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Characterizing the atmospheric conditions during the 2010 heatwave in Rio de Janeiro marked by excessive mortality rates

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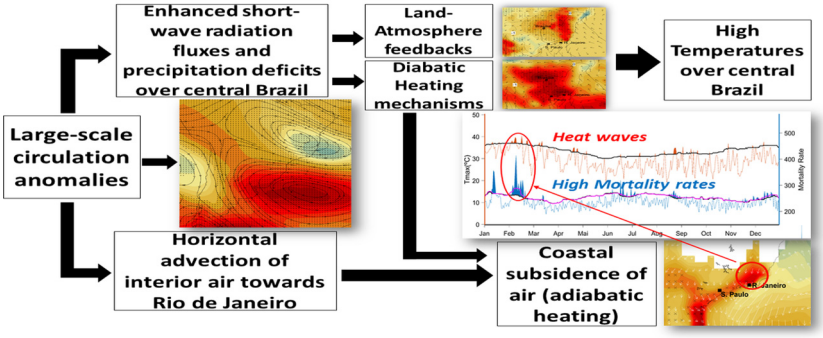
HIGHLIGHTS

- A total of 3006 deaths was recorded representing an excess of 737 deaths.
- Higher mortality risk for women compared to men and particularly for the elderly
- Quasi-stationary mid-atmospheric anticyclonic anomaly over the South Atlantic
- Relevant soil-atmosphere feedback mechanisms for the Heat Wave development
- Regional katabatic winds were responsible for heating the already warm air mass.

GRAPHICAL ABSTRACT



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ABSTRACT

Global temperatures have increased considerably over the last decades, directly impacting the number, intensity and duration of extreme events such as heat waves. Climate model projections accounting for anthropogenic factors indicate that deadly mega-heat waves are likely to become more frequent in the future. Although the atmospheric features and social-economic related impacts of heat waves have already been documented in various regions around the world, for other highly populated regions, such as the Metropolitan Region of Rio de Janeiro (MRRJ), a similar objective assessment is still needed. Heat waves directly impact the public health sector and particularly the less wealthy and elderly population groups. During February 2010, an elevated mortality peak occurred during a 8-day period (from 2 to 9 Feb 2010) characterized as a heat wave episode in MRRJ. A total excess of 737 deaths was recorded with the elderly group registering the highest mortality incidence. During this heat wave period, a quasi-stationary anticyclonic anomaly forced in altitude by a Rossby wave train was established over the south Brazilian coast. At the surface, the meteorological scenario from January 2010 to the heat wave period was marked by clear sky conditions, large precipitation deficits, and enhanced diabatic heating. During the heat wave period, warm and dry air masses were advected from interior regions towards the MRRJ, exacerbating temperature conditions by

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pronounced subsidence and adiabatic heating mechanisms. All these conditions contributed to pronounced positive temperature anomalies, reinforced by land-atmosphere feedbacks.

1. Introduction

The pervasive positive temperature trend in various parts of the world has become a high-priority issue for today's society, generating growing concern about current and future impacts of associated extremes events such as droughts, floods, storms, heat and cold waves (IPCC, 2012). The beginning of the 21st century in agreement with the previous 1990s and 1980s decades of the 20th century, have been characterized by a continuous rise in the global mean temperature with 17 out of the 18 warmest years on record all occurring in the beginning of the 21st century (IPCC, 2014; NOAA, 2018). Moreover, temperature extremes, such as heat waves (HWs) have been continuously showing increasing trends regarding frequency, intensity, and duration (Seneviratne et al., 2014). As a consequence, during the last years, a new HW class was identified, the so-called mega HWs characterized by historical record events regarding the spatial extent, duration, intensity and the severity of their impacts on ecosystems and society (Barriopedro et al., 2011; Miralles et al., 2014). Examples of these mega HWs are the 2003 and 2017 European HWs, as well as the 2010 Russian and the 2011 US (Texas) HWs (Qian et al., 2016).

HWs are known to impinge a wide range of impacts in public health (Gasparrini and Armstrong, 2012), in several socio-economic sectors (Garcia-Herrera et al., 2010; Linares and Díaz, 2008), in ecosystem's water availability and in vegetation/animal stress levels including vegetation fires (Bastos et al., 2014; Gusso et al., 2014). Extremely hot temperatures are capable of perturbing the human biological mechanisms, especially those related to thermoregulatory body response, which might, in turn, aggravate some diseases, particularly cardiovascular and respiratory conditions (Braga et al., 2002; Hajat et al., 2005). Recent studies have established a relationship between mortality and several environmental variables, especially temperature (Gasparrini et al., 2015; Gasparrini and Armstrong, 2012; McMichael et al., 2008; Son et al., 2016). The heat effects are felt with more intensity by some population sectors, the so-called risk groups, such as elderly people and fragile individuals with chronic illnesses or pre-existing heart and respiratory diseases (Basu and Samet, 2002; Barnett, 2007; Bell et al., 2008; Trigo et al., 2009; Åström et al., 2011). Several studies have reported excess mortality rates during HW events primarily in the U.S.A., Australia, and Europe. For instance, at least 40.000 deaths were reported when extremely high temperatures were recorded during the 2003 European mega HW (Garcia-Herrera et al., 2010; Robine et al., 2008). In contrast, there are fewer studies evaluating the impact of HWs in mortality over South-America, although Muggeo and Hajat (2009) and Bell et al. (2008) observed an increase in non-accidental mortality among the elderly due to persistently warmer days. Gouveia et al. (2003) and Son et al. (2016) also reported an association between high temperatures in São Paulo and excess mortality rates, mainly due to respiratory diseases.

