

# The heat wave in Phalodi, Rajasthan, India, 19 May 2016

## Science summary

## Key messages

- Consistent with human-caused climate change, annual mean temperatures across India are increasing.
- Heat waves in a relatively small area of India are becoming more frequent and more intense, but this is not true for most of the country.
- On 19 May 2016, the city of Phalodi in Rajasthan set an all-time record for any calendar day, hitting 51°C.
- This analysis used peer-reviewed methods to see if climate change is affecting the risk of record heat like that on 19 May 2016 in north-western India, and like that of a similar one-day heat event in Andhra Pradesh in May 2015.
- The analysis did not find that human-induced climate change played a role in these individual heat waves. This runs counter to studies done on similar extreme heat events in other parts of the world.
- The lack of a detectable climate change trend may be due to the masking effect of aerosols on warming, and increased use of irrigation.

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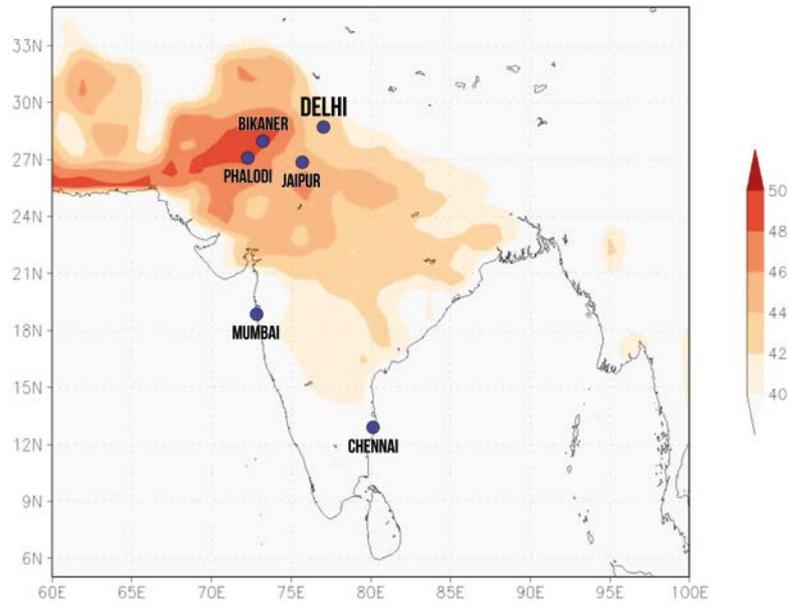
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## Context

On Thursday 19 May 2016, India experienced an all-time record high temperature for any calendar day.<sup>1</sup> The high temperature reached 51°C in the city of Phalodi in the Jodhpur district of the state of Rajasthan (Figure 1). By some accounts it was the third-highest temperature ever documented globally.<sup>2</sup> It was so hot that many residents of this city of about 50,000 simply remained indoors.<sup>3</sup> Those who did venture outside in Gujarat's Valsad found their sandals sticking to molten roads.<sup>4</sup>

Temperatures were high across much of Rajasthan on that day, with a majority of stations recording maximum temperatures above 46°C. The state capital of Jaipur saw its hottest day in

**Figure 1. Highest daily maximum temperature of the year up to September 2016<sup>5</sup>**



the past 11 years, with a maximum temperature of 46.5°C, while Delhi, India’s capital, reached 46.8°C (Table 1).

The record topped India’s previous all-time record high of 50.6°C in the city of Alwar, also in Rajasthan, which was set back in 1956.

**Table 1. Maximum temperatures in selected Indian cities on 19 May 2016<sup>6</sup>**

City	State	Temperature high (°C)
Phalodi	Rajasthan	51.0
Churu	Rajasthan	50.2
Barmer	Rajasthan	49.5
Bikaner	Rajasthan	49.5
Sri Ganganagar	Rajasthan	49.1
Jaisalmer	Rajasthan	49.0
Jodhpur	Rajasthan	48.8
Kandla	Gujarat	48.4
Kota	Rajasthan	48.2
Banda	Uttar Pradesh	47.2
Akola	Maharashtra	47.1
Delhi	–	46.8
Allahabad	Uttar Pradesh	46.7
Jaipur	Rajasthan	46.5
Gwalior	Madhya Pradesh	46.4
Hisar	Haryana	46.0

May is typically the hottest month across India, with temperatures reaching up to 40°C in the hottest areas before the cooling south-west monsoon rains arrive in July.<sup>7</sup> Rajasthan, home to the Thar desert, typically records the highest temperatures in India. However, the intensity of this particular heat wave left many wondering whether climate change might be contributing to the record-breaking nature of the event.

