Concerning the Measurability of a Global Mean Surface Temperature

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March 11, 2006   Revised March 30, 2026

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Abstract

Global climate models typically assume the existence of a well-defined global mean surface temperature (GMST), defined as the spatial average of the local temperature field $\theta(X, t)$ [2]. An increase in GMST is internationally accepted as the definition of *warming*. The scientific unit of warming is thus the degree kelvin (K).

This concept of warming should be distinguished from that of the *Earth's Energy Imbalance* (EEI), which is the net energy gain at the top of the atmosphere, measured in $\mathrm{W\,m^{-2}}$. According to [3] the observed positive trend in EEI is related to anthropogenic forcing, which is why the Earth is warming.

We show here, using a result from rational thermodynamics, that the temperature-based metric $\hat{\theta}$ can transiently decouple from the planet's energy budget. In particular, significant heat can be stored (for example, in ocean heat uptake or latent-heat reservoirs) without a detectable change in global mean surface temperature. This illustrates one limitation of GMST as the sole metric of global climate change. The analysis rests on Truesdell's constitutive relation for homogeneous bodies; any extrapolation to the heterogeneous Earth's surface must therefore be regarded as qualitative.

1 Introduction

Simple theoretical models [1] of the earth's climate based on the thermodynamics of homogeneous fluid bodies, or on statistical mechanics, predict that certain gases such as CO_2 and methane can trap long-wavelength radiant energy leading to temperature increases. Problems arise, however, when attempting to apply such models to a multi-factorial, inhomogeneous, non-equilibrium, thermo-mechanical and chemical system, such as the earth's climate, whose complexity far exceeds that of any feasible model. Simulations of climate based upon such models may also be computationally intractable and/or sensitive to initial conditions, making realistic climate predictions impossible. A number of climate models have attempted to predict the earth's temperature distribution and in particular the global mean surface temperature.

In reality, when a planetary body is subject to a positive radiative forcing, three distinct possibilities exist for its global mean surface temperature $\hat{\theta}$:

1. $\hat{\theta}$ rises (warming by the conventional definition),
2. $\hat{\theta}$ falls (cooling),
3. $\hat{\theta}$ remains exactly constant (neither warming nor cooling).

This fact may have contributed to the persistent discrepancies among different analyses of the Earth's surface temperature record and raises serious questions about the reliability of this parameter and even its definition.

An extreme illustration of the third case is a hypothetical planet whose entire surface is at the melting point of water (0°C). It can absorb enormous latent heat while its global mean surface temperature remains exactly (0°C), yet—by the usual definition—no warming has occurred. The mean temperature metric therefore fails to register certain energetically significant phase changes. Indeed, all three cases are possible at *any* temperature within the constitutive domain of a homogeneous fluid body. As shown by Truesdell [4], the latent heat associated with isothermal ($\dot{\theta} = 0$) volume change allows a body to absorb or release energy without any change in the temperature θ. This follows from

Axiom 1 *The heating (i.e., the inward rate of flow of heat), Q, of a body of volume V and temperature θ in any process $(V(t), \theta(t))$ is determined, in its constitutive domain, by differentiable functions Λ, the latent heat with respect to volume, and K, the specific heat at constant volume, both having continuous partial derivatives such that*

$$Q = \Lambda(V, \theta)\,\dot{V} + K(V, \theta)\,\dot{\theta}.$$

It should be emphasized here that Truesdell's axiom applies to a single homogeneous body, whereas the Earth's surface is a heterogeneous, multi-phase, non-equilibrium field. In so far as one extrapolates to planetary GMST, then so too is the possibility that significant energy can be stored temporarily in ocean heat uptake without altering the surface temperature. Consequently, the arithmetic mean surface temperature $\hat{\theta}(t)$ cannot be guaranteed to correctly capture the direction and magnitude of net heat change, underscoring its limitations as the sole metric of global climate change. The frozen-planet example at 0°C is merely a special instance of this more general thermodynamic behaviour.

2 Conclusion

Much effort has been expended in recent years to measure and model changes in the global climate, and in particular the global mean surface temperature. Because models suggest that human activities may play a significant role in climate change, the issue is now both scientifically and politically important. Discrepancies in empirical data and differences between models continue to fuel controversy.

This analysis highlights one possible limitation of the global mean surface temperature as a climate-change metric: its inability, in certain circumstances, to guarantee capture of the direction and magnitude of net planetary heat change. It therefore underscores the need for careful mathematical and philosophical scrutiny of this concept and its use as the sole indicator of global warming.

This paper in no way disputes the essential correctness of simple heat-trapping models. To the extent that model predictions are mathematically rigorous, they are theorems and hence true in any system satisfying their hypotheses. In the real world, however—which is far more complex—these simple models may or may not fully reflect actual climate processes. That anthropogenic activities are one factor in the complex, multi-variable system that comprises Earth's climate(s) is indisputable. In a system as sensitive to initial conditions as the Earth's climate, almost all activities of humans and other organisms will have some effect.

What remains important to ascertain is whether these effects are:

C1. Sufficiently pernicious to warrant radical human intervention.

C2. Susceptible to amelioration in a manner that is less pernicious than the problem itself.

This paper suggests reasons to question assertions—based solely on global mean temperature measurements—that the answers to C1 and C2 are no longer open.

References

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