2022 EDITION

CORRUPTED CLIMATE STATIONS

The Official U.S. Temperature Record Remains Fatally Flawed

By Anthony Watts

THE HEARTLAND INSTITUTE

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FOREWORD

This report examines the accuracy and reliability of U.S. temperature stations from which official temperature records are reported, following up from a March 2009 study, titled "[Is the U.S. Surface Temperature Record Reliable?]"[1] The original report found the ground-based system for measuring surface temperatures in the United States was biased by asphalt, machinery, and other heat-producing, heat-trapping, or heat-accentuating objects located near many official temperature stations and their sensory equipment. The new study reexamines these temperature stations and equipment to determine whether there remains flaws in the official U.S. surface temperature record. This report finds approximately 96 percent of U.S. temperature stations fail to meet what the National Oceanic and Atmospheric Administration (NOAA) considers to be "acceptable," uncorrupted placement. These findings strongly undermine the legitimacy and the magnitude of the official consensus on long-term climate warming trends.

The U.S. surface temperature record is determined from data gathered by the Cooperative Observer Network (COOP), administered by NOAA's National Weather Service (NWS) division.[2] Data are then compiled and presented to the public for climate change tracking by the National Centers for Environment Information (NCEI), formerly known as the National Climatic Data Center (NCDC).[3] NOAA defines the NWS COOP Network as:

> The National Weather Service (NWS) Cooperative Observer Program (COOP) is a network of daily weather observations taken by more than 8,500 volunteers. These data, which include observations from the late 1800's, are vital to understanding the U.S. climate, and also provide near real-time information that supports forecasts, warnings and alerts, and other public service programs. Observations are taken from around the U.S. and its territories at National Parks, seashores, mountaintops, farms, and many urban and suburban areas. COOP data usually consist of daily maximum and minimum temperatures, snowfall, snow depth, and 24-hour precipitation totals. Observations may include additional hydrological or meteorological data such as evaporation or soil temperatures.

The quality of temperature data gathered via the COOP network of stations is what is examined in this report.[i]

[i] For a glossary of acronyms and terms used in this report, please reference Appendix C.

REVIEW OF THE 2009 REPORT[ii]

In the 2009 report, station inspection concentrated on a subset of the COOP network called the United States Historical Climatology Network (USHCN). At the time, USHCN was comprised of 1,225 stations out of the 8,700 stations making up the greater COOP network.[4] The USHCN subset provided a representative sample of the entire system.

A depiction of station coverage in the contiguous United States can be seen in Figure 1.

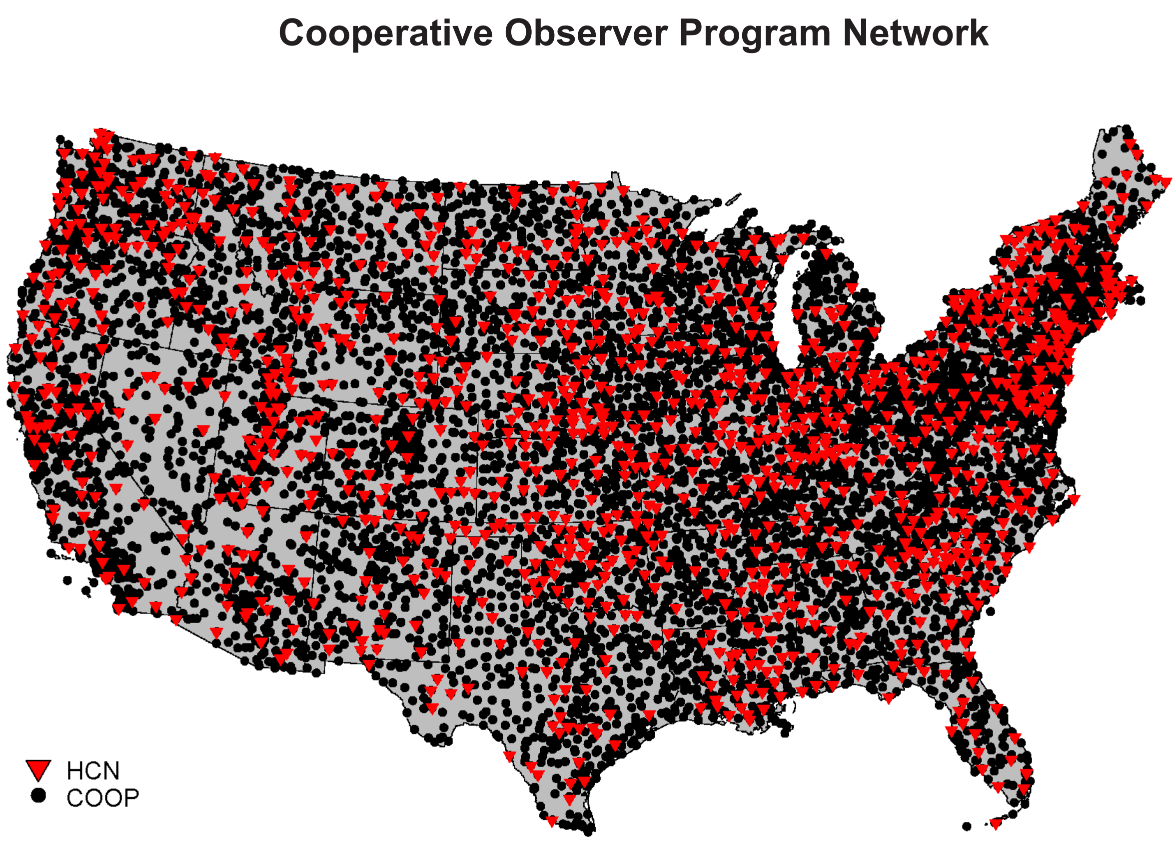


Figure 1: Map of station placement in the U.S. Cooperative Observer Network in black combined with station placement in the U.S. Historical Climatology Network (HCN) in red. Source: NOAA / NCEI.[5]

As seen in Figure 1, the United States is broadly covered with weather stations used for both weather and climate monitoring. All of the stations are placed, maintained, and administered by the NWS utilizing personnel at local and regional NWS Forecast offices.[6]

[ii] The following pages review the 2009 report findings, and reactions from the government and scientific community. For a review of the 2022 report's new findings, skip to page 20.

The COOP and USHCN stations consist of two types of temperature measurement equipment given to the volunteer observers by the NWS. When the network was originally established in 1890, Stevenson Screen or Cotton Region Shelter (CRS) enclosures were used to house mercury-based glass thermometers. This system was gradually phased out by newer Maximum Minimum Temperature Systems (MMTS) housing Nimbus digital thermometers starting in the 1980s. Figure 2 illustrates the comparison between CRS and MMTS enclosures.

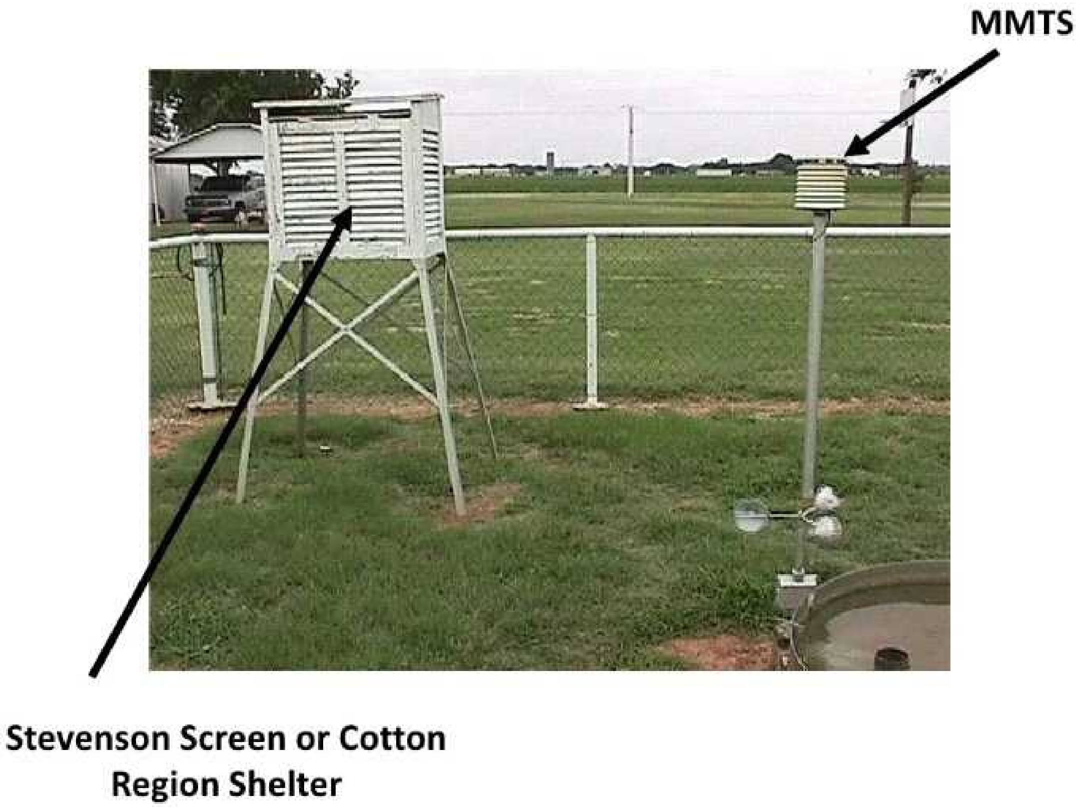


Figure 2: Examples of Stevenson Screen aka Cotton Region Shelter enclosures (left) and the newer MMTS electronic sensor enclosure (right). Source: Pat Guinan.[7]

