that shift with both GMST and ENSO. For this region, there is no discernible change in the model fits and the trends by including ENSO as an additional covariate. Further, the similarity in the goodness of fit estimates based on Akaike Information Criterion (AIC, shown in Appendix Table A1(a)) between the two models confirms that the TX3day in this region is not sensitive to ENSO in any of the datasets. Therefore, we do not include Niño3.4 as a covariate for the trend-fitting, return period estimation and attribution analysis based on climate models, for the WA domain.

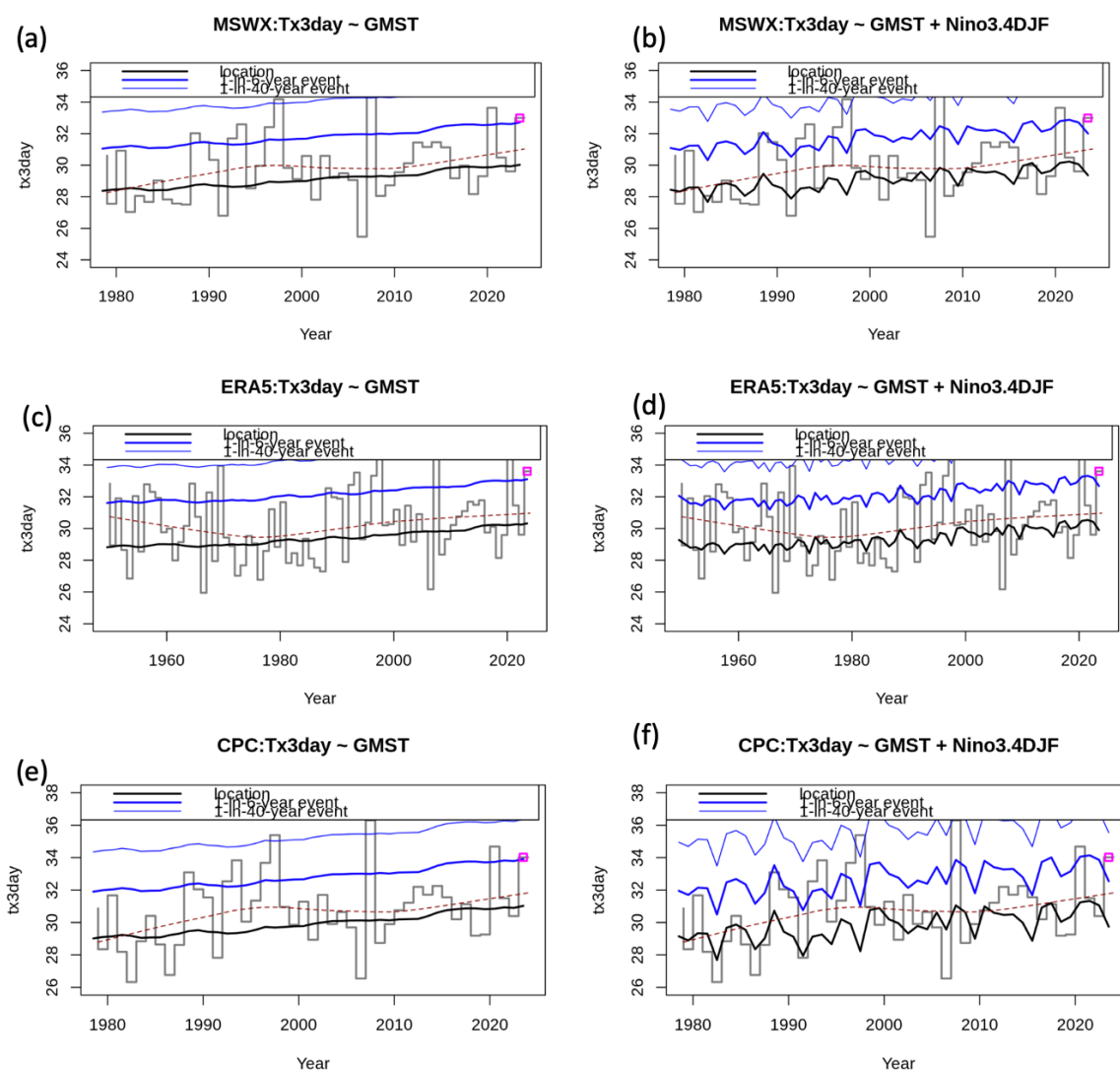


Figure 4: Time series of March-April Tx3day over the WA region for the three gridded datasets- MSWX (a-b), ERA5 (c-d), CPC(e-f). The magenta dot marks the 2024 event; the heavy black line indicates the mean of the fitted model and the blue line indicates the expected return levels of 6- and 40-year events.

Figure 5 shows the results from the trend analysis and the return period curves from fitting GEV probability distributions that shift with GMST to the March-April maximum Tx3day time series derived from three gridded datasets- MSWX, ERA5 and CPC, area- averaged over the WA study region. The left panels show the response of March-April maximum Tx3day in the study region to GMST. All three datasets show an increasing tendency in 3-day maximum temperatures during the season due to increasing global temperatures. The 2024 event has a return period of 6 years (uncertainty: 2-32 years) in the MSWX dataset, in the 2024 climate. The Probability Ratio between the 2024 climate and a 1.2°C cooler climate prior to anthropogenic warming is 707 (uncertainty: 12 to inf), suggesting that the chances of witnessing a 3-day heatwave event such as this one has been made ~700 times more likely due to climate change. Following from this, a 1-in-6 year event such as the 2024 event is 1.28°C hotter (uncertainty: 0.83°C to 1.75°C) as compared to the pre-industrial climate. In the longer ERA5 dataset (begins in the year 1950 as compared to MSWX and CPC datasets that begin in the year 1979), the event has a return period of 9 years (uncertainty: 4 to 27 years). However, the PR is smaller, with climate change likely to have increased the chances of an

event by around 4 times (uncertainty 1 to 28), and made hotter by 1.6°C (uncertainty 0.1°C to 3.22°C). In the third dataset analysed in this study- CPC, the 2024 event has a return period of 6 years (uncertainty: 3-29 years). The chances of an event at least as hot as the observed event is made 10 times more likely (uncertainty: 0.96 to inf) due to climate change and 2.85°C hotter (uncertainty: 0.05°C to 5.44°C).

For the attribution analysis including climate models, we define the 2024 heatwave event in the WA domain, characterised by Tx3day during March-April to be a 1-in-10 years.

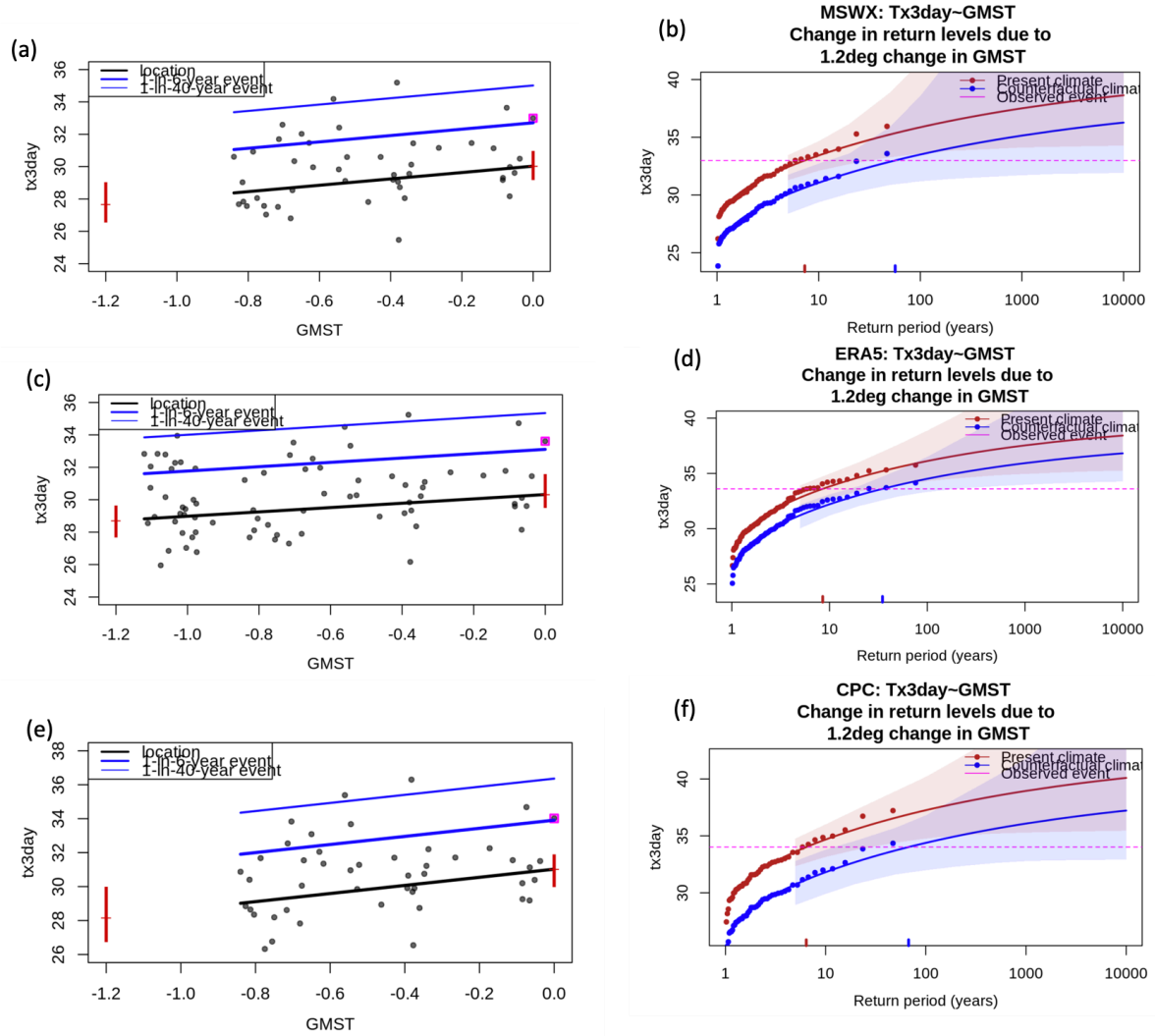


Figure 5: Left: Linear trend in March-April maxima of Tx3day over the WA study region as a function of GMST based on (a) MSWX (c) ERA5 and (e) CPC datasets. The thick black line denotes the location parameter of the fitted distribution, and the blue lines show estimated 6- and 40-year effective return levels for each year. The 2024 observation is highlighted in magenta. Right: the corresponding return period figure for GMST of 2024 (red lines) and 1.2°C lower GMST (blue line), based on (b) MSWX (d) ERA5 and (f) CPC datasets. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The magenta line shows the observed value of 2024 March- April maximum Tx3day in the respective datasets.

3.1.2 Southeast Asia- the Philippines

Figure 6 shows the time series of annual maximum Tx15day area-averaged over the Philippines overlaid with the estimates from the fitted models, for the three gridded datasets. The left panels show the model estimates from fitted GEV models that shift with GMST only and the right panels show the respective estimates from fitted GEV models that shift with both GMST and ENSO. For this region, ENSO is an important driver of the year-to-year variability in temperature, with temperatures higher during El-Niño years, as evidenced in the panels in the right where the GEV model that shifts with GMST and Niño are able to mirror the peaks in the El-Niño years including 1998/99, 2012/13, 2015/16, 2023/24), and the AIC numbers (Appendix Table A1(b)).

