Insights from the first Brazilian Symposium on Human Biometeorology

Krüger, E; Gomes, ACDS; Lucio, PS; Gobo, JPA; Nedel, AS; Gonçalves, FLT; Piacenti-Silva, M; Napoli, CD; Lam, CKC

Published in:
Revista Brasileira de Ciências Ambientais

DOI:
10.5327/z2176-94781643

Publication date:
2023

Technical Note

Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Insights from the first Brazilian Symposium on Human Biometeorology

Reflexões sobre o primeiro Simpósio Brasileiro de Biometeorologia Humana

Eduardo Krüger[1], *Ana Carla dos Santos Gomes*[2], *Paulo Sérgio Lucio*[3], *João Paulo Assis Gobo*[4], *Anderson Spohr Nedel*[5], *Fabio Luiz Teixeira Gonçalves*[6], *Marina Piacenti-Silva*[7], *Claudia Di Napoli*[8], *Cho Kwong Charlie Lam*[9]

ABSTRACT

A current systematic literature review has stated several deficiencies and knowledge gaps in biometeorology research conducted in Brazil. This finding encouraged a group of local professionals in the field to foster research initiatives in topics and regions yet unexplored in the country. Motivated by that, the group organized the first Brazilian Symposium on Human Biometeorology between July 4 and 8, 2022, in Natal (RN), northeastern Brazil. This paper aims to summarize the main studies presented at the symposium and highlight a few ideas that could be pursued next in human biometeorology in future research initiatives.

Keywords: urban climatology; heat-related mortality; climate-driven diseases.

RESUMO

Uma recente revisão sistemática da literatura revelou várias deficiências e lacunas de conhecimento na pesquisa na área de Biometeorologia realizada no Brasil. Tal fato estimulou um grupo de pesquisadores da área a fomentar iniciativas de pesquisa em temas e regiões ainda pouco exploradas no país. Motivado por isso, o grupo organizou o primeiro Simpósio Brasileiro de Biometeorologia Humana entre 4 e 8 de julho de 2022, em Natal (RN). Este artigo visa resumir os principais estudos apresentados no simpósio e destacar algumas ideias a serem seguidas em biometeorologia humana em futuras iniciativas de pesquisa.

Palavras-chave: climatologia urbana; mortalidade relacionada ao calor; doenças relacionadas ao clima.

[1]Universidade Tecnológica Federal do Paraná – Curitiba (PR), Brazil.

[2]Universidade Federal do Oeste do Pará – Santarém (PA), Brazil.

[3]Universidade Federal do Rio Grande do Norte – Natal (RN), Brazil.

[4]Universidade Federal de Rondônia – Porto Velho (RO), Brazil.

[5]Universidade Federal da Fronteira Sul – Cerro Largo (RS), Brazil.

[6]Universidade de São Paulo – São Paulo (SP), Brazil.

[7]Universidade Estadual Paulista "Júlio de Mesquita Filho" – Bauru (SP), Brazil.

[8]European Centre for Medium-Range Weather Forecasts – Reading, United Kingdom.

[9]University of Plymouth – Plymouth, United Kingdom.

Correspondence address: Eduardo Krüger – Departamento de Construção Civil, Universidade Tecnológica Federal do Paraná, *Campus* Curitiba, Sede Ecoville – Rua Deputado Heitor Alencar Furtado, 4900 – Campo Comprido – CEP: 81280-340 – Curitiba (PR), Brazil. E-mail: ekruger@utfpr.edu.br

Conflicts of interest: the authors declare no conflicts of interest.

Funding: none.

Received on: 06/21/2023. Accepted on: 09/11/2023.

https://doi.org/10.5327/Z2176-94781643

Introduction

In Brazil, the relationship between health issues and climate-driven factors takes place in multiple ways. To this matter, authors such as Souza Hacon et al. (2019) have identified that increases in the frequency of heat waves, drought episodes, rainfalls, and extreme weather events in general will have direct and severe impacts on public health. On the other hand, climate change is expected to aggravate the frequency and severity of vector- and water-borne diseases, and the extent of air pollutant emissions, which will cause severe burdens on human health, particularly for the most vulnerable part of the Brazilian population. Health impacts will likely be further exacerbated due to deficiencies in the national healthcare system.

In terms of water scarcity and the occurrence of extreme weather events, half of all natural disasters in Brazil are drought-related (Vanham et al., 2021). The northeastern semi-arid region of Brazil has been particularly suffering from a history of droughts (Vanham et al., 2021). Since that region is already burdened by high poverty and illiteracy levels, also exhibiting the lowest Human Development Index (HDI) levels in the country (Sena et al., 2014), a perverse weather/climate-socio-economic conundrum emerges. Floods, occurring more frequently in summer — between December and April — are a major concern too, and mortality rates from river floods are among the highest worldwide (Alfieri et al., 2020). Quite recently, in the summer of 2022, severe floods and landslides caused widespread displacements and injuries, resulting in over 200 documented deaths in the city of Petrópolis in the Brazilian state of Rio de Janeiro, with demonstrated burdens on healthcare (The Rio Times, 2022) and increased pressure on a political solution for that matter. Reported disasters in the news dramatically set the stage for increased climate research in Brazil. The issue deserves more and more attention in the media, and increased awareness of the population to even more frequent extreme events in the context of climate change.

Risk assessment of extreme heat on public health should also be a matter of concern in Brazil. A recent study on heat stress vulnerability in six Brazilian metropolitan areas showed that heat-induced risk tends to be higher in regions where socio-economic conditions are the worst, and in cities more evidently in less developed parts (Lapola et al., 2019). Lapola et al. (2019) thus advocate for short-term adaptation measures ranging from risk communication (e.g., alert systems) to urban greenery schemes. Another study, which proposes different indices to assess vulnerability (socio-economic, epidemiological, climatological), evidenced that the wealthiest states of Brazil present the lowest "general vulnerability" to heat (Confalonieri et al., 2009). For the worst-case future climate scenario (4°C warming) in Brazil, Souza Hacon et al. (2019) concluded that strong or extreme heat stress situations are expected to affect children, the elderly, and outdoor workers. This future heat stress would result in detrimental consequences for the country's public health as well as its labor productivity. In the productive sector, outdoor workers in agriculture and construction are among the most vulnerable as they are exposed more frequently to extreme weather conditions, including intense heat (Bitencourt et al., 2020). The Lancet Countdown 2020 report estimated that in 2019 alone Brazil lost 4.0 billion work-hours due to excess heat compared to 2.8 billion in 2000 (Watts et al., 2021), a rise of over 40%. Improving working conditions through diminishing risk exposure and refining technological developments related to outdoor labor activities should be a primal concern in terms of heat-mitigating measures from the viewpoint of human health. In addition, changes in employment legislation should mitigate heat-related impacts (Bitencourt et al., 2020).

Brazil can thus be considered a "climate-health hotspot", i.e., a country where the climate affects local populations negatively through multiple pathways (Di Napoli et al., 2022). Existing deficiencies demand feasible solutions in the short- and mid-terms, and knowledge gaps need to be filled by looking at the climate dimensions of tourism, vector-borne diseases, mortality, and morbidity, particularly in Brazilian urban centers, as current urbanization trends in the country show a high proportion, with over 80% of Brazilians living in cities (Krüger et al., 2022; IBGE, 2023). The first Brazilian Symposium on Human Biometeorology (*Simpósio Brasileiro de Biometeorologia Humana 2022*) was organized and held at the Federal University of Rio Grande do Norte (UFRN) in Natal, northeastern Brazil, between July 4 and 8, 2022, with the main goal of showcasing existing problems in the research area, and proposing solutions along with a work frame in the near future for human biometeorology research. The current article aims to synthesize this first Brazilian symposium with recommendations for future research on pressing matters in the context of human biometeorology.

The First Brazilian Symposium on Human Biometeorology

As put forth by McGregor (2012), "human biometeorology focuses on understanding the reciprocal, but often inequitable, relationship between atmospheric processes and humans, and how this plays out at a range of time and spatial scales". The topics covered in the symposium fit into this description and included three relevant subfields of human biometeorology, as presented by McGregor (2012): 1. assessment of human thermal comfort; 2. detrimental effects of ultraviolet (UV) radiation; and 3. climate sensitivity to vector-borne diseases. Another line of research recurrently addressed during the symposium was the evaluation of observed changes in weather extremes, specifically their duration, variability, and representativeness in Brazilian regions, a subject matter recently explored by Basarin et al. (2020) in a review paper for Europe. Adaptation and mitigation measures for climate change impacts were also discussed, along with the need for climate-related communication and early warning systems.

