Torrid Temperature Tribulations

by Walter Lyons

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Zbriskie Point in Death Valley, California, one of the hottest locations in the world.

Back in the early 2000s, when I was teaching Introduction to Meteorology, the textbook's "Heat" lesson displayed *The World's Hottest Temperature*! It was a remarkable 136 °F, at El Azizia, Libya, on September 13, 1922, a record standing unchallenged for eight decades. I wondered aloud to the students how much longer that record would hold, given the long-predicted global temperatures rise induced by massive greenhouse gas releases was by then becoming clearly evident, even to a nonclimate specialist.

Fast forward to 2020, which started off with the warmest January global average temperature ever. The day after New Year's, some residents of Sunndalsora, on Norway's west coast near the Arctic Circle, swam in a fjord as the thermometer registered a record 66 °F. In February, not one but two reports arrived from Antarctica besting the existing warmth record for the icy continent. The year 2019 barely missed being the warmest recorded globally, just behind 2016. Nine of the planet's 10 warmest years have occurred since 2005. Last year, new national all-time maximum temperature records were reported for France, Belgium, and the Netherlands. Earth's temperature, like the sea surface during a rising tide, shows short-term peaks and dips, but the upward trend is relentless. Differing methods characterize the magnitude of the rise since the start of industrial age, but by 2020 a typical value quoted is ~2.0 °F (~1.1 °C).

The warming is not spatially uniform, and through the vicissitudes of the winds, even a few spots have turned cooler, while arctic regions have warmed at 2–3 times the average rate. Polar sea ice is retreating. U.S. record high temperatures routinely outnumber new record lows, growing seasons are longer, the Alps ski season has shortened by more than 30 days since 1970, and heat waves last longer and afflict larger regions.

On a recent road trip, we stopped in the city of Lake Havasu City, Arizona (population ~60,000), not only to see the relocated (stone by stone!) London Bridge, but

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Lake Havasu, between Arizona and California.

also to visit the hottest large population center in the Americas, by virtue of a 128 °F reading on June 29, 1994. That sizzling day is a source of great civic pride, the desk clerk informed us at the Heat Hotel, as we were handed the key to the Inferno Suite. But this was just a brief detour from our ultimate destination: Death Valley—home to the hottest temperature ever recorded in the western hemisphere. As we pulled off Interstate 15 at Baker, California, "The Gateway to Death Valley," one could not fail to notice the illuminated World's Tallest Thermometer (created by the same firm that does many of Las Vegas' famous neon signs). Situated outside the Temp134 Gift Shop, it was indeed 134 feet tall, commemorating the *World's Hottest Temperature*, 134 °F, on July 10, 1913, some 90 miles up the road.

Wait a minute! The *world's* hottest? What happened to the 136 °F at El Azizia? Turns out, the 1922 record was disallowed in 2012, leaving the 1913 Death Valley mark to again claim world's hottest status. Yet as discussed in a number of venues (including *Weatherwise* articles by Sean Potter [July/August 2010] and Christopher Burt [March/April 2011]), some doubt the validity of the 134 °F Death Valley mark. The next hottest in some compilations, 131 °F at Kebili, Tunisia, has its critics as well. What is going on here? The planet is warming, yet the all-time hottest temperature record is decreasing?

Turns out the planet is not cooling at all, but rather with each passing decade we are improving our ability to measure temperature, and in the process discovering that methodologies employed at some sites many decades ago were less than ideal. Just what are the factors that make for a proper temperature measurement? And just who, by the way, certifies that a given temperature report is valid, and deserving of world record status? This article is about how science works, its self-correcting nature, and above all, the primacy of the quality of data needed to advance our understanding of the natural world.

WHAT IS TEMPERATURE?

Temperature reflects how much heat energy a substance contains and is proportional to the vibrational speed of its molecules. If all molecular vibrations were to cease, the temperature would have reached absolute zero. One unit of heat (measured in calories) may increase the temperature of one substance by X degrees, but another by, say, twice or half as many degrees (a property called specific heat capacity). Heating wet sand requires almost double the solar energy as dry sand, because the water it contains requires twice again as much energy to bump up its temperature by one degree. That's why the sun baked dry beach sand can burn your feet while the nearby sand moistened by water remains cool.

