

Interactive comment on “Extreme heat in India and anthropogenic climate change” by Geert Jan van Oldenborgh et al.

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We thank the reviewer for her comments on our article on the attribution of heat waves in India. Below we answer her comments and questions and show how these have been taken into account in the revised text.

The subject of the article is very interesting and provides a sound climate data base. However, there are 2 issues where I found room for improvement:

To evaluate the impact on mortality due to extreme heat: absolutely numbers or adjectives (“ very lethal”) are not the clearest ways to express it. The death figures is likely that they are much higher than the registered as heat related illness is often recorded inaccurately and figures from rural areas are hard to attain. To provide a sound evi-

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dence of the real impact I recommend to use variations on the mortality rate occurred during the two extreme heat events analysed. This rate could support sentences as 'The previous year, a widely-reported very lethal heat wave occurred in the southeast, in Andhra Pradesh and Telangana, killing thousands of people' (page 1, 12-3). 'From a health impact point of view, the severity of heat waves has increased in India'.

The first sentence was only included to show that the impact of the heat waves was large. As the reviewer states, death figures from the rural areas where most deaths were (anecdotally) reported are not known, and tracing these and tying them to heat is a job for specialists. At this moment we cannot do more than state that there has been anecdotal impact of the heat waves on mortality, especially the 2015 Andhra Pradesh event.

The second sentence the reviewer quotes is based on generalities: although we do not find any evidence that the hottest day of the year has increased, the humidity and air pollution in these very hot days have increased so that the impact of these high temperatures must have increased. We updated that sentence to 'From these factors it follows that, from a health impact point of view, the severity of heat waves has increased in India.'

*Although the article insists in the impact on mortality during heat waves, I would recommend analysing the increase of mortality during extreme hot single days. A study conducted in Catalonia concluded that 40% of deaths due to heat, occurred in single days of extreme temperature. Xavier Basagaña et al. "Heat Waves and cause-specific mortality at all ages". *Epidemiology*. Volume 22, number 6, November 2011. DOI: 10.1097/EDE.0b013e31823031c5.*

Indeed we use the single-day maximum temperature and maximum wet bulb temperature for this study, based on the anecdotal observation that most casualties were outdoor labourers that succumbed to heat stress. We thank the reviewer for the reference, of which we were not aware, and have added it to the text:

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‘The one-day length of the definition was chosen because of anecdotal evidence that the main victims in the 2015 heat wave were outdoor labourers. Basagaña et al. (2011) also find no stronger effect from longer heat waves in Catalonia. In contrast, in urban areas it is often found that longer heat waves have larger impacts, as the heat takes some time to penetrate the buildings to the most vulnerable population (e.g., Tan et al., 2007; D’Ippoliti et al., 2010).’

The relation of air pollution and temperature is partly addressed: although some air pollutants have a cooling effect, others are climate forcers, which have a potential impact on the planet’s climate and global warming in the short term (i.e. decades). Tropospheric O₃ and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers and that contribute directly to global warming. (Air Quality in Europe 2015 EEA Report No 5/2015).

While it is true that pollutants have both cooling and warming effects, the incident solar radiation at the surface is reduced by all scatterers and absorbers in the atmosphere. The net climate effect of India’s air pollution is estimated to have cooled the Indian subcontinent with up to -0.3 degrees since 1970s (Krishnan and Ramanathan, 2002) and thus reduced daily maximum 2-m temperatures. At the same time atmospheric heating is increased. Krishnan and Ramanathan suggest that the atmospheric warming is being distributed regionally and could contribute to reduced tropical precipitation. While such wider climate effects of the atmospheric heating are very uncertain, the surface cooling below the haze layers relevant in this study on heatwaves is undisputed. To better explain that we are referring to a surface cooling effect (instead of climate cooling) by both scattering and absorbing aerosols ‘cooling’ is replaced by ‘surface cooling’ at a couple of places in the paper. Furthermore we added a few sentences in the aerosol section: ‘Note that all types of aerosols block part of the incident sunlight and thus cool the surface, decreasing maximum temperatures. Absorbing aerosols additionally heat the lower atmosphere and are thought to affect the regional climate through changes in cloudiness and tropical precipitation (Krishnan and Ramanathan,

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2002). The redistribution of the enhanced atmospheric heating by black carbon is still poorly understood.’.

Therefore, revision is needed in sentences as:

- *Decadal variability cannot explain this, but both increased air pollution with aerosols blocking sunlight and increased irrigation leading to evaporative cooling have counteracted the effect of greenhouse gases up to now. (page 1, l 6-9)*

Unchanged.

- *For the next decades, we expect the trend due to global warming to continue, but the cooling effect of aerosols to diminish as air quality controls are implemented. The expansion of irrigation will likely continue, though at a slower pace, mitigating this trend somewhat. Humidity will probably continue to rise. The combination will give a strong rise of the temperature of heat waves. The high humidity will make health effects worse, whereas decreased air pollution would decrease the impacts (page 1, l 14-17)*

Text change: ‘the cooling effect’ has been changed to ‘the surface cooling effect’

- *The second is a masking due to a trend in aerosols, i.e., worsening air pollution that causes less sunshine to reach the ground and thus a cooling influence, especially in dry seasons. (page 10, l 25)*

Text change: ‘a cooling influence’ has been changed to ‘a surface cooling influence’

- *Besides the obvious benefits, a reduction in air pollution will lead to even higher maximum temperatures during heat waves. (page 17, 5)*

Text not changed

- *Homeless and outdoors professionals, should be added to the sentence Children and the elderly are most vulnerable (page 2, l 5)*

Indeed, thank you for the suggestion.

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