The symposium was organized by a research collaboration on human biometeorology started in 2021 in the country by a group of Brazilian researchers that culminated in a joint systematic review (Krüger et al., 2022).

The organizing committee was composed of the authors of the aforementioned publication. The geographical distribution of the organizers in Brazil as well as the location of the speakers worldwide is shown in Figure 1.

The symposium was partly sponsored by the International Society of Biometeorology (ISB) and had the purpose of mirroring the Triennial Congress from the ISB, which provides "the forum for the latest biometeorology research to be presented, current collaborations to be reinforced and for new interdisciplinary collaborations to be formed" (Keatley, 2017, p. 11). The symposium pursued the same goals, yet in the context of Brazil.

More importantly, the first Brazilian Symposium on Human Biometeorology aimed to promote human biometeorology research conducted in the country and to identify knowledge gaps reported in a comprehensive systematic literature review (Krüger et al., 2022).

In order to achieve these purposes, the symposium focused on five topics: a) climate-driven diseases; b) thermal comfort, urban, and architectural biometeorology; c) atmospheric pollution and health; d) climate change; and e) climate, health, and climate change. The daily program included three sections: presentations by keynote speakers; round table discussions; and afternoon technical sessions held by graduate and undergraduate students. Altogether, there were five keynote presentations followed by many round tables and over 25 short presentations. Keynote speakers and presenters have different backgrounds and research interests ranging from climatology, geography, and meteorology to medicine and zootechny. The symposium was held as a hybrid event with recorded, live-streamed sessions on YouTube to guarantee the widest reach in terms of audience. Approximately 25 participants (students, researchers, and professors) attended in person.

A note on the summary of the symposium was presented: "For the preparation of each description, we invited speakers to read through the text on their talk and perhaps add a few things more if they wished. Many of them have added their own references, others chose to include other, third-party references."

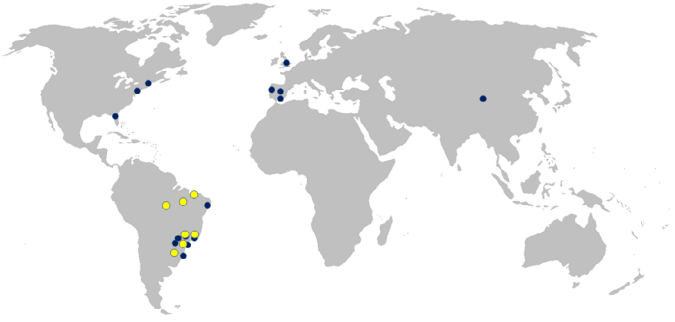

Figure 1 – Map with organizers (yellow circles) and speakers (dark blue circles) of the symposium on a public domain world map (Available at: https://commons.wikimedia.org/w/index.php?curid=868126).

Summary of the symposium contents

The five days of the symposium are described in the following sections of this paper, providing useful references to each of the talks presented either as keynotes or round table talks.

Day 1: climate-driven diseases

The opening ceremony saw the participation of local authorities from UFRN, the host institution, ISB representatives in Brazil, and the local organizer of the symposium.

The opening keynote presentation was held by Pablo Fernández de Arroyabe (Universidad de Cantabria; ISB Past President), titled "The influence of atmospheric processes on human health in the framework of climate-dependent diseases". Fdez-Arroyabe first evidenced the existing relationships between atmospheric processes, climate change, and human health, outlining existing research gaps. Symptoms from climate-dependent diseases have been highlighted, which were then linked to individual and weather-related variables, also dependent on the vulnerability level of the population. The need for transdisciplinary work was also stressed. Warning systems that can be tailored to integrate monitoring systems, global data sources, innovative models and approaches, geographic information system (GIS) data, biometeorological profiles, and dedicated apps were suggested (Fdez-Arroyabe et al., 2018). Challenges for pursuing such topics further include the development and implementation of wearable and implantable medical devices (Fdez-Arroyabe et al., 2020). Concerning climate change and climate-dependent diseases, air-, vector- and water-borne diseases have been described as well as models that have been or still need to be developed due to the inherent complexity behind the impacts of climate change on human health. In this respect, monitoring and risk-analysis systems were exemplified. The consequences of unsustainable land use on environmental degradation and the development of vector-borne diseases in Latin America were also addressed. Finally, the issue of air pollution and its consequences on human health was described (Royé et al., 2019). Fdez-Arroyabe identified gaps in such topics that warrant future research endeavors, including indoor thermal comfort and climate-related occupational health (Vega-Calderón et al., 2021), atmospheric electric fields (Fdez-Arroyabe et al., 2021), atmospheric nanoparticles in relation to human health (Fdez-Arroyabe et al., 2022), among others.

The round table was composed of two speakers with 30-minute presentations and time left for discussion. The first presenter was Marcelo de Paula Corrêa (Institute of Natural Resources of the Federal University of Itajubá [IRN-UNIFEI], Itajubá-MG) who talked about the "exposome" (*expossoma*), showcasing climate impacts on human skin and hair. The exposome is the combined effect of a multitude of factors on health resulting from intrinsic factors (lifestyle and personal habits) and extrinsic factors (UV radiation, temperature, humidity, and pollution). It affects skin and hair aging and potentially leads

to skin cancer. In the context of tropical regions, which characterize most Brazilian territory, UV radiation figures as a relevant research topic (de Paula Corrêa and Pires, 2013). Research projects with mobile field measurements on bicycles were shown for the Brazilian cities of Rio de Janeiro (RJ) and Recife (PE) with extreme UV levels (de Paula Corrêa et al., 2021). The multidisciplinary approach of the research area was highlighted, with interactions between gathering of environmental data, skin health data, big data, and artificial intelligence for exposome mapping.

Priscilla Venâncio Ikefuti (University of São Paulo [USP], São Paulo-SP) gave her talk on the relationship between climate and health focusing on chronic diseases, particularly cardiovascular, which belong to the most common mortality causes across the world and in Brazil (World Health Organization [WHO], 2011). The indirect impact of climate on cardiovascular diseases was emphasized. Despite no consensus being found in the literature for such a relationship, mortality among the elderly due to climate is known to be an influential factor, though climate alone is not a causal agent. A field study was presented for the city of São Paulo that accounted for the lag effect of atmospheric changes due to cold and warm fronts on mortality (Ikefuti et al., 2018). Another study showed a comparison of cardiovascular mortality in two different cities, Bogotá and São Paulo, suggesting that seasonal changes in climate are indeed responsible for changes in mortality (Garcia et al., 2016). As in the previous presentation, a multidisciplinary approach was recommended for this research area.

Day 2: thermal comfort, urban and architectural biometeorology

The keynote was given by Cho Kwong Charlie Lam (Sun Yat-sen University, Zhuhai, China). The title of his talk was "Climate change adaptation and the design of healthy cities". The presentation focused on outdoor environments and looked into the multisensory interaction of diverse factors regarding environmental quality and perception. Moreover, it provided an overview of the theoretical framework and past research concerning multisensory interactions affecting human perception of outdoor settings (Lam et al., 2020). Most of the studies presented consist of fieldwork observations, surveys, and numerical simulations. Among the diverse strategies for climate-responsive urban planning and design, the frequently adopted strategy of urban greenery was highlighted as a feasible solution to improve thermal and visual comfort and reduce noise levels and air pollution in urban areas. Among other heat-mitigating alternatives, including localized evaporative cooling, the use of water bodies in the city, shading strategies (building spatiality, designing street canyons), and modifications in albedo, urban greenery is the most feasible and the truly "nature-based heat mitigation" strategy. Lam's talk tackled this urban design strategy, showing the complexity behind its implementation in terms of heat stress attenuation, using the Index of Thermal Stress in that analysis (Chen et al., 2021). Additional issues relevant to studies on outdoor thermal comfort have also been addressed in his talk, such as acclimatization and psychological thermal adaptation (Lam et al., 2021a, 2021b, 2021c), which ought to be included in adaptation assessments in the context of climate change.