Solar heat energy is transferred to the air via three processes: radiation, conduction, and convection. Aside from some upper atmosphere gases like ozone, air is largely transparent to solar radiation. Sunshine directly heats the surface, with rock, grass, water, etc. reaching different temperatures. Cool morning air in contact with rapidly heating ground is warmed very efficiently by conduction. Heated air, being a fluid, also can and will move. Convective clouds (cumulus and cumulonimbus) mark upward heat transport (convection) from the surface by the cloud's updrafts. This differs from horizontal heat transport (i.e., warming on strong southerly winds), which is termed

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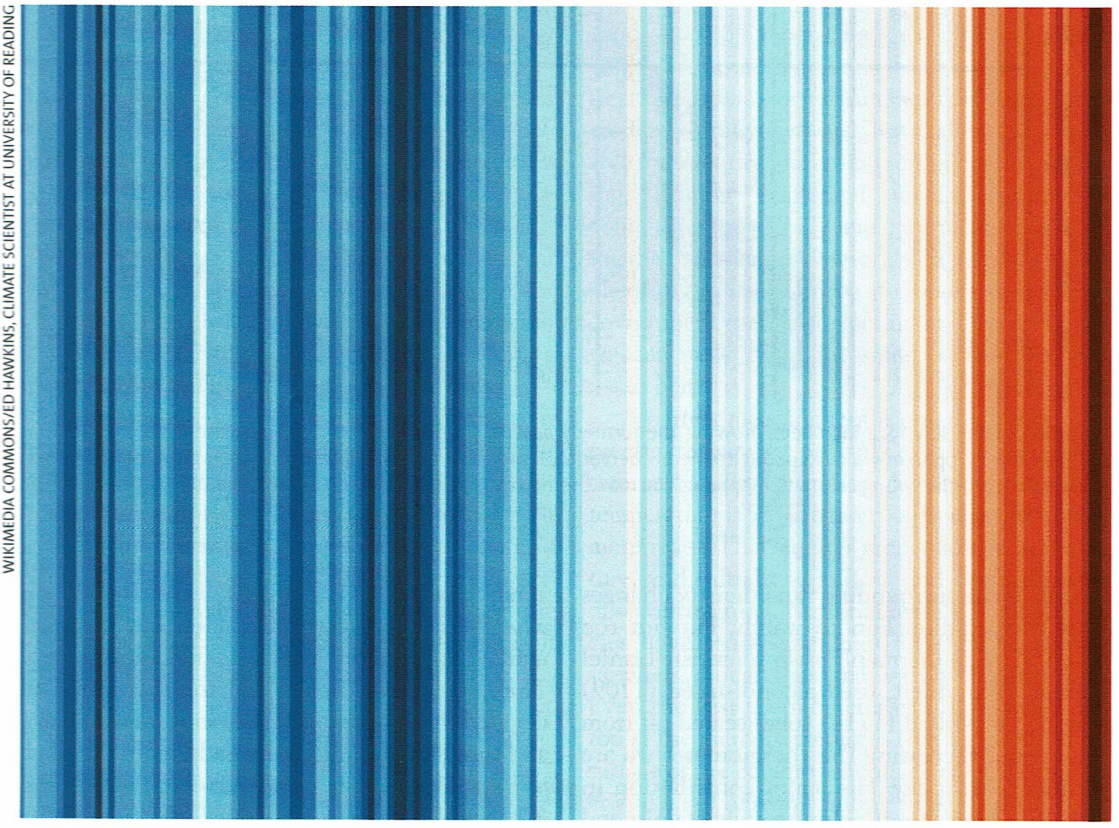
The world's tallest thermometer in Baker, California, stands outside the TEMP134 gift shop, celebrating the currently accepted world's hottest measured air temperature.

advection. When air masses become stagnant, conduction is working overtime to make for a sizzling hot summer day. The character of the ground surface (hot rocks, moist grassy fields, etc.) makes a big difference in how hot the day will be.