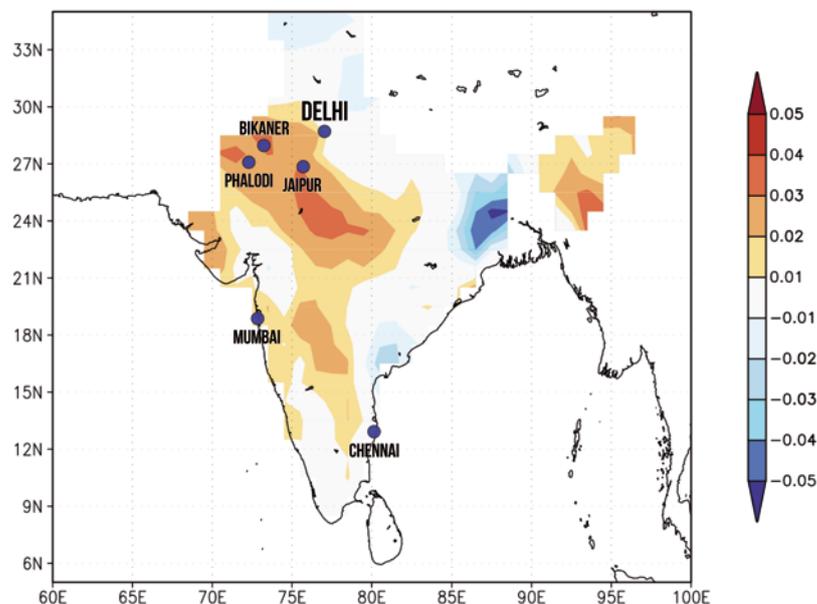
This summary presents an overview of what is currently known about the changing nature of high temperatures in India. Included is an analysis of the highest daily maximum temperature of the year (TXx) for Rajasthan, the region that set the recent record. For comparison, the same analysis is provided for the location of the 2015 heat wave in Andhra Pradesh. Using both observational data and models, these analyses aim to offer a better understanding of the role of human-caused climate change as well as other factors, notably aerosols and irrigation.

## Observational record of temperature in India

According to several studies, parts of India are seeing increasing heat waves (defined as a maximum temperature at or above 40°C, maximum temperature departure from normal 4.5–6.4°C above average, or maximum temperatures at or above 45°C) and severe heat waves (maximum temperature departure from normal 6.5°C, or maximum temperature at or above 47°C) (see <http://imd.gov.in/section/nhac/termglossary.pdf>). However, other regions see decreases, the trend varying depending on the region. According to the India Meteorological Department, the frequency of heat waves and severe heat waves has increased in aggregate across India, while large areas show no clear trend since the 1970s.

An analysis of 103 stations across India reports that while most stations showed an increase in heat waves and severe heat waves, seven stations showed a decrease (five with respect to heat waves and two with respect to severe heat waves).<sup>8</sup>

**Figure 2. Trend in maximum temperature of the hottest day of the year for the period 1971–2012<sup>9</sup>**



A similar analysis uses Excess Heat Factor and 90th percentile of maximum temperatures to assess changes in heat wave frequency, total duration and maximum duration over parts of north-west India (22°N–31°N, 70°E–77°E) over the period 1961–2013.<sup>10</sup> They conclude that in this part of the country, frequency of heat waves increased by one event in 20 years; average total duration of heat waves increased by two days per decade; and maximum duration increased by about 1.5 days per decade. However, across the rest of India they find no significant trend.

## Assessing the role of global warming

Recent advances in the science of extreme event attribution now make it possible for scientists rapidly to provide an objective, quantitative initial estimate of the relative contribution of global warming to specific classes of extreme weather (heat waves, cold waves, drought and heavy rainfall). Using peer-reviewed methods, these analyses provide estimates of the return-time period of the event both today and in the past – before there was a strong human influence on the climate system. The ratio of these is a measure of the extent to which climate change affected the likelihood of the event. Overall, extreme event attribution can provide valuable information to decision-makers faced with difficult and critical questions about changing risks and underpin adaptation strategies at a more local level.