These electronic thermometers utilize cables from the outdoor sensor that connect to Nimbus electronic readouts located in homes and offices, thereby limiting where the sensors could be placed. The inability of NWS personnel to bury cable under sidewalks, driveways, and roads often resulted in MMTS thermometers being placed closer to buildings, heat sinks, and heat sources compared to their original locations.

The 2009 report surveyed and photographed more than 850 USHCN stations, providing an analysis of their temperature data. The peer-reviewed paper was published and distributed to thousands of lawmakers, scholars, and scientists. Some of the most important findings in the original report are listed below:

- Many climate monitoring stations were located next to exhaust fans of air conditioning units, surrounded by asphalt parking lots and roads, located on blistering-hot rooftops, or placed near sidewalks and buildings that absorb and radiate heat.

- Sixty-eight stations were located at waste-water treatment plants (WWTP), where the process of waste digestion creates higher temperatures than in surrounding areas. In addition, the infrastructure of WWTPs is almost entirely asphalt and concrete, making them unrepresentative of the surrounding area and unsuitable for thermometer placement to measure long-term changes in temperature.

- Approximately 90 percent of the USHCN stations failed to meet the NWS's own siting requirements, which stipulate that stations must be 30 meters (100 feet) or more away from an artificial or radiating / reflecting heat source.[8] A rating system based on official NOAA documents was employed to assess each station.[9] See Figure 3.

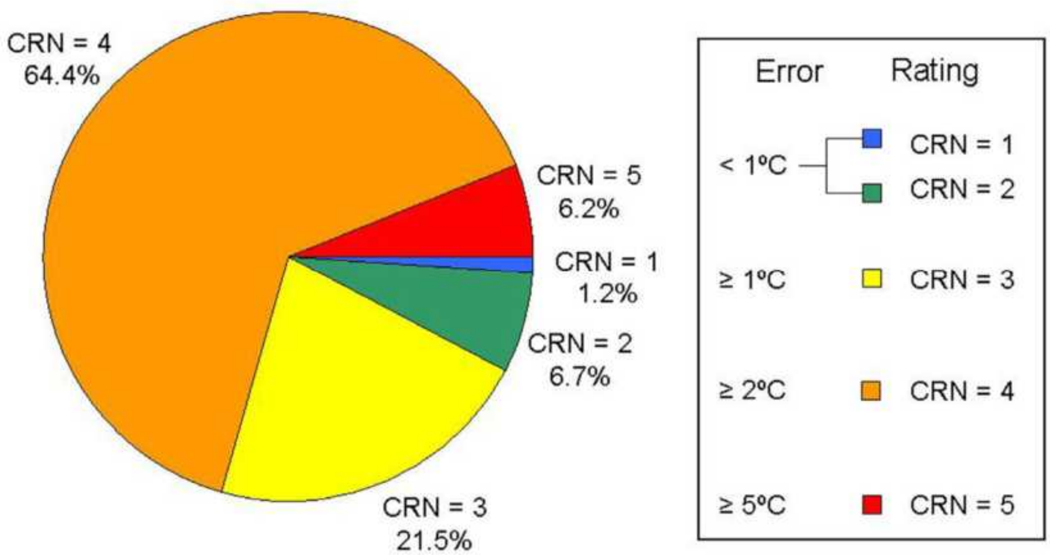


Figure 3: Station quality ratings of the USHCN surveyed in the 2009 report. Stations with CRN ratings of 3, 4, and 5 are deemed unacceptable. In this figure, representing 1,007 USHCN stations out of 1,221, 92.1 percent of all stations surveyed in the USHCN were unacceptably sited by NOAA's own standards. Source: Anthony Watts graphic at surfacestations.org, using data from NOAA / NCDC / NCEI.[10]

Class 1 (CRN1) - Flat and horizontal ground surrounded by a clear surface with a slope below 1/3 (< 19 degrees). Grass / low vegetation ground cover < 10 centimeters high. No artificial heating or reflecting surfaces (buildings, concrete, parking lots) within 100 meters. Far from large bodies of water unless representative of the area, and then located at least 100 meters away. No shading when the sun elevation > 3 degrees.

Class 2 (CRN2) - Same as Class 1 with the following differences: surrounding vegetation < 25 centimeters high, no artificial heating sources within 30 meters, no shading when sun elevation > 5 degrees.

Class 3 (CRN3) - (temperature error >= 1°C) - Same as Class 2, except no artificial heating sources within 10 meters.

Class 4 (CRN4) - (temperature error >= 2°C) - Artificial heating sources < 10 meters.

Class 5 (CRN5) - (temperature error >= 5°C) - Temperature sensor located next to / above an artificial heating source, such as a building, roof top, parking lot, or concrete surface.

- Many stations often had missing, incomplete, or erroneous data, perhaps due to the volunteer-based network of observers who could not always record or report data based upon illness, week-day only reporting, and/or vacation days.

- The report found that major gaps in the data record were "infilled" with temperature data from nearby sites, compounding errors from other stations that were also non-compliant with station siting requirements.

- The report observed that changes in the technology of temperature stations over time resulted in many being placed closer to buildings, as well as other heat sinks such as asphalt, concrete, and brick infrastructure. In some cases, official NWS thermometers were moved to parking lots and next to external heat-generating air conditioner units from previously cooler locations that were no longer available for thermometer placement. See Figure 4.

Figure 4: Old Stevenson Screen / CRS and new MMTS / Nimbus electronic thermometer in Bainbridge, GA, circa 2008. The new MMTS station moved about 150 feet closer to the building to accommodate the new MMTS sensor cable length. The MMTS is recording heat from the air conditioning unit exhaust, house, cars, and asphalt parking lot, whereas the original placement had none of these issues. The station has since been closed by NOAA / NWS. Source: Joel McDade.

- Prior to the 2009 Surface Stations project, the weather stations that produced data for inclusion into the USHCN dataset had never undergone network-wide site quality assessment. The placement, maintenance, and calibration of each site is left up to the COOP manager at local National Weather Service Forecast Offices (NWSFOs).

- The gradual introduction of the MMTS / Nimbus electronic thermometers since their inception in the mid-1980s has likely introduced a slow warming bias. This is due to thermometers being moved closer to buildings, asphalt, concrete, and other man-made influences from older Stevenson Screen and Cotton Region Shelter enclosures. By February 2009, MMTS thermometers outnumbered CRS thermometers by a 2-to-1 margin. See Figure 5. The ratio in 2022 has likely increased significantly due to continuous upgrades over the past 13 years.

