



OPINION ARTICLE

REVISED Heat remains unaccounted for in thermal physiology and climate change research [version 2; referees: 2 approved]

Andreas D. Flouris ^{1,2}, Glen P. Kenny²

¹FAME Laboratory, Department of Exercise Science, University of Thessaly, Trikala, Greece

²Human and Environmental Physiology Research Unit, School of Human Kinetics, University of Ottawa, Ottawa, ON, Canada

v2 First published: 06 Mar 2017, 6:221 (doi: 10.12688/f1000research.10554.1)
 Latest published: 15 Mar 2017, 6:221 (doi: 10.12688/f1000research.10554.2)

Abstract

In the aftermath of the Paris Agreement, there is a crucial need for scientists in both thermal physiology and climate change research to develop the integrated approaches necessary to evaluate the health, economic, technological, social, and cultural impacts of 1.5°C warming. Our aim was to explore the fidelity of remote temperature measurements for quantitatively identifying the continuous redistribution of heat within both the Earth and the human body. Not accounting for the regional distribution of warming and heat storage patterns can undermine the results of thermal physiology and climate change research. These concepts are discussed herein using two parallel examples: the so-called slowdown of the Earth’s surface temperature warming in the period 1998-2013; and the controversial results in thermal physiology, arising from relying heavily on core temperature measurements. In total, the concept of heat is of major importance for the integrity of systems, such as the Earth and human body. At present, our understanding about the interplay of key factors modulating the heat distribution on the surface of the Earth and in the human body remains incomplete. Identifying and accounting for the interconnections among these factors will be instrumental in improving the accuracy of both climate models and health guidelines.

Open Peer Review

Referee Status:

	Invited Referees	
	1	2
version 2 published 15 Mar 2017		 report
version 1 published 06 Mar 2017	 report	 report

- 1 **Juha Oksa** , Finnish Institute of Occupational Health Finland
- 2 **Eugene A. Kiyatkin**, National Institutes of Health (NIH) USA, **Keaton T. Cameron-Burr**, National Institutes of Health (NIH) USA

Discuss this article

Comments (0)

Corresponding author: Andreas D. Flouris (andreasflouris@gmail.com)

How to cite this article: Flouris AD and Kenny GP. **Heat remains unaccounted for in thermal physiology and climate change research [version 2; referees: 2 approved]** *F1000Research* 2017, **6**:221 (doi: [10.12688/f1000research.10554.2](https://doi.org/10.12688/f1000research.10554.2))

Copyright: © 2017 Flouris AD and Kenny GP. This is an open access article distributed under the terms of the [Creative Commons Attribution Licence](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Data associated with the article are available under the terms of the [Creative Commons Zero "No rights reserved" data waiver](#) (CC0 1.0 Public domain dedication).

Grant information: This work has received funding from the European Union's Horizon 2020 research and innovation programme (grant no., 668786).

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: No competing interests were disclosed.

First published: 06 Mar 2017, **6**:221 (doi: [10.12688/f1000research.10554.1](https://doi.org/10.12688/f1000research.10554.1))

REVISED Amendments from Version 1

We wish to thank all Reviewers for their efforts in reviewing the manuscript and for their constructive and helpful comments. Following the Reviewers' recommendations, the revised version of the paper includes: (i) information about the previous evaluations of the TLV guidelines; (ii) clarification that the Earth is a "passive system" with no active regulation of temperature or heat content; (iii) indication that heat distribution is important in both the Earth and the human body and our understanding and measurements of it need to be improved in the interest of human health; (iv) clarification that the findings of Nieves *et al.* were confirmed by a wealth of observational and simulated data, not by the record-breaking temperatures throughout 2015 and 2016; (v) correction of some slightly awkward phrasing; and (vi) brief comments about the effects of heat redistribution on the brain thermal homeostasis.

See referee reports

Introduction

The Agreement reached in Paris during December 2015, under the auspices of the United Nations Framework Convention on Climate Change, binds countries to "...pursue efforts to limit the [global] temperature increase to 1.5°C above pre-industrial levels". The same document also invites the Intergovernmental Panel on Climate Change (IPCC) to "...provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways" (full document: Paris Agreement, FCCC/CP/2015/10/Add.1, annex. UNFCCC secretariat. Retrieved 20 January 2017). In doing so, the IPCC must provide useful and robust evidence, which can be a challenge, as previously suggested (Hulme, 2016), given the limited analyses conducted thus far on the global and regional impacts of 1.5°C warming. Another challenge for the IPCC, and the scientific community, is to develop the integrated approaches necessary to evaluate the health, economic, technological, social, and cultural impacts of 1.5°C warming. As illustrated by a recent scientific conundrum (described in the following section), the concept of heat should be central to these integrated approaches. In this light, the objective of this article is to explore the fidelity of remote temperature measurements for quantitatively identifying the continuous redistribution of heat within both the Earth and human body.