The round table that followed keynote talk had as the main discussion topic "thermal comfort, urban and architectural biometeorology". Four 30-minute presentations were held on that rather comprehensive topic. Loyde Abreu-Harbich (Mackenzie Presbyterian University [UPM], São Paulo-SP) introduced several studies on thermal comfort in urban areas employing different assessment methods such as *in situ* measurements, urban climate simulations, and mobile measurements on the microscale. The main heat mitigation strategy addressed was shading by urban greenery, with analysis of tree distribution, its radius of influence, and the impacts of arboreal elements in urban areas in terms of heat mitigation (Abreu-Harbich et al., 2014). As in Lam's keynote presentation, attenuations in comfort-related variables, more evidently in solar radiation amount, were observed with the introduction of trees in urban areas. Derived comfort indices such as the Universal Thermal Climate Index (UTCI), the Physiologically Equivalent Temperature (PET) index, and the mean radiant temperature component that primarily affects biometeorological indices also reinforce such observations (Abreu-Harbich et al., 2015). In landscape planning, deploying adequate vegetation and greenery distribution in urban settings can mitigate heat stress and increase human thermal comfort in a great part through shading. The need for developing urban design guidelines based on tree shading was underlined, which could promote resilience in the context of climate change.

Margarete Amorim (São Paulo State University [UNESP], Presidente Prudente-SP) focused her presentation on the urban surface heat island in an inland city in the state of São Paulo, aiming at municipal regulations regarding its mitigation. The method of evaluation based on satellite imagery backed with *in situ* measurements was presented for understanding the Urban Heat Island (UHI) phenomenon, its spatial distribution, and cause-and-effect relationships with urban morphological attributes, also featuring urban greenery aspects of the points of analysis (Amorim et al., 2021). The occurrence of atmospheric stability conditions was highlighted, which notably enhanced the UHI magnitude. The obtained model of UHI development and spatial distribution in a mid-sized city is a relevant input to urban planning. Again, urban greenery stood out among the various nature-based heat mitigation strategies.

Sheila Tavares Nascimento (State University of Maringá [UEM], Maringá-PR), the current head of the Brazilian ISB branch, held a presentation on the thermal comfort of swine in Brazilian savannah climate, a line of research primarily related to animal biometeorology. The aim of this research is to improve the animals' well-being to obtain higher productivity. Nature-based solutions for rearing swine in free-range systems were revealed. Solar radiation effects and those from the

mean radiant temperature on the physiological response of sows were evaluated with different shading strategies comprising natural (e.g., trees) and artificial solutions (mesh) (do Nascimento Mós et al., 2020). Heat mitigation and shading potentials of various native tree species and phenology have been proposed as an interesting carbon sink and CO_2 sequestration measure in the Brazilian savannah (Teixeira et al., 2022). As seen previously, the benefits of vegetation from the biometeorology viewpoint for improving comfort levels in human biometeorology in Abreu's presentation became evident.

The closing presentation by Francisco Mendonça (Federal University of Paraná [UFPR], Curitiba-PR) linked animal biometeorology (in this case, related to mosquitos) to human biometeorology with an overview of the two fields. Topics covered in his presentation ranged from epidemiology, criminality, and vulnerable populations to vector-borne diseases in relation to climatic variables and features, and climate change.

Day 3: atmospheric pollution and health

Luis Fernando Amato-Lourenço (Institute of Advanced Studies, USP) was the keynote speaker on the third day of the symposium. The topic of his presentation was the deleterious impacts of microplastics on human beings. Studies described ranged from a study on the presence of microplastics in human lung tissue (Amato-Lourenço et al., 2021) and a study on atmospheric fallout in outdoor and indoor environments (Amato-Lourenço et al., 2022a) to a study on the combination of airborne microplastics and the severe acute respiratory syndrome coronavirus 2 (SARS-COV-2) in total suspended particles (Amato-Lourenço et al., 2022b). In the first study, Amato-Lourenço showed a research based on the autopsy of non-smoking patients who had lived at least a decade in the city of São Paulo, which revealed that particles and fibers were present in their lungs. Autopsies of a control group of stillborns, though, showed no signs of such elements in their lungs. The second study provided evidence, through the sampling of airborne particulates, that microplastics existed both in outdoor and indoor environments, in a higher proportion in the latter. The third study, actually more related to human biometeorology than the first two ones, quantified SARS-COV-2 RNA (ribonucleic acid) and microplastics around the largest medical center in Latin America in connection to weather variables. Results showed that SARS-COV-2 genes could be observed in airborne microplastics, acting as potential disease vectors. Negative correlations between microplastics with SARS-COV-2 were found for temperature and humidity, reinforcing the climate-dependent pattern of transmission of the virus. In occupational health, there is already evidence of the deleterious impact of pristine particulates on human health, yet it is still an unanswered question up to which level the observed microplastics in human lungs can be damaging to human health. Further studies discussed in the presentation showed that microplastics can be seen even in human placenta and in human blood. Amato-Lourenço concluded his keynote presentation by emphasizing that the study of the deleterious impacts of microplastics needs to look at possible sources of contamination (air, water, soil) so that interventions can be devised and implemented.

The round table that followed the keynote talk was composed of five speakers. The first speaker was Marcelo Félix Alonso (Federal University of Pelotas [UFPel], Pelotas-RS) and his talk focused on air pollution and air quality in the southern Brazilian state of Rio Grande do Sul. The issues of monitoring, modeling, and inventory of air quality in cities have been underlined, starting with the presentation of health hazards caused by air pollution in the urban atmosphere, ranging from carbon monoxide to particulates. The Brazilian air quality network is still insipient and relatively new, starting in the 1960s in the city of Rio de Janeiro, and faces maintenance problems and vandalism, which severely impact the access to reliable air-quality data. From monitoring, inventories can be made which serve as important databases (global, regional, local, at city scale) (Huneeus et al., 2020) for the diagnosis of the impact of certain gases and also for modeling purposes. The need for updating such inventories was emphasized. The modeling process of air quality was presented, particularly the Brazilian Regional Atmospheric Modeling System (BRAMS) (Freitas et al., 2017) used in Brazil mainly for monitoring wildfires. Examples were given by Alonso for the Brazilian city of Porto Alegre (RS) in the metropolitan area (Chovert and Alonso, 2017) with a prognosis of air quality conditions facing the rise of vehicular traffic, for a rural location (Sapiranga) impacted by wildfires (Gidhagen et al., 2015), and for Curitiba for evaluating air quality conditions in relation to mass transportation (Gidhagen et al., 2021). Alonso finished his talk by introducing the 'ImpactAr Tool', that aims to monitor the "magnitude of the variations on the number of fatalities and hospitalizations and the consequent economic and welfare costs related to changes in air pollution levels caused by modifications in the Brazilian urban bus fleets" (https://www.wri.org/research/impactar-tool-air-quality-health-impacts-urban-bus-fleet-brazil-2022).

The second speaker was Ediclê de Souza Fernandes Duarte (University of Évora, Portugal). His presentation was focused on assessing the impact of wildfire exposure on the Portuguese population, and the forecasts of particulate matter (PM10, PM2.5) and black carbon (BC) over Portugal-Europe on October 15–16, 2017 during a wildfire episode by using a dispersion model at high resolution. Duarte started his talk by stressing that air pollution is a global problem due to long-range pollutant transport and has a strong impact on human health. The convection and advection processes responsible for the transport from the source to other locations have been highlighted, followed by the explanation of an ongoing project analyzing the effects of the wildfire seasons (June-July-August-September-October) on monthly mortality in Portugal by using data from dispersion models, air quality stations, remote sensing, and mortality for exposure assessment, cluster analyses, and regression models. The derived indices for interactions

between pollutants and climatic drivers showed epidemiological evidence that heat stress combined with air pollution emitted by wildfires contribute to increased cardiorespiratory mortality. These interactions open up an interesting avenue for future research. Does this mean that heat stress has a direct effect on cardiorespiratory fitness and an indirect effect by increasing the likelihood of wildfires, which generates particulate matter and black carbon? If so, this might be stated more explicitly. The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler, 2006; Stein et al., 2015; Rolph et al., 2017) showed the spatial distribution and spread of the particulates from wildfires in the region of analysis. It was shown that the model results fit the behavior of the observations and presented a positive correlation. The take-home message is that assessing population's exposure to wildfires could greatly benefit from smoke forecasting during wildfire seasons.

The next speaker was Carolina Zilli Vieira (Harvard School of Public Health, U.S.A.). The topic of her talk was the interaction between health outcomes, air pollutants, and solar activity. In this case, solar activity (on the Sun, driven by the solar magnetic field) has an effect on what we receive at the surface of the Earth as incoming solar radiation. Solar activity affects the space environment around Earth and the terrestrial systems, impacting the biosphere and human health. The network of worldwide stations that monitor solar-related geomagnetic alterations was introduced. Such alterations impact the 24-hour circadian rhythm, heart and brain rhythms. It has also been suggested that solar activity indirectly impacts the climate. Zilli Vieira presented two studies on the impacts of solar and geomagnetic activity. The first one focused on air pollution and heart health of patients with cardiovascular disease, using case-crossover analysis on circulatory and respiratory hospital admissions, across the different regions in the U.S.A. (Vieira et al., 2022). The other focused on pulmonary function due to exposure to pollutants related to solar and geomagnetic activity (Anand et al., 2022).

