

## Where Are the Hottest Spots on Earth?

The location of the hottest spot on the Earth's surface has long been a source of interest and curiosity. With images of blazing desert landscapes, several places have proudly claimed the title of 'hottest place on Earth.' Death Valley, California, the hottest place in North America, held the world record air temperature of 56.7°C from 1913 to 1922, until the current world record air temperature of 58.0°C was recorded in 1922 in El Azizia, Libya. Until recently, only point-based air temperature measurements in scattered locations were available to researchers trying to understand maximum temperatures. This incomplete picture, based largely on the locations of weather stations, clearly suggested that hotter air temperatures were occurring, but measurements on the scale needed to locate the hottest place simply were not practical.

Standard weather station air temperature is measured 1.5 meters above ground level, from sensors protected from short- and long-wave radiation and installed in such a position as to ensure that measurements are representative of the free air circulating in the area. In reality, the hottest temperature is at the surface of the Earth, where the thermal energy is more concentrated. With remote sensing data based on improved methods, the thermal surface maxima across the global land surface now can be mapped accurately and with continuous spatial coverage, allowing for exploration of the broad spatial patterns of maximum land surface temperatures and the interaction with vegetation while also pinpointing the hottest spot on the Earth's surface annually.

To identify the hottest places on Earth, this article presents a synthesis of remotely sensed radiometric land surface temperatures (LSTs). Studying patterns of maximum LSTs across the global land surface and the interaction with vegetation, or the absence of vegetation, can help develop an improved methodology for detecting land cover change and understanding the potential consequences of land cover change.

### Finding the Hottest Spot on Earth

LST is defined as the radiation emitted by the top of the land surface and can be likened to 'skin temperature,' or the temperature a person would feel if touching the land surface. Land surface refers to canopy in vegetated areas or to soil surface in bare areas

By D. J. MILDREXLER, M. ZHAO, AND S. W. RUNNING

[Wan *et al.*, 2004]. Because air is such a poor heat conductor, the LST in midsummer can be 30°–40°C higher than air temperature. Imagine the searing heat of beach sand (i.e., LST) on a hot summer day, when running from shade patch to water is the only way to avoid burning one's feet, compared with the air temperature 1.5 meters, or nearly 5 feet, above the sand at head level.

In 2003, the hottest LST detected on the Earth's surface was 69.3°C, in Queensland, Australia (21.5°S, 143.2°E; Figure 1). In 2004, the hottest spot on the Earth's surface was 68.0°C, in the Lut desert of Iran's Kerman Province (30.1°N, 59.3°E). Described as the 'thermal pole of the Earth,' the Iranian deserts are regarded as among the hottest, driest desert regions in the world. In fact, the Lut is so inhospitable to life that not even bacteria can survive (<http://www.wonderquest.com/DesertDriest.htm>). In 2005, the Lut desert reached 70.7°C (29.9°N, 59.1°E) and again registered the hottest LST on Earth. Numerous pixels from the collected satellite images, each representing approximately five square kilometers of the land surface of the Iranian deserts, exceeded 70°C.

Over only three years of data, the hottest place on Earth moved between two continents, demonstrating the importance of remote sensing data to detect the variability of maximum LST. Climate, a main driver of maximum LST, is highly dynamic and directionally changing. Therefore, remote sensing systems that provide accurate and spatially continuous data over the global land surface, such as from the latest generation of Moderate Resolution Imaging Spectroradiometer (MODIS) systems, are critical in order to monitor the multiyear trends in thermal surface maxima and explore questions such as the location of the hottest place on Earth.

To reveal the hottest spot on Earth, this study used annual maximum compositing of the 0.05° (approximately 5.6 kilometers at the equator) Aqua/MODIS LST data. The highest LST recorded at each pixel during any eight-day period over an annual period was extracted and combined into one image. The resulting composite images are spatially continuous illustrations of the hottest LST detected at every pixel on Earth's surface. The hottest spot on Earth during 2003, 2004, and 2005 was determined by selectively screening out all pixels on the global land surface below an incrementally increased threshold until, finally, only one place remained.