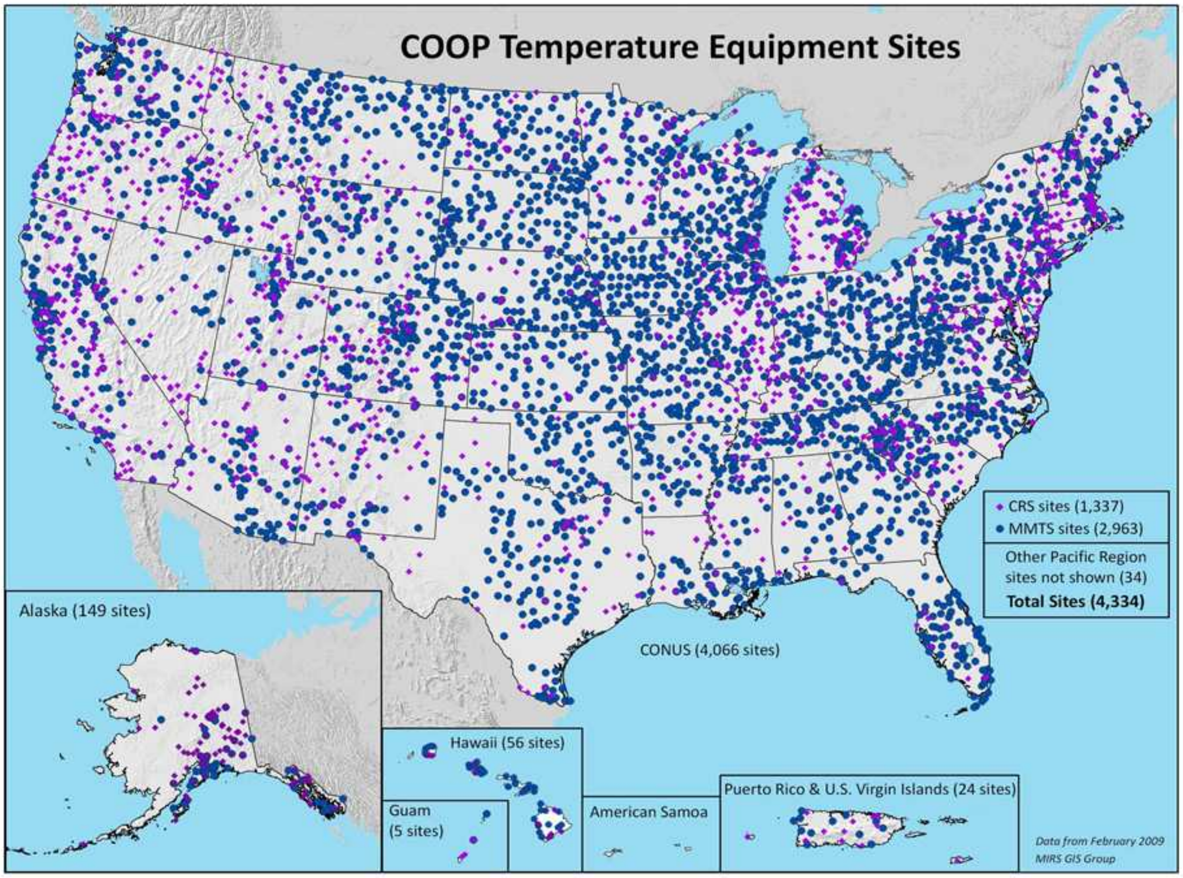


Figure 5: Map of contiguous United States, plus Alaska, Hawaii, and U.S. Territories showing CRS vs. MMTS temperature station placements, as of February 2009. Source: NOAA / NCEI.[11]

- The report concluded that nine of every 10 USHCN stations were likely reporting inaccurately high temperatures because they were poorly sited and in violation of NOAA / NWS published standards for thermometer placement.[12] An additional rating system was also used, pioneered by Michel Leroy of Météo-France, which allowed classification of stations by distance to buildings, asphalt, concrete, and other man-made influences.[13]

- The report suggested that adjustments to the temperature data by NOAA / NCEI also cause recent temperatures to appear higher, due to the infilling mechanism for missing data employed during creation of a national temperature average, as well as other adjustments.

GOVERNMENT RESPONSES TO THE 2009 SURFACE STATIONS REPORT

When "Is the U.S. Temperature Record Reliable?" was published in March 2009, reactions were swift from social media, news outlets, government agencies, and the academic community. Outlets such as Fox News, *The New York Times*, the *Rush Limbaugh Show*, and many others covered the story, which elicited such broad interest because no comprehensive site quality assessment had ever been undertaken.

NOAA's National Climatic Data Center (NCDC) responded on June 12, 2009, with a memo containing "talking points," for which no author was attributed. The memo appeared designed for the media to rebut the findings of the March 2009 Surface Stations report. See Figure 6.

Figure 6: Screencap of the NCDC website from June 12, 2009. This memo has been removed from the internet, with this screencap seemingly the only record of its existence. Source: Anthony Watts.

A new version of these talking points was published on July 6, 2009, adding references to the U.S. Climate Reference Network and the USHCN modernization program (USHCN-M) that began in 2008.[14,15] Clearly, NOAA knew USHCN contained inherent problems and reacted by modernizing the network.

Climatologist Roger Pielke critiqued NOAA's press release.[16] He wrote of the problems:

> In their news release, they perpetuate the myth that they can correct "less-than-ideal" sites. The news release writes:
>
> > "Data gathered by those existing HCN stations that were located in less-than-ideal areas have been statistically corrected in the analysis of climate trends routinely reported by NOAA. Though some individual stations were placed in less-than-ideal areas, these data anomalies did not significantly alter overall climate measurements. The modernization will relocate these stations in areas that are closer to ideal."
>
> This ignores the evidence to the contrary that we have published in peer-reviewed papers.

On September 29, 2009, the U.S. Office of the Inspector General (OIG) sent a memorandum to NOAA Director Jane Lubchencko concluding that USHCN must undergo a review based upon "a congressional inquiry on the reliability of the network's data."[17]

OIG published its findings on July 29, 2010, essentially echoing Pielke's concerns. The report states:

> NOAA acknowledges that there are problems with the USHCN data due to biases introduced by such means as undocumented site relocation, poor siting, or instrument changes. The agency has taken steps to improve data quality by implementing enhanced quality control steps and algorithms (referred to as USHCN Version 2) and having them peer reviewed. According to the peer reviews we examined, the resulting dataset improves upon the algorithms in the prior Version I data.
>
> The respondents to our inquiries about the use of and adjustments to the USHCN data generally expressed confidence in the Version 2 dataset. Although experts from the three professional organizations we contacted had no official position on the efficacy of the adjustments, two of the experts stated that in their professional view the USHCN Version 2 dataset has value, with one expert saying it is the best dataset for detecting climate change and trends. All of the experts thought that an improved, modernized climate reporting system is necessary to eliminate the need for data adjustments. [18]

Another investigation into the USHCN was launched by the U.S. Government Accountability Office (GAO), which was published on August 31, 2011.[19] It noted a number of problems related to NOAA's quality-control system, concluding:

> GAO reviewed data and documents, interviewed key NOAA officials, surveyed the 116 NOAA weather forecast offices responsible for managing stations in the USHCN, and visited 8 forecast offices. According to GAO's survey of weather forecast offices, about 42 percent of the active stations in 2010 did not meet one or more of the siting standards… NOAA does not centrally track whether USHCN stations adhere to siting standards and the requirement to update station

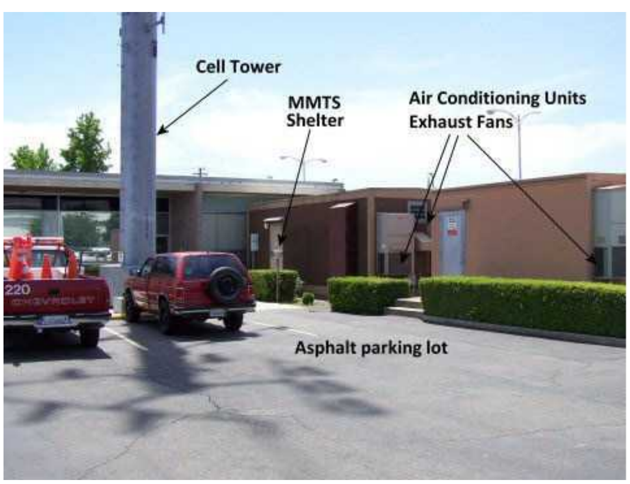
> records, and it does not have an agency-wide policy regarding stations that do not meet its siting standards…
>
> Without centrally available information, NOAA cannot easily measure the performance of the USHCN in meeting siting standards and management requirements. Furthermore, federal internal control standards call for agencies to document their policies and procedures to help managers achieve desired results. NOAA has not developed an agencywide policy, however, that clarifies for agency staff whether stations that do not adhere to siting standards should remain open because the continuity of the data is important, or should be moved or closed. As a result, weather forecast offices do not have a basis for making consistent decisions to address stations that do not meet the siting standards.[20]

GAO subsequently recommended NOAA enhance its information systems to centrally capture information useful in managing the USHCN and develop a policy on how to address stations that do not meet its siting standards. NOAA agreed with GAO's recommendations.

Yet, one weakness of the report is GAO did not visit any faulty USHCN stations, instead relying upon interviews with NOAA / NWS personnel. This may account for the discrepancy in station siting non-compliance between GAO (42 percent) and the Surface Stations project (90 percent).