**The analysis did not find that human-induced climate change played a role in the individual heat waves, in contrast to studies in other parts of the world.**

To assess the potential link between the highest daily maximum temperature of the year in north-western India or Andhra Pradesh and human-caused greenhouse gases in the atmosphere, the World Weather Attribution team (<https://wwa.climatecentral.org/about/partners>) conducted independent assessments using three peer-reviewed approaches: statistical analyses of the historical temperature record; the temperature trends in global coupled climate models; and the results of thousands of simulations of possible weather with a global climate model. Applying multiple methods provides scientists with a means to assess confidence in the results.

As discussed above, the observational analysis shows very low or no trends in most of India, and positive trends in the north-east. The return time of the observed 2016 temperature record at the nearest station with a long time series, Bikaner, is between 13 and 180 years. For the Andhra Pradesh heat wave, the return time was about 10 years. Given the limited area covered by the latter heat wave, events like this may be expected almost every year somewhere in South Asia.

The analysis of climate models always starts with a quality check. Are the models realistic enough for the event that is being studied? In this case, the global coupled climate models, such as the CMIP5 ensemble,<sup>11</sup> show trends in sea surface temperature and heat waves that are not compatible with the observed trends. Therefore that ensemble was not used for further analysis.

Finally, the regional model that was forced with observed sea surface temperatures shows a spatial pattern of an increase and no-increase in maximum temperatures over India that is more comparable with observations. Although the magnitude of the change differs from observations, we use this model for analysis as it allows conclusions to be drawn on the influence of sea surface temperatures on the likelihood of record-breaking heat.

The analysis found that human-induced climate change increased the risk of 51°C maximum temperatures to be exceeded in the grid box around Phalodi in 2015 from a 1 in 20–30-year event to a 1 in 7–10-year event, so a small increase in probability. At the same time, an event of this magnitude is expected to occur only every 40–49 years in a year of the same overall warming as

2015, but without the specific sea surface temperatures that were observed. The influence of the sea surface temperatures, and thus natural inter-annual variability on the likelihood of an event like this to occur, is therefore higher than the influence of human-induced warming.

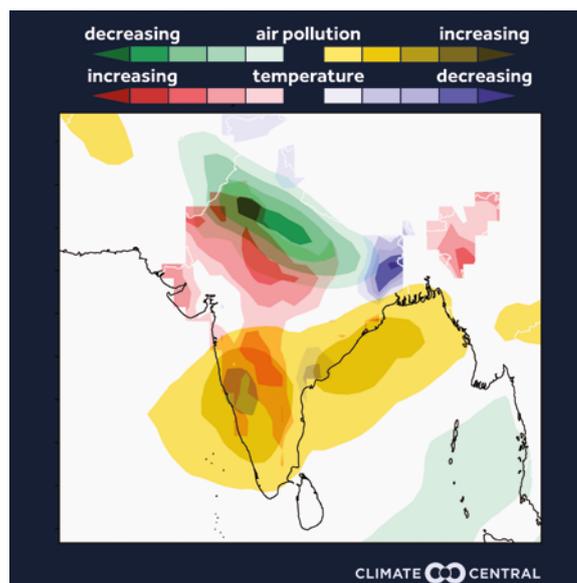
In conclusion, the two approaches that are trusted give an increase in probability of heat waves in both regions, but the increase is not statistically significant and may be due to a lack of data homogeneities (trends in missing data) and remaining model inaccuracies. This is in contrast to other parts of the world, such as Europe, where the role of human-induced climate change in heat waves is very pronounced. The question is therefore why the increase is so much less, and in some regions absent. Two factors can counteract the warming effect of greenhouse gases: the cooling effects of aerosols and of irrigation.

## Aerosols

Increasing concentrations of aerosols in the atmosphere block sunlight and so cause a cooling effect on the ground.<sup>12</sup> In Europe, summer temperatures hardly increased up to the 1980s, when reductions in aerosol use began to become effective. (Afterwards, the trend was higher than expected due to greenhouse gases alone.) There is qualitative evidence that the same effect is operating in India over the past few decades.