Unaccounted heat in climate research

Hailed as "one of the biggest mysteries in climate science" (Tollefson, 2013), the slowdown of the Earth's surface temperature warming in the period 1998–2013 undermined, for a number of years, the idea that human-generated greenhouse gases are the main driver and cause of climate change (Nieves *et al.*, 2015). During this period, the existing climate models were unable (on average) to reproduce the observed atmospheric temperature trend. Several theories were proposed to explain this surface temperature "hiatus". One of the first explanations put forth was that it is normal for warming rates to plateau occasionally (Trenberth, 2015). Other factors that were extensively investigated included the increased volcanic activity and the high levels of air pollution in China during the hiatus period, since atmospheric particles reflect more of the Sun's energy back into space (Solomon *et al.*, 2011). The ever-increasing decline in solar activity since 2000 was also considered as a possibility, since it reduces the amount of energy

reaching the Earth (Ineson *et al.*, 2015). Ultimately, in 2015, Nieves and colleagues showed that what was interpreted as a change in the planet's warming rate was, in fact, a redistribution of heat within the ocean (Nieves *et al.*, 2015). Specifically, Nieves *et al.*, showed that heat moved from the surface of the Pacific Ocean to the deeper layers of the Western Pacific and Indian Oceans, a finding that was confirmed using a wealth of observational and simulated data. As a result, the net ocean heat uptake remains dangerously high (Nieves *et al.*, 2015), and the rate of global warming may have actually increased during the hiatus period (IPCC, 2014). The observed record-breaking temperatures throughout 2015 and 2016 (<https://www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-globally>) support the findings of Nieves *et al.*

Research aiming to understand the 1998–2013 hiatus significantly benefited from studies investigating the causes of a much longer hiatus observed from the 1950s to the 1970s. During this period, global mean surface temperature remained approximately constant despite increased burden from anthropogenic factors. Interestingly, as in the case of the 1998–2013 hiatus, the ocean heat uptake was a very important contributing factor to this longer offsetting of the warming rate (England *et al.*, 2014). This is because ocean circulation changes have a vast impact on the geographical distribution of warming and heat storage patterns, which ultimately affect the planet's surface climate (Nieves *et al.*, 2015). Measuring atmospheric temperature at specific regions can only indicate regional changes in heat content and – as in the case of the 1998–2013 hiatus – can lead to wrong conclusions about the planet's warming rate.

Unaccounted heat in thermal physiology research

Although the Earth is a "passive system" with no active regulation of temperature or heat content (based on current knowledge, that is), the effect of ocean heat uptake on the geographical distribution of warming and the heat storage patterns on the surface of the planet closely mirror thermodynamic processes within the human body. Blood within the circulatory system is constantly redistributed, not only to meet the demands of metabolic and immune processes, but also to move heat from/to specific regions and maintain thermal homeostasis (Flouris *et al.*, 2006; Flouris & Cheung, 2009; Kiyatkin, 2010; Kenny & Jay, 2013). These blood flow adaptations can reach dramatic proportions in the human body. For instance, during rest in thermoneutral conditions, 0.5 L/min of blood (5–10% of cardiac output) supplies the skin (Lossius *et al.*, 1993). Nevertheless, during heat stress, up to 8 L/min of blood (50–70% of cardiac output) is directed to the cutaneous circulation, mainly by restricting visceral and renal blood flow (Lossius *et al.*, 1993). These enormous changes in blood flow have a vast effect on the regional distribution of heat and the heat storage patterns, which ultimately affect the entire body's thermal homeostasis. Therefore, measuring temperature in specific regions of the body, such as the rectum, esophagus, or the visceral organs, can only indicate regional changes in heat content (Flouris & Cheung, 2010; Flouris & Cheung, 2011; Kenny *et al.*, 2015; Kenny *et al.*, 2017; Taylor *et al.*, 2014; Webb, 1986). Moreover, peripheral tissues can tolerate greater changes in heat with less threat to the health and survivability of the organism, whereas increases in specific organ structures such as the

brain can threaten organism health (Kiyatkin, 2010). Nevertheless, for more than 100 years, scientists have been using single region temperature measurements to make assumptions about the thermal strain across the entire body. Moreover, the currently recommended criterion when addressing heat-related health risks is a single temperature measurement in the rectum (World Meteorological Organization and World Health Organization, 2015).