THE FEDERAL GOVERNMENT CLOSES SOME OF THE WORST USHCN STATIONS

After these problems were exposed, NOAA / NWS began to close some of the worst USHCN stations. The first of these was in Marysville, California, which was highlighted in the 2009 Surface Stations report as the worst offender and served as the impetus for further national investigation. Marysville was the **very first** of the "How Not to Measure Temperature" series published by WattsUpWithThat.com on May 26, 2007.[21] Just over a year after the 2009 Surface Stations report was released, NOAA reported it had closed Marysville. See Figure 7.[22]



2008-07-01

REASON: UPDATE PUBLICATION; DATA NO LONGER PUBLISHED. DATA ONLY GOES TO WFO/STO. DATA THAT IS RECIEVED FROM THIS STATION WILL BE USED AS BACK UP TO TO MARYSVILLE AIRPORT DATA (04-5388) WHICH IS NOW BEING PUBLISHED.

2007-10-24

BEGIN PUBLICATION OF 24 HR MX/MN AND PCPN IN CD, AND HOURLY PCPN IN HPD. STATION DATA TO BE PUBLISHED IN LIEU OF THE MARYSVILLE FIRE STATION DATA (04-5385) WHICH HAS BECOME UNRELIABLE AND HAS A QUESTIONABLE EXPOSURE.

Figure 7: Photograph of Marysville, CA, USHCN site taken in May 2007 (left). Report from NOAA Historical Observing Metadata Repository (HOMR) website on closure in July 2008 (right). Source: Anthony Watts (left), NOAA (right).

The NOAA HOMR database also reported that the duties of temperature and precipitation reporting at the Marysville station were assumed by the automated station at the Marysville airport.[23]

Soon after, NOAA closed the USHCN station at the University of Arizona Atmospheric Sciences Department in Tucson, Arizona. This station had been placed in the parking lot—by scientists who clearly should have known better—and quickly became a prime example of the inherent flaws within the COOP network. As seen in Figure 8, the station was closed just a few months after the 2009 report was published. The NOAA HOMR database confirms the station is closed and no longer produces data.[24]

Figure 8: Top: placement of CRS in parking lot at University of Arizona Atmospheric Sciences Department on July 21, 2007. Lower left: detail at ground level of CRS placement on July 21, 2007. Lower right: detail at ground level of CRS after removal on November 23, 2007. Source: Warren Meyer, Bob Thompson.

The 2009 report also describes two USHCN climate stations in which MMTS enclosures were mounted directly adjacent to city streets, compromising the integrity of site data. USHCN stations in Ardmore and Perry, Oklahoma, have since been closed for temperature reporting, as seen in Figures 9 and 10.

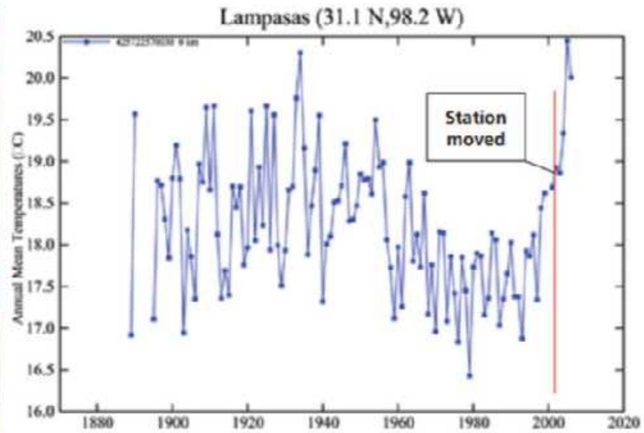
Figure 9: Before and after photographs of the Ardmore, OK, USHCN station. Source: Anthony Watts.

Figure 10: Before and after photographs of the Perry, OK, USHCN station. Top: natural and infrared photos indicating heat effects of building wall in January 2009. Bottom: Perry, OK, street view from August 2016. Source: Anthony Watts, Google Earth.

Ardmore, Oklahoma remains open as a precipitation reporting station at a new location, but the USHCN temperature sensor was removed in December 2009 according to the NOAA HOMR database.[25]

Perry, Oklahoma remains open as a precipitation reporting station only, and was moved 1.8 miles west to the city fire department building in December 2009. The USHCN thermometer was removed.[26]

Lampasas, Texas was home to one of the most poorly-sited stations in the USHCN network, being located in front of a radio station only a few feet away from a four-lane highway. The station received a large amount of media coverage, as its temperature record showed a clear warming spike after it was moved to that location. NOAA / NWS closed it in March 2013. Figure 11 illustrates the Lampasas station's exceptionally poor siting, along with the spike in temperature that occurred when it was moved. Figure 11 also shows the remarks entered into the NOAA HOMR database about its unsuitability in June 2011 and eventual closure in March 2013.[27] NOAA / NWS did not remove the temperature sensor, which still remains visible today.[28]



Remarks

DATES	TYPE	REMARK
2013-03-02 to Present	NWS COOP INGEST	CLOSING STATION
2013-03-02 to Present	NWS COOP INGEST	INACTIVATE STATION. DATA AT THIS LOCATION IS NO LONGER REPRESENTATIVE DUE TO CONSTRUCTION AND URBANIZATION. THIS IS AN HCN SITE. THIS STATION WILL BE REACTIVATED UPON RECRUITMENT OF SUITABLE OBSVR OR CLOSED IAW NWS INSTRUCTIONS.
2011-06-01 to Present	NWS COOP INGEST	REACTIVATE STATION AT SAME LOCATION WITH NEW PRIMARY OBSERVER. REACTIVATION AT THIS LOCATION WILL BE TEMPORARY UNTIL A MORE SUITABLE LOCATION CAN BE FOUND. DATA AT THIS LOCATION IS MARGINALLY SUITABLE DUE TO CONSTRUCTION AND URBANIZATION. THIS IS AN HCN SITE.

Figure 11: Top left: USHCN temperature sensor (MMTS) in front of radio station on US 193 in Lampasas, TX. Top right: graph of temperature data at the Lampasas station showing the spike in temperature after the station was moved (NASA GISS). Bottom: screen capture of the remarks section of the NOAA HOMR database on the Lampasas station. Source: 2009 Surface Stations report.

It is clear the 2009 Surface Stations report had a substantial impact upon decisions to close the worst stations, based upon the aforementioned information.

SCIENTIFIC RESPONSES TO THE 2009 SURFACE STATIONS REPORT

The scientific community reacted swiftly to the 2009 report. *The Journal of Geophysical Research* published the first attempt to rebut the 2009 Surface Stations report in June 2010. The article by Menne *et al.* was written entirely by government employees at the National Climatic Data Center in Asheville, North Carolina.[29] The authors ultimately dismissed the 2009 report's findings, asserting statistical manipulation could account for and correct the siting problems observed at each station.

No evidence was cited to support the authors' claims. However, the paper left the door open for other possibilities, admitting in its concluding remarks: "Given the now extensive documentation by surfacestations.org that the exposure characteristics of many USHCN stations are far from ideal, it is reasonable to question the role that poor exposure may have played in biasing CONUS temperature trends… our analysis does provide evidence of bias in poor exposure sites relative to good exposure sites."[30]

Michel Leroy contributed a 2010 paper that examined the methodology used to quantify temperature biases in station siting, adding a critically important variable.[31] Previously, only distance to heat sinks, heat sources, and other biases was used to rate a station. This methodology was used in setting up the state-of-the-art Climate Reference Network utilizing Leroy's work from 1998, which spawned the 1 to 5 classification system. Leroy updated the methodology to include the surface area of biasing factors within a 100-meter radius of the thermometer.

After an extensive peer-reviewed process, the Surface Stations project authors published a 2011 report coming to a very different conclusion than the NCDC authors.[32] The paper incorporated comprehensive data analysis from both well-sited and poorly-sited stations, using a larger sample size of stations than NCDC's 2010 report, while remaining true to the NCDC's rating approach. The 2011 paper concluded, "According to the best-sited stations, the diurnal temperature range (DTR) in the lower 48 states has no century-scale trend."[33]

This report's finding of a zero-DTR trend is tremendously important, as DTR is an important climate trend indicator.[34] Since the daily high to low temperature (diurnal temperature) of the best-sited stations showed no global warming trend over 100 years of data, there is a strong possibility that NOAA's reports of rising temperatures were biased by the substantial number of stations classified as a CRN3, CRN4, and CRN5. Essentially, the overwhelming amount of "bad" data were swamping the "good" data.