The spatially continuous global maps of maximum LST present the first opportunity to

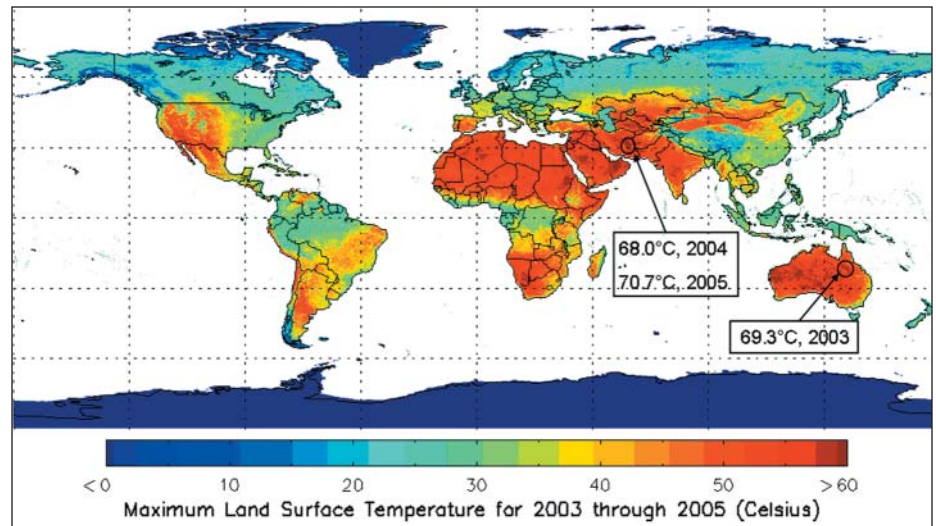


Fig. 1. The average of the hottest annual maximum land surface temperatures (LSTs) at each pixel over a three-year period illustrate that the hottest places on Earth are barren landscapes, such as the deserts of Iran and Australia, which were the hottest places on Earth from 2003 to 2005. Global, automated maps of annual maximum LST based on highly calibrated, geolocated, satellite data with continuous spatial coverage from the Aqua/MODIS sensor allow for easy monitoring of variability and trends in maximum LST.

visually analyze the patterns of the hottest temperatures across the Earth's surface. Mountain ranges tend to have lower maximum LSTs, as is seen in the Rocky Mountains, the Cascade Mountains, and the Sierra Madre Mountains of western North America, and the Andes Mountains of South America. The Tibetan Plateau, the largest, highest area on Earth, stands out for having maximum LSTs cooler than the surrounding landscape. The polar regions show up in dark blue with maximum LSTs less than 0°C, suggesting their importance as a cooling engine for the Earth's atmosphere and ocean.

Arid, sparsely vegetated, and barren landscapes, such as large areas in western North America, the Sahara desert, Egypt, India, the Middle East, the Gobi desert, and most of Australia, stand out in bright orange and red that signifies LSTs that regularly exceed 60°C. By contrast, highly vegetated areas such as the Brazilian Amazon, central Africa's rain forests, western China, the eastern United States, and much of Europe have some of the coolest maximum LSTs of any vegetated land cover, ranging from 25°C to 35°C. The boreal forest covers nearly 15% of the Earth's surface (<http://www.whrc.org/borealamerica/index.htm>) and does not exceed 35°C.

### Influence of Vegetation on Maximum LST

The coupling of decreasing vegetation density with increasing LST is well established [Goward *et al.*, 1985; Nemani and Running, 1997]. The underlying principle is that surface temperature decreases with an increase in vegetation density through latent heat transfer. But how dynamic are satellite-derived, annual maximum composite LST

data across vegetation density gradients and changes in land cover type? The lush Congo rain forests of central Africa grow at nearly the same latitude as vast semiarid landscapes, providing a contrasting environment to examine the influence of vegetation on maximum LST. The semiarid land area has maximum LSTs that range from 50°C to 60°C, whereas the rain forest maintains maximum LSTs within the 25–35°C range, an approximately 30°C difference (Figure 2).

Forests, with their deep root systems, can access groundwater even during dry conditions and continue transpiring. Forests partition a larger proportion of incoming solar radiation to latent heat flux compared with other land cover types and thereby maintain LSTs well below 40°C. This is a clear indication of the hydrologic cycle and the continuous interaction between a climate that is wet enough to support vegetation, and the transpiration from forests reinforcing rainfall.

### Influence of Irrigation on Maximum LST

Just as rainfall enhances vegetation density and thereby lowers maximum LST, irrigation can artificially enhance vegetation density in the same way. The influence of irrigation on satellite-derived maximum LST can be examined by comparing one of the most heavily irrigated crops in the Columbia River Basin (*Populus spp.* tree farm) with the directly adjacent semiarid natural vegetation of eastern Oregon's high desert (Figure 3a).