A recent paper on occupational heat exposure (Meade *et al.*, 2016) provides an example of the limitations inherent in single temperature measurements used to assess whole-body thermal strain. In hot environments, industries must take preventive measures to protect their workers against heat-related injury and illness. To determine what protections should be used, they may follow guidelines from bodies of knowledgeable experts. One such set of guidelines comes from the American Conference of Governmental Industrial Hygienists (ACGIH, 2007); they recommend that industries employ the Threshold Limit Values (TLV) for work in hot environments. The TLV consider both environmental conditions and work demands, with the goal of maintaining the internal body temperatures of workers within safe limits. However, it is unclear if these guidelines adequately protect workers. While the history of the TLV guidelines starts in 1971 (ACGIH, 2007), to the best of our knowledge, the aforementioned recent paper is the only one that directly assessed the influence of the work exposure limits outlined in the TLV on core temperature responses during work and the associated changes in whole-body heat content. This study applied the TLV recommendations for work-rest periods by having a group of participants perform moderate intensity work bouts in progressively hotter environments. According to the TLV, as environmental heat levels increased, the recovery periods between work bouts were lengthened (Meade *et al.*, 2016). Once these guidelines are applied, the TLV predict that the participant's core temperature should be minimally affected. Yet, the core temperatures of the young physically active adults tested in this study rose continuously. Overall, the findings demonstrated that, under the work conditions tested, the TLV do not adequately protect workers from potentially dangerous increases in their internal temperatures. As mentioned above, these findings are likely ascribable to a heterogeneous distribution of heat within the body's 'core' tissues (i.e., organs, muscles) (Taylor *et al.*, 2014), which may be influenced by the profound thermoregulatory and cardiovascular (the majority of heat transfer within the body occurs through convective transfer via blood) alterations associated with recovery from exercise (Halliwill *et al.*, 2014; Kenny & Journeay, 2010; Kenny & Jay, 2013). If this peripheral heat storage is transferred from the tissues to the body's core, it presents an increased risk of heat related illness and injury during work. Therefore, the TLV guidelines should be revised, especially given the warming climate and the increase in the frequency and intensity of extreme heat events.

Heat parallels in the two disciplines

Heat distribution (and its associated temperature variation) is important in both the Earth and the human body and our understanding and measurements of it need to be improved in the interest of human health (since human thermal homeostasis is largely dependent on environmental temperature). In this light, recognition that ocean heat uptake plays a key role in modulating human-caused global surface warming has been one of the many

valuable ancillary benefits of research aiming to understand the 1998–2013 hiatus. Identifying and accounting for errors in ocean heat uptake estimations has been vital in this improved understanding (Fyfe *et al.*, 2016) and will be instrumental in improving the accuracy of future climate predictions. For instance, climate models accounting for these recent advances suggest a transition to a positive phase of the Interdecadal Pacific Oscillation, which will increase the warming rate of global surface temperature (Hawkins *et al.*, 2014; Thoma *et al.*, 2015). Similarly to climate studies, thermal physiology research employing calorimetric methods has shown that temperature measurements at a single region of the body's core do not (on average) reflect whole-body thermal strain [(Flouris & Cheung, 2010; Kenny *et al.*, 2013; Kenny *et al.*, 2017; Meade *et al.*, 2016; Stapleton *et al.*, 2014; Stapleton *et al.*, 2015; Webb, 1986), including reviews (Benzinger *et al.*, 1961; Taylor *et al.*, 2014; Webb, 1995)]. In addition to their limited accuracy, such measurements contain a significant time lag, which makes them less effective for scientific purposes and potentially problematic when used in health-related settings. Indeed, core temperature readings are notorious for responding with delays of 10–30 minutes (Kenny & Jay, 2013), even when the human body undergoes extreme discomfort, such as a sudden passive immersion in 12°C water (Flouris & Cheung, 2009). Interestingly, a similar time lag exists in the Earth's warming rate phenomenon, since 80% of the heat added to the climate system is being taken up by the ocean (IPCC, 2014). As a result, even if greenhouse gas concentrations were to drastically reduce, the planet would continue to warm for many decades (IPCC, 2014).