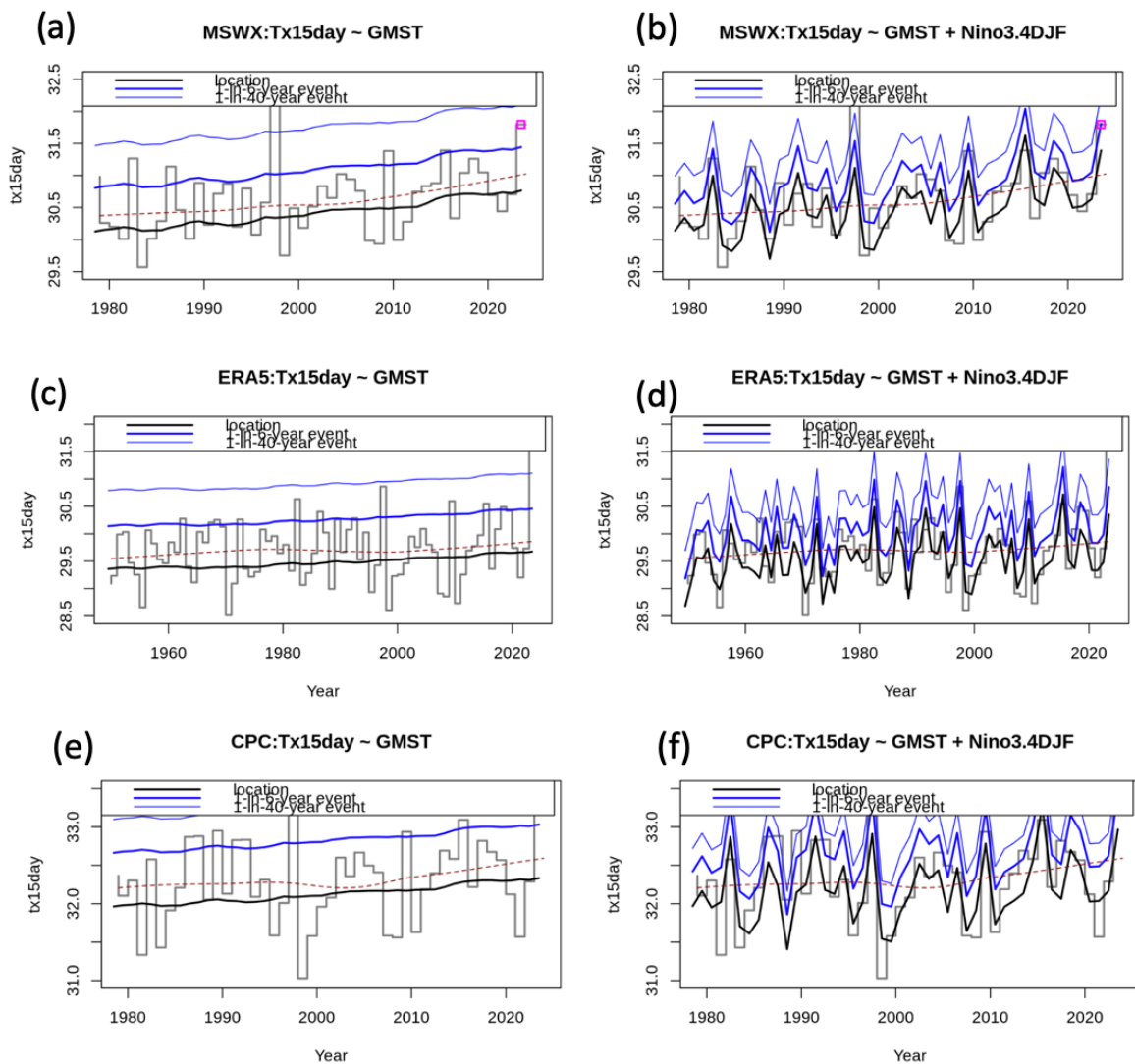


Figure 6: Time series of annual Tx15day over the Philippines for the three gridded datasets- MSWX (a-b), ERA5 (c-d), CPC(e-f). The magenta dot marks the 2024 event; the heavy black line indicates the mean of the fitted model and the blue line indicates the expected return levels of 6- and 40-year events.

Figure 7 shows the results from the trend analysis and the return period curves from fitting GEV probability distributions that shift with GMST to the annual maximum Tx15day time series derived from three gridded datasets- MSWX (Fig. 7 (a-c)), ERA5 (Fig 7(d-f) and CPC (Fig. 7 (g-i), area-

averaged over the Philippines. There is an increasing tendency towards higher temperatures in the Philippines as GMST increases in all three datasets (left panels in Fig. 7), and as the ENSO conditions move to the positive (or El Niño) phase (middle panels in Fig. 7). The 2024 event has a return period of 6 years (2 to 32 years) and 8 years (uncertainty: 3 to 2000 years) in the current climate and the 2023/24 Niño conditions in the MSWX and CPC datasets, respectively. In ERA5, the event is more extreme with a return period of 200 years (uncertainty: 41 years to inf). However, at the time of the analysis, the ERA5 dataset for the month of April is the analysis data and not reanalysis, which is often different to the reanalysis data. Therefore, for the attribution analysis including climate models, we define the 2024 heatwave event in the Philippines to be a 10 year event.

The event has a probability ratio of 707 (uncertainty: 12 to $1.19\text{E}+08$) and $1.19\text{E}+08$ (uncertainty: 11 to $1.42\text{E}+20$) in the MSWX and CPC datasets, suggesting that the chances of an event as hot or hotter than the observed 2024 event occurring in an El-Niño year in the 1.2°C cooler climate (representative of the pre-industrial climate) would have been near-zero. In ERA5, the probability ratio is 23 (uncertainty: 3 to $1.1\text{E}+04$). Following from this, this year's event is hotter as compared to an event with the same return period as that of the 2024 event in the pre-industrial climate under similar El-Niño conditions by 1.28°C (uncertainty: 0.83 to 1.75°C) in MSWX, by 0.6°C (0.3 to 0.88°C) in ERA5 and by 0.87°C (uncertainty: 0.36 to 1.46°C) in CPC. For determining the contribution of the 2023/24 El-Niño to the observed extreme temperature, we compare the observed event with a counterfactual climate with 2024 GMST and neutral ENSO conditions. The change in intensity due to 2023/24 El-Niño are 0.2°C (uncertainty: 0.17°C to 0.27°C), 0.24°C (uncertainty: 0.2°C to 0.28°C) and 0.2°C (uncertainty: 0.16°C to 0.27°C) in the MSWX, ERA5 and CPC datasets, respectively. Therefore, the overall contribution from the 2023/24 El-Niño conditions is about 0.2°C , based on the observed datasets.

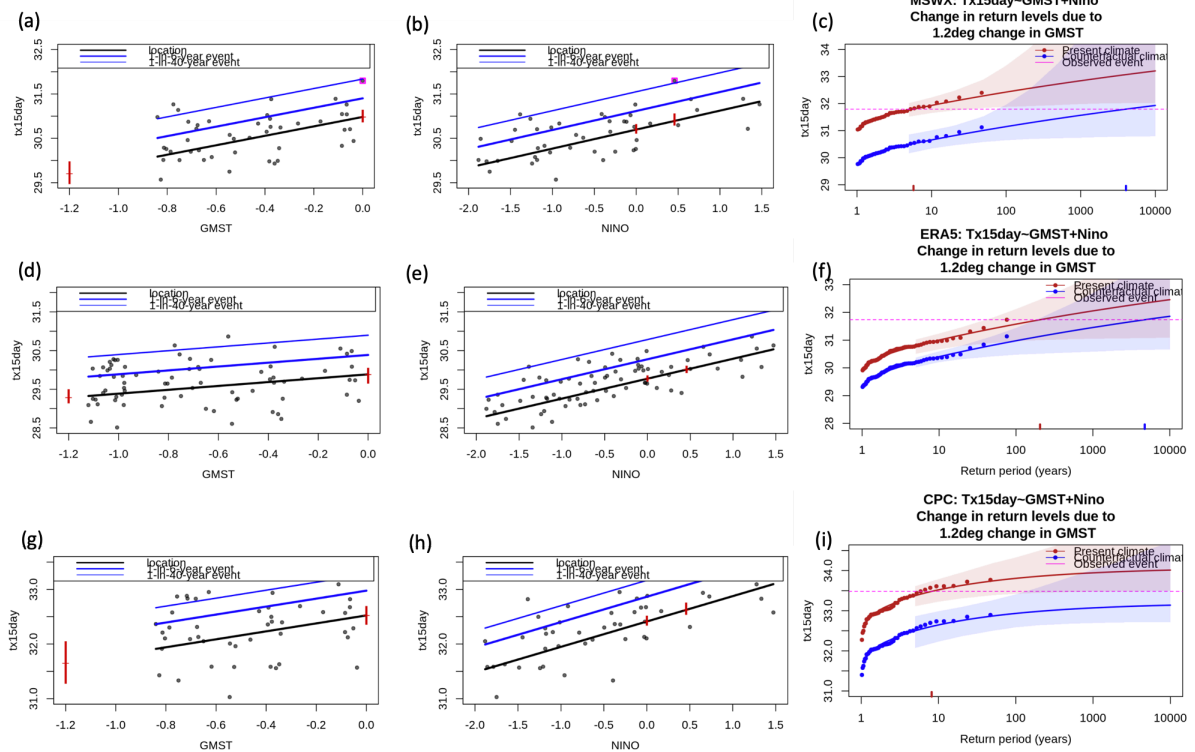


Figure 7: Left: Linear trend in annual maxima of Tx15day over the Philippines as a function of GMST based on (a) MSWX (c) ERA5 and (e) CPC datasets. The thick black line denotes the location parameter of the fitted

distribution, and the blue lines show estimated 6- and 40-year effective return levels for each year. The 2024 observation is highlighted in magenta. Right: the corresponding return period figure for GMST of 2024 (red lines) and 1.2°C lower GMST (blue line), based on (b) MSWX (d) ERA5 and (f) CPC datasets. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The magenta line shows the observed value of 2024 annual maxima of Tx15day in the respective datasets.

3.1.3 South Asia

On analysing the time series of April mean temperatures, averaged over the selected domain over South Asia, and overlaid with the estimates from the fitted Gaussian models, for the three gridded datasets, we find that the time series reflects the link between the ENSO phase and temperature in this large region, as evidenced by the peaks in temperature estimated from the Gaussian models that shifts with GMST and Niño during El-Niño years (see Figure 8). However, the model performance metrics for the two models are fairly close for all datasets (Appendix Table A1(c)), indicating that at this large spatial scale, the change in ENSO phase is not expected to influence the GMST driven trend in April mean temperatures. Therefore we carry out the trend analysis and calculate the return period of the 2024 event in the current climate by fitting Gaussian distributions that shift with GMST.