The next speaker was Rose Ane Pereira de Freitas (UFPel), whose presentation focused on air quality monitoring vis-à-vis human thermal comfort in the mid-sized city of Pelotas, located in the Brazilian state of Rio Grande do Sul. Pelotas presents a wide range of temperature variations and thermal impacts from relevant water bodies around the city, such as Lagoa dos Patos. The project involved extensive monitoring of particulates and air quality, also comparing standard equipment to low-cost air-quality stations for monitoring particulate matters (Galetti et al., 2020). Thermal comfort analyses were performed within the framework of research initiatives funded by the main research-funding agency in Brazil (National Council for Scientific and Technological Development [CNPq]), looking at meteorological and climate impacts on, first, human health, and second, physical activity levels and thermal comfort of a population sample. The latter was aimed at children and their mothers as part of a project involving hospitals and the epidemiology research group of UFPel. Dataloggers were deployed indoors and outdoors at several dwellings in and around the city center of Pelotas, and monitoring took place from January through August 2019 (Nedel et al., 2021). The ongoing study aims to evaluate potential impacts on health during the monitoring period, comfort levels of the dwellers by means of questionnaires surveys, and generate reliable models for estimating thermal performance and health risks from climate projections.

The last presenter was Alfésio Braga (Catholic University of Santos [UNISANTOS], Experimental Air Pollution Laboratory/Faculty of Medicine of the University of São Paulo [LPAE/FMUSP], Foundation of Social Studies of Paraná [FESP]) with the general topic "The effects of air pollution on human health". A study was described that exposed rats to atmospheric conditions in São Paulo and Atibaia (a mid-size, inland city in the state of São Paulo) and, after six-month exposure, the nostrils of the "urban" rats were severely damaged (Saldiva et al., 1992). Braga stated that vulnerable groups, such as very young children and the elderly, are more prone to be affected by pollution, with chances of showing acute and chronic symptoms, from asthma to cancer, with episodic symptoms or even death risk. On top of that, socio-economic constraints can additionally lead to increased health risks; Braga exemplified this with a study on daily mortality due to particulate matter in São Paulo, where hotspots were found in the poorest neighborhoods of the megacity (Martins et al., 2004). As the impacts of air pollution on human health tend to accentuate inflammatory processes while diminishing the body's defense mechanisms against viruses and bacteria, adverse effects of pollution on the elderly will have more serious consequences in neighborhoods with lower income and lower level of education (Martins et al., 2004). In this case, it is postulated that the vulnerability of the population exposed to air pollution interferes with the magnitude of the damages caused by it to health conditions. Also, being part of the more vulnerable portion of the population, children show other kinds of adverse health impacts from pollution than the elderly, such as hematological disorders (Barbosa et al., 2015), rheumatic diseases, neurodevelopmental disorders (including autism) still during pregnancy when the mother is exposed to particulate matter, cognitive performance and behavioral adverse effects (Lin et al., 2022). Solutions demonstrated in this presentation include strict control of the sources of pollution; urban planning towards reducing exposure to pollutants (schools, hospitals, public squares, etc.); education and conscientization; and, raising awareness of health risks associated to pollution for interventions to be implemented by means of public policies (Henschel et al., 2012).

Day 4: climate change

Claudia Di Napoli (University of Reading, UK) gave a keynote presentation titled "Human health in a changing climate: can we monitor it?". Her talk focused on climate change from the perspective of human

health and pointed up to the complexity behind monitoring and providing reliable data in this respect. The "Lancet Countdown: tracking progress on health and climate change" initiative consists of the development of worldwide monitoring systems that are able to track the multiple pathways in which climate change and weather extremes have been affecting human health since the 1980s. The Lancet Countdown platform provides climate-health indicators by means of a hazard-exposure-vulnerability overlaying framework, with worldwide coverage (Di Napoli et al., 2022), which can be retrieved for free (https://www.lancetcountdown.org/data-platform/). Di Napoli showed a few examples of such indicators, recently in the 2021 annual report, focusing on those that link heat, heat extremes, and human health. The cause for alarm is that between 2018 and 2019, Brazil had the greatest absolute increase in heat-related mortality (Romanello et al., 2021).

The first presenter of the round table was Priscilla Teles (UNESP), who reported data from the Intergovernmental Panel on Climate Change (IPCC) — Assessment Report (AR) 6 — Working Group (WG) II (Cissé et al., 2022), focusing on the vulnerability of different demographic groups (women, children and the elderly, low-income population, people with deficiency, and indigenous groups) to extreme climate and water scarcity. Climate change drives the intensification of urban heat islands alongside air quality concerns in urban areas whereas in rural locations food supply becomes a major concern. The various interactions with climate change pointed out by Di Napoli were addressed here from the Brazilian viewpoint. These include the need for additional workload in rural areas due to food scarcity and food insecurity induced by a warming climate as well as heat-related diseases and vector-borne diseases caused by mosquitoes. Apart from physical and mental health and well-being issues, impacts have been observed concerning climate change, concluding that research on vulnerable groups regarding climate change is still lacking in Brazil.

The second speaker at the round table, Lincoln Muniz Alves (National Institute for Space Research [INPE]) focused on climate change impacts on human health in Brazil. Alves debated that climate change is responsible for an increase in the frequency of heat waves. As a result of rising temperatures, implications for health and the environment have been more frequently reported. It was also highlighted that outdoor labor activities deserve special attention, as in the case of agricultural and construction workers exposed to extreme weather conditions (Bitencourt et al., 2021). Alves' presentation also addressed the spread of vector-borne diseases induced by climate change in Brazil. AdaptaBrasil (https://adaptabrasil.mcti.gov.br) was introduced, an online platform developed to consolidate, integrate, and disseminate robust information in a centralized and easily accessible manner. This platform analyzes observed and projected impacts on selected strategic sectors such as food, energy, health, and water security, and potentially provides greater awareness and understanding of how climatic and non-climatic aspects are interrelated in generating risks to society.

The third speaker of the round table was Paulo Sérgio Lúcio (UFRN) who addressed the issue of climate-dependent vector-borne diseases within the context of the FIFA 2014 World Cup. An R package was developed for assessing risk factors that could be input into action plans in Brazilian capitals where the matches took place. Such information can be used in the future as an important directive for establishing the best periods of the year (i.e., periods with diminished transmission risks) for scheduling soccer matches, and possibly for tourism as well.

Laurence Kalkstein (Arsht-Rockefeller Foundation Resilience Center, Arsht-Rock, U.S.A.) showed his most recent project that aims to categorize heat waves from the viewpoint of their impacts on human health (Axios, 2022). Such categorization is based on a synoptic classification of air masses using mortality data in order to establish various levels of impact of excessive heat on humans (Nairn and Fawcett, 2015). A ranking system is proposed that should integrate a dedicated heat warning system. With the use of such a platform, stakeholders, policymakers, and authorities can then take actions or interventions that could potentially curb the foreseeable impacts of upcoming heat waves. The system is currently in the test stage in cities in the U.S.A. and Europe, but could, in principle, be applied worldwide including Brazil. Kalkstein's presentation also called attention to the importance of facilitating the access to relevant health-climatological information by local governments.

The last speaker was Adam Kalkstein (US Military Academy, West Point, U.S.A.), whose research deals with weather- and climate-related impacts on human health. His talk focused on the effects of weather on the coronavirus disease (COVID-19) pandemic, specifically the correlations between climatic variables (temperature, humidity) and COVID-19 transmission. The work was motivated by the recent IPCC, AR6, WGII, Chapter 7, which discussed any potential correlations between weather and COVID-19 in somewhat vague terms. Here, a literature review of current research highlighted relationships between seasonality and the disease spread, along with the impacts of temperature and humidity on virus transmission. Temperature is notably inversely correlated to COVID-19 spread, including data for Brazil, though there are some outliers. Humidity shows stronger consistency in such relationships, and lower absolute or specific humidity is often closely associated with increases in the disease. Other environmental factors such as UV radiation also play a role.