Our bodies sense heat and cold, but how does one measure temperature in a quantitative manner? A wire's electrical resistance changes with temperature. Measure the resistance, and the temperature can be deduced. Solids, liquids, and gases usually expand by known amounts when heat is added. Given that expansion per degree differs by metal type, two kinds of metal welded together (a bimetallic strip) will warp in a known manner. Quantify the warp, and the temperature can be ascertained. Some liquids expand significantly when warmed. Mercury confined to a very narrow tube expands or contracts with each degree sufficiently to be easily visible. Though if someone says the mercury fell to –50 °F they are wrong, because it freezes solid at –38 °F. Thus, the popularity of alcohol-based thermometers.

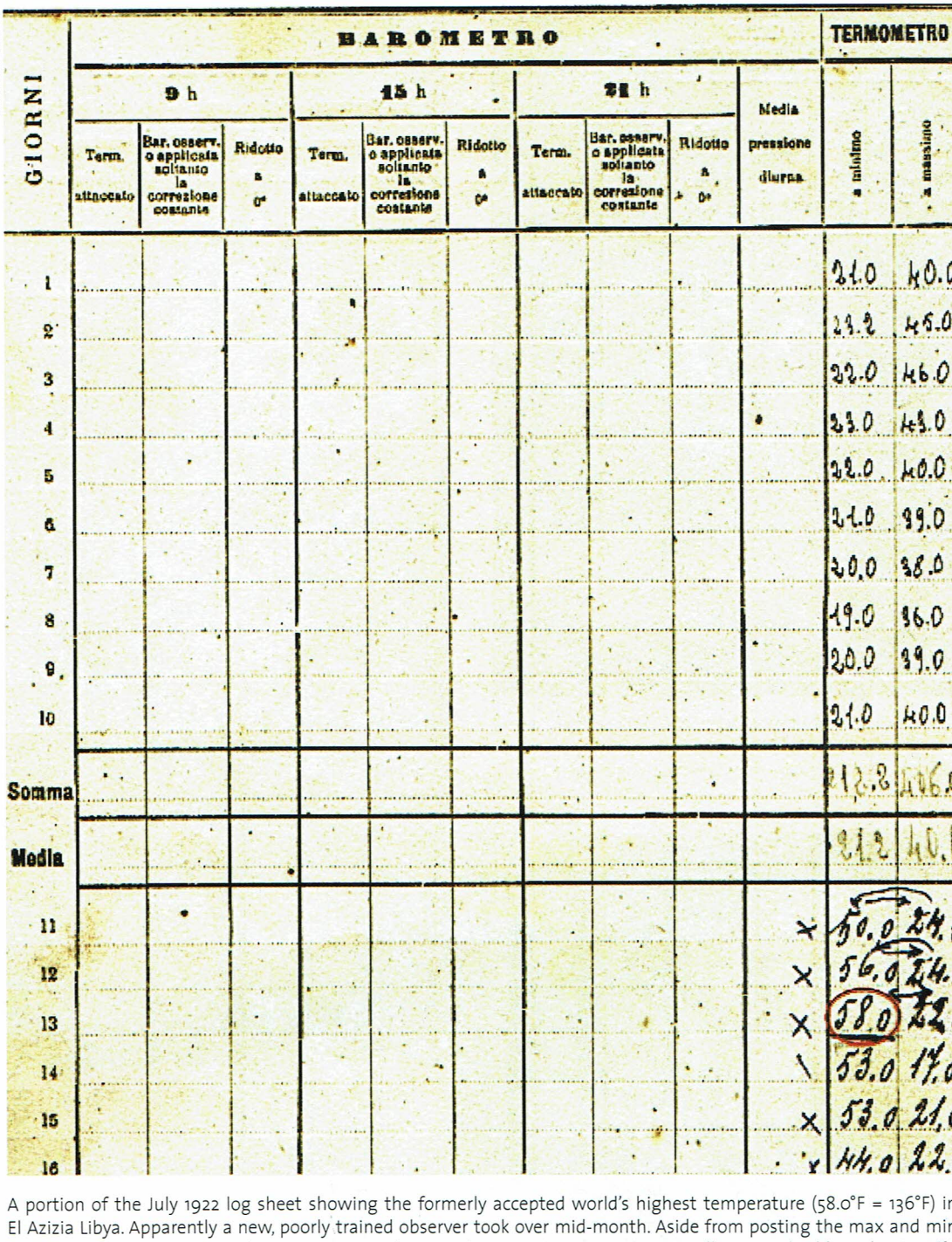
Attempts to measure air temperature can be traced back to at least Galileo in the early 17th century. A Galileo thermometer (a staple of many science store gift shops, though probably not invented by Galileo himself) uses known weights floating in a fluid-filled column that rise