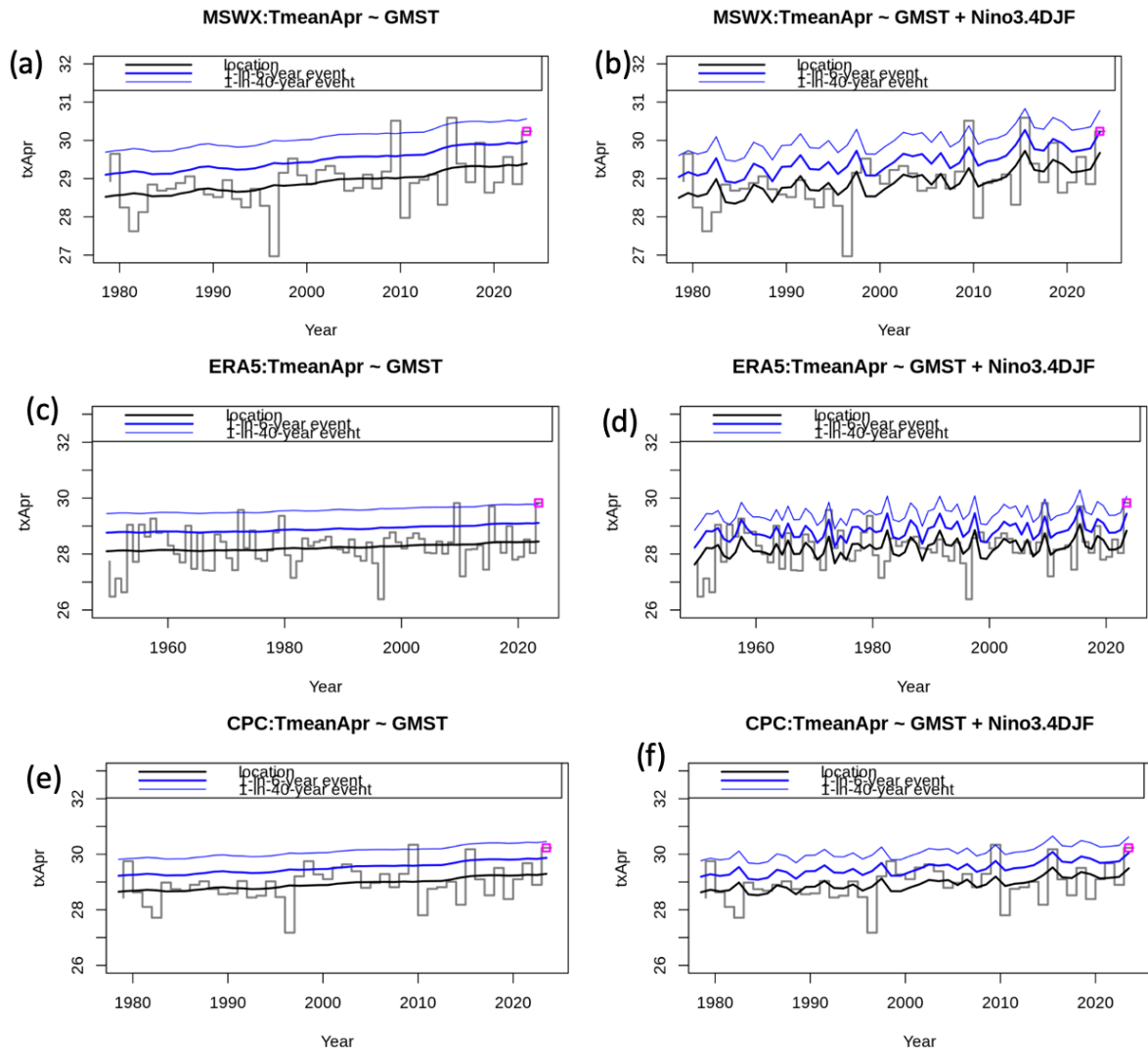


Figure 8: Time series of mean temperature in April over the South Asia domain for the three gridded datasets- MSWX (a-b), ERA5 (c-d), CPC(e-f). The magenta dot marks the 2024 event; the heavy black line indicates the mean of the fitted model and the blue line indicates the expected return levels of 6- and 40-year events.

Figure 9 shows the results from the trend analysis and the return period curves from fitting Gaussian probability distributions that shift with GMST to the April mean temperature time series derived from three gridded datasets- MSWX (Fig. 9 (a)), ERA5 (Fig 9(c) and CPC (Fig. 9 (e)), area- averaged over the South Asian study domain. There is an increasing tendency in April mean temperatures in the study region due to increasing GMST, across all three datasets. The event has a return period of 12 years (uncertainty: 4 years to 155 years) in MSWX (Fig. 9(b)), 50 years (uncertainty: 13 years to 440 years) in ERA5 (Fig. 9(d)) and 17 years (6 years to 167 years) in CPC (Fig. 9(f)). At the time of writing this report, the ERA5 dataset for the month of April is analysis data and not reanalysis, which is often different to the reanalysis data. Therefore, from the numbers associated with the CPC and MSWX datasets, the event is expected to have a return period between 17 and 50 years, of about 30 years. The event has a probability ratio of 337(uncertainty: 10 to 1.5E+05) in MSWX, 4 (uncertainty: 0.4 to 53) in ERA5 and 64 (uncertainty: 2 to 1.4E+04) in CPC, with respective intensity changes of 1.25°C (uncertainty: 0.5°C to 2°C), 0.4°C (uncertainty: 0.2°C decrease to 1°C increase) and 0.9°C (0.1°C to 1.7°C).

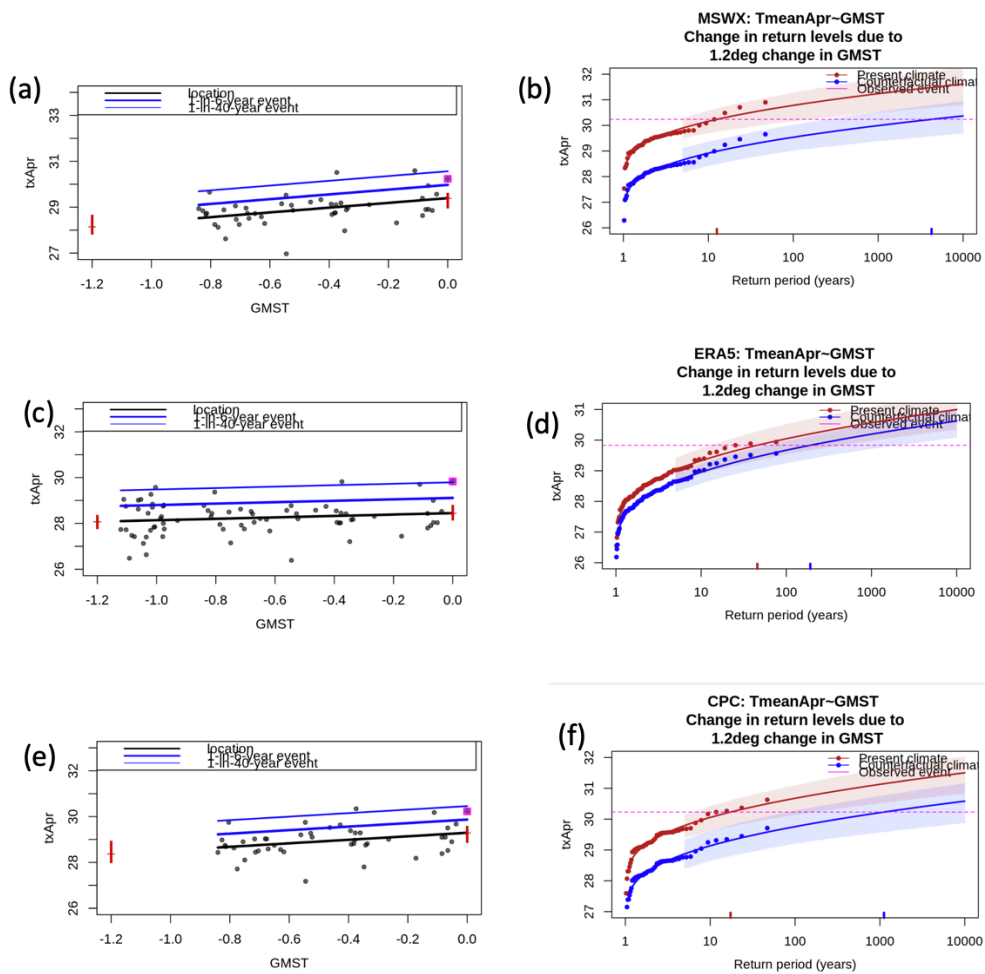


Figure 7: Left: Linear trend in mean temperature in April over the South Asia domain as a function of GMST based on (a) MSWX (c) ERA5 and (e) CPC datasets. The thick black line denotes the location parameter of the

fitted distribution, and the blue lines show estimated 6- and 40-year effective return levels for each year. The 2024 observation is highlighted in magenta. Right: the corresponding return period figure for GMST of 2024 (red lines) and 1.2°C lower GMST (blue line), based on (b) MSWX (d) ERA5 and (f) CPC datasets. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The magenta line shows the observed value of 2024 mean temperature in April in the respective datasets.

4 Model evaluation

In the subsections below we show the results of the model evaluation for the West Asia domain and over the Philippines per framing or model setup we also use models that only just pass the evaluation tests if we only have five models or less for that framing that perform well. Tables 1-2 show the model evaluation results for the two regions.

The climate models are evaluated against the observations in their ability to capture:

1. Seasonal cycles: For this, we qualitatively compare the seasonal cycles based on model outputs against observations-based cycles. We discard the models that exhibit multi-modality and/or ill-defined peaks in their seasonal cycles.
2. Spatial patterns: Models that do not match the observations in terms of the large-scale temperature patterns are excluded.
3. Parameters of the fitted GEV models. We discard the model if the model and observation parameters ranges do not overlap.

The models are labelled as ‘good’, ‘reasonable’, or ‘bad’ based on their performances in terms of the three criteria discussed above. A model is given an overall rating of ‘good’ if it is rated ‘good’ for all three characteristics. If there is at least one ‘reasonable’, then its overall rating will be ‘reasonable’ and ‘bad’ if there is at least one ‘bad’.

4.1 West Asia

Table 1: Evaluation results of the climate models considered for attribution analysis of March-April Tx3day over the West Asia study region. For each model, the best estimate of the dispersion and the 95% confidence interval obtained via bootstrapping.

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape parameter
MSWX			1.80 (1.10 ... 2.21)	-0.16 (-0.43 ... 0.29)
ERA5			1.94 (1.46 ... 2.32)	-0.20 (-0.41 ... 0.047)
CPC			1.96 (1.43 ... 2.36)	-0.17 (-0.42 ... 0.079)
CMIP6				
AWI-CM-1-1-MR_ssp585_r1i1p1f1 ()	good	good	2.19 (1.55 ... 2.66)	-0.19 (-0.53 ... 0.076)
E3SM-1-0_ssp585_r1i1p1f1 ()	reasonable	reasonable	2.07 (1.62 ... 2.46)	-0.15 (-0.59 ... 0.049)

EC-Earth3_ssp585_r1i1p1f1 ()	good	good	2.44 (1.70 ... 2.96)	-0.25 (-0.54 ... 0.13)
EC-Earth3-Veg-LR_ssp585_r1i1p1f1 ()	good	good	2.29 (1.64 ... 2.83)	-0.39 (-0.83 ... -0.24)
INM-CM4-8_ssp585_r1i1p1f1 ()	reasonable	reasonable	1.89 (1.43 ... 2.24)	-0.31 (-0.57 ... -0.11)
INM-CM5-0_ssp585_r1i1p1f1 ()	reasonable	reasonable	2.07 (1.43 ... 3.03)	-0.22 (-1.0 ... 0.20)
KACE-1-0-G_ssp585_r1i1p1f1 ()	reasonable	good	3.03 (2.08 ... 3.78)	-0.33 (-0.70 ... 0.011)
MIROC6_ssp585_r1i1p1f1 ()	bad	reasonable	2.81 (2.04 ... 3.40)	-0.18 (-0.40 ... -0.0024)
MPI-ESM1-2-HR_ssp585_r1i1p1f1 ()	good	good	2.72 (2.11 ... 3.27)	-0.34 (-0.60 ... -0.16)
MPI-ESM1-2-LR_ssp585_r1i1p1f1 ()	good	reasonable	2.41 (1.79 ... 3.43)	-0.39 (-1.1 ... -0.039)
NESM3_ssp585_r1i1p1f1 ()	reasonable	reasonable	2.21 (1.39 ... 2.84)	-0.29 (-0.57 ... 0.030)
NorESM2-LM_ssp585_r1i1p1f1 ()	good	reasonable	2.49 (1.88 ... 2.97)	-0.34 (-0.74 ... -0.045)
CORDEX-MNA-22				
EC-EARTH_RCA4_r12i1p1_MNA-22 ()	good	good	2.51 (1.94 ... 3.25)	-0.29 (-0.82 ... -0.042)
GFDL-ESM2M_RCA4_r1i1p1_MNA-22 ()	good	good	2.72 (1.68 ... 3.40)	-0.25 (-0.52 ... 0.24)
CORDEX-MNA-44				
CNRM-CM5_RCA4_r1i1p1_MNA-44 ()	good	good	1.85 (1.32 ... 2.30)	-0.27 (-0.58 ... 0.010)
EC-EARTH_RCA4_r12i1p1_MNA-44 ()	good	good	2.52 (1.84 ... 3.31)	-0.38 (-0.83 ... -0.018)
GFDL-ESM2M_RCA4_r1i1p1_MNA-44 ()	good	good	2.52 (1.84 ... 3.09)	-0.30 (-0.65 ... 0.087)

4.1 Southeast Asia-the Philippines

Table 2: Evaluation results of the climate models considered for attribution analysis of annual $Tx15day$ over the Philippines. For each model, the best estimate of the dispersion and the 95% confidence interval obtained via bootstrapping.