Day 5: climate, health, and climate change

The keynote presentation of the last day of the symposium was given jointly by the organizers on the publication (Krüger et al., 2022) that arose from the discussions and research collaboration started during the preparations of the 1st virtual and 22nd International Congress of Biometeorology, in September 2021. The study leans on a systematic review aimed to present an overview of the research area of human

biometeorology in Brazil, research trends, represented by published papers with national and international authorship, main contributions and shortcomings, as well as challenges and prospects of research in this area of study up to July 2021. Scopus, Web of Science, and Science Direct databases were surveyed in order to reveal relevant publication outputs related to the research area. Gaps in knowledge and research outputs were highlighted in particular regions of the country such as the Amazon and in the Brazilian Midwest regions. Research is still lacking on the climate dimensions of tourism, vector-borne diseases, mortality, and morbidity in urban centers.

The short round table that followed was, in part, an informal closing session. Fábio Luis Teixeira Gonçalves (USP) gave a provocative talk on the relationship between climate and the development of human "races", giving tools for thought on the implications of climate change on phenotypic evolution. A discussion was introduced linking human features to natural selection, and phenotypic adaptation, and blood types to climate distribution.

Paulo Sérgio Lúcio (UFRN) concentrated his talk on the development of an Outdoor Thermal Comfort (OTC) index to assist planning and management of urban spaces. Based on calculations that aggregate meteorological variables, the Principal Components Analysis (PCA) was adopted in order to obtain a thermal comfort index, which was exemplified for the host cities of the 2022 Qatar FIFA World Cup. Such analyses took into account meteorological data and atmospheric variability. Results presented by Lúcio discuss monthly variability in OTC as well as seasonal aspects, whereas the validity of the new index was based on a direct comparison to established comfort indices such as Temperature Humidity Index (THI), Humidity Index (HUMIDEX), Standard Effective Temperature (SET), and Universal Thermal Climate Index (UTCI). In the end, a new empirical index named 'PCAIDEX' was introduced which can be implemented without any adaptation, in any world climate, since the index, in principle, captures the highest local climate variability. PCA weights for a given climate in which meteorological variables are more likely to contribute to the index value and, thus, to predict thermal sensation. Future work should test its applicability in other climates and validate index results against OTC data (from surveys, for example).

Technical sessions

After the keynote presentations and the roundtable discussion, the first Brazilian Symposium on Human Biometeorology had oral presentations in the afternoon, presented in 10 to 15-minute technical sessions. The talks were presented by undergraduate students in meteorology, atmospheric and Earth sciences, as well as by graduate students in climate sciences, environmental engineering, urban environmental sustainability, and civil engineering from institutes across Brazil. Thus, we had presentations of studies conducted at the following universities: Federal University of Western Pará (northern region); Federal University of Rio Grande do Norte, Federal University of Alagoas and Federal University of Paraíba (northeastern region), National Institute for Space Research (southeastern region); Federal University of Technology of Paraná; Federal University of Pelotas; and Federal University of Fronteira Sul (southern region).

Altogether, out of a total of 46 abstracts received, 37 were accepted and 25 were approached in the technical sessions. Due to the hybrid nature of the event and to technical reasons related to the internet connection, some presentations unfortunately did not take place. Despite that, most of them did occur.

Among the studies presented, the most discussed topic (56%) was human thermal comfort, mostly adopting the following methods: diverse temperature and humidity indexes, Effective Temperature (ET), Discomfort Index (DI), and HUMIDEX. Still related to human thermal comfort, microclimatic studies of urban environments were introduced, which aimed at densification strategies to promote greater pandemic resilience and the use of energy-performance computer simulation taking into account the microclimate factor in order to assess appropriate geometric shapes for enhancing indoor thermal comfort. Furthermore, studies on Urban Heat Islands (UHI) were also presented, which used the methodology of kriging interpolation and the verification of how the composition and configuration of the urban landscape affect the UHI from a network of wireless sensors for temperature monitoring. A bioclimatic backpack was introduced, which uses low-cost sensors (Arduino type) to measure meteorological variables, emphasizing that the contributions can be promising in the context of low-budget scenarios.

The studies on the second most addressed topic (28%) were related to weather-dependent diseases such as asthma, dengue, acute myocardial infarction, and heart failure and their connection to meteorological variables such as rainfall, temperature, and relative humidity. Other studies (16%) addressed temperature trends according to IPCC scenarios, and analysis of temporal trends in historical series of meteorological variables in Brazil. Finally, one study focused on the characterization of global solar radiation and UV radiation in a mid-latitude city in Brazil looking at harmful and biological effects, such as damages to DNA and provision of Vitamin D.

In general, most of the studies presented were at an early stage, which suggests the importance of disseminating the relationship between climate and human health and establishing adequate methods used to study meteorotropism (i.e., the effect of climate on biological processes).

Concluding Remarks and Way Forward

This account attempted to discuss the main topics presented during the 5-day meeting of the first Brazilian Symposium on Human Biometeorology.

On the first day, the keynote and the two 30-minute presentations successfully provided evidence of climatic impacts on human

health. There was the case of the exposome, through the combination of diverse inadvertent effects, some of them strongly related to urban microclimate, and intrinsic factors, such as the propensity to develop cardiovascular diseases. The keynote presentation set the stage for the symposium and the presentations and discussions that occurred during the following days of the event.

From the many talks during the second day of the symposium, nature-based solutions were proposed as relevant steps to curb heat stress in cities and rural areas (linkage to animal biometeorology). Vegetation stood out among the main strategies in this context. The closing talk by Mendonça gave an overview of the greater area of bioclimatology on that day.

The talks of the third day reinforced the need for general awareness, education, and sensibilization of the public towards environmental problems (pollution, climate change), and above all the importance of public policies that could more effectively promote such interventions.

On the fourth day of the symposium, central arguments put forward by the keynote speaker Claudia Di Napoli were discussed in the round table that followed, more specifically, within the Brazilian context. Climate change research demands a great deal of effort regarding monitoring, risk analyses, preparation of valuable information to be provided to the public and, more importantly, the development of action plans to raise commitment and responsibility in the population.

The closing session wrapped up discussions from the previous days and also conferred an opportunity for the organizers to start planning ahead. The broad scope of the addressed topics provided an overview of the area, covering some of the limitations in human biometeorology research conducted in Brazil as identified in the systematic literature review (Krüger et al., 2022). These limitations include the still minute publication output in the international context and point to the need for intensifying studies on urban heat islands, tourism, and vector-borne diseases in connection with human biometeorology.

The symposium was a further step beyond the systematic literature review conducted for Brazil by the event organizers, strengthening the working group on Human Biometeorology towards a more consistent development and promotion of the area in the country.

The need for more studies aimed at improving human biometeorological conditions in urban areas and "climate-health hotspots" (Di Napoli et al., 2022) was frequently emphasized by presenters and moderators during the meeting in Natal. Possibilities and intentions of starting research collaborations were discussed, such as the implementation in Brazil of early heat-warning systems such as the one proposed by Laurence Kalkstein (Arsht-Rock, U.S.A.) on the fourth day of the symposium. The symposium was a further step beyond the systematic literature review conducted for Brazil by the authors (Krüger et al., 2022) toward a more consistent development and promotion of the broad area of human biometeorology in the country. It is intended that other symposiums shall be organized in the near future, on a biannual basis.

Many research gaps have been introduced in the talks, but a serious handicap of that symposium was that it took place during the last stage of the COVID-19 pandemic in hybrid sessions that were in the majority viewed remotely. Thus, a second edition of the symposium is already in planning. The intention is to address other branches of biometeorology such as animal and plant since, in some cases, interesting interactions between these areas can occur. It is difficult to foresee what impacts this first symposium will generate, as one of its limitations is that no written record was made of the many talks and presentations given (as in a book of proceedings). This paper thus fulfills part of the desire to divulge the talks and ideas put worth during the symposium.

Acknowledgments

The symposium was partly funded by the International Society of Biometeorology (travel grant). Claudia Di Napoli was supported by a Wellcome Trust grant (209734/Z/17/Z).

Contribution of authors:

KRÜGER, E.L. conceptualization, writing — original draft, writing — review & editing. GOMESA. C. S.: resources, writing — original draft. LUCIO, P.S.: resources. GOBO, J.P.A.: resources. NEDEL, A.S.: resources. GONÇALVES, F.L.T: resources. PIACENTI-SILVA, M: resources. DI NAPOLI, C.: writing — review & editing. LAM, C.K.C.: writing — review & editing.