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## EDITORIAL

### Advocacy and Integrity

Many learned and professional societies at some time have strayed beyond the limits of what they can support from their scientific knowledge base. Unfortunately, these excursions can alter their image and hurt their credibility. However tempting it is to espouse positions that make a large fraction of members feel good, it is dangerous and in AGU's view wrong to do so. Opposition to the Vietnam War distracted some in the 1970s. The Space Station drew opponents and proponents, in many cases on economic rather

than scientific grounds. And today 'climate change' is evoking extreme reactions from some industries and government entities that support the research enterprise and from individual environmental activists and skeptics across the spectrum of opinion.

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A reputation for integrity and statements based on the best available science are critical characteristics that should differentiate a scientific society from other types of organizations. Many other organizations, understandably, advocate from their heart or their pocketbook.

AGU's goal is to encourage policy makers around the world to make wise use of the current base of scientific understanding as they develop laws, regulations, and public policy. In doing so, the Union frequently works with other scientific and professional societies. In most cases, the end product of policy makers is a political decision that

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Individual members of AGU may use the statements adopted by the Union when they communicate with local or national policy makers. It is important, however, for each of us to maintain the same level of honesty in these communications that we apply to our research. If we stray from our scientific base when speaking as scientists, we do damage to the overall integrity of science and lose the trust of policy makers and in turn of the public.

With your support, AGU can maintain its fine reputation and continue to accomplish more and more each year.

—SOROOSH SOROOSHIAN, Chair, AGU Committee on Public Affairs

## Hottest Spots

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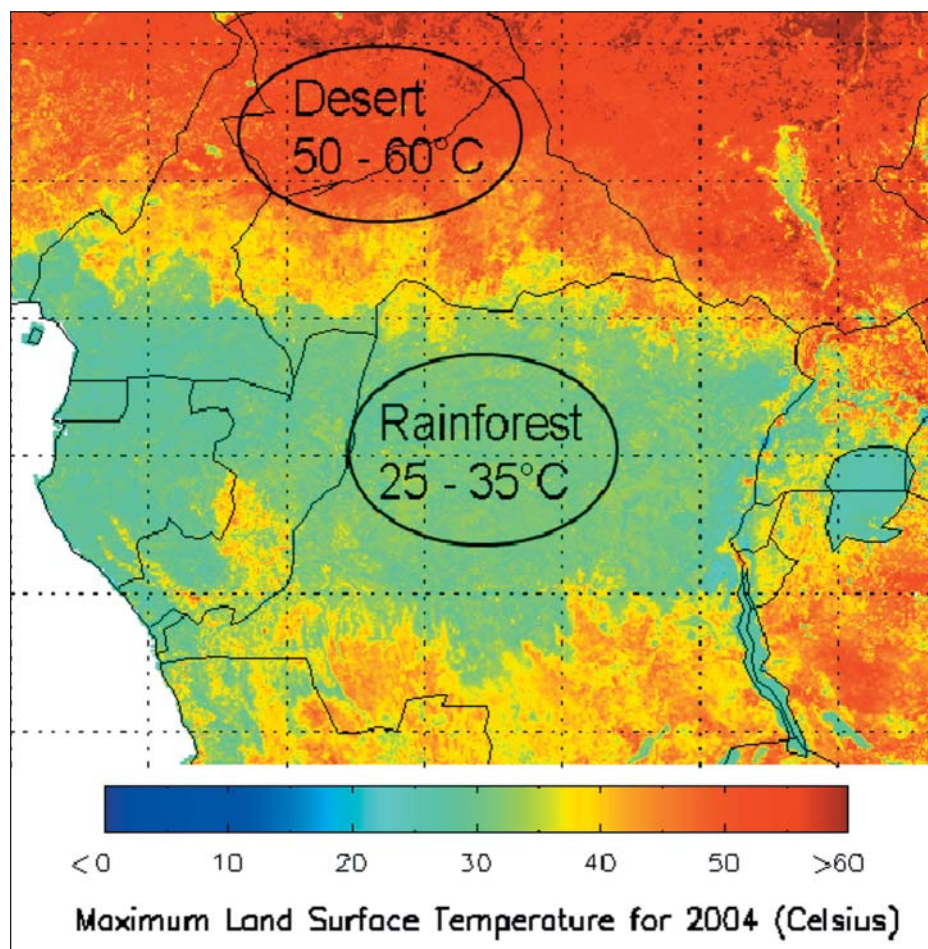


Fig. 2. The Congo rain forest maintains maximum LSTs nearly 30°C cooler than the adjacent semiarid lands due to energy partitioning of incoming solar radiation to latent heat flux. With improved and readily available remote sensing data, maps of global thermal surface maxima have been produced and show that forest ecosystems do not exceed 40°C anywhere on Earth.