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape parameter
MSWX			0.259 (0.182 ... 0.316)	-0.062 (-0.39 ... 0.28)
ERA5			0.313 (0.258 ... 0.354)	-0.072 (-0.36 ... 0.12)
CPC			0.341 (0.223 ... 0.419)	-0.31 (-0.61 ... 0.036)
CORDEX SEA-22				
CNRM-CM5_RCA4_r1i1p1_SEA-22 ()	bad	good	0.368 (0.243 ... 0.492)	-0.17 (-0.66 ... 0.28)

HadGEM2-ES_RCA4_r1i1p1_SEA-22 ()	good	good	0.320 (0.214 ... 0.380)	-0.025 (-0.43 ... 0.35)
HadGEM2-ES_REMO2015_r1i1p1_SEA-22 ()	bad	good	0.765 (0.531 ... 0.946)	-0.23 (-0.57 ... 0.069)
MPI-ESM-LR_REMO2015_r1i1p1_SEA-22 ()	good	good	0.604 (0.356 ... 0.741)	-0.44 (-0.79 ... 0.28)
MPI-ESM-MR_RegCM4-7_r1i1p1_SEA-22 ()	good	good	0.458 (0.287 ... 0.586)	-0.37 (-0.78 ... -0.037)
NorESM1-M_RegCM4-7_r1i1p1_SEA-22 ()	good	good	0.554 (0.374 ... 0.678)	-0.28 (-0.68 ... 0.14)
NorESM1-M_REMO2015_r1i1p1_SEA-22 ()	good	good	0.540 (0.378 ... 0.624)	-0.19 (-0.58 ... 0.13)

5 Multi-method multi-model attribution

Tables 3-4 shows the Probability Ratios and change in intensity ΔI for models and also includes the return levels for the 1-in-10 year event from the models in the current climate.

5.1 West Asia

Table 3: Probability ratio, change in intensity of an event such as the 2024 March-April Tx3day event in the West Asia domain, due to changing GMST, from pre industrial climate to the present, and from now to a future 0.8°C warmer world. The return level corresponding to a return period of 1-in-10 years in the models are also recorded here.

Model / Observations	Threshold for return period 10 yr	Current warming level [°C]	Probability ratio PR [-]	Change in intensity ΔI [°C]	Future warming level [°C]	Probability ratio PR [-]	Change in intensity ΔI [°C]
MSWX	32.992 °C	1.2	7.8 (1.1 ... 3.0e+3)	2.4 (0.12 ... 4.4)			
ERA5	31.735 °C	1.2	4.1 (1.1 ... 28)	1.6 (0.98 ... 3.2)			
CPC	34.018 °C	1.2	11 (0.97 ... 1.3e+4)	2.9 (0.055 ... 5.4)			
AWI-CM-1-1-MR_ssp585_r1i1p1f1 ()	36 °C	1.2	8.8 (3.7 ... 41)	2.2 (1.2 ... 3.3)	2.0	2.3 (2.0 ... 2.8)	1.5 (1.1 ... 1.9)
E3SM-1-0_ssp585_r1i1p1f1 ()	24 °C	1.2	6.4 (2.4 ... 64)	2.0 (0.75 ... 3.0)	2.0	1.9 (1.4 ... 2.9)	0.75 (0.43 ... 1.1)
EC-Earth3_ssp585_r1i1p1f1 ()	36 °C	1.2	6.2 (2.7 ... 36)	2.0 (1.0 ... 3.2)	2.0	2.3 (1.9 ... 3.0)	1.2 (0.94 ... 1.5)
EC-Earth3-Veg-LR_ssp585_r1i1p1f1 ()	36 °C	1.2	7.3 (2.4 ... 81)	2.1 (0.88 ... 3.3)	2.0	2.3 (2.0 ... 2.9)	1.4 (1.0 ... 1.9)
INM-CM4-8_ssp585_r1i1p1f1 ()	38 °C	1.2	8.0 (2.9 ... 4.6e+2)	2.0 (0.89 ... 3.1)	2.0	2.5 (2.1 ... 3.4)	1.3 (0.94 ... 1.7)

INM-CM5-0_ssp585_r1i1p1f1 ()	37 °C	1.2	2.2 (0.70 ... 5.9)	0.93 (-0.33 ... 2.1)	2.0	1.6 (1.2 ... 2.0)	0.73 (0.27 ... 1.2)
KACE-1-0-Gssp585_r1i1p1f1 ()	38 °C	1.2	2.3 (1.1 ... 5.0)	1.3 (0.16 ... 2.7)	2.0	1.6 (1.4 ... 1.9)	0.83 (0.48 ... 1.2)
MPI-ESM1-2-HR_ssp585_r1i1p1f1 ()	35 °C	1.2	6.2 (1.5 ... 46)	1.8 (0.42 ... 3.1)	2.0	2.0 (1.6 ... 2.5)	1.2 (0.65 ... 1.8)
MPI-ESM1-2-LR_ssp585_r1i1p1f1 ()	32 °C	1.2	1.5 (0.41 ... 3.7)	0.43 (-0.81 ... 1.6)	2.0	1.4 (0.90 ... 1.7)	0.54 (-0.10 ... 1.0)
NESM3_ssp585_r1i1p1f1 ()	28 °C	1.2	5.3 (2.1 ... 23)	2.0 (0.82 ... 3.2)	2.0	2.1 (1.7 ... 2.8)	1.1 (0.72 ... 1.4)
NorESM2-LM_ssp585_r1i1p1f1 ()	32 °C	1.2	1.0 (0.12 ... 6.2)	0.051 (-1.8 ... 1.9)	2.0	1.7 (1.2 ... 2.2)	1.1 (0.30 ... 1.8)
EC-EARTH_RCA4_r12i1p1_MNA-22 ()	35 °C	1.2	14 (1.5 ... 1.1e+4)	2.4 (0.43 ... 5.3)	2.0	1.9 (1.3 ... 2.8)	0.94 (0.35 ... 1.7)
GFDL-ESM2M_RCA4_r1i1p1_MNA-22 ()	36 °C	1.2	4.2 (1.1 ... 2.4e+2)	2.0 (0.13 ... 4.5)	2.0	2.0 (1.3 ... 2.8)	1.2 (0.49 ... 2.0)
CNRM-CM5_RCA4_r1i1p1_MNA-44 ()	34 °C	1.2	5.4 (0.45 ... 9.4e+3)	1.1 (-0.30 ... 2.6)	2.0	1.8 (1.2 ... 2.3)	0.88 (0.22 ... 1.5)
EC-EARTH_RCA4_r12i1p1_MNA-44 ()	36 °C	1.2	1.4e+4 (4.5 ... 4.4e+14)	3.3 (1.2 ... 5.1)	2.0	2.3 (1.3 ... 3.9)	1.1 (0.43 ... 1.9)
GFDL-ESM2M_RCA4_r1i1p1_MNA-44 ()	36 °C	1.2	16 (1.7 ... 1.4e+4)	2.4 (0.52 ... 4.5)	2.0	2.1 (1.2 ... 3.2)	1.1 (0.28 ... 1.9)

5.2 Southeast Asia-the Philippines

Table 4: Probability ratio, change in intensity of an event such as the 2024 annual Tx15day event in the Philippines, due to changing GMST while holding the Niño levels fixed at the observed 2023/224 Niño levels, from pre industrial climate to the present, and from now to a future 0.8°C warmer world. The return level corresponding to a return period of 1-in-10 years in the models are also recorded here.

Model / Observations	Threshold for return period 10 yr	Current warming level [°C]	Probability ratio PR [-]	Change in intensity ΔI [°C]	Future warming level [°C]	Probability ratio PR [-]	Change in intensity ΔI [°C]
MSWX	31.797 °C	1.2	7.1e+2 (13 ... 1.2e+8)	1.3 (0.83 ... 1.7)			
ERA5	31.735 °C	1.2	23 (2.9 ... 1.1e+4)	0.60 (0.30 ... 0.88)			
CPC	33.482 °C	1.2	1.2e+8 (11 ... 1.5e+29)	0.87 (0.36 ... 1.5)			
HadGEM2-ES_RCA4_r1i1p1_SEA-22 ()	32 °C	1.2	84 (5.4 ... 3.1e+5)	0.89 (0.69 ... 1.1)	2.0	4.7 (3.5 ... 7.5)	0.67 (0.59 ... 0.73)

MPI-ESM-LR_ REMO2015_r 1i1p1_SEA-22 ()	35 °C		1.2	7.1e+5 (4.4 ... 3.1e+21)	1.4 (0.82 ... 1.9)	2.0	4.2 (2.7 ... 11)	0.79 (0.57 ... 0.99)
MPI-ESM-MR_ RegCM4-7_r 1i1p1_SEA-22 ()	32 °C		1.2	7.1e+5 (42 ... 3.4e+18)	1.3 (0.83 ... 2.0)	2.0	4.8 (2.4 ... 9.4)	0.94 (0.70 ... 1.2)
NorESM1-M_ RegCM4-7_r1 i1p1_SEA-22 ()	31 °C		1.2	7.1e+5 (9.0 ... 3.5e+20)	0.94 (0.35 ... 1.5)	2.0	5.1 (3.5 ... 18)	0.57 (0.43 ... 0.76)
NorESM1-M_ REMO2015_r 1i1p1_SEA-22 ()	34 °C		1.2	91 (4.6 ... 7.1e+5)	1.2 (0.46 ... 1.9)	2.0	3.6 (2.4 ... 7.9)	0.61 (0.41 ... 0.82)

6 Hazard synthesis

For the two event definitions described above, WA and the Philippines, we evaluate the influence of anthropogenic climate change on the events by calculating the probability ratio as well as the change in intensity using the observation-based products and climate models described above. Models which do not pass the evaluation detailed in section 4 are excluded from the analysis. The aim is to synthesise results from models that pass the evaluation along with the observations-based products, to give an overarching attribution statement. Figures.10-13 show the changes in probability and intensity for the observations (blue) and models (red). Before combining them into a synthesised assessment, first, a representation error is added (in quadrature) to the observations, to account for the difference between observations-based datasets that cannot be explained by natural variability. This is shown in these figures as white boxes around the light blue bars. The dark blue bar shows the average over the observation-based products. Here, we only added this representative error to the results over West Asia, and not to the Philippines due to the fact that the change in probability for the Philippines is infinite in the upper bound for all three observations based products (indicated by the exclamation marks next to the product name in fig.11), but also infinite in the best estimate for the CPC observations (indicated by the second exclamation mark in fig.11). While this means they clearly differ more than natural variability can explain, adding statistical errors symmetrically would lead to artificially increasing the uncertainty towards spanning several orders of magnitude in both directions, i.e. including negative trends, which is clearly unphysical and does not represent the observations nor physical understanding. We note however, that due to the infinite probability ratios, all quantitative assessments of a change in probability are largely less informative.

Next, a term to account for intermodel spread is added (in quadrature) to the natural variability of the models. This is shown in the figures as white boxes around the light red bars. The dark red bar shows the model average, consisting of a weighted mean using the (uncorrelated) uncertainties due to natural variability plus the term representing intermodel spread (i.e., the inverse square of the white bars). Again, this is only added for West Asia as shown in Figure 10.