In South America, and particularly in Brazil, an increase in the frequency and intensity of extreme heat events has also been observed since the second half of the twentieth century (Bitencourt et al., 2016; Ceccherini et al., 2016; Cerne and Vera, 2011; Geirinhas et al., 2017; Hannart et al., 2015; Renom et al., 2011; Rusticucci, 2012; Rusticucci et al., 2017, 2016). For instance, extremely hot and dry conditions over southeastern Brazil (SEB) during the 2001 and 2014 summers led to a severe water resources crisis and important electricity production deficits (Herring et al., 2015; Coelho et al., 2016), a scenario that imposed constraints on the population for reaching thermal body comfort. In addition to the severe water supply crisis, the 2014 event triggered a dramatic increase in the number of forest fires in the region (Rodrigues et al., 2018).

Hot and dry summer events over the southeast region of Brazil have been associated to persistent anticyclonic patterns over the South Atlantic, near the south and southeast coasts of Brazil (Coelho et al., 2016; Grimm, 2003). This large-scale anticyclonic configuration is often related to an upper-level atmospheric wave-type flow and Rossby wave trains. Such wave trains induce a large-scale teleconnection between the Southeast Pacific, South America, and the South Atlantic Ocean, the so-called Pacific – South American Modes (Irving and Simmonds, 2016; Mo and Paegle, 2001; Renwick and Revell, 1999). The year of 2010 was also exceptionally hot and dry over all South America, being characterized by the occurrence of a large number of HW events in many Brazilian cities, namely São Paulo, Manaus, Recife and Brasília (Geirinhas et al., 2017). Moreover, during the 2009–2010 hydrological year the Amazon region experienced a historical drought, in association with a significant and prolonged precipitation deficit coupled to both high-temperature values and evaporation rates (Lewis et al., 2011; Marengo et al., 2011; Panisset et al., 2018). Such anomalous conditions have been linked to the manifestation of an El Niño event with anomalously warm sea surface temperatures (SST) in the central and eastern Pacific, and also to anomalously warm SST over the tropical North Atlantic Ocean (Coelho et al., 2012; Marengo and Espinoza, 2016).

Despite the role played by the El Niño event and the anomalously warm tropical North Atlantic, it is important to note that these extreme climatic events occurred within the context of positive temperature trends (regarding both Tmax and Tmin values) recorded since 1960 over South America and Brazil (Marengo and Camargo, 2008; de Barros Soares et al., 2017). The atmospheric mechanisms contributing to the manifestation of northern hemisphere HW events, such as the European 2003 and the Russian 2010 mega HWs, have been well identified and characterized (e.g., Trigo et al., 2005; Fischer et al., 2007; Garcia-Herrera et al., 2010; Fischer, 2014; Qian et al., 2016; Tomczyk, 2017). However, for South America, relatively fewer studies have explored the main large-scale and regional atmospheric circulation mechanisms during the preceding weeks/months and the HW period itself.

One of the most intense and prolonged HW affecting the Metropolitan Region of Rio de Janeiro (MRRJ), a major population center in Brazil, was recorded at the beginning of 2010, during the week spanning from 2 and 9 February 2010. This event was characterized by daily maximum temperatures (Tmax) higher than the calendar day climatological Tmax 90th percentile for eight consecutive days. According to the local and national media, this period was defined as an extremely hot episode associated to abnormally high mortality. Besides the early February 2010 HW event, the city of Rio de Janeiro recorded several other periods of consecutive days with abnormally high-temperature values. However, to the best of our knowledge, the 2010 HW event has never been properly assessed, neither from the meteorological perspective nor from the excessive mortality induced. By combining the knowledge produced when characterizing the atmospheric circulation conditions that prevailed during the manifestation of the observed HWs, with the proper use of weather and climate forecast models, which are designed to anticipate the occurrence of these conditions, it is becoming possible to predict the occurrence and the intensity of HWs. This knowledge and predictions are of extreme importance for preventing society and health services from potential mortality risk periods, particularly in densely populated areas. In fact, due to the so-called urban heat island effect and considering the projected increase in surface temperatures for the next decades (IPCC, 2014), people living in the metropolitan regions