Using Leroy's new methodology, the surfacestations.org team reanalyzed its earlier work to include surface areas and distances of heat sinks and sources within 100 meters of the thermometer. New tools, such as an enhanced version of Google Earth Pro, facilitated this process.[35,36] The authors presented the findings of their paper at the 2015 American Geophysical Union (AGU) convention.[37]

The Watts *et al.* paper introduced the concept of "unperturbed" stations. Through careful examination of each USHCN station, 410 stations were identified that experienced no changes in time of observation or geographical location from 1979 to 2008. Their stability made them excellent candidates for the study. The new heat sink evaluation process was applied to the entire sample.

The paper explains its methodological approach:

> Distance measurements of visible encroachments of heat sinks and sources were made, and a calculation was done to determine the percentage of area within the different radii (3m, 5m, 10m, 30m, and 100m) surrounding the thermometer per Leroy 2010, containing heat sinks and/or heat sources. The class rating assigned to the stations corresponds to the portion of the Leroy 2010 rating system dealing with artificial surfaces. The distance and area values were applied to the final rating for each station. Quality control checks were routinely done to ensure that the proper station was identified, that it matched descriptions in metadata provided by NCDC, that it was consistent with the latitude and longitude given for the station, and that the equipment seen in photography and described in survey reports matched the equipment description according to the NCDC HOMR database.

An example of a USHCN station analysis measuring surface area of heat sinks and heat sources is shown in Figure 12.

Figure 12: Analysis of artificial surface areas within 10- and 30-meter radii at Ashland, NE, USHCN station (COOP# 250375) using Google Earth tools. The NOAA temperature sensor is labeled as MMTS. The figure illustrates how the USHCN station, which was evaluated per Leroy (2010) procedures, showing the 10- and 30-meter radii, along with polygon surface (area outlines of visible heat sinks created with Google Earth Pro tools, providing a value of approximately 373 square meters of heat sink surface area within the 30-meter radius, and approximately 24 square meters within the 5-10-meter annulus). Source: Anthony Watts and Evan Jones.

The stations were classified based on proximity to artificial surfaces, buildings, and other such objects with unnatural thermal mass—the total measure of the heat sink effect, combining both surface area and distance—using guidelines established by Leroy's 2010 report.

The United States temperature trends estimated from the relatively few stations in the classes with minimal artificial impact were found to be collectively about 2/3 as large as U.S. trends estimated in the classes with greater expected artificial impact. The trend differences are largest for night-time low temperatures and are statistically significant at the regional scale, across different types of instrumentation, and degrees of urbanization.

KEY FINDINGS OF WATTS *ET AL.*, 2015

It is well-established in peer-reviewed literature that heat sinks impact short-term temperature changes. Watts *et al.* demonstrated that the heat sink effect manifests itself in long-term temperature trends as well, contradicting the conclusions of the NCDC's rebuttal to the Surface Stations report. The overall warming effect of a heat sink on a nearby sensor is greater at the end of a warming phase than at its beginning. Therefore, the warming trend displayed over the 30-year study period is exaggerated, as it has been confounded by the heat sink effect.[iii]

The 30-year average temperature trend (Tmean) of unperturbed, well-sited stations is significantly lower than the Tmean of the official NOAA / NCDC record for all 1,218 USHCN stations. See Figure 13.

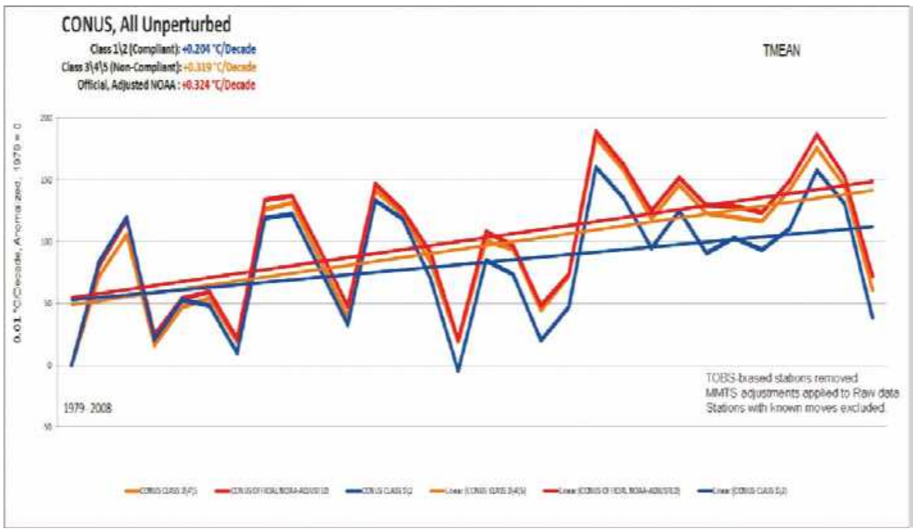


Figure 13: From Watts, *et al,* 2015. Comparisons of 30-year temperature trends for unperturbed and compliant Class 1 and 2 USHCN stations to unperturbed and non-compliant Class 3, 4, and 5 USHCN stations, compared to NOAA final adjusted V2.5 USHCN data in CONUS. Bias at the microsite level (the immediate environment of the sensor) in the unperturbed subset of USHCN stations has a significant effect on the mean temperature (Tmean) trend. Well-sited stations show significantly less warming from 1979 - 2008. Source: Evan Jones.

Two prominent peer-reviewed publications bolstered the findings of the 2015 report. A study by Kevin Gallo and George Xian found the problems related to Impervious Surface Areas (ISAs)—for example, asphalt, brick, concrete, and buildings—were only worsening.[38]

The authors discovered 32 percent of USHCN stations recorded at least a 20 percent temperature increase in the area of heat sinks within 100 meters of the thermometer. In the larger urban heat island areas, more than 52 percent of the USHCN stations saw a temperature increase of 20 percent or more from surfaces within 1,000 meters of the station producing a heat sink effect. Essentially, the presence of heat sinks is heavily correlated to high temperature readings.

The trend is clear: increased urbanization changes the environment near the thermometers to one that will hold more heat, thus supporting the conclusions of Watts *et al.*

The most significant response to the original 2009 Surface Stations report came from an experiment conducted by researchers at NOAA's Atmospheric Turbulence and Diffusion Laboratory in Oak Ridge, Tennessee, and published in the *Bulletin of the American Meteorological Society.* The NOAA Oak Ridge Laboratory developed an experiment to measure the effects of heat sinks in proximity to thermometers.[39]

[iii] See Appendix B for the science behind heat sinks near these weather stations.

The abstract of the ATDD's 2019 report explains the experimental design:

> A field experiment was performed in Oak Ridge, TN, with four instrumented towers placed over grass at increasing distances (4, 30, 50, 124, and 300 m) from a built-up area. Stations were aligned in such a way to simulate the impact of small-scale encroachment on temperature observations. As expected, temperature observations were warmest for the site closest to the built-up environment with an average temperature difference of 0.31 and 0.24 °C for aspirated and unaspirated sensors respectively. Mean aspirated temperature differences were greater during the evening (0.47 °C) than day (0.16 °C) …
>
> These results suggest that small-scale urban encroachment within 50 meters of a station can have important impacts on daily temperature extrema (maximum and minimum) with the magnitude of these differences dependent upon prevailing environmental conditions and sensing technology.

The 2019 NOAA Oak Ridge Laboratory publication vindicated the findings of the original 2009 Surface Stations publication as well as Watts et al.'s 2015 follow-up.

ELIMINATION OF THE ENTIRE USHCN DATASET AND THE 'BAND-AID' REPLACEMENT

NOAA and its subordinate agencies clearly went to great lengths to defend the quality of the USHCN network. However, NOAA abruptly stopped using the USHCN dataset in 2014, switching to a new dataset called "*n*ClimDiv."[40]

USHCN's 1,218 stations were dwarfed by the nascent *n*ClimDiv initiative, which incorporates more than 10,000 installations in a network called "*n*ClimGrid." This new network combines the USHCN stations, in addition to thousands of stations from the Global Historical Climatology Network (GHCN).

The switch was likely a strategic maneuver by NOAA to draw attention away from the fact that its long-maintained USHCN had been riddled with poorly sited locations, compromising the temperature records it produced. Perhaps NOAA believed changing the name and the method would shield the system from further criticism.