WIKIMEDIA COMMONS/ED HAWKINS, CLIMATE SCIENTIST AT UNIVERSITY OF READING

Global average temperatures 1850-2018 (left to right). Each stripe represents one year. Blue stripes are cooler years, red stripes are warmer years. Yes, you can purchase a t-shirt or a tie with this iconic graphic!

RANDALL CERVENY



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A portion of the July 1922 log sheet showing the formerly accepted world's highest temperature (58.0°F = 136°F) in El Azizia Libya. Apparently a new, poorly trained observer took over mid-month. Aside from posting the max and min temperatures in the wrong columns, it appears the max thermometer was systematically misread, adding about 12.6° to the reading.

or sink as the surrounding fluid density changes with temperature. Fun to watch, but not too practical. The German/Polish scientist, Daniel Gabriel Fahrenheit, used alcohol-filled (1709) and mercury-filled (1714) tubes sealed off from the open air, creating the thermometer we are familiar with today. His major contribution in 1724, however, was attaching a scale of units and calibrating the device—essentially inventing "the degree." There is a story, probably apocryphal, that Fahrenheit went outside on what he thought was the coldest day possible marked the mercury level, and that became zero. Then, to get an upper end for the scale, he decided the human body temperature would do and thus the speculation he had the flu that day as his reading was what we now call 100 °F. The F is for Fahrenheit, a scale in which "freezing" is 32 °F and water boils at 212 °F. It is rather clumsy and today only the United States, along with

The road to Badwater Basin. The lowest point in the Americas (282 ft below sea level) lies beyond the next hill. The terrain is mostly barren, dark-colored rock. It can be argued that this area may be even hotter than Furnace Creek to its north, the locale of the currently accepted world's highest temperature.

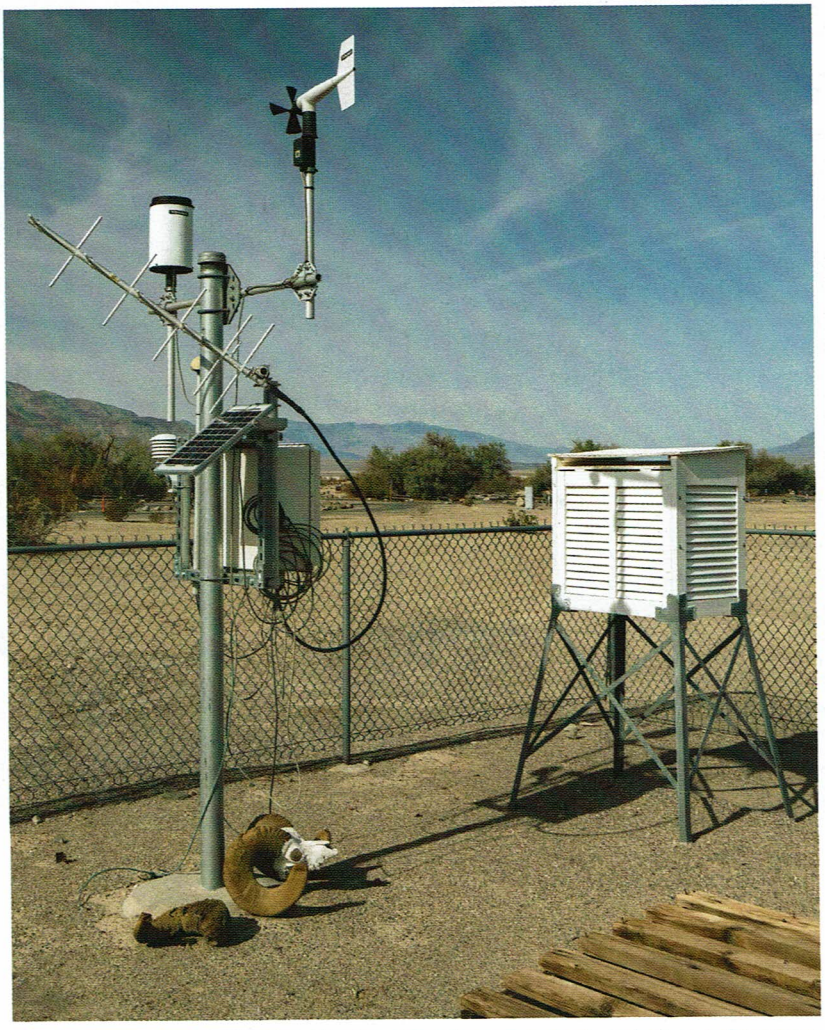
Liberia, the Bahamas, and about a dozen other small nations, still uses the F scale.