Observation-based products and models are combined into a single result in two ways. Firstly, we neglect common model uncertainties beyond the intermodel spread that is depicted by the model

average, and compute the weighted average of models (dark red bar) and observations (dark blue bar): this is indicated by the magenta bar. As, due to common model uncertainties, model uncertainty can be larger than the intermodel spread, secondly, we also show the more conservative estimate of an unweighted, direct average of observations (dark red bar) and models (dark blue bar) contributing 50% each, indicated by the white box around the magenta bar in the synthesis figures.

In both cases, observations and models both show a strong increase in likelihood and intensity. In West Asia the trends are well-quantified as can be seen in Figure 10 and models and observations show very similar changes, qualitatively as well quantitatively. We thus report the best estimates of the synthesised results as the overarching results: a factor 5 (3.5 - 13) for the probability ratio and an increase in intensity of 1.7 (1.5 - 2.3) °C. In the Philippines, the change in likelihood is so large (Figure 11(a)) that the event would have been impossible to occur without human-caused climate change in observations and all models with respect to the upper bound, and in many also with respect to the best estimate or even lower bounds (indicated by exclamation marks in Figure 11(a)). We thus do not aim to quantify the probability ratio, but state the impossibility of the occurrence of the event as observed as the main finding. For the intensity change, observations and models also show a large spread, averaged to 1.2 (0.8 - 1.5) °C as an overarching result.

This result is very similar to the change in intensity based on observations alone, which has a best estimate of 1.2°C as well. We thus also report the assessment of the role of ENSO for the extreme heat in the Philippines (described in section 3.1.2)- the contribution from ENSO is estimated at 0.2°C within the context of the synthesised results for the role of human-induced climate change in the key findings.

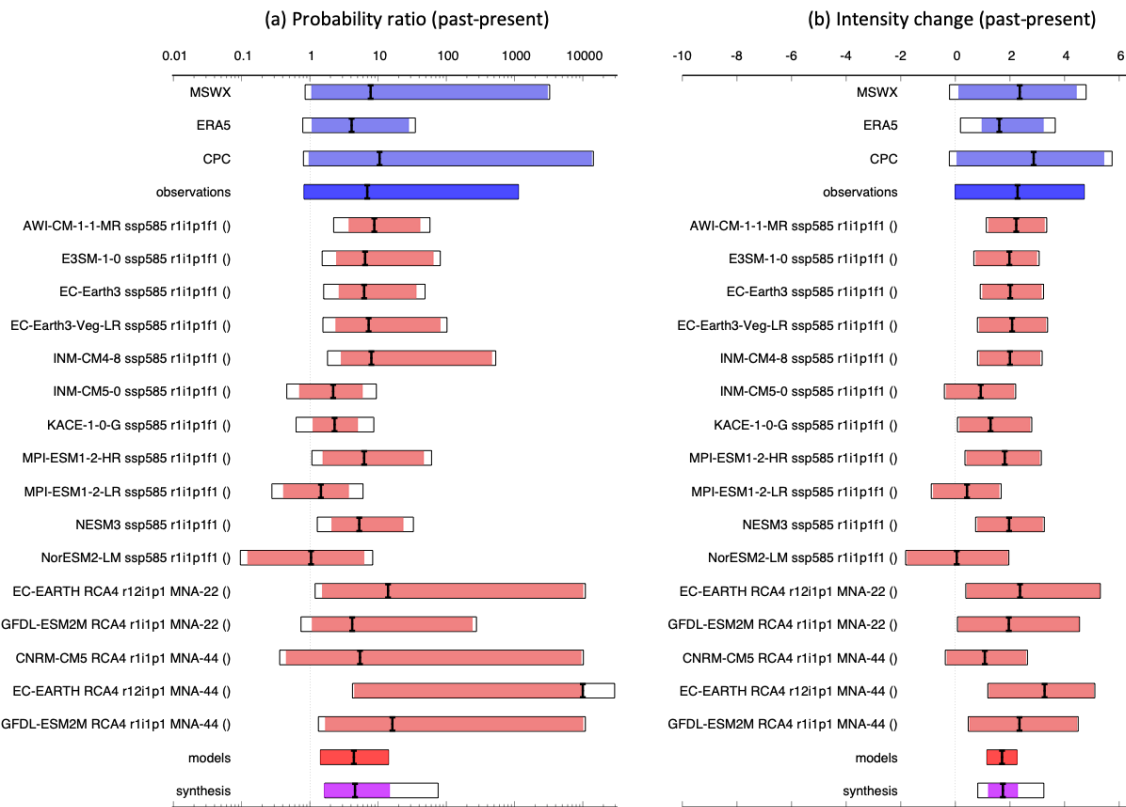


Figure 10: Synthesis of (a) probability ratios and (b) relative intensity changes of March-April 3-day maximum

day-time temperature in the WA domain in the 2024 climate and a 1.2°C cooler climate.

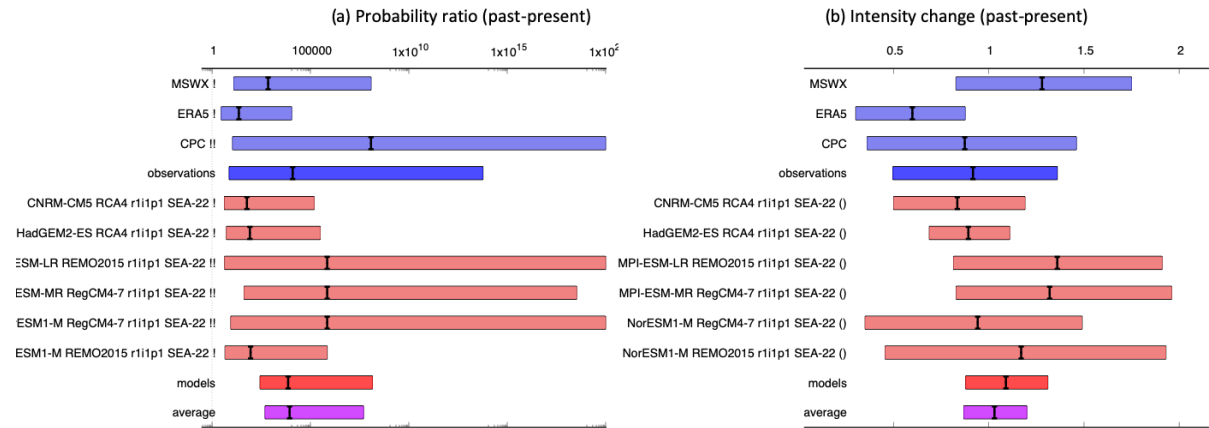


Figure 11: Synthesis of (a) probability ratios and (b) relative intensity changes of annual maxima of 15-day maximum day-time temperature over the Philippines in the 2024 climate and a 1.2°C cooler climate.

When repeating the analysis comparing the present climate at 1.2°C warmer than pre-industrial with a future 0.8°C warmer climate (2°C global warming since pre-industrial times) there is an additional increase of about 1°C for West Asia (Figure 12(b)) while the increase in the intensity is again smaller for the Philippines with a best estimate of 0.8°C (Figure 13(b)).

For the 2°C global warming since pre-industrial era, we also calculate the change in likelihood compared to the present climate and find a factor of 2 in West Asia (Figure 12(a)), and a factor of 4 over the Philippines (Figure 13(a)) if the world warms to 2°C above pre-industrial global mean temperatures. As none of these results are new, we only report the probability ratios in the key findings.

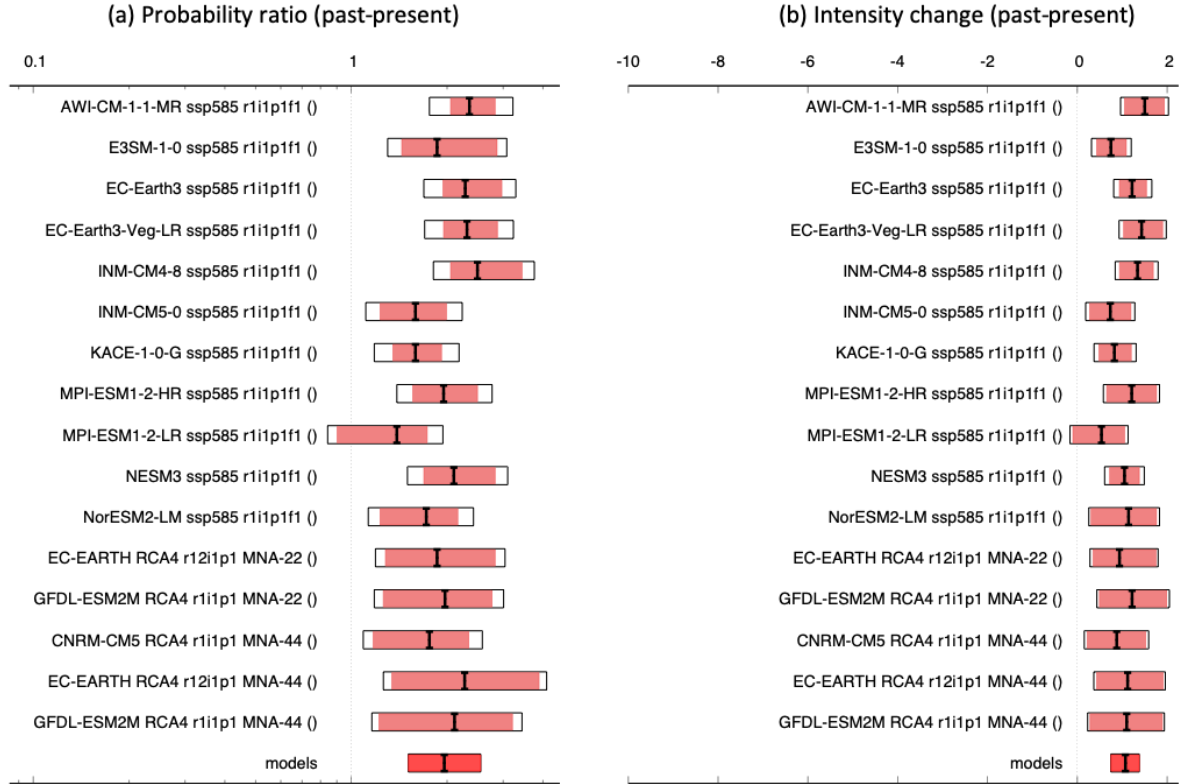


Figure 12: Synthesis of (a) probability ratios and (b) relative intensity changes of March-April 3-day maximum day-time temperature in the WA domain in the 2024 climate and a future 0.8°C warmer climate.

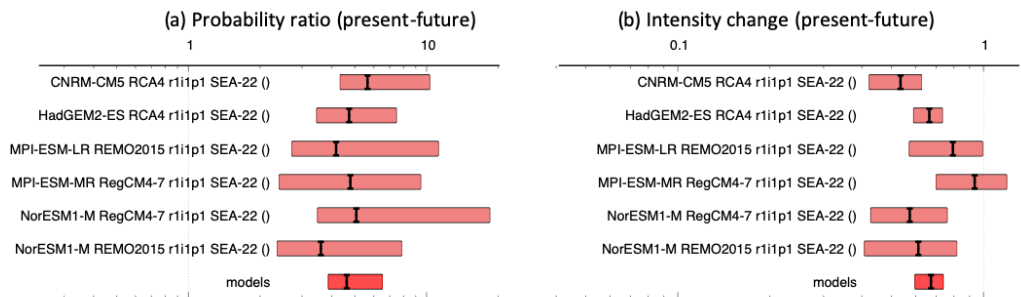


Figure 13: Synthesis of (a) probability ratios and (b) relative intensity changes of annual maxima of 15-day maximum day-time temperature over the Philippines in the 2024 climate and a future 0.8°C warmer climate.