References

Abreu-Harbich, L.V.; Labaki, L.C.; Matzarakis, A., 2014. Thermal bioclimate as a factor in urban and architectural planning in tropical climates – the case of Campinas, Brazil. Urban Ecosystems, v. 17, (2), 489-500. https://doi.org/10.1007/s11252-013-0339-7

Abreu-Harbich, L.V.; Labaki, L.C.; Matzarakis, A., 2015. Effect of tree planting design and tree species on human thermal comfort in the tropics. Landscape and Urban Planning, v. 138, 99-109. https://doi.org/10.1016/j.landurbplan.2015.02.008

Alfieri, L.; Dottori, F.; Salamon, P.; Wu, H.; Feyen, L., 2020. Global modeling of seasonal mortality rates from river floods. Earth's Future, v. 8, (9), e2020EF001541. https://doi.org/10.1029/2020EF001541

Amato-Lourenço, L.F.; Carvalho-Oliveira, R.; Ribeiro Júnior, G.; dos Santos Galvão, L.; Ando, R.A.; Mauad, T., 2021. Presence of airborne microplastics in human lung tissue. Journal of Hazardous Materials, v. 416, 126124. https://doi.org/10.1016/j.jhazmat.2021.126124

Amato-Lourenço, L.F.; dos Santos Galvão, L.; Wiebeck, H.; Carvalho-Oliveira, R.; Mauad, T., 2022a. Atmospheric microplastic fallout in outdoor and indoor

environments in São Paulo megacity. Science of The Total Environment, v. 821, 153450. https://doi.org/10.1016/j.scitotenv.2022.153450

Amato-Lourenço, L.F.; Xavier Costa, N.S.; Dantas, K.C.; dos Santos Galvão, L.; Moralles, F.N.; Spina Lombardi, S.C.F.; Mendroni Júnior, A.; Lindoso, J.A.L.; Ando, R.A.; Lima, F.G.; Carvalho-Oliveira, R.; Mauad, T., 2022b. Airborne microplastics and SARS-CoV-2 in total suspended particles in the area surrounding the largest medical centre in Latin America. Environmental Pollution, v. 292, (Part A), 118299. https://doi.org/10.1016/j.envpol.2021.118299

Amorim, M.C.D.C.T., Dubreuil, V.; Amorim, A.T., 2021. Day and night surface and atmospheric heat islands in a continental and temperate tropical environment. Urban Climate, v. 38, 100918. https://doi.org/10.1016/j.uclim.2021.100918

Anand, K.; Vieira, C.L.; Garshick, E.; Wang, V.; Blomberg, A.; Gold, D.R.; Schwartz, J.; Koutrakis, P., 2022. Solar and geomagnetic activity reduces pulmonary function and enhances particulate pollution effects. Science of The Total Environment, 156434. https://doi.org/10.1016/j.scitotenv.2022.156434

Axios (Accessed June 8, 2022) at:. https://www.axios.com/2022/06/08/hurricanes-wildfires-heat-waves-names-categories?utm_source=newsletterandutm_medium=emailandutm_campaign=newsletter_axiospmandstream=top

Barbosa, S.M.D.M.; Farhat, S.C.L.; Martins, L.C.; Pereira, L.A.A.; Saldiva, P.H.N.; Zanobetti, A.; Braga, A.L.F., 2015. Air pollution and children's health: sickle cell disease. Cadernos de Saúde Pública, v. 31, (2), 265-275. https://doi.org/10.1590/0102-311X00013214

Basarin, B.; Lukić, T.; Matzarakis, A., 2020. Review of biometeorology of heatwaves and warm extremes in Europe. Atmosphere, v. 11, (12), 1276. https://doi.org/10.3390/atmos11121276

Bitencourt, D.P.; Alves, L.M.; Shibuya, E.K.; Cunha, I.A.; Souza, J.P.E., 2020. The heat exposure risk to outdoor workers in Brazil. Archives of Environmental and Occupational Health, v. 75, (5), 281-288. https://doi.org/10.1002/joc.6877

Bitencourt, D.P.; Muniz Alves, L.; Shibuya, E.K.; de Angelo da Cunha, I.; Estevam de Souza, J.P., 2021. Climate change impacts on heat stress in Brazil – Past, present, and future implications for occupational heat exposure. International Journal of Climatology, v. 41, (51), E2741-E2756. https://doi.org/10.1002/joc.6877

Chen, T.; Pan, H.; Lu, M.; Hang, J.; Lam, C.K.C.; Yuan, C.; Pearlmutter, D., 2021. Effects of tree plantings and aspect ratios on pedestrian visual and thermal comfort using scaled outdoor experiments. Science of The Total Environment, v. 801, 149527. https://doi.org/10.1016/j.scitotenv.2021.149527

Chovert, A.D.; Alonso, M.F., 2017. Estimated evolution of total pollutant gas emissions associated with vehicle activity in the Metropolitan Region of Porto Alegre until 2030. Anais da Academia Brasileira de Ciências, v. 89, (3), 1971-1983. https://doi.org/10.1590/0001-3765201720160117

Cissé, G.; McLeman, R.; Adams, H.; Aldunce, P.; Bowen, K.; Campbell-Lendrum, D.; Clayton, S.; Ebi, K.L.; Hess, J.; Huang, C.; Qiyong, L.; McGregor, G.; Semenza, J.; Tirado, M.C., 2022. 2022: health, wellbeing, and the changing structure of communities. In: Climate change 2022: impacts, adaptation and vulnerability: contribution of Working Group II to the sixth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press & Assessment, pp. 1041-1170.

Confalonieri, U.E.C.; Marinho, D.P.; Rodriguez, R.E., 2009. Public health vulnerability to climate change in Brazil. Climate Research, v. 40, (2-3), 175-186. https://doi.org/10.3354/cr00808

de Paula Corrêa, M.; Pires, L.C.M., 2013. Doses of erythemal ultraviolet radiation observed in Brazil. International Journal of Dermatology, v. 52, (8), 966-973. https://doi.org/10.1111/j.1365-4632.2012.05834.x

de Paula Corrêa, M.; Marciano, A.G.; Carvalho, V.S.B.; de Souza, P.M.B.; Ripper, J.D.S.C.; Roy, D.; Breton, L.; De Vecchi, R., 2021. Exposome extrinsic factors in the tropics: The need for skin protection beyond solar UV radiation. Science of The Total Environment, v. 782, 146921. https://doi.org/10.1016/j.scitotenv.2021.146921

Di Napoli, C.; McGushin, A.; Romanello, M.; Ayeb-Karlsson, S.; Cai, W.; Chambers, J.; Dasgupta, S.; Escobar, L.E.; Kelman, I.; Kjellstrom, T.; Kniveton, D.; Liu, Y.; Liu, Z.; Lowe, R.; Martinez-Urtaza, J.; McMichael, C.; Moradi-Lakeh, M.; Murray, K.A.; Rabbaniha, M.; Semenza, J.C.; Shi, L.; Tabatabaei, M.; Trinanes, J.A.; Vu, B.N.; Brimicombe, C.; Robinson, E.J., 2022. Tracking the impacts of climate change on human health via indicators: lessons from the Lancet Countdown. BMC Public Health, v. 22, (1), 1-8. https://doi.org/10.1186/s12889-022-13055-6

do Nascimento Mós, J.V.; Nascimento, S.T.; Murata, L.S.; Santos, V.M.; Steidle Neto, A.J.; Oliveira, E.M.; Lisboa, Á.S.; Silva, L.F., 2020. Thermal comfort of sows in free-range system in Brazilian Savanna. Journal of Thermal Biology, v. 88, 102489. https://doi.org/10.1016/j.jtherbio.2019.102489

Draxler, R.R., 2006. The use of global and mesoscale meteorological model data to predict the transport and dispersion of tracer plumes over Washington, DC. Weather and Forecasting, v. 21, (3), 383-394. https://doi.org/10.1175/WAF926.1

Fdez-Arroyabe, P.; Fernández, D.S.; Andrés, J.B., 2020. Work environment and healthcare: a biometeorological approach based on wearables. Wearable and Implantable Medical Devices, Applications and Challenges, Volume 7 in Advances in ubiquitous sensing applications for healthcare, pp. 141-161. https://doi.org/10.1016/B978-0-12-815369-7.00006-9