In the 1740s, Sweden's Anders Celsius inspired the much more sensible centigrade scale, in which 0 °C is the melting point of ice (bulk water, unless it is totally pure, does not always freeze at 0 °C). The boiling point of water was set at 100 °C. Of course, one must calibrate the thermometer at mean sea level pressure, as the boiling point decreases with lowering pressure. In Denver, potatoes take longer to cook, given that the boiling point is 203 °F. This was so much more useful in a metric world the scale is now named after Celsius (replacing centigrade). We will use Fahrenheit scale in this article. The international meteorological community still must routinely deal with converting between degrees Fahrenheit and Celsius. The arithmetic isn't hard (there's an app for that), but rounding up and down to whole degrees of different sizes can create small round-off errors, which at times can be of consequence.

METROLOGY FOR METEOROLOGY

Metrology is the science of measurement. But measuring meteorological temperature can't be that hard, can it? Then again, how often does your car dashboard temperature agree with the roadside bank thermometer, or one bank agree with the next? Approximate measurements of temperature are fairly straightforward, but making those suitable for scientific purposes such as weather reporting, driving numerical forecasting models, computing the global temperature, and determining the exact values of weather extremes is a complex field in itself. Entire textbooks and weighty government manuals expound on this topic, and we can only highlight some of the pertinent issues here.

A perfect measurement is one that is accurate, precise, repeatable, properly exposed, representative, and quality controlled. Accuracy means if the temperature is 95 °F, then that is what the instrument reads. This requires proper design, manufacture, and initial calibration, and comprehensive observer training. National meteorological agencies have strict guidelines for their equipment suppliers, though these may vary with jurisdiction. Even the best thermometer can be misread. The top of the mercury meniscus (the lens-shaped top surface of the column) should be at eye level, otherwise a tall observer failing to bend down could "cool" the temperature. Precision refers to how many decimal points one employs. A report of 32 °F is valuable during a threat of freezing rain,



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The current National Weather Service observing equipment, including a Stevenson screen, at the National Park visitor center on the northern edge of the vegetated "oasis" at Furnace Creek, Death Valley. The ram skull is not regulation equipment.

but far more useful would be knowing if it is 31.8 °F or 32.2 °F. A repeatable measurement means the same air temperature continues to give the same readout over time. If the calibration drifts with sensor age, errors creep in. Proper exposure is essential. Air temperature must be in taken in the shade, shielded from direct solar heating. The classic thermometer shelter is called a Stevenson screen, a four-sided box of louvered slats allowing for free air ventilation, painted white to reflect the maximum solar energy. The access door must face poleward to prevent sunlight striking the instruments. The thermometer ideally should be positioned 1.25–2.0 meters above (preferably) grass or a surface characteristic of the local environment. The screen (or the modern cylindrical ventilation shield equivalent) should be sufficiently far from artificial heat sources (i.e., air conditioning exhaust). If the white paint on the shelter becomes dirty over time, the temperature will creep upward. What makes for a representative siting can be open to some debate. A temperature measured on a third-story rooftop covered in black tar may be accurate but hardly representative of the nearby airport runway (as was the case at the [then] U.S. Weather Bureau station, where I began my career.)