NOAA / NCDC concurrently rolled out the new U.S. "Climate Reference Network" (USCRN), which it described as thusly:

> NCDC developed the U.S. Climate Reference Network (USCRN) to address the most basic of climate change questions that Americans will ask in the mid-21st century, "How has the climate of the Nation changed in the last 50 years?" The USCRN measures temperature with superior accuracy and continuity in places that land-use change will not likely impact during the next five decades. Built specifically for this purpose, it is unlike any other climate observation network in the United States. NCDC began the USCRN build-out in the lower 48 states in 2000 and completed the last of 114 station installations in 2008. Since 2005, the USCRN has operated a sufficient number of stations to generate accurate annual national temperature averages.
>
> The USCRN serves, as its name and original intent imply, as a reference network for operational

> estimates of national-scale temperature. NCDC builds its current operational contiguous U.S. (CONUS) temperature from a divisional dataset based on 5-km resolution gridded temperature data. This dataset, called *nClimDiv,* replaced the previous operational dataset, the U.S. Historical Climatology Network (USHCN), in March 2014.[41]

Surprisingly, NOAA, NCDC, and NCEI do not use or cite the high-quality temperature data produced by the USCRN in any public reports.[42] Instead, they use *n*ClimDiv data, which contains all of the poorly sited USHCN stations, in addition to thousands of other stations that likely have the same set of station siting problems. NOAA / NCDC claims they then "adjust" the *n*ClimDiv data to closely match the data from the USCRN. This "Band-Aid" approach does little to address problems that have been identified, and instead creates a dataset rife with multitudes of adjustments that may or may not fairly represent long-term temperature trends. Moreover, this approach does not address problems with individual station records, such as heat sink effects and biased temperature readings.

Furthermore, adjusting the *n*ClimDiv data to closely match the data from the USCRN only affects 17 years of data, failing to address any data produced before USCRN became operational in 2005. This means all of the temperature data showing climate warming in the 20th century was not adjusted in the same manner as data gathered after 2005, creating a disjointed U.S. climate dataset.

Ironically, monthly data from the USCRN in Figure 14 show significantly oscillating temperature changes, with little to indicate a warming trend from 2005 to 2022. In fact, the graphic clearly shows the United States to be cooler in May 2022 compared to January 2005.[43]

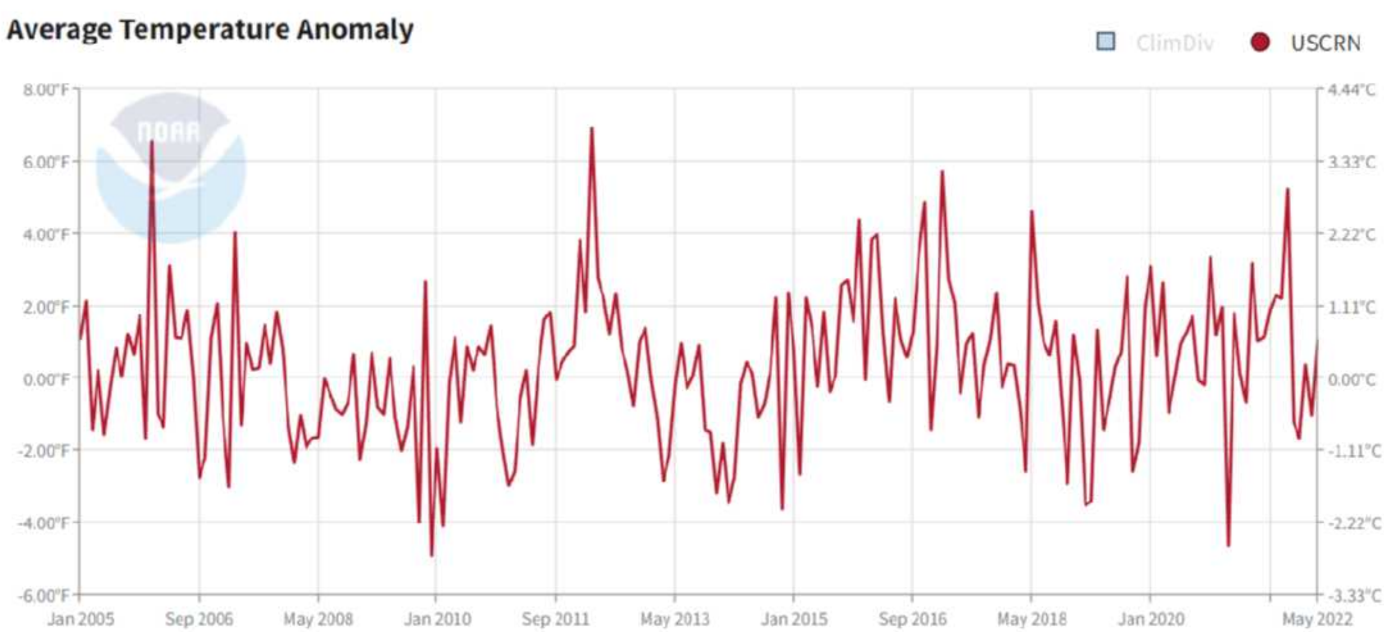


Figure 14: Screen capture of USCRN monthly average temperature data. Source: NCDC / NOAA.

Given that NOAA / NCEI is eschewing the high-quality unadjusted data from USCRN in favor of the adjusted and biased *n*ClimDiv data, the need for a new Surface Stations survey emerged.

THE 2022 SURFACE STATIONS SURVEY

The introduction of the new *n*ClimDiv methodology necessitated a reevaluation of stations used to collect temperature data in the United States. With thousands of new stations added to the network, it is important to determine whether the GHCN stations—now constituting the vast majority of the network—suffer from the same problems that have historically plagued the USHCN.

Project Goals

1. Photographically review as many of the USHCN stations cited in the original 2009 survey as possible.
2. Note differences between 2009 and 2022 with emphasis on closures, moves, and equipment changes.
3. Determine if station ratings have changed due to additional encroachments or station moves.
4. Expand the photographic survey to look at GHCN stations where possible to determine if GHCN stations have the same type of problems that plagued the USHCN.
5. Note the most egregious station siting violations, and bring those to the attention of the NWS manager in charge.
6. Publish the photographic survey for USHCN before and after, plus new GHCN stations.
7. Examine station continuity data for the entire GHCN network to determine how much change has occurred over time.
8. Establish conclusions from the new survey.
9. Make recommendations for the future.

Survey Methods

Like the 2009 Surface Stations project, the 2022 Surface Stations survey uses photographic documentation combined with GPS and Google Earth Pro location assistance. Anthony Watts and a team of volunteers conducted all in-person site visits, following the process below:

1. Determine station type (USHCN or GHCN) from the NOAA HOMR Station Database.
2. Determine if station has been moved or closed from NOAA HOMR Station Database remarks section.
3. If open, determine station GPS location coordinates from the NOAA HOMR Station Database.
4. Extract GPS coordinates from NOAA HOMR Station Database, insert into Google Earth Pro for location and driving directions.
5. Note if the station location has any likely restrictions, such as fences or gates.
6. Avoid surveying stations on private property unless they are visible from a public street.
7. Drive to station, photograph from four compass points if possible, plus one or two overall photographs to determine the character of the site.
8. Make observations and note anything out of the ordinary.
9. Submit photographs by e-mail to report author.
10. Author to compare station photographs and Google Earth measurements to NOAA/NWS official publication on station placement, NWSI 10-1302, dated April 20, 2018.[44]
11. Author to determine if the station complies with published NOAA standards.

Figure 15 illustrates the station siting compliance standards from NWSI 10-302.

NWSI 10-1302 APRIL 20, 2018

3.1 Air Temperature Measurement

Install the temperature instrument according to the following standards:

1. Over level terrain (earth or sod) typical of the area around the station, and, at least 100 feet from any extensive concrete or paved surface.

Figure 15: Screen capture of section 3.1.1 of NOAA / NWS publication 10-1302, "REQUIREMENTS AND STANDARDS FOR NWS CLIMATE OBSERVATIONS," citing 100 feet of separation between the temperature sensor and concrete of paved surfaces. Source: NOAA / NWS.