Fdez-Arroyabe, P.; Kourtidis, K.; Haldoupis, C.; Savoska, S.; Matthews, J.; Mir, L.M.; Kassomenos, P.; Cifra, M.; Barbosa, S.; Chen, X.; Dragovic, S.; Consoulas, C.; Hunting, E.R.; Robert, D.; van der Velde, O.A.; Apollonio, F.; Odzimek, A.; Chilingarian, A.; Royé, D.; Mkrtchyan, H.; Price, C.; Bór, J.; Oikonomou, C.; Birsan, M.V.; Crespo-Facorro, B.; Djordjevic, M.; Salcines, C.; López-Jiménez, A.; Donner, R.V.; Vana, M.; Pedersen, J.O.P.; Vorenhout, M.; Rycroft, M., 2021. Glossary on atmospheric electricity and its effects on biology. International Journal of Biometeorology, v. 65, (1), 5-29. https://doi.org/10.1007/s00484-020-02013-9

Fdez-Arroyabe, P.; Lecha Estela, L.; Schimt, F., 2018. Digital divide, biometeorological data infrastructures and human vulnerability definition. International Journal of Biometeorology, v. 62, (5), 733-740. https://doi.org/10.1007/s00484-017-1398-x

Fdez-Arroyabe, P.; Salcines, C.; Kassomenos, P.; Santurtún, A.; Petäjä, T., 2022. Electric charge of atmospheric nanoparticles and its potential implications with human health. Science of The Total Environment, v. 808, 152106. https://doi.org/10.1016/j.scitotenv.2021.152106

Freitas, S.R.; Panetta, J.; Longo, K.M.; Rodrigues, L.F.; Moreira, D.S.; Rosario, N.E.; Martins, L.D., 2017. The Brazilian developments on the Regional Atmospheric Modeling System (BRAMS 5.2): an integrated environmental model tuned for tropical areas. Geoscientific Model Development, v. 10, (1), 189-222. https://doi.org/10.5194/gmd-10-189-2017

Galetti, G.D.; Feitosa, O.M.; Vianna, J.C.T.; Alonso, M.F.; Carvalho, J.D.C., 2020. Desenvolvimento e aplicação de uma estação de qualidade do ar de baixo custo para monitorar a concentração de material particulado. Brazilian Journal of Development, v. 6, (12). https://doi.org/10.34117/bjdv6n12-573

Garcia, S.D.; Ikefuti, P.; Ribeiro, H., 2016. Mean temperature and cardio-respiratory mortality in elderly from Bogota and Sao Paulo. ISEE Conference Abstracts, v. 1. https://doi.org/10.1289/isee.2016.4680

Gidhagen, L.; Krecl, P.; Nedel, A.S.; Alonso, M.F.; Mariano, G.L.; Davila, M.; Wiegand, F.; Schneider, I.L.; Tagle, M.; Diaz, X.; Oyola, P.; Bennet, C., 2015.

Emissions and impact on air quality of PM and BC in Sapiranga, Rio Grande do Sul – field campaign and model assessment 2014. (Research report – SMHI – Billateral Cooperarion in Brazil).

Gidhagen, L.; Krecl, P.; Targino, A.C.; Polezer, G.; Godoi, R.H.M.; Felix, E.; Cipoli, Y.A.; Charres, I.; Malucelli, F.; Wolf, A.; Alonso, M.; Segersson, D.; Castelhano, F.J.; Amorim, J.H.; Mendonça, F., 2021. An integrated assessment of the impacts of PM2. 5 and black carbon particles on the air quality of a large Brazilian city. Air Quality, Atmosphere and Health, v. 14, (9), 1455-1473. https://doi.org/10.1007/s11869-021-01033-7

Henschel, S.; Atkinson, R.; Zeka, A.; Tertre, A.L.; Analitis, A.; Katsouyanni, K.; Chanel, O.; Pascal, M.; Forsberg, B.; Medina, S.; Goodman, P.G., 2012. Air pollution interventions and their impact on public health. International Journal of Public Health, v. 57, (5), 757-768. https://doi.org/10.1007/s00038-012-0369-6

Huneeus, N.; Denier van der Gon, H.; Castesana, P.; Menares, C.; Granier, C. Granier, L.; Alonso, M.; Andrade, M.d.F.; Dawidowski, L.; Gallardo, L.; Gomez, D.; Klimont, Z.; Janssens-Maenhout, G.; Osses, M.; Puliafito, S.E.; Rojas, N.; Sánchez-Ccoyllo, O.; Tolvett, S.; Ynoue, R.Y., 2020. Evaluation of anthropogenic air pollutant emission inventories for South America at national and city scale. Atmospheric Environment, v. 235, 117606. https://doi.org/10.1016/j.atmosenv.2020.117606

Ikefuti, P.V.; Barrozo, L.V.; Braga, A.L., 2018. Mean air temperature as a risk factor for stroke mortality in São Paulo, Brazil. International Journal of Biometeorology, v. 62, (8), 1535-1542. https://doi.org/10.1007/s00484-018-1554-y

Instituto Brasileiro de Geografia Estatística (IBGE), 2023. Áreas urbanizadas do Brasil: 2019/IBGE. Coordenação de Meio Ambiente, Rio de Janeiro, IBGE (Accessed August 15, 2023) at:. https://www.ibge.gov.br/geociencias/cartas-e-mapas/redes-geograficas/15789-areas-urbanizadas.html.

Keatley, M.R., 2017. Developments in the International Society of Biometeorology over the decade, 2007–2016. International Journal of Biometeorology, v. 61, (1), 11-18. https://doi.org/10.1007/s00484-017-1396-z

Krüger, E.L.; Gobo, J.P.A.; Nedel, A.S.; Gonçalves, F.L.T.; Lucio, P.S.; Tejas, G.T.; Piacenti-Silva, M., 2022. A first approach to human biometeorology research in Brazil: a systematic review and meta-analysis. International Journal of Biometeorology, v. 66, 1297-1315. https://doi.org/10.1007/s00484-022-02288-0

Lam, C.K.C.; Yang, H.; Yang, X.; Liu, J.; Ou, C.; Cui, S.; Kong, X.; Hang, J., 2020. Cross-modal effects of thermal and visual conditions on outdoor thermal and visual comfort perception. Building and Environment, v. 186, 107297. https://doi.org/10.1016/j.buildenv.2020.107297

Lam, C.K.C. Krüger, E.L. Callejas, I.J.A. Wagner, A., 2021a. Long and short-term acclimatization effects on outdoor thermal perception versus UTCI. In: Krüger, E.L. (Ed.). Applications of the Universal Thermal Climate Index UTCI in Biometeorology. Springer International Publishing, Switzerland, pp. 81-112. https://doi.org/10.1007/978-3-030-76716-7

Lam, C.K.C.; Hang, J.; Zhang, D.; Wang, Q.; Ren, M.; Huang, C., 2021b. Effects of short-term physiological and psychological adaptation on summer thermal comfort of outdoor exercising people in China. Building and Environment, v. 198, 107877. https://doi.org/10.1016/j.buildenv.2021.107877

Lam, C.K.C.; Gao, Y.; Yang, H.; Chen, T.; Zhang, Y.; Ou, C.; Hang, J., 2021c. Interactive effect between long-term and short-term thermal history on outdoor thermal comfort: Comparison between Guangzhou, Zhuhai and Melbourne. Science of The Total Environment, v. 760, 144141. https://doi.org/10.1016/j.scitotenv.2020.144141

Lapola, D.M.; Braga, D.R.; Di Giulio, G.M.; Torres, R.R.; Vasconcellos, M.P., 2019. Heat stress vulnerability and risk at the (super) local scale in six Brazilian capitals. Climatic Change, v. 154, (3), 477-492. https://doi.org/10.1007/s10584-019-02459-w

Lin, L.Z.; Zhan, X.L.; Jin, C.Y.; Liang, J.H.; Jing, J.; Dong, G.H., 2022. The epidemiological evidence linking exposure to ambient particulate matter with neurodevelopmental disorders: A systematic review and meta-analysis. Environmental Research, v. 209, 112876. https://doi.org/10.1016/j.envres.2022.112876

Martins, M.C.H.; Fatigati, F.L.; Véspoli, T.C.; Martins, L.C.; Pereira, L.A.A.; Martins, M.A.; Saldiva, P.H.N.; Braga, A.L.F., 2004. Influence of socioeconomic conditions on air pollution adverse health effects in elderly people: an analysis of six regions in Sao Paulo, Brazil. Journal of Epidemiology and Community Health, v. 58, (1), 41-46. http://dx.doi.org/10.1136/jech.58.1.41

McGregor, G.R., 2012. Human biometeorology. Progress in Physical Geography, v. 36, (1), 93-109. https://doi.org/10.1177/0309133311417942

Nairn, J.R.; Fawcett, R.J., 2015. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. International Journal of Environmental Research and Public Health, v. 12, (1), 227-253. https://doi.org/10.3390/ijerph120100227