The data must also be recorded. Making hourly manual checks is likely to miss higher and lower values between readings. Thermographs, where the pen traces the temperature on a revolving drum, solve that problem. But one current heat record for a site in Israel, when re-examined, shows that the observer misread 54 °C rather than the actual 53 °C. Data quality control often picks up errors, like transposing 48 °F to 84 °F on the log sheet, but like the prior example, some slip errors through. Maximum–minimum thermometers record the highest and lowest values in the interval since the last reading, *if* the observer remembers to reset the metallic "index" marker in the tube. Electronic systems can avoid some problems, but their electronics can release unwanted heat, sensors can degrade, air vents can clog with dust and spider webs, and on and on. Taking quality data for scientific purposes requires dedication and constant double-checking.

JUST HOW HOT CAN IT GET?

Several mid-20th century scientific papers proposed the maximum possible air temperature at 1.5 meters above ground is about 131–133 °F. Related investigations proposed the hottest ground surfaces (bone dry, dark-colored rock with low thermal conductivity) could reach the 194–212 °F range. (The radiation calculations likely used the then-prevailing atmospheric CO_2 levels. Perhaps the theoretical maximum air and ground temperatures under ideal conditions might increase by a few degrees when using higher current values?)

What would the ideal conditions be? The sun's elevation at noon should be close to overhead. Because the sun's rays must reach and warm the underlying ground, one would need no clouds, low humidity, and very low aerosol or pollution concentrations (which reflect sunlight). During droughts, little water evaporates from wet soil or evapotranspires from plants, which would otherwise cool the environment. Even better would be a vegetation-free, barren desert. A regional high-pressure system would clamp down on vertical convective mixing and cloud cover. The lowest terrain elevations are favored, given the temperature above sun-heated ground increases at a rate of 5.4 °F per 1,000 feet (or even more close the surface) as one descends. Deep valleys limit the advection of cooler air from distant sources, such as oceans or large lakes. Also upward flow on the heated adjacent mountain slopes results in sinking and compressional warming of the air over the valley proper.

On the floor of Death Valley, hemmed in by mountains on both sides, looking south towards Badwater Basin, at -282 ft elevation, the lowest and hottest location in the Americas.

WHO DECIDES IF IT IS A RECORD?

When does a report become an "official record?" Over the century or more that lists of extreme weather records have been compiled, it has been a pretty ad hoc affair. Each national meteorological agency selected its own equipment, sites, and maintenance methods, and recorded and quality controlled the data by a variety of means. (Though increasingly, standardization was promoted through the World Meteorological Organization [WMO].) Also, all weather stations are not created equal. Some data are taken for research purposes by top scientists, many are from airport stations run by civilian and military meteorologists, while others are "second-order" sites with more modest equipment and less well-trained observers. In the United States, over 11,000 dedicated "citizen scientist" cooperative observers using government-approved equipment do their best to get the readings right. In past decades, most nations kept their own informal lists of apparent records, as do State Climatologists in the United States. In 1997, the U.S. Army Corps of Engineers published an extensive compilation of weather extremes from multiple sources to guide their operations. In light of global climate change concerns, some order has been imposed. The U.S. National Climate Extremes Committee, drawing from multiple federal and state agencies, began evaluating existing national records for temperature and other key parameters in 1997. By 2007, the growing need prompted the WMO Commission for Climatology to empower a Rapporteur for Climate Extremes to create an archive by verifying, certifying, and storing world weather extremes (see https://wmo.asu.edu). When a new observation challenges an existing record, an ad hoc committee with subject matter expertise reviews the claim. Existing records tend not to be overturned, but rather like instant video replay in sports, if there is compelling evidence that the initial call was missed, a record can be decertified.

AND THE WINNER IS...

We almost certainly do not know the actual hottest air temperature reached on Earth simply because either no one lived or properly recorded weather data in that locale. But it is not 136 °F in 1922 Libya. In 2012, a WMO expert panel met and dug into the purported 1922 record from El Azizia taken by the Italian Colonial