Based on the qualitative analysis of trends in aerosol optical depth and highest daily maximum temperature of the year, it is likely that aerosols are helping to offset the surface warming trend over India – particularly when it comes to maximum temperatures in the pre-monsoon season. Figure 3 shows the trend in aerosol optical depth overlaid on the trend in highest daily maximum temperature of the year. Optical depth over the period 2003–2015 is decreasing (clearer skies) to the north and increasing (more pollution) to the south. There is general agreement between the decreasing trend in optical depth and increasing trend in maximum temperature.

**Figure 3. Trends in aerosol optical depth and highest daily maximum temperature of the year<sup>13</sup>**



**The lack of a detectable climate change trend may be due to the masking effect of aerosols on warming, and increased use of irrigation.**

This hypothesis is supported by other research. Kumari and co-workers, using station data collected from the India Meteorological Department, find that the average solar dimming as a result of increased aerosols from human activity is approximately  $-0.86 \text{ W/m}^2$  per year over India for the period 1981–2004.<sup>14</sup> Over the past decade, aerosol optical depth has been increasing by 4% per year over India.<sup>15</sup> As energy policies shift away from fossil fuels, it is likely that the cooling effect of aerosols across Asia will diminish, resulting in an increase in the intensity of heat waves over the coming decades. Earth System Model experiments indicate an increase in the intensity, duration and frequency of severe heat waves for the 2070–2099 period in most parts of India, with the highest increase in intensity projected to occur in northern India.<sup>16</sup>

High temperatures with polluted air kill many more people than high heat alone. This means that the impacts of heat waves may well have become worse, even if the maximum temperatures have not shown strong trends.

## Irrigation

Another well known effect that can counteract heating, especially in the maximum temperatures, is increased irrigation. The extra water availability means that incoming solar energy is used more for evaporation and less for raising temperatures. There is evidence that increased irrigation has decreased dry-season maximum temperatures in many regions of the world, for example by up to  $5^\circ\text{C}$  in California.<sup>17</sup> In India, relative humidity has increased significantly in the northern and central regions, corresponding with regions that are said to have more irrigation. This trend probably also contributes to the lower or absent trends in pre-monsoon maximum temperatures.

It should be noted that, just as with air pollution, increased humidity also exacerbates the health effects of heat waves. Even if the maximum temperatures do not increase much, the combination of high temperatures with increasing humidity makes the impacts of heat waves more dangerous. This is reflected in an upward trend of the highest wet bulb temperatures.

## Vulnerability and exposure

Excessive heat can have a devastating impact on human health, resulting in heat cramps, exhaustion, and life-threatening heat strokes where children and the aged are most vulnerable. It can also aggravate pre-existing pulmonary conditions, cardiac conditions, kidney disorders and psychiatric illness. High air pollution in India exacerbates many of these problems. According to newspaper reports, at least 17 heat-related deaths occurred in Gujarat state, seven in Madhya Pradesh and 16 in the western state of Rajasthan,<sup>18</sup> where the highest temperatures were recorded during the heat wave around 19 May 2016. Hundreds more people were admitted to hospitals in western India with signs of heat-related illness. In addition, hundreds of millions of Indians were affected by the failure of crops due to the excessive heat.<sup>19</sup> For health impacts, heat combined with humidity can also be more dangerous than dry heat. High humidity slows down the evaporation of sweat from the skin, preventing the body from cooling properly. This can be particularly dangerous for anyone who works outdoors.

The groups most vulnerable to heat extremes are typically the elderly, the very young, the mentally ill and those with certain pre-existing health problems; however, there are gaps in the current understanding of vulnerable groups in the Indian social and economic context. Overall, heat-health impacts in India are probably underestimated due to a lack of reporting and of systematic public record-keeping.

### Summary of key scientific parameters

<b>Variable</b>	TXx
<b>Event definition</b>	Hottest day of year, Rajasthan 2016 Hottest day of year, Andhra Pradesh 2015
<b>Domain</b>	India, zoom in to Rajasthan and Andhra Pradesh
<b>Observational data</b>	Maps from ECMWF (re)analysis, station data $T_{max}$ from GHCN-D (GTS) <sup>20</sup>
<b>Models used</b>	CMIP5 (considered but not used) weather@home <sup>21</sup> model: HadAM3P at 50 km resolution over South Asia, driven by HadAM3P and GloSEA5 <sup>22</sup> SSTs
<b>Results</b>	A positive trend in heat waves in the two regions but not statistically significant

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