Nedel, A.S.; Alonso, M.F.; Freitas, R.A.P.; Trassante, F.C.; Silva, H.N.; De Bortolli, E.; Medeiros, M.A.F.; Hallal, P.C.; Vianna, J.C.T., 2021. Analysis of indoor human thermal comfort in Pelotas municipality, extreme southern Brazil. International Journal of Biometeorology, v. 65, (3), 419-428. https://doi.org/10.1007/s00484-020-02015-7

Rolph, G.; Stein, A.; Stunder, B., 2017. Real-time environmental applications and display system: READY. Environmental Modelling and Software, v. 95, 210-228. https://doi.org/10.1016/j.envsoft.2017.06.025

Romanello, M.; McGushin, A.; Di Napoli, C.; Drummond, P.; Hughes, N.; Jamart, L.; Kennard, H.; Lampard, P.; Solano Rodriguez, B.; Arnell, N.; Ayeb-Karlsson, S.; Belesova, K.; Cai, W.; Campbell-Lendrum, D.; Capstick, S.; Chambers, J.; Chu, L.; Ciampi, L.; Dalin, C.; Dasandi, N.; Dasgupta, S.; Davies, M.; Dominguez-Salas, P.; Dubrow, R.; Ebi, K.; Eckelman, M.; Ekins, P.; Escobar, L.; Georgeson, L.; Grace, D.; Graham, H.; Gunther, S.H.; Hartinger, S.; He, K.; Heaviside, C.; Hess, J.; Hsu, S-C.; Jankin, S.; Jimenez, M.P.; Kelman, I.; Kiesewetter, G.; Kinney, P.L.; Kjellstrom, T.; Kniveton, D.; Lee, J.K.W.; Lemke, B.; Liu, Y.; Liu, Z.; Lott, M.; Lowe, R.; Martinez-Urtaza, J.; Maslin, M.; McAllister, L.; McMichael, C.; Mi, Z.; Milner, J.; Minor, K.; Mohajeri, N.; Moradi-Lakeh, M.; Morrissey, K.; Munzert, S.; Murray, K.A.; Neville, T.; Nilsson, M.; Obradovich, N.; Odhiambo Sewe, M.; Oreszczyn, T.; Otto, M.; Owfi, F.; Pearman, O.; Pencheon, D.; Rabbaniha, M.; Robinson, E.; Rocklöv, J.; Salas, R.N.; Semenza, J.C.; Sherman, J.; Shi, L.; Springmann, M.; Tabatabaei, M.; Taylor, J.; Trinanes, J.; Shumake-Guillemot, J.; Vu, B.; Wagner, F.; Wilkinson, P.; Winning, M.; Yglesias, M.; Zhang, S.; Gong, P.; Montgomery, H.; Costello, A.; Hamilton, I., 2021. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. The Lancet, v. 398, (10311), 1619-1662. https://doi.org/10.1016/S0140-6736(21)01787-6

Royé, D.; Zarrabeitia, M.T.; Fdez-Arroyabe, P.; Gutiérrez, A.Á.; Santurtún, A., 2019. Role of apparent temperature and air pollutants in hospital admissions for acute myocardial infarction in the North of Spain. Revista Española de Cardiología (English Edition), v. 72, (8), 634-640. https://doi.org/10.1016/j.rec.2018.07.009

Saldiva, P.H.N.; King, M.; Delmonte, V.L.C.; Macchione, M.; Parada, M.A.C.; Daliberto, M.L.; Sakae, R.S.; Criado, P.M.P.; Parada, P.L.P.; Zin, W.A.; Böhm, G.M., 1992. Respiratory alterations due to urban air pollution: an experimental study in rats. Environmental Research, v. 57, (1), 19-33. https://doi.org/10.1016/S0013-9351(05)80016-7

Sena, A.; Barcellos, C.; Freitas, C.; Corvalan, C., 2014. Managing the health impacts of drought in Brazil. International Journal of Environmental

Research and Public Health, v. 11, (10), 10737-10751. https://doi.org/10.3390/ijerph111010737

Souza Hacon, S.D.; Oliveira, B.F.A.D.; Silveira, I., 2019. A review of the health sector impacts of 4 c or more temperature rise. Climate Change Risks in Brazil, 67-129. https://doi.org/10.1007/978-3-319-92881-4_4

Stein, A.F.; Draxler, R.R.; Rolph, G.D.; Stunder, B.J.B.; Cohen, M.D.; Ngan, F., 2015. NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System. Bulletin of the American Meteorological Society, v. 96, 2059-2077. https://doi.org/10.1175/BAMS-D-14-00110.1

Teixeira, B.E.; Nascimento, S.T.; Mós, J.V.N.; Oliveira, E.M.; Santos, V.M.; Maia, A.S.C.; Fonsêca, V.F.C.; Passos, B.M.; Murata, L.S., 2022. The potential of natural shade provided by Brazilian savanna trees for thermal comfort and carbon sink. Science of The Total Environment, 157324. https://doi.org/10.1016/j.scitotenv.2022.157324

The Rio Times. 2022. Brazil: Death toll from rains in Petrópolis rises to 231. The Rio Times. 1 March 2022 (Accessed March 4, 2022) at:. https://www.ibge.gov.br/geociencias/cartas-e-mapas/redes-geograficas/15789-areas-urbanizadas.html.

Vanham, D.; Alfieri, L.; Flörke, M.; Grimaldi, S.; Lorini, V.; de Roo, A.; Feyen, L., 2021. The number of people exposed to water stress in relation to how much water is reserved for the environment: a global modelling study. The Lancet Planetary Health, v. 5, (11), e766-e774. https://doi.org/10.1016/S2542-5196(21)00234-5

Vega-Calderón, L.; Almendra, R.; Fdez-Arroyabe, P.; Zarrabeitia, M.T.; Santurtún, A., 2021. Air pollution and occupational accidents in the Community of Madrid, Spain. International Journal of Biometeorology, v. 65, (3), 429-436. https://doi.org/10.1007/s00484-020-02027-3

Vieira, C.L.Z.; Link, M.S.; Garshick, E.; Peralta, A.A.; Luttmann-Gibson, H.; Laden, F.; Liu, M.; Gold, D.R.; Koutrakis, P., 2022. Solar and geomagnetic activity enhance the effects of air pollutants on atrial fibrillation. EP Europace, v. 24, (5), 713-720. https://doi.org/10.1093/europace/euab269

Watts, N.; Amann, M.; Arnell, N.; Ayeb-Karlsson, S.; Beagley, J. BA; Belesova, K.; Boyoff, M.; Byass, P.; Cai, W.; Campbell-Lendrum, D.; Capstick, S.; Chambers, J.; Coleman, S.; Dalin, C.; Daly, M.; Dasandi, N.; Dasgupta, S.; Davies, M.; Di Napoli, C.; Dominguez-Salas, P.; Drummond, P.; Dubrow, R.; Ebi, K.; Eckelman, M.; Ekins, P.; Escobar, L.E.; Georgeson, L.; Golder, S.; Grace, D.; Graham, H.; Haggar, P.; Hamilton, I.; Hartinger, S.; Hess, J. MD; Hsu, S-C.; Hughes, N.; Jankin Mikhaylov, S.; Jimenez, M.P.; Kelman, I.; Kennard, H.; Kiesewetter, G.; Kinney, P.L.; Kjellstrom, T.; Kniveton, D.; Lampard, P.; Lemke, B.; Liu, Y.; Liu, Z.; Lott, M.; Lowe, R.; Martinez-Urtaza, J.; Maslin, M.; McAllister, L.; McGushin, A.; McMichael, C.; Milner, J.; Moradi-Lakeh, M.; Morrissey, K.; Munzert, S.; Murray, K.A.; Neville, T.; Nilsson, M.; Sewe, M.O.; Oreszczyn, T.; Otto, M.; Owfi, F.; Pearman, O.; Pencheon, D.; Quinn, R.; Rabbaniha, M.; Robinson, E.; Rocklöv, J.; Romanello, M.; Semenza, J.C.; Sherman, J.; Shi, L.; Springmann, M.; Tabatabaei, M.; Taylor, J.; Triñanes, J.; Shumake-Guillemot, J.; Vu, B.; Wilkinson, P. FRCP; Winning, M.; Gong, P.; Montgomery, H.; Costello, A., 2021. The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises. The Lancet, v. 397, (10269), 129-170. https://doi.org/10.1016/S0140-6736(20)32290-X

World Health Organization (WHO), 2011. Global atlas on cardiovascular disease prevention and control. Geneva: World Health Organization.