Study shows land surface temperatures follow simple physics, likely due to complexity of processes involved

July 13 2023

Land surface temperatures are shaped mostly by the heating by sunlight, but also by evaporation and convective heat transfer in the vertical. Credit: Axel Kleidon, MPI-BGC

Radiation largely shapes variations of temperatures across continents, but evaporation and turbulent heat transfer also play their part. These are inherently complex processes. Following a new physical approach, the observed temperature patterns follow relatively simple and predictable rules.

A new study just published in *Proceedings of the National Academy of Sciences* by scientists from the Max-Planck-Institute for Biogeochemistry in Jena, Germany, used a novel approach to determine the contribution of evaporation and turbulent heat transfer to the temperatures across continents. Temperatures on land reflect the balance of heating and cooling. The surface is heated by solar radiation and by the radiation emitted downward by the atmosphere, the latter also known as atmospheric greenhouse effect. This warming is balanced by the cooling from emitting radiation, evaporating water, and by transferring heat into the atmosphere, which is accomplished by convective, turbulent motion.

While radiation is very well understood and commonly observed, the extent to which evaporation and motion cool the surface is controlled by many factors, and semi-empirical approaches are often used to describe them.

The authors took a different approach to describing these complex processes, drawing on basic physics: A power source is needed to drive motion, similar to how an engine powers the motion of a car. In the case of the atmosphere, the heating of the surface powers the motion. But the consequences of motion also need to be considered.

Sarosh Alam Ghausi, lead author of the study, explains, "With more motion, you cool the surface more. It is like blowing over hot soup—the more you blow, the faster it cools." But this cooling, in turn, makes the power generation process less efficient, resulting in a reduced power maximum. This maximum can be calculated and used to quantify the cooling effects of evaporation and motion in land surface temperatures.

The researchers used satellite-derived radiation datasets and implemented the maximum power approach mathematically to estimate heating and cooling rates across continents and seasons. With this, they predicted temperatures, evaporation, and heat fluxes that matched observations remarkably well. They then used this approach to understand why temperatures vary across continents as they do, looking specifically at the role that water availability plays. But they did not find what they expected.

"I thought that the lack of water would make deserts warmer," says Ghausi, with his background as a hydrologist. "But we found that the maximization of power was more important than the lack of water. The missing water is compensated for in such a way that more heat was transferred into the atmosphere."

The warmer temperatures in deserts were then attributed to two effects: Deserts have fewer clouds, so that more sunshine heats the surface more strongly than in rainforests. The second effect is less trivial: deserts are typically located in the subtropics, where the atmosphere transports heat horizontally through the so-called Hadley circulation. This heat is not added to the surface where it could drive the engine for motion, but to the atmosphere above.

This makes the power generation process at the surface less efficient, resulting in less cooling and a warmer surface. With these two factors the authors were able to explain the temperature variations from rainforests to deserts.

Erwin Zehe, professor for hydrology at the Karlsruhe Institute of Technology and co-author of the study sees a great potential in this approach. "Our findings are really surprising, because usually evaporation is deemed as being the key to cool the environment. And I imagine this approach can really move things forward by setting a new gold standard, improving today's empirical approaches to model evaporation."

Axel Kleidon, group leader at the Max-Planck-Institute for Biogeochemistry, and senior author of the study, interprets these results in a more general way. "It is not quite clear why this simple, but physical approach works so well. One way to understand it is that these processes are so complex that the ultimate limitation that they encounter is in the physics of power generation."

The authors expect that they can apply their approach more widely to identify the basic mechanisms that shape the climate around us and how they respond to global warming.

More information: Sarosh Alam Ghausi et al, Radiative controls by clouds and thermodynamics shape surface temperatures and turbulent fluxes over land, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2220400120

Provided by Max Planck Society