Concluding remarks

Scientists in thermal physiology and climate change research are measuring temperature but, very often, they are missing the heat. Relying on indicators that provide a less accurate and/or delayed view of a natural phenomenon is dangerous. In the case of climate change research, interpreting the slowdown of atmospheric temperature rise during 1998–2013 as a change in the planet's warming rate would have given way to lax policies in environmental monitoring. In the 15 years required to identify the key factors involved, obtain more accurate data, and reassess the situation, these policies could have produced devastating effects and pushed the planet's climate into uncharted territory. In a similar way, interpreting the minimal temperature changes often observed in a single region of the body's core as a lack of whole-body thermal strain, gives way to an impassable abyss of controversial results in scientific experiments and, even worse, ineffective guidelines for work in hot environments, as well as delayed application of treatment in occupational or clinical settings.

The concept of heat is of major importance for the integrity of systems, such as the Earth (IPCC, 2014; Nieves *et al.*, 2015) and the human body (Borden & Cutter, 2008; Flouris & Piantoni, 2015; Luber & McGeehin, 2008). At present, our understanding about the interplay of key factors modulating the heat distribution on the surface of the Earth and in the human body remains incomplete. Identifying and accounting for the interconnections among these factors will be instrumental in improving the accuracy of both climate models and health guidelines. In the aftermath of the Paris Agreement, there is a need for scientists in both thermal physiology and climate change research to embrace integrated approaches that provide comprehensive views of the natural phenomena under

study, taking into account the distribution of warming and heat storage patterns. For on that may depend the future in these scientific disciplines and, possibly, the future of the planet.

Author contributions

Both authors conceived the main idea of this paper. ADF prepared the first draft of the manuscript. Both authors revised the draft manuscript and have agreed to the final content.

Competing interests

No competing interests were disclosed.

Grant information

This work has received funding from the European Union's Horizon 2020 research and innovation programme (grant no., 668786).