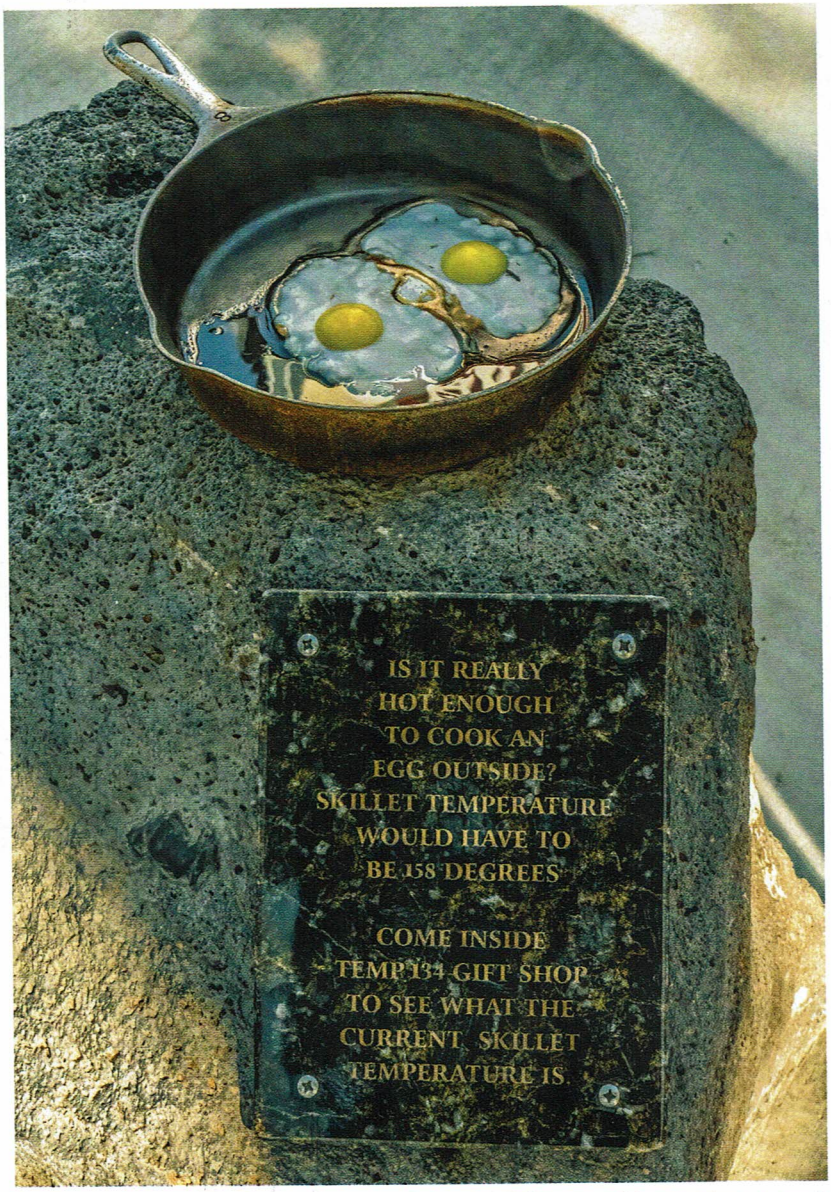

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Exhibit outside the TEMP134 gift shop in Baker, CA. If the ground temperature exceeds 158°F, an egg will begin to cook. But Death Valley National Park rangers are now pleading with tourists to please stop this practice, as they are leaving behind omelette-like messes throughout the park.

Meteorological Service. First, a new and possibly ill-trained observer had just taken over, and on that month's log sheet, the only record of the event, made errors such as posting the maximum temperature in the minimum column. Also, the damaged regulation mercury thermometer had been replaced by a maximum–minimum instrument more commonly used in civilian households. On the "record" day, no other temperature in the surrounding region came close to 136 °F. The shelter was sited over a tar-coated concrete plaza. Hardly ideal. After the shelter was relocated to a better site in 1927, readings only twice exceeded 122 °F in the ensuing 48 years. But most telling is that an inexperienced observer reading the top, rather than the bottom, of the index bar inside the tube would inadvertently add about 12.6 °F to the measurement, as systematically appeared to be the case after the new recruit took over. With so many red flags, the "record" was invalidated.

Death Valley certainly checks off most criteria for an extreme maximum temperature location. It features the lowest elevation (–282 ft) in the Americas with 500 square miles below sea level, and is rimmed by mountains over 11,000 ft to the west and 8000 ft to the east. Long and narrow, covered almost entirely in rock, sand, and salt flats, it has little vegetation due to only ~2 inches of rain per year. Research instruments have monitored soil surface temperatures in the area as hot as 201 °F (June 15, 1972), accompanied by 128 °F air temperatures.