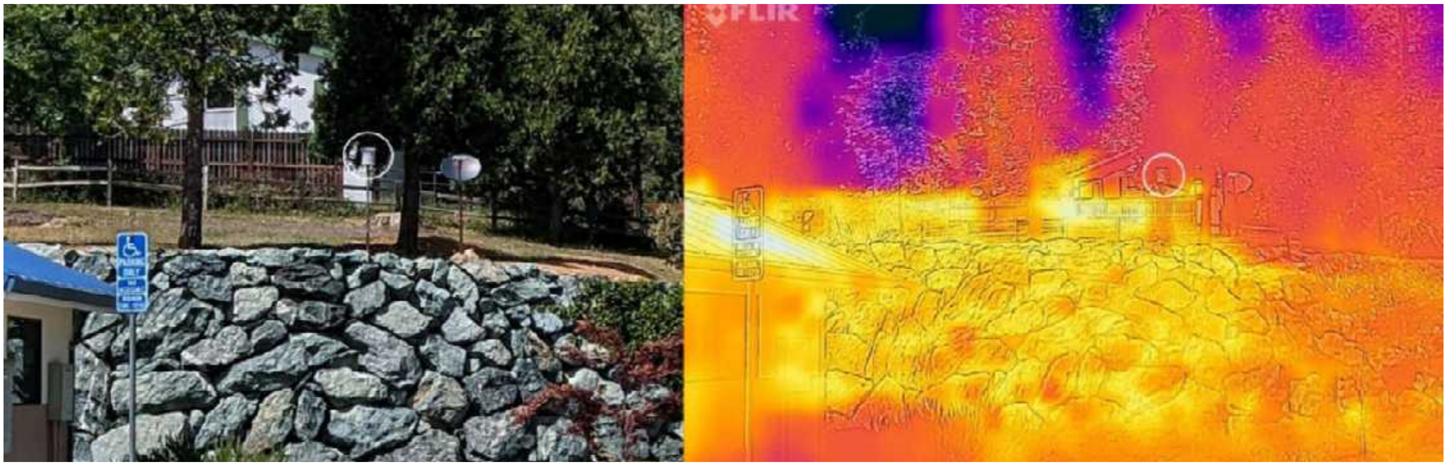
2022 SURFACE STATIONS SURVEY: EXAMPLES OF SITING ISSUES, GOOD AND BAD

This section presents photographic examples of USHCN and GHCN station siting. The majority of stations are not in compliance with NWS publication 10-1302, but examples of those in compliance are also given. Station locations, observed issues, and explanations are given in the image captions.

Visible and infrared photos of MMTS placement near roof and large parking lot at Woodland, CA, GHCN Station at the Yolo County Office of Weights and Measures. Source: Anthony Watts.

Visible and infrared photos of MMTS placement near sunlit wall and large parking lot at Arco, ID, GHCN Station. Source: Anthony Watts.

MMTS placement in COOP observer's yard next to an ODOT maintenance facility in Basque, OR. Note the very large asphalt parking lot in the aerial photo and the yellow marker indicating the MMTS placement. Basque is an isolated small town, with the next town 30 miles away. It would be categorized as exceptionally rural, yet the GHCN thermometer is placed directly next to the largest heat sink. Source: Anthony Watts, Google Earth.



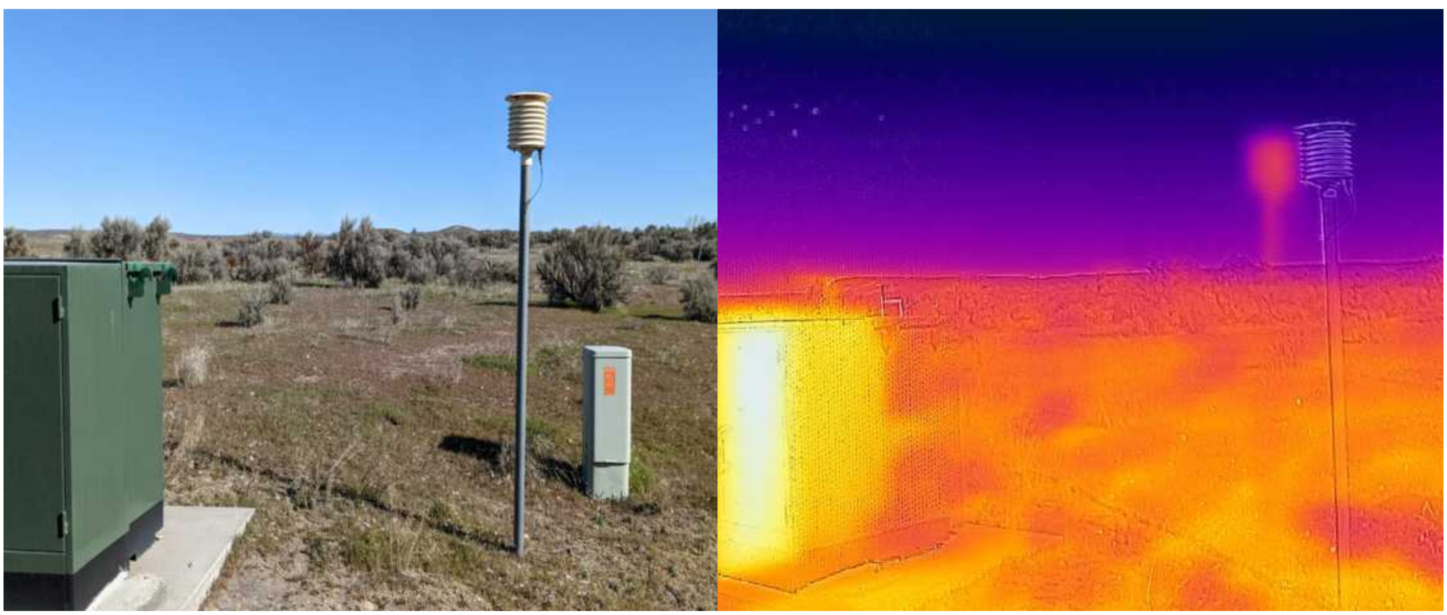
Visible and infrared MMTS placement near large sunlit rock wall and large parking lot at Colfax, CA, USHCN Station. MMTS temperature sensor is circled in both photos. The previous placement was in a grass field before the fire station was renovated. Source: Anthony Watts.

Visible and infrared photos of MMTS placement near large sunlit wall and electric power generation plant at Dillon, MT, USHCN Station at Western Montana University. Source: Anthony Watts.

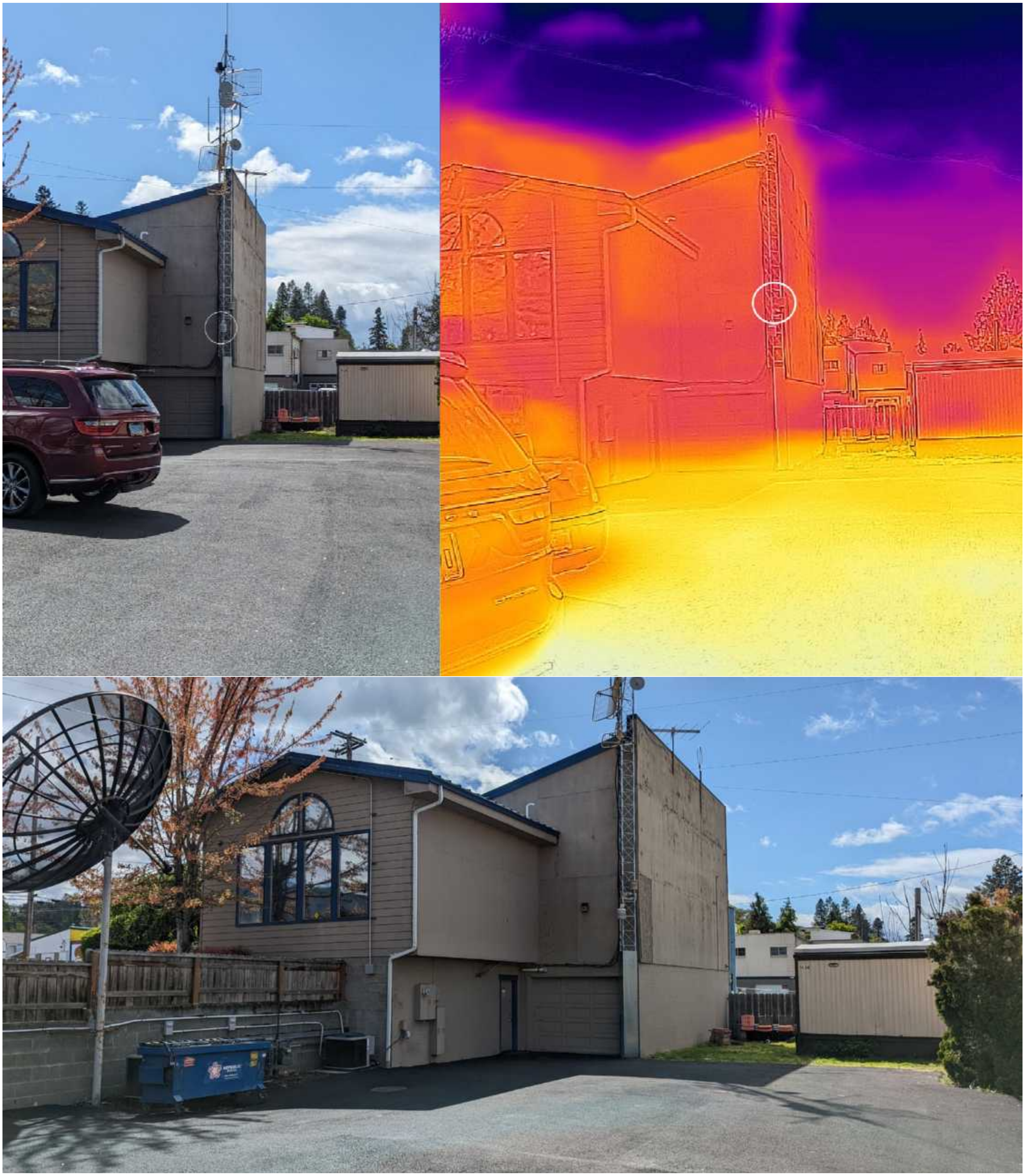
MMTS and CRS placement in a large grass field at USDA Agricultural Research Farm in Dubois, ID. This station is properly sited, and is one of two Class 1 rated stations located in the 2022 survey. Source: Anthony Watts.