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

References

- ACGIH: **Heat stress and strain**. In: *Documentation of the Threshold Limit Values for Physical Agents Documentation*. Cincinnati (OH): ACGIH; 2007.
- Benzinger TH, Pratt AW, Kitzinger C: **The thermostatic control of human metabolic heat production**. *Proc Natl Acad Sci U S A*. 1961; **47**(5): 730–739. [PubMed Abstract](#) | [Free Full Text](#)
- Borden KA, Cutter SL: **Spatial patterns of natural hazards mortality in the United States**. *Int J Health Geogr*. 2008; **7**: 64. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- England MH, McGregor S, Spence P, et al.: **Recent intensification of wind-driven circulation in the pacific and the ongoing warming hiatus**. *Nature Clim Change*. 2014; **4**: 222–227. [PubMed Abstract](#) | [Free Full Text](#)
- Flouris AD, Cheung SS, Fowles JR, et al.: **Influence of body heat content on hand function during prolonged cold exposures**. *J Appl Physiol (1985)*. 2006; **101**(3): 802–808. [PubMed Abstract](#) | [Publisher Full Text](#)
- Flouris AD, Cheung SS: **Influence of thermal balance on cold-induced vasodilation**. *J Appl Physiol (1985)*. 2009; **106**(44): 1264–1271. [PubMed Abstract](#) | [Publisher Full Text](#)
- Flouris AD, Cheung SS: **Thermometry and calorimetry assessment of sweat response during exercise in the heat**. *Eur J Appl Physiol*. 2010; **108**(5): 905–911. [PubMed Abstract](#) | [Publisher Full Text](#)
- Flouris AD, Cheung SS: **Thermal basis of finger blood flow adaptations during abrupt perturbations in thermal homeostasis**. *Microcirculation*. 2011; **18**(1): 56–62. [PubMed Abstract](#) | [Publisher Full Text](#)
- Flouris AD, Piantoni C: **Links between thermoregulation and aging in endotherms and ectotherms**. *Temperature (Austin)*. 2015; **2**(1): 73–85. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Fyfe JC, Meehl GA, England MH, et al.: **Making sense of the early-2000s warming slowdown**. *Nature Clim Change*. 2016; **6**: 224–228. [PubMed Abstract](#) | [Free Full Text](#)
- Halliwil JR, Sieck DC, Romero SA, et al.: **Blood pressure regulation x: what happens when the muscle pump is lost? Post-exercise hypotension and syncope**. *Eur J Appl Physiol*. 2014; **114**(3): 561–578. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Hawkins E, Edwards T, McNeall D: **Pause for thought**. *Nat Clim Chang*. 2014; **4**: 154–156. [PubMed Abstract](#) | [Free Full Text](#)
- Hulme M: **1.5 °C and climate research after the paris agreement**. *Nat Clim Chang*. 2016; **6**: 222–224. [PubMed Abstract](#) | [Free Full Text](#)
- Ineson S, Maycock AC, Gray LJ, et al.: **Regional climate impacts of a possible future grand solar minimum**. *Nat Commun*. 2015; **6**: 7535. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- IPCC: **Climate change 2014: Synthesis report**. *Contribution of working groups i, ii and iii to the fifth assessment report of the intergovernmental panel on climate change*. Geneva, Switzerland: IPCC. 2014. [Reference Source](#)
- Kenny GP, Journeay WS: **Human thermoregulation: Separating thermal and nonthermal effects on heat loss**. *Front Biosci (Landmark Ed)*. 2010; **15**: 259–290. [PubMed Abstract](#) | [Publisher Full Text](#)
- Kenny GP, Jay O: **Thermometry, calorimetry, and mean body temperature during heat stress**. *Compr Physiol*. 2013; **3**(4): 1689–1719. [PubMed Abstract](#) | [Publisher Full Text](#)
- Kenny GP, Stapleton JM, Yardley JE, et al.: **Older adults with type 2 diabetes store more heat during exercise**. *Med Sci Sports Exerc*. 2013; **45**(10): 1906–1914. [PubMed Abstract](#) | [Publisher Full Text](#)
- Kenny GP, Larose J, Wright-Beatty HE, et al.: **Older firefighters are susceptible to age-related impairments in heat dissipation**. *Med Sci Sports Exerc*. 2015; **47**(6): 1281–1290. [PubMed Abstract](#) | [Publisher Full Text](#)
- Kenny GP, Poirier MP, Metsios GS, et al.: **Hyperthermia and cardiovascular strain during an extreme heat exposure in young versus older adults**. *Temperature*. 2017; **4**(1): 79–88. [PubMed Abstract](#) | [Publisher Full Text](#)
- Kiyatkin EA: **Brain temperature homeostasis: physiological fluctuations and pathological shifts**. *Front Biosci (Landmark Ed)*. 2010; **15**: 73–92. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Lossius K, Eriksen M, Walløe L: **Fluctuations in blood flow to acral skin in humans: Connection with heart rate and blood pressure variability**. *J Physiol*. 1993; **460**(1): 641–655. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Luber G, McGeehin M: **Climate change and extreme heat events**. *Am J Prev Med*. 2008; **35**(5): 429–435. [PubMed Abstract](#) | [Publisher Full Text](#)
- Meade RD, Poirier MP, Flouris AD, et al.: **Do the Threshold Limit Values for Work in Hot Conditions Adequately Protect Workers?** *Med Sci Sports Exerc*. 2016; **48**(6): 1187–1196. [PubMed Abstract](#) | [Publisher Full Text](#)
- Nieves V, Willis JK, Patzert WC: **GLOBAL WARMING. Recent hiatus caused by decadal shift in Indo-Pacific heating**. *Science*. 2015; **349**(6247): 532–535. [PubMed Abstract](#) | [Publisher Full Text](#)
- Solomon S, Daniel JS, Neely RR 3rd, et al.: **The persistently variable “background” stratospheric aerosol layer and global climate change**. *Science*. 2011; **333**(6044): 866–870. [PubMed Abstract](#) | [Publisher Full Text](#)
- Stapleton JM, Larose J, Simpson C, et al.: **Do older adults experience greater thermal strain during heat waves?** *Appl Physiol Nutr Metab*. 2014; **39**(3): 292–298. [PubMed Abstract](#) | [Publisher Full Text](#)
- Stapleton JM, Poirier MP, Flouris AD, et al.: **Ageing impairs heat loss, but when does it matter?** *J Appl Physiol (1985)*. 2015; **118**(3): 299–309. [PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Taylor NA, Tipton MJ, Kenny GP: **Considerations for the measurement of core, skin and mean body temperatures**. *J Therm Biol*. 2014; **46**: 72–101. [PubMed Abstract](#) | [Publisher Full Text](#)
- Thoma M, Greatbatch RJ, Kadow C, et al.: **Decadal hindcasts initialized using observed surface wind stress: Evaluation and prediction out to 2024**. *Geophys Res Lett*. 2015; **42**(15): 6454–6461. [PubMed Abstract](#) | [Free Full Text](#)
- Tollefson J: **Climate change: The forecast for 2018 is cloudy with record heat**. *Nature*. 2013; **499**(7457): 139–141. [PubMed Abstract](#) | [Publisher Full Text](#)
- Trenberth KE: **CLIMATE CHANGE. Has there been a hiatus?** *Science*. 2015; **349**(6249): 691–692. [PubMed Abstract](#) | [Publisher Full Text](#)
- Webb P: **Afterdrop of body temperature during rewarming: an alternative explanation**. *J Appl Physiol (1985)*. 1986; **60**(2): 385–390. [PubMed Abstract](#)
- Webb P: **The physiology of heat regulation**. *Am J Physiol*. 1995; **268**(4 Pt 2): R838–850. [PubMed Abstract](#)
- World Meteorological Organization, World Health Organization: **Heatwaves and health: Guidance on warning-system development**. Geneva, Switzerland: World Meteorological Organization. 2015. [Reference Source](#)