6.1. Hot April in South Asia, 2024: Observed trends and context from WWA studies on previous events in 2022 and 2023.

As discussed in Section 1.1, for the larger South Asia domain, we restrict trend assessment of the April mean temperatures to the observed datasets. This is because we do not expect the attribution results to qualitatively differ from the previous assessments of the 2022 and 2023 heat episodes over domains within this large region. In the 2023 study, we focused on the maximum 4-day heat index and the 4-day maximum temperature in April over the regions outlined in figure A1, encompassing India

and Bangladesh (excluding the arid regions in central India), as well as Thailand and Lao PDR. These variables were motivated by the impacts on human health in these regions from surging temperatures and accompanying humidity. The 2022 study focused on Pakistan and Northwestern India (Figure A2), and analysed maximum temperatures across the whole months of March and April, which were anomalously high in that year and led to widespread agricultural loss.

Even though these previous studies differed in the characteristics of the extreme heat event - focussing on dry heat at monthly temperatures and humid heat and extreme temperatures at short timescales respectively - they found very similar results, with human-induced climate change increasing the likelihood of both the 2022 and 2023 events by at least a factor of 30. In the 2023 study, the maximum 4-day temperature in April 2023 was found to be made 40 times more likely and 0.6°C more intense due to climate change in the India-Bangladesh region, and around 27 times more likely and 1°C hotter in the region over Thailand and Lao PDR. The numbers from the 2022 study echoes these trends, attributing a 30-fold increase in event probability and a temperature rise of around 1°C in average daily maximum temperatures during March and April to climate change.

For this reason, here we do not give a full attribution combining observations and climate model data for the south Asia heat in 2024, but we do analyse the event using observational data. From this brief analysis, we find that the 2024 April mean temperature over South Asia is a 1-in-30 year event in the current climate, based on MSWX, ERA5 and CPC. The synthesis of the observations reveals a strong climate change signal (Figure 14). The best estimate of the probability ratio is 45 (uncertainty: 7 to 777) and the change in intensity is 0.85°C (uncertainty: 0.44 to 1.26°C). In other words, the event has been made around 45 times more likely due to climate change and about 0.85°C hotter. As the results from two other studies in a similar region and across different event definitions were consistent, we are confident in stating that the current heatwave was amplified by climate change and made more likely by at least a factor of 30 and in intensity by around 0.8 to 1 °C.

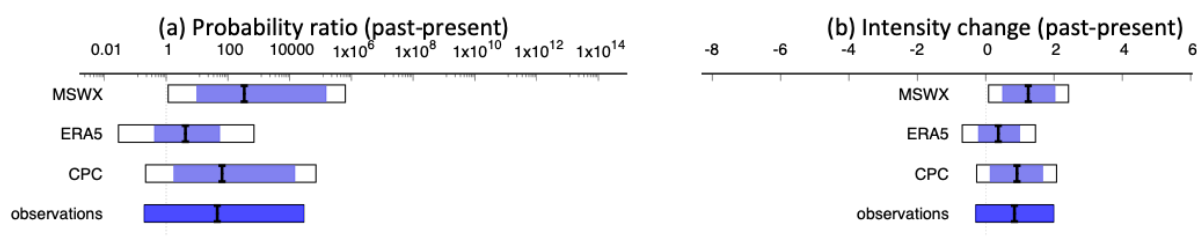


Figure 14: Synthesis of (a) probability ratios and (b) relative intensity changes of mean temperature in the month of April over the South Asia domain, in the 2024 climate and a 1.2°C cooler climate.

7 Vulnerability and exposure

Prolonged extreme heat was observed across a large swath of Asia in April 2014. The heat affected human health, well-being, and livelihoods, while significantly disrupting education systems, straining electricity grids, and impacting crops, livestock, and water availability. The risks and impacts resulting from the heat are a function of the heat itself (the hazard), but also of the vulnerability, exposure, and responses taken ([Simpson et al., 2021](#)). Certain groups are much more vulnerable or exposed to extreme heat than others, such as people with physiological conditions which make them more susceptible to heat stroke (e.g. elderly, children, people with high blood pressure, etc.), outdoor workers including informal workers and farmers, racial and ethnic minority groups, and those with

lower income ([Deivanayagam et al., 2023](#)). For the people who are displaced and already living in dire conditions, the heat is adding another layer to human suffering ([Climate Centre, 2024](#)).

In light of the broad geographic scope covered in this study, the following review is divided into two sub-regions based on similar climates and built environment landscapes. These are: (i) South and Southeast Asia, covering India, Bangladesh, Myanmar, Lao PDR, Vietnam, Thailand, Cambodia, and the Philippines, and (ii) Western Asia, covering Palestine, Israel, Jordan, Lebanon, and Syria. It is crucial to recognize and highlight the differences in vulnerability which are present between as well as within countries. Given the rapid nature of this analysis, anecdotal examples at a national and sub-national level are included, rather than an in-depth exploration of similarities and differences at a national and sub-national level across these geographies.

7.1 South and Southeast Asia: India, Bangladesh, Myanmar, Lao PDR, Vietnam, Thailand and Cambodia & The Philippines

7.1.1 Household coping strategies

To deal with and adapt to the extreme heat, people take various measures, which generally highlight the importance of trees and shade, water, and electricity for cooling. While the use of air-conditioning (AC) could increase emissions as well as the risk of energy poverty ([Randazzo et al., 2020](#)), it remains a clear life saving strategy for maintaining indoor thermal comfort for those that can access and afford it. With rising incomes and rapid urbanisation, the ownership of AC units has surged remarkably, as one of the most popular coping mechanisms in India ([Mogul and Iyer, 2024](#); [Pavanello et al., 2021](#)). As India grappled with the heat amid an ongoing six-week general election, the extreme heat posed challenges for campaigning and voting processes for party workers, as well as common citizens ([Limaye, 2024](#)). Extra measures were taken in some polling stations, such as adding coconut leaves to create shade, and providing ventilation and water ([NOS, 2024](#)). In Manila, the metropolitan capital of the Philippines, people sought relief from the heat in air-conditioned shopping malls. Moreover, while inflatable pools were set up on roads in informal settlements, people also sought cooling in the waters of Manila Bay, even though swimming in the Bay is prohibited due to high levels of pollution ([Aljazeera, 2024](#); [NY Times, 2024](#)). Previous studies have shown that a large share of the urban Philippine population is experiencing heat stress, which has been linked to greater desire to move to cooler areas nearby ([Zander et al., 2018](#); [Zander et al., 2019](#)).

Various countries experienced problems with electricity demand and supply due to the heat. People and businesses across the Philippines were urged to reduce power consumption particularly during peak demand hours, due to high demand and operational challenges in various power plants ([Lopez, 2024](#); [Castro, 2024](#)). In Thailand, the demand for electricity saw a record peak during the studied period ([Arab Times, 2024](#)). In Myanmar, the ongoing unrest and resulting power blackouts have hampered people's ability to maintain thermal comfort by using fans and ACs ([AFP, 2024](#)).

With Islam being the second most practised religion in South Asia, the heatwave in April coincided with the holy month of Ramadan, with many finding staying hydrated during the month-long period of fasting extremely challenging ([Chen, 2024](#)).

7.1.2 Informality and urban planning for heat

Various characteristics of the built environment can influence temperatures both indoors and outdoors, and urban areas are generally hotter compared to rural surroundings due to the urban heat island effect ([Heaviside et al., 2017](#)). South and Southeast Asia host some of the largest and fastest-growing cities in the world, which has in many cases led to unplanned development, increased concrete infrastructure, a loss of green spaces and water, and poor infrastructure, all increasing the urban heat island effect ([Debnath et al., 2023](#); [Khan & Blackwell, 2022](#)). Many of the cities across South and Southeast Asia contain extremely high levels of pollution, compounding the effects of extreme heat, drastically increasing health impacts ([Firdaus et al., 2023](#); [Aljezeera, 2024](#); [Hasan et al., 2023](#)). In Dhaka, Bangladesh, unplanned urbanisation, depletion of water bodies and greenery, and rapid construction of built up areas are predicted to be some of the key drivers of extreme temperature in the city ([Daily Star, 2024](#)). Manila in the Philippines is expected to be one of the largest megacities in the world by 2050 ([Desiderio, 2024](#); [Fleck, 2023](#)), and green spaces have already drastically decreased in Manila over the past years ([Saloma & Akpedonu, 2021](#); [Olfato-Parojinog et al. 2024](#)). To lower vulnerability to extreme heat in Philippine cities, various options have been mentioned such as poverty reduction, enhancement of healthcare services, urban greening, and reducing electricity costs to enable wise use of air-conditioning ([Estoque et al., 2020](#)). Passive cooling solutions, like adding reflective coatings to cool roofs in Indonesia, or enforcing and implementing building codes and sustainable cooling measures in urban areas of Vietnam and Cambodia have also picked up pace in the last years, as coping measures from recurrent heatwaves ([Cava, 2023](#)). A review by Kotharkar & Ghosh ([2021](#)) discusses existing urban policies for extreme heat across South Asia, highlighting long-term adaptation management plans (such as greening buildings) and climate change policies across Bangladesh and India.

7.1.3 Agriculture, water, and animal health

Many countries experienced recurrent episodes of extreme heat, droughts and other extremes (such as flooding) in the past years, which has reduced their coping capacity to withstand the impacts from the current heatwave event, putting increased and systematic pressure on farmers, water resources, and agricultural systems. The April 2024 heatwave once again significantly affected agriculture in South and Southeast Asia, by damaging crops, reducing crop yields, impacting livestock, with a consequent surge in food prices. Thailand expects an 8% increase in farmers' debt this year due to decreased crop yields ([Arunmas, 2024](#)). Vietnam, one of the world's major rice exporters, is currently facing challenges in its Mekong delta region due to inadequate rainfall and facing difficulties in crop transportation due to low water levels in canals. Vietnamese media reports indicate that rice fields and rivers have dried up, leaving farmers to contend with the absence of rainwater for their crops ([Chen, 2024](#)). During the same time, Vietnam has also declared a state of emergency following unusually high temperatures in the southern region, leading to the desiccation of entire rice fields ([Chen, 2024](#)). In 2023, Indonesia required military assistance for rice planting due to a shortage of farmers after they left for cities in search of work during a prolonged dry period ([Pelham, 2023](#)). Farmers, who have already been struggling with an extremely warm 2023, are now bearing the brunt of the extreme weather which is expected to continue in May. Reduced crop yields are likely to worsen food insecurity and inflation risks in Southeast Asia in the coming months ([The Guardian, 2024](#)). Across India, the extreme heatwave event in April has posed significant risks to millions of people as over 50% of the workforce is engaged in agriculture ([Mogul and Iyer, 2024](#)). In the Philippines, water levels have been extremely low, impacting irrigation and water availability for Nueva and surrounding regions ([The Guardian, 2024](#)). A recent report found that extreme heat reduces economic output in agriculture, manufacturing, and services production in the Philippines, and economic losses of 0.37% are seen with every degree of warming ([Armas et al., 2023](#)). Negative coping strategies, such as

selling of livestock was also reported from Thailand, as the extreme heat prevented ducks from laying eggs and made their maintenance particularly challenging with water shortages ([Ratcliffe, 2024](#)). Various tourist destinations across Thailand were also affected due to the water shortages ([The Star, 2024](#)).

The heat also greatly impacted animal health and well-being. In Vietnam, nearly all fish in the Song May reservoir died due to low water levels, partly due to the lack of rain, and as water was discharged downstream to save agricultural crops ([CNA, 2024](#)). In northwestern Cambodia, concerns arose regarding the availability of water for the diverse array of wildlife residing in the Sang Rukhavoan community forest, such as raccoons, monkeys, and wild boars, due to the presence of dry rivers ([REA, 2024](#)). In Thailand, pigs were reported to have suffered from the heat, as well as chickens and ducks, which produced less to no eggs ([Jones & Azmi, 2024](#)). Those who rely on livestock as their primary source of income, therefore, were especially impacted by the heatwave.