The 134 °F reading was made at the oddly named Greenland Ranch (subsequently more aptly renamed Furnace Creek Ranch), a U.S. Weather Bureau cooperative weather station established in 1911 at 177 feet below sea level. The Greenland moniker may reflect the results of a local spring watering a ~100-acre oasis of trees and alfalfa fields to feed cattle for the miners at the local borax mine (the home of the famous 20-Mule Team). The readings were not taken by a meteorologist, but rather by Oscar Denton, a new company employee. Could Mr. Denton have been so bothered that the readings in his official shelter were much lower than those on the sunlit thermometers hanging on the sides of buildings that he padded the values a bit to obtain bragging rights for the discomfort he endured? If so, why just for that one week, in which readings of 130 °F and 131 °F were also logged? In 1949, California State Climatologist Arnold Court noted eyewitness reports on July 10 (on which a tourist apparently died from the heat in his car) that there was a sandstorm driven by strong winds (not uncommon in the valley). Court theorized that the intense, but localized, winds blew super-heated soil and dust into the Stevenson screen (which was sited only 3.5–4 feet above the ground), thus further heating the enclosure. This may explain why no other stations in the general region came within 15 °F of the Greenland Ranch reading. Despite numerous critiques, however, the WMO committee has, unless new evidence should emerge, decided to let this record stand.

If 134 °F were to fall, the next hottest temperature might be the 131 °F at Kebili in the Tunisian desert on July 7, 1931. Pre-1950 climate records from colonial military bases are viewed with some skepticism, and indeed, there is no information on either the thermometer or type of shelter used. And after a subsequent sensor relocation, Kebili never again reported such high readings. (The same happened for Lake Havasu City's

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On the road to Badwater Basin, in Death Valley, California, descending towards -282 ft elevation. The barren rocky terrain results in extremely hot ground temperatures, which in turn heat the overlying air.

thermometer. After the observation site was moved in 1999, the 128 °F has not been approached again.)

If Kebili's record were invalidated (though WMO has no plans at this time to challenge it unless and until new evidence is presented) that leaves several high-quality reports of 129 °F at Furnace Creek, the most recent on June 20, 2013. We should note, however, that the deepest part of Death Valley is the desolate Badwater Basin, 14 miles to the south, far from any irrigated fields or trees, with even a lower elevation of 282 feet below sea level. Unpublished studies conducted by a Park Service ranger in summer 1959, using regulation equipment, found Badwater Basin high temperatures were routinely 3–5 °F higher than the station at Furnace Creek. So…?

Perhaps the next heat champion will come from Asia? The WMO committee has officially endorsed as Asia's highest temperature both 129.0 ± 0.2 °F at Mitribah, Kuwait, on July 7, 2016, and 128.7 ± 0.7 °F at Turbat, Pakistan, on May 5, 2017. For these, the committee exhaustively and physically examined the actual instruments and every aspect of the measurements, thus the ability to derive error bars and a precision of 0.1 °F.

Maybe a new weather station about to be established in some inhospitable and previously unmonitored desert location will soon eclipse 129 °F, 131 °F, or 134 °F? Time will tell. If the world's hottest temperature were unexpectedly demoted to Death Valley's 129 °F, the Temp 134 Gift Shop owner could probably just cut a few feet off the big sign and rename the store. If a new record is set in some distant middle eastern or Asian city, new signage—*Western Hemisphere's Hottest*—would still mark an impressive milestone. Given the unsettling impacts of climate change being projected by the Intergovernmental Panel on Climate Change, updating a gift shop's sign is one of the less worrisome threats from our changing atmosphere.

Weather enthusiasts contributing their data to organizations such as CoCoRaHS might be surprised how their data might someday be used, perhaps in reconstructing a weather disaster or even in a court case. So, continue to give your measurements care and thought. Has a tree branch grown over your rain gauge? Is your maximum–minimum thermometer closer to your outdoor grill than you realized? Weirder things have happened! Taking good data requires diligence, but it is well worth it for us all and our future generations. W

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