Open Peer Review

Current Referee Status:  

Version 2

Referee Report 16 March 2017

doi:[10.5256/f1000research.12019.r21009](https://doi.org/10.5256/f1000research.12019.r21009)



Eugene A. Kiyatkin

Behavioral Neuroscience Branch, National Institute on Drug Abuse – Intramural Research Program, National Institutes of Health (NIH), Baltimore, MD, USA

The Authors properly responded to all comments of our previous review.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Version 1

Referee Report 08 March 2017

doi:[10.5256/f1000research.11373.r20720](https://doi.org/10.5256/f1000research.11373.r20720)



Eugene A. Kiyatkin¹, Keaton T. Cameron-Burr²

¹ Behavioral Neuroscience Branch, National Institute on Drug Abuse – Intramural Research Program, National Institutes of Health (NIH), Baltimore, MD, USA

² National Institute of Drug Abuse, Intramural Research Program, National Institutes of Health (NIH), Baltimore, MD, USA

Title: Heat remains unaccounted for in thermal physiology and climate change research

Comments:

- This opinion piece touches on an important issue. It is critical to accurately measure the redistribution of heat within both climate and physiological systems. The authors correctly note the interconnectedness of the two: as the earth warms, heat-related health risks will rise as the dynamics of energy transfer between organism and environment change. Standards to protect workers and the environment should be updated to reflect the most accurate and helpful measurements and information as is possible.

Major comments:

- The authors draw a parallel between heat distribution in human and heat distribution within climate systems throughout the piece. While I see the analogy, it might be best to reign in this comparison in some places, specifically, on page 3 under the heading “Heat parallels in the two disciplines”. While the point is well taken, the human body has many mechanisms that actively work to maintain thermo-homeostasis. The earth, on the other hand, is a passive system with no “goal temperature”, as it were. Would it be better simply to state that temperature distribution is important in both systems and that our understanding and measurements of it need to be improved in the interest of human health? Given that heat distribution in humans is dependent on the temperature of the environment, there is a strong argument to be made linking these two variables without drawing a comparison between an actively regulated homeostatic system and system in which heat distribution occurs through passive mechanisms. The first paragraph of “Unaccounted heat in thermal physiology research” contains this analogy as well.

Minor:

- The authors put forward that the findings of Nieves *et al.* were confirmed by increased temperatures in 2015 and 2016 (Page 2). When considering global trends, single year data is a fraught method of proof given the degree of between-year variability in temperature. By the same logic, the climate change slowdown from 1998-2013 discussed in this paper was used to justify a lack of action around climate change.
- Some slightly awkward phrasing persists in this article. For example, the first sentence of the second paragraph on page 2 under “Unaccounted heat in climate research” could be re-written as “Research aiming to understand the 1998-2013 hiatus significantly benefited from studies investigating the causes...”. The sentence, “This is not surprising.” Under the same heading on page 2, does not add to the paragraph and could be cut.
- “Unaccounted heat in thermal physiology research” could benefit from some discussion of the importance of brain temperature (Kiyatkin 2010 for review¹). Individuals may experience robust changes in brain temperature during behavioral activation such as manual labor or intense exercise that can result, under conditions of diminished heat dissipation, in pathological hyperthermia². Hyperthermia increases permeability of the blood-brain barrier, predisposing individuals to the development of vasogenic edema and damage of brain cells. Increased global temperature may also pose increased health risks for people using psychomotor stimulant drugs of abuse, the effects of which are greatly potentiated by increased ambient temperature. This is critical when considering issues of heat distribution in which peripheral tissues can tolerate greater changes in heat with less threat to the health and survivability of the organism, whereas increases in specific organ structures such as the brain can threaten organism health.