7.1.4 Workers' safety

Outdoor workers, ranging from farmers, fishermen, construction workers, linemen, to street vendors, are highly exposed to the high temperatures, facing compound impacts from the heat. On one hand, the heat impacts their livelihoods and causes a reduction in income, and on top of that, exposure to heat due to the nature of their work results in personal health risks. Most people have limited choice to adapt work habits or activities to reduce risk and exposure from the heat, and there is a lack of policies and regulations that protect them ([Pena, 2024](#); [Abad, 2024](#)). In Myanmar, taxi drivers reported a large reduction in their income, as fewer people go out during the hot weather ([Straits Times, 2024](#)). Across India, long working hours under unbearably hot conditions have worsened the plight of informal workers ([Sinha and Pegu, 2024](#)), and adaptation behaviours are generally only adopted on the basis of economic feasibility ([Kotharkar et al., 2022](#)). Studies have shown the need for welfare facilities at workplaces to deal with heat across Southern India ([Latha et al., 2022](#)). Last year in the Philippines, the Department of Labor and Employment's Labor Advisory No. 8, series of 2023 directed "all employers to conduct health risk assessment due to extreme heat, provide better ventilation and adequate water, adjust rest breaks and launch information and education campaigns on what is heat stress and how to avoid it" ([Aning, 2024](#)). In early April 2024, the Trade Union Congress of the Philippines (TUCP) called for workplaces to address heat risks to workers through a comprehensive heat risk action plan (*ibid.*).

7.1.5 Heat action planning, preparedness, and response

In order to improve preparedness and response to extreme heat, South and Southeast Asia countries have put several strategies in place which are effective in reducing heat risks, including early warning systems and corresponding heat action plans, heatwave early action protocols, and more. In 2020, the South Asia Heat Health Information Network was put in place to share lessons and build capacity to deal with extreme heat across South Asia ([SAHHIN, n.d.](#)).

National weather agencies across the region forecasted and warned for the heat, sometimes with minor recommendations on actions to take. In Lao PDR, the weather bureau warned against outdoor activities and to take precautions ([the Star, 2024](#)). In Vietnam, the national weather agency has warned the population of the risk of forest fires, dehydration and heat stroke ([Zargar, 2024](#)). The national weather agency of the Philippines (PAGASA) issued several warnings for the extreme heat across the country, and released an official statement on creating an extreme heat protocol to improve the heat index monitoring and early warning system across the country ([PAGASA, 2024](#)). In Thailand,

authorities have been urging elderly people and those with underlying medical conditions including obesity to stay indoors and drink water regularly ([AFP, 2024](#)), and to avoid heavy labour and exercise outdoors ([WMO, 2024](#)). While it is crucial to avoid exposure to the sun especially during the hottest time of the day, indoor temperatures may be hotter than certain outdoor (shaded) areas, especially in low quality housing with certain roof materials which exacerbate the heat (e.g. [Mukhopadhyay et al., 2021](#)).

Gradually, more countries across South and Southeast Asia have started to develop national and sub-national heat action plans ([Kotharkar & Ghosh, 2022](#)), with India pioneering state-level heat action plans for more contextually appropriate heat strategies ([Magotra et al., 2022](#)). Although there has been substantial progress in plans, there are critical gaps, e.g. plans are often underfunded, do not account for local contexts, lack proper identification and targeting to vulnerable groups, and lack period evaluations ([Magotra et al., 2022](#); [Pallai, 2023](#)). Still, this year, India has been effectively implementing comprehensive heat-health forecast action plans and *#BeatTheHeat* campaigns, providing practical advice and information ([WMO, 2024](#)). In the Philippines, the Mayor of Manila called for city stakeholders to draft a heat action plan which specific local measures at each alert level which PAGASA issues, including the city's health office, social welfare services, and disaster risk reduction and management office ([Patinio, 2024](#)).

In Bangladesh, specific health programmes and vulnerability assessments of heat-prone areas have been initiated in recent years, including operational health programmes to track heat-related mortality and morbidity, and population vulnerability ([Kotharkar & Ghosh, 2021](#)). In May 2024, a national guideline was launched to protect children and vulnerable populations, including pregnant women from heat-related health risks, prioritising proactive measures like online training of healthcare professionals who are responsible for implementing the guidelines nationally ([Rita, 2024](#)). The Bangladesh Red Crescent Society activated its Early Action Protocol (EAP) for Heatwave in Dhaka on 21st April 2024, with a budget of 499,930 Swiss francs (approx. 547,000 US dollars/511,000 euros) to support actions that will target 123,700 vulnerable people, initiating a series of anticipatory actions to support people at risk before the worst impacts of the heat wave are felt ([BDRCS, 2024](#)).

As education systems were also significantly disrupted across the region due to the heat, countries across the region have started to develop guidelines. In the Philippines, thousands of schools closed down and in-person classes were suspended, impacting 3.6 million students and teachers ([Reuters, 2024](#)). The Department of Education indicated they will revise the policy on class suspension for public schools and have decided to move the school calendar such that students are free during the hot season ([Sevillano, 2024](#)). Most schools in the Philippines have no air-conditioning, but some measures were taken during this event, such as providing water dispensers, distributing spray bottles, reducing outdoor activities, and allowing cooler clothing instead of uniforms, and moving to online classes ([Cotejar, 2024](#)). Pupils in India and Bangladesh have been also told to stay at home and learn remotely due to severe health risks while in Cambodia school hours have been reduced ([Skynews, 2024](#)). In the midst of the extreme heat this year, Delhi government's Directorate of Education in India developed advisories with nine mandatory guidelines for schools to prevent heat-related illnesses among students, including mandatory display of heatwave prevention posters, no open air classes, mandatory water breaks during classes, reporting of heat-related illnesses, sensitizing parents, and others ([Jain, 2024](#)).

7.2 Western Asia: Palestine, Israel, Jordan, Lebanon, Syria

7.2.1 Conflict and displacement

Conflict and displacement can create extremely complex and precarious environments, which are intensified by the effects of extreme weather events including extreme heat. Conflict and instability across Western Asia has led to devastating consequences for the region and depleted the coping capacity of communities. Again, it is important to recognize the stark differences in vulnerabilities across regions.

At present, the extreme heat has compounded an already extremely dire humanitarian situation in the Gaza Strip and the West Bank ([Climate Centre, 2024](#)). Between October 2023 and March 2024, at least 30,000 Palestinians have been reportedly killed and over 70,000 injured in Gaza and West Bank, with over 50% being women and children ([UN, 2024](#); [OHCHR, 2024](#)). Up to 1.7 million Palestinians have been displaced in the past months, which accounts for nearly 85% of the population ([Diakonia, 2024](#)), many of which are sheltering in UNRWA facilities (*ibid.*). Often, displaced populations live in overcrowded and inadequate shelters, or even outdoors ([Conzatti et al., 2022](#); [UNRWA, 2023](#)). Makeshift shelters and tents made with plastic sheets increase and hold temperatures through night and day, which increases the risk of heat-related illness as the body is faced with more chronic exposure to extreme heat ([Alghoul & Roston, 2024](#)). In fact, along with the duration of the event, high nighttime temperatures have been identified as one of the key drivers of impacts associated with heat waves ([Beckmann et al., 2021](#); [Fischer & Schär, 2010](#)). Studies have investigated and highlighted the importance of thermal performance in shelter design and propose certain design adaptation solutions, for example in Jordan ([Fosas et al. 2020](#); [Dominguez-Amarillo et al. 2021](#); [Marwa & Ahmad, 2015](#)), and other contexts ([Karanja et al. 2023](#), [Cao et al., 2023](#)). So far, at least three people, of which two children, were reported to have died due to the heat in Gaza ([NPR, 2024](#), [ILKHA, 2024](#)).

On top of increased thermal stress, a lack of access to essential resources such as clean water and electricity further worsens health risks in conflict settings, and hampers the storage for both food and medicines ([Shbair & Yazbek, 2024](#)). At the time of writing of this study, certain regions such as Rafah have no remaining infrastructure or access to healthcare services ([Mercy Corps, 2024](#)). Due to poor waste management and unsafe water, the spread of water-borne diseases has also been reported ([Reuters, 2024](#); [Alghoul & Roston, 2024](#)). A lack of access to healthcare and emergency services in conflict-affected areas, already trying to respond to conflict-related health consequences, limits the ability to respond to a sudden surge in heat-related illnesses and emergencies ([Ekezie et al., 2020](#)).

Next to the dire situation in Gaza, long-standing and widespread conflict across Western Asia has impacted the lives of millions of people. Jordan hosts over 745,000 refugees, the largest number of refugees per capita globally, majority of whom are Syrians and children ([ILO, n.d.](#); [Climate Centre, 2021](#)). In semi-arid Jordan, the unbearable thermal comfort in long-term encampments in the desert has been emphasised in various studies (both hot and cold) ([Aburamadan, 2022](#)), as well as conflicting issues between ventilation, privacy, and security ([Albadra et al., 2017](#)). In Lebanon, as of April 2024, 92,621 people are displaced ([IOM, 2024](#)). In these contexts, populations already facing serious conflict and displacement related risks, some of which have just experienced other extreme weather (e.g. cold wave and floodings; [UNHCR, 2024](#)), and are now faced with the compounding risk of extreme heat, without adequate clean water, food, or health care.

7.2.2 Household coping strategies

Although people across the region have been dealing with high temperatures and have learnt to adapt to heat through various different ways, the changes in heatwave characteristics due to climate change,

compounded with regional vulnerabilities, is affecting how people cope with extreme heat. Furthermore, there exists large inequalities across and within countries. For example, Lebanon ranks 129 out of 141 in terms of income inequality ([Climate Centre, 2024](#)). AC demand has been growing across various countries in the region. For example, 80% of Israeli homes have air conditioning, and 45% of the country's electricity usage is due to AC ([Doehler, 2020](#)). Although AC is a clear life-saving strategy against extreme heat, it is not a viable solution for households who cannot afford it, people experiencing homelessness, and regions with unreliable electricity supply. For example, in Lebanon, since the financial crisis in 2019, blackouts have become longer and those with AC have been unable to use these systems to cool down ([Vohra, 2021](#)). However, across Jordan and Lebanon, the Cool Up programme has been implemented to address the impacts of rising cooling demand, focusing on natural refrigerants (e.g. ammonia) and energy efficient solutions like ACs with compression or brine chillers ([Offerman et al., 2022](#)).

During this heat event, on April 24, in Israel over 20,000 people sought respite from the heat in the Sea of Galilee and 100,000 people visited national parks around the country to find shade and water ([All Israel News, 2024](#)). In Syria, during previous heatwaves, people sought cooling in the Orontes River and the al-Zarqa and Mideanki Lakes, and public pools ([Hezaber & Suleiman, 2023](#)). Although water bodies can help cool one's body during extreme heat, some places may be unsafe and risk of drowning is observed to increase during heat events and at least 26 people drowned in northwestern Syria during the heat last year ([Sindall et al., 2022](#); [Hezaber & Suleiman, 2023](#)).

Furthermore, in refugee camps, people are faced with limited options to adapt to extreme heat. In Syria, during previous heat episodes, people sought shade under trees ([Karam, 2023](#)), cooling through spraying with water ([Suleiman & Hezaber, 2023](#)), and creating temporary pools in the back of trucks in displacement camps ([UN OCHA, 2022](#)). Families also covered children and tents with dampened blankets, and dug holes inside the tent and placed a bucket with water covered with a damp cloth, to maintain coolness ([Karam, 2023](#)). Studies have shown that wetting clothes, self dousing, and for example covering strollers with a moist cloth can effectively reduce air temperature ([Jay et al., 2021](#); [Bin Maideen et al., 2023](#)), yet water must be readily available for these methods. However, literature has shown that social norms can affect the adoption of protective behaviours, making certain groups more vulnerable to extreme heat ([Shih et al., 2022](#)). For example, in Gaza, it was reported that women are expected to spend more time in their tents (where temperatures may be higher than outdoors) and are less encouraged to wear loose and light clothing ([Alghoul & Roston, 2024](#)).