For example, a poplar tree farm (45.8°N, 119.5°W) can be seen in the center of the 15-meter-resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image as dark red blocks that contrast sharply with the surrounding landscape (Figure 3b). The Aster imaging instrument, onboard the Terra satellite, is part of NASA's Earth Observing System (EOS). The Columbia River bisects the top of the image; various agricultural lands, as well as undeveloped areas, surround the poplar plantation. One-kilometer Aqua/MODIS LST data was used for this microscale analysis, and the annual maximum LST during 2003 and 2004 was extracted along three five-pixel transects, one within the poplar tree farm and the second and third within the adjacent natural plant communities. The maximum LST in the poplar tree farm during 2003 was 33.0°C, nearly 30°C lower than the directly adjacent natural cover types (Figure 3b). The 2004 maximum LST for the poplar tree farm was 36.0°C, and the adjacent areas had LSTs of 57.2°C and 59.4°C.

The nearly 30°C difference between the poplar tree farm and the adjacent land covers illustrates that the annual maximum LST is directly related to vegetation density

and that irrigation can have a significant indirect influence on the energy balance of an area. As demand on freshwater resources continues to grow, tracking the annual maximum composite LSTs could provide valuable information on the impacts of climate change and land cover change over irrigated land areas.

### Background on MODIS Sensors

As part of EOS, two MODIS instruments have been launched to provide information for global studies of atmosphere, land, and

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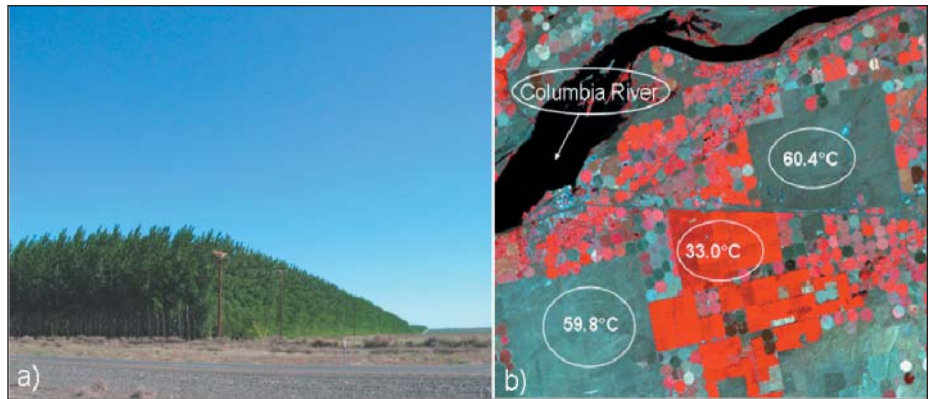


Fig. 3. (a) A dense poplar tree farm adjacent to natural vegetation thrives in northeastern Oregon's semiarid climate due to heavy irrigation. (b) The false-color ASTER image shows the heavily irrigated, 17,000-acre hybrid poplar plantation (center, in red) just south of the Columbia River. The nearly 30°C difference found in this microscale area is similar in magnitude to the LST difference found between the Congo rain forests and adjacent arid lands over a much larger area (Figure 2).

ocean processes. The first instrument was launched on 18 December 1999 on the morning platform called Terra, and the second was launched 4 May 2002 on the afternoon platform called Aqua. The MODIS LST products have been validated within 1°C at multiple sites and in a wide range of surface and atmospheric conditions [Wan et al., 2004], and they provide a vastly improved LST product compared with Advanced Very High Resolution Radiometer (AVHRR)-derived LST used in previous studies. The Aqua/MODIS sensor was chosen to detect the hottest spot on Earth because Aqua's orbit passes the equator and each latitude of the Earth at 1:30 P.M. local time each day. Aqua's afternoon overpass time is much closer to the maximum daily temperature of the land surface compared with the Terra/MODIS sensor's overpass time of 10:30 A.M. Aqua's afternoon overpass retrieves LSTs close to the peak of diurnal fluctuation and better reflects the thermal response of rising leaf temperatures due to decreased latent heat flux as stomata close, and soil litter surfaces dry, accentuating differences in LST among vegetation covers [Mildrexler et al., 2006].

With a simple, automated algorithm, based on new and improved satellite data, answers to interesting curiosities, such as the hottest spot on Earth, can be provided along with a means to follow vegetation change across the global land surface. In a 'warming world,' where extreme LSTs are predicted to occur more frequently, global maps of maximum LST based on high-resolution satellite data

provide the means to keep track of where things are heating up.

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