References

1. Kiyatkin EA: Brain temperature homeostasis: physiological fluctuations and pathological shifts. *Front Biosci (Landmark Ed)*. 2010; **15**: 73-92 [PubMed Abstract](#)
2. Kiyatkin EA, Sharma HS: Environmental conditions modulate neurotoxic effects of psychomotor stimulant drugs of abuse. *Int Rev Neurobiol*. 2012; **102**: 147-71 [PubMed Abstract](#) | [Publisher Full Text](#)

We have read this submission. We believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Competing Interests: No competing interests were disclosed.

Author Response 09 Mar 2017

Andreas Flouris, FAME Laboratory, Department of Exercise Science, University of Thessaly, Greece

We wish to thank you for reviewing the manuscript and for your constructive and helpful comments. We made appropriate changes in the paper based on your comments. The appropriate responses to all points that you raised appear below with each of your comments in underlined italics and our responses in **bold font**. **Bold underlined font** is used to indicate revised parts of the text.

Comments:

This opinion piece touches on an important issue. It is critical to accurately measure the redistribution of heat within both climate and physiological systems. The authors correctly note the interconnectedness of the two: as the earth warms, heat-related health risks will rise as the dynamics of energy transfer between organism and environment change. Standards to protect workers and the environment should be updated to reflect the most accurate and helpful measurements and information as is possible.

Thank you for your encouraging comments.

Major comments:

The authors draw a parallel between heat distribution in human and heat distribution within climate systems throughout the piece. While I see the analogy, it might be best to reign in this comparison in some places, specifically, on page 3 under the heading “Heat parallels in the two disciplines”. While the point is well taken, the human body has many mechanisms that actively work to maintain thermo-homeostasis. The earth, on the other hand, is a passive system with no “goal temperature”, as it were. Would it be better simply to state that temperature distribution is important in both systems and that our understanding and measurements of it need to be improved in the interest of human health? Given that heat distribution in humans is dependent on the temperature of the environment, there is a strong argument to be made linking these two variables without drawing a comparison between an actively regulated homeostatic system and system in which heat distribution occurs through passive mechanisms. The first paragraph of “Unaccounted heat in thermal physiology research” contains this analogy as well.

We agree with your observation. Specific comments were added in the relevant sections of the paper to improve clarity.

1st paragraph of section “Unaccounted heat in thermal physiology research”:

“Although the Earth is a “passive system” with no active regulation of temperature or heat content (based on current knowledge, that is),...”

1st paragraph of section “Heat parallels in the two disciplines”:

“Heat distribution (and its associated temperature variation) is important in both the Earth

and the human body and our understanding and measurements of it need to be improved in the interest of human health (since human thermal homeostasis is largely dependent on environmental temperature).”

Minor:

The authors put forward that the findings of Nieves et al. were confirmed by increased temperatures in 2015 and 2016 (Page 2). When considering global trends, single year data is a fraught method of proof given the degree of between-year variability in temperature. By the same logic, the climate change slowdown from 1998-2013 discussed in this paper was used to justify a lack of action around climate change.

To improve clarity, we revised the 1st paragraph of section “Unaccounted heat in climate research” as follows:

“Specifically, Nieves et al., showed that heat moved from the surface of the Pacific Ocean to the deeper layers of the Western Pacific and Indian Oceans, **a finding that was confirmed using a wealth of observational and simulated data**. As a result, the net ocean heat uptake remains dangerously high (Nieves et al., 2015), and the rate of global warming may have actually increased during the hiatus period (IPCC, 2014). **The observed record-breaking temperatures throughout 2015 and 2016** (<https://www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-glob>) **support the findings of Nieves et al.**”

Some slightly awkward phrasing persists in this article. For example, the first sentence of the second paragraph on page 2 under “Unaccounted heat in climate research” could be re-written as “Research aiming to understand the 1998-2013 hiatus significantly benefited from studies investigating the causes...”. The sentence, “This is not surprising.” Under the same heading on page 2, does not add to the paragraph and could be cut.

As suggested, the following revisions were done:

“Research aiming to understand the 1998–2013 hiatus significantly benefited **from** studies **investigating** the causes of a much longer hiatus observed from the 1950s to the 1970s.”

“This is **because** ocean circulation...”