7.2.3 Informality and urban planning for heat

Various characteristics of the built environment can influence temperatures both indoors and outdoors, and urban areas are generally hotter compared to rural surroundings due to the urban heat island effect ([Heaviside et al., 2017](#)). Due to the high population density in various cities across Western Asia, average temperatures are found to be much higher compared to rural surroundings. For example, Lebanon is highly urbanised, and green spaces have drastically decreased over the years ([Chaoul et al., n.d.](#)). Research highlights the importance of green space – in Beirut, Lebanon, research found that areas with more green space with larger garden fractions are up to 6 °C cooler temperatures than surrounding dense artificial areas, and also have a reduced energy demand for cooling during the summer ([Kaloustian & Diab, 2015](#)).

In Israel, studies have found urban areas to be up to 3.6 °C higher in Tel Aviv ([Mandelmilch et al., 2020](#)) and up to 6.9 °C higher in Beer Sheva ([Potchter et al., 2006](#)). Moreover, research by Houssein et al. ([2023](#)) suggests a significant urban heat island effect in Amman, Jordan. Still, Jordan is using

solar energy to cool buildings and reduce cooling power consumption ([Bergh, 2022](#)). In Syria, indoor thermal discomfort has been observed in social housing due to a lack of passive cooling and lack of access to energy ([Ali, 2022](#)). Various cities are taking measures to improve the built environment for hotter temperatures. For example, a mapping initiative has mapped high-resolution street and neighbourhood-level shade across Tel Aviv, which can highlight areas with limited shade and can inform tree planting ([Aleksandrowicz et al., 2020](#)). Israel has recently announced a national plan to shade and cool urban spaces, with a target of planting 450,000 trees by 2040 ([Ministry of Environmental Protection, 2022](#)). Urban green spaces have a substantial effect on reducing temperatures in cities ([Knight et al., 2021](#)), with studies across Israel reporting up to 4 °C reduction in temperature ([Hiemstra et al. 2017](#)). Green building standards and passive cooling measures have also been introduced across the country, as well as innovating AC systems to use seawater instead of gas to reduce the environmental impact ([Doehler, 2020](#)).

7.2.4 Agriculture and water

Ongoing water scarcity poses a large crisis for countries across Western Asia. For example, Jordan is one of the most water scarce countries in the world ([World Bank, 2023](#)). The compounding factors of rapid population growth, increased water demand from industrial and agricultural sectors, depletion of groundwater reservoirs, and climate change will likely further worsen the water crisis in Jordan ([UNICEF, n.d.](#)). In Lebanon, a range of factors are also putting pressure on water systems, with the demand exceeding water supply ([Climate Centre, 2024](#)).

Across the past years, farming practices in some regions have become increasingly unsustainable particularly among large-scale farmers, and resource use policies remain vague. Generally, this trend threatens to impair the agriculture sector's capacity to meet the escalating demand for food worldwide, setting off a domino effect of economic strains ([Dirani et al., 2021](#)). However, there are also positive efforts underway. For example, across Lebanon, the International Center for Agricultural Research in Dry Areas (ICARDA) (originally based in Syria), is selecting and preserving seeds which are resilient to drought and heat, enhancing livelihoods and promoting sustainable agricultural practices ([Vidal, 2022](#)). The Center has so far released over 30 improved varieties of wheat, barley, chickpea, lentil, fava beans, and forage legumes. Also in Jordan, farmers have been exploring with innovative strategies such as hydroponic and aquaponic farming, and the government has launched a new water strategy for the years 2023-2040 ([UN, 2023](#)).

7.2.5 Heat action planning, preparedness, and response

In general, countries across the region have limited government capacity to develop (heatwave) early warning systems, heat action plans, or urban development strategies ([Bergh, 2022](#); [Kotharkar & Ghosh, 2022](#)). In Lebanon, the meteorological service is facing serious issues with few weather stations operational across the country, but a simplified Early Action Protocol for extreme heat is being developed at the moment. In Jordan, although the Jordan Meteorological Department (JMD) reported the high temperatures forecast across the region ([Roya News, 2024](#)), people's response and trust in weather forecasts is reported to be flawed ([Hazaimah, 2018](#)). Recently, the Israeli government created an emergency plan for dealing with extreme temperatures and added heatwaves to Israel's "threat map" ([Leichman, 2022](#)), and later published a reference scenario for heatwaves which together with the National Meteorological Service ([Yaron, 2023](#)).

Although early warning systems are fundamental to prepare in advance of an event, in conflict-affected zones, people and organisations have limited to no options to prepare or adapt even

with an early warning. Furthermore, instability across the region diminishes both resources and the scope of policy-making, constraining the ability to engage in the long-term planning and investments necessary for adaptation to extreme heat ([Vohra, 2021](#)).

7.3 V&E Conclusions

The past nine years have been the hottest on record, and the extreme heat observed last year, in 2023, was already exceptional and incomparable to any other previous year ([Perkins-Kirkpatrick et al., 2024](#)). This event has once again highlighted the need for urgent and targeted action across the Asian continent. Although significant efforts are underway to better prepare for and respond to extreme heat across Asia, notably through early warning systems and detailed heat action plans, accelerated and expanded action is needed to protect communities against extreme heat, focusing on the most vulnerable people.

Although anybody may be at risk from extreme heat, impacts are disproportionately and unequally distributed. The disproportionate impact of heat on certain occupational groups, including construction workers, transport drivers, farmers, and fishermen, imposes dual burdens of economic instability and personal health risks. While efforts to mitigate heat-related issues are underway in many cities through initiatives such as cool roofs and climate-informed building codes, challenges persist due to urban expansion, informal settlements, and inadequate infrastructure. Despite the existence of comprehensive heat action plans in some countries, the necessity for mandatory regulations, including workplace interventions like scheduled rest breaks and hydration programs, remains unfulfilled in many affected regions. Urgent attention is required to enhance cross-sectoral collaboration and prioritise immediate relief measures during heatwaves to mitigate their recurrent impacts and safeguard vulnerable populations effectively.

Data availability

Almost all data are available via the Climate Explorer.

Appendix

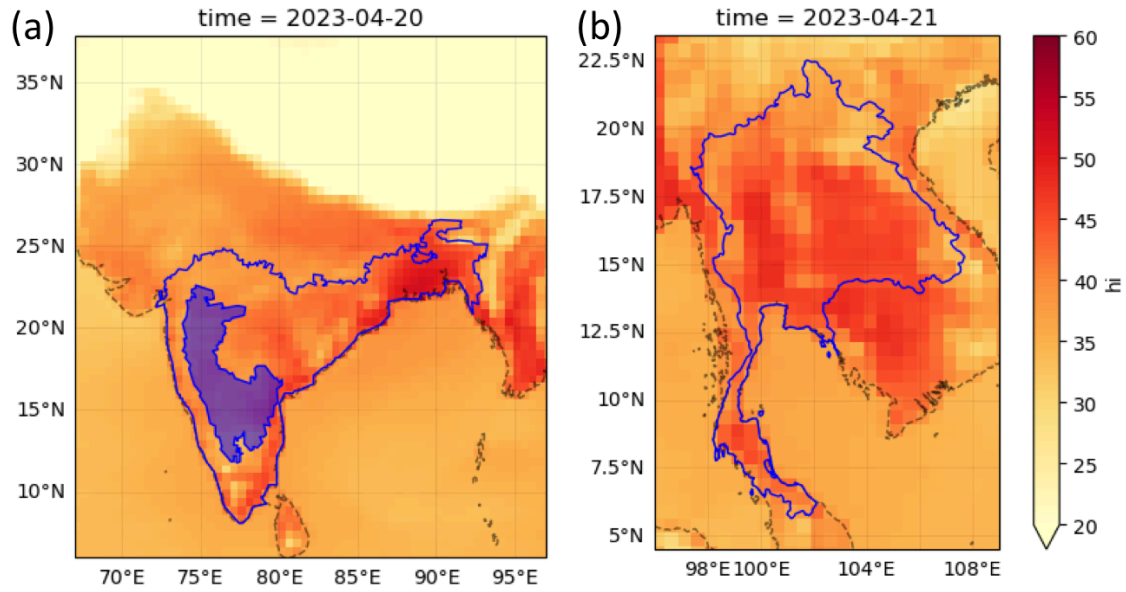


Figure A1. (a) Heat Index (calculated from ERA5 near-surface temperature and dew point temperature) [$^{\circ}\text{C}$] showing 4-day average daily maximum for the period from 17th to 20th of April 2023 for the India-Bangladesh region (outlined in blue). The dry, semi-arid region along the rain-shadow of the Western Ghats in India, as shown by the filled polygon is excluded from the analysis as the impacts defined by the combination of high humidity and high temperatures is not applicable in this region. (b) 4-day average daily maximum Heat Index during 18-21 April, 2023, over the Thailand-Lao PDR region (outlined in blue).

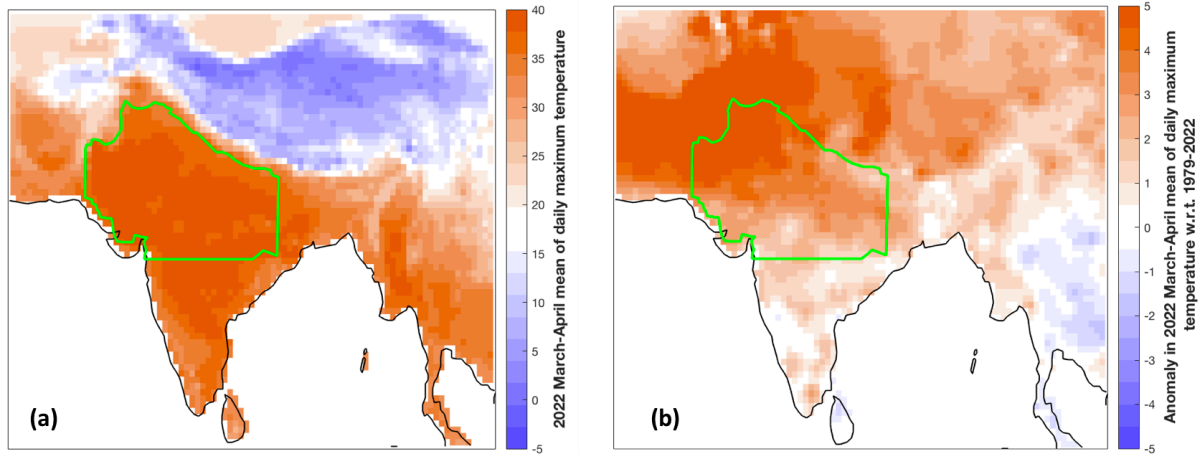


Figure A2: (a) March-April average daily maximum temperature for the year 2022 as observed in the CPC dataset. The study region is highlighted by the green polygon. (b) same as (a) for anomalies w.r.t. 1979-2022.

Table A1: Assessment of goodness of fit of the tested models to determine the best-fitting model. T

(a) West Asia		
Model	Tx3day~GMST	Tx3day~GMST+Niño3.4
Dataset		

MSWX	198.833	198.876
ERA5	327.797	328.266
CPC	205.984	202.703

(b) The Philippines

Model	Tx15day~GMST	Tx15day~GMST+Niño3.4
Dataset		
MSWX	70.77	28.07
ERA5	133.37	66.54
CPC	78.87	40.82

(c) South Asia

Model	TmeanApr~GMST	TmeanApr~GMST+Niño3.4
Dataset		
MSWX	89.02	85.89
ERA5	162.14	150.43
CPC	88.63	88.11

References

All references are given as hyperlinks in the text.