“Unaccounted heat in thermal physiology research” could benefit from some discussion of the importance of brain temperature (Kiyaktin 2010 for review1). Individuals may experience robust changes in brain temperature during behavioral activation such as manual labor or intense exercise that can result, under conditions of diminished heat dissipation, in pathological hyperthermia2. Hyperthermia increases permeability of the blood-brain barrier, predisposing individuals to the development of vasogenic edema and damage of brain cells. Increased global temperature may also pose increased health risks for people using psychomotor stimulant drugs of abuse, the effects of which are greatly potentiated by increased ambient temperature. This is critical when considering issues of heat distribution in which peripheral tissues can tolerate greater changes in heat with less threat to the health and survivability of the organism, whereas increases in specific organ structures such as the brain can threaten organism health.

As suggested, we added the following sentence in the 1st paragraph of the section entitled “Unaccounted heat in thermal physiology research”:

“Moreover, peripheral tissues can tolerate greater changes in heat with less threat to the health and survivability of the organism, whereas increases in specific organ structures such as the brain can threaten organism health (Kiyatkin, 2010).”

Competing Interests: No competing interests were disclosed.

Referee Response 16 Mar 2017

Eugene A. Kiyatkin, NIDA-IRP, NIH, USA

The Authors properly responded to all comments raised in our review.

Competing Interests: No competing interests were disclosed.

Referee Report 07 March 2017

doi:10.5256/f1000research.11373.r20753



Juha Oksa 

Physical Work Capacity team, Finnish Institute of Occupational Health, Oulu, Finland

The opinion article by Dr's Flouris and Kenny nicely describes the similarities in the changes of heat content pattern between the Earth and the human body. The difference between these two is naturally the time frame, the response of the Earth being several years and that of the human, minutes.

Given that Earth is warming, extreme heat wave episodes are increasing and the study the authors are referring to (Meade *et al.* 2016¹) points to the possibility that the existing TLV guidelines may not be sufficient in protecting labor force from excessive heat strain (as the authors state). Therefore, a re-evaluation of the current TLV guidelines might be desirable.

However, it would also be desirable to see previous evaluations regarding the usability and effectiveness of the current guidelines. Has it been successful in preventing excessive heat strain? If not, what has been the causes? This might increase the justification for re-evaluation of the current TLV guidelines.

References

1. Meade RD, Poirier MP, Flouris AD, Hardcastle SG, Kenny GP: Do the Threshold Limit Values for Work in Hot Conditions Adequately Protect Workers?. *Med Sci Sports Exerc.* 2016; **48** (6): 1187-96 [PubMed Abstract](#) | [Publisher Full Text](#)

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Author Response 09 Mar 2017

Andreas Flouris, FAME Laboratory, Department of Exercise Science, University of Thessaly, Greece

We wish to thank you for reviewing the manuscript and for your constructive and helpful comments. We made appropriate changes in the paper based on your comments. The appropriate responses to all points that you raised appear below with each of your comments in underlined italics and our responses in **bold font**. **Bold font** is used to indicate revised parts of the text.

The opinion article by Dr's Flouris and Kenny nicely describes the similarities in the changes of heat content pattern between the Earth and the human body. The difference between these two is naturally the time frame, the response of the Earth being several years and that of the human, minutes. Given that Earth is warming, extreme heat wave episodes are increasing and the study the authors are referring to (Meade et al. 20161) points to the possibility that the existing TLV guidelines may not be sufficient in protecting labor force from excessive heat strain (as the authors state). Therefore, a re-evaluation of the current TLV guidelines might be desirable.

Thank you for your encouraging comments.

However, it would also be desirable to see previous evaluations regarding the usability and effectiveness of the current guidelines. Has it been successful in preventing excessive heat strain? If not, what has been the causes? This might increase the justification for re-evaluation of the current TLV guidelines.

The history of the TLV guidelines starts in 1971 (ACGIH, 2007). However, to the best of our knowledge, the study referenced in our paper is the only one that directly assessed the influence of the work exposure limits outlined in the TLV on core temperature responses during work and the associated changes in whole-body heat content. To clarify this further, we added a relevant comment in the paper [2nd paragraph of section “Unaccounted heat in thermal physiology research”]:

“While the history of the TLV guidelines starts in 1971 (ACGIH, 2007), to the best of our knowledge, the aforementioned recent study is the only one that directly assessed the influence of the work exposure limits outlined in the TLV on core temperature responses during work and the associated changes in whole-body heat content.”

Competing Interests: No competing interests were disclosed.