CRS placement at rear of Cooperative Observer's residence at Elkton, ID. Note the deterioration of the CRS, including rot, mold, and peeling paint. Observations are still taken daily here. Source: Anthony Watts.

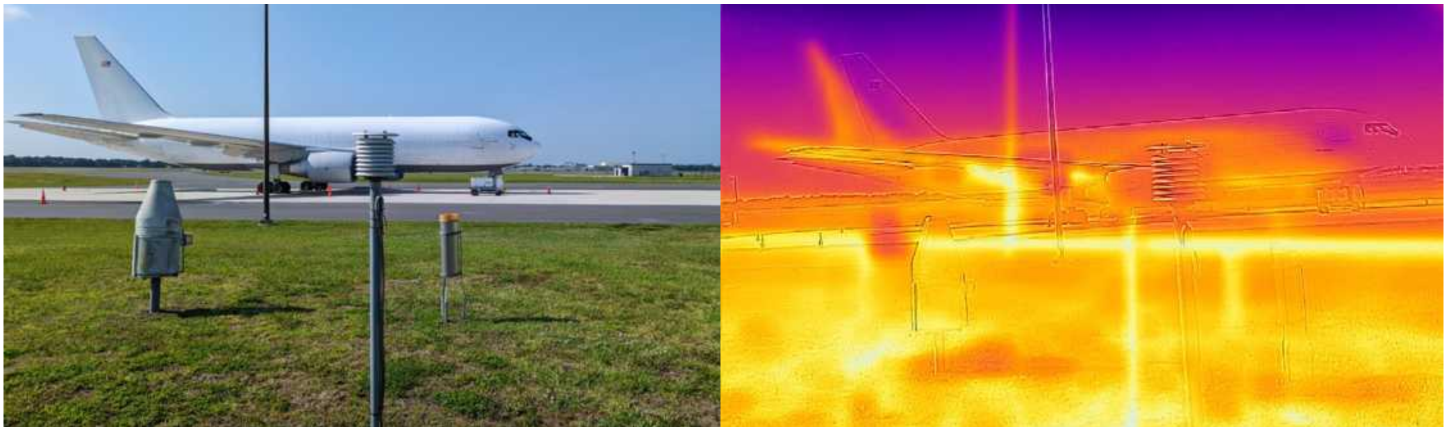
MMTS placement near a building and five air conditioner units at a WWTP, a GHCN station in Fort Pierce, FL. The a/c units produce waste heat, which can easily bias the sensor warmer. Source: Tim Benson.



MMTS placement near a ground mounted power transformer at USHCN station in Glens Ferry, OR. This station was surveyed as part of the original 2009 report and was identified as being biased, but has not been corrected as of 2022. Source: Anthony Watts.



Visible and infrared photo of MMTS placement on tower above a parking lot at Grants Pass, OR, USHCN station. In the bottom photo, air conditioner units that produce warm exhaust that rises can be seen. This is a Class 5 station, wholly unsuitable for climate measurements, and likely the worst station in the entire 2022 survey. Source: Anthony Watts.



Visible and infrared photos of MMTS placement near airport ramp tarmac at GHCN station in Lakeland, FL. Source: Anthony Watts.

MMTS placement at Lava Hot Springs, ID, GHCN station. This is a tourist attraction where the MMTS sensor was placed into a natural hole in the ground where hot water for bathing and swimming emanates from the natural depression in the ground. In addition, the MMTS is next to a parking lot, a stone wall, and a sidewalk, all of which are heat sinks. The nearby electrical panel may generate heat. Because the MMTS is below average ground level in the natural depression, it is also wind-sheltered, which prevents atmospheric mixing and thus will not be representative of temperatures in the nearby landscape. Source: Anthony Watts.

This is the official USHCN station for New Orleans, LA, located at Audubon Park. The NWS is quite proud of it, displaying placards on station history and stylish iron fencing complete with the fleur-de-lis designs to help it blend into the architecture of the region. However, the NWS poured a concrete slab directly under the MMTS, and the station is just feet away from an industrial facility. Source: Linnea Lueken.

MMTS at a WWTP in Ocala, FL, a USHCN station. The station siting is reasonably good, likely a Class 2 station, but is marred by the lack of maintenance of the MMTS, as seen in the close-up. Mold growing on the MMTS darkens it, absorbing more sunlight, making it warmer. Source: Anthony Watts.

USHCN station at Paso Robles, CA, on Paso Robles Boulevard. Note it is located between U.S. Route 101 and is directly over a concrete slab. This is a Class 5 station that is saturated with heat sinks. Source: Dacre Bush / Google Earth Street View.

GHCN station at the rear of the Pocatello, ID, National Weather Service Forecast Office. Note the bank of a/c units on the right, the MMTS (circled in red) and the airport tarmac in the background. Source: Anthony Watts.

Visible and infrared photos of GHCN station located at the FBO office at Punta Gorda Airport, FL. The station is surrounded by heat sinks. Source: Anthony Watts.

Visible and infrared photos of MMTS placement of GHCN station for Shoshone, ID, next to a junk yard at the city maintenance facility. The station is surrounded by heat sinks. Source: Anthony Watts.

MMTS placement at USHCN station in Spanish Fork, UT. Note the a/c unit and the power substation. Also note the proximity of the roof, due to the thermometer’s elevation. The location is at a power generation facility. Source: Steve Randle and Ron Broadaway.

MMTS placement at the airport fire station in Tallahassee, FL, a GHCN station. Note the proximity of multiple heat sources and sinks. Source: Anthony Watts.

USHCN station at WWTP in Tifton, GA. Note the MMTS is directly over a sidewalk, near a brick wall, and near a/c units. This is a Class 5 station. Note in the second photo the discoloration of the MMTS, making it darker, prone to absorb more sunlight, and subsequently warmer. Source: Alan Watt.

Visible and infrared photos of USHCN station in Troy, AL, at a radio station parking lot. Multiple heat sinks and sources are visible within feet of the sensor, including a/c units, asphalt, and concrete. The MMTS is mounted on top of a brick retaining wall. Previously, it was placed in the grass near the satellite dish. Source: Anthony Watts.

MMTS placement at the Storey County Volunteer Fire Department in Virginia City, NV. This is a GHCN station with records dating back to 1887. Note in the close-up photo, the top solar shield cap of the MMTS is missing. Multiple heat sinks are in proximity to the sensor, including asphalt, concrete, a barbecue grill, two a/c units, a generator, and multiple structures providing wind sheltering. Source: Anthony Watts.

MMTS placement at the Auburn, CA, post office, a GHCN station. Note the multiple heat sinks near the sensor, which is surrounded by asphalt, concrete, and brick buildings. Source: Anthony Watts.

MMTS and CRS, at a GHCN station in the Paris, TX, city maintenance yard. Heat sinks surround this station. Source: H. Sterling Burnett.

USHCN Station at Sandpoint, ID, showing the original location in a grassy area, at the Agricultural Experiment Station, and then after, where the MMTS has been placed in the parking lot of the Sandpoint airport. The Agricultural Experiment Station was closed, and to get a continuity of temperature readings, the NWS relocated the MMTS to the office of Granite Aviation, which provides daily readings. The new location is only feet from automobile radiators, and entirely surrounded by asphalt due to the parking lot and the airport tarmac. It is a prime example of the NWS preferring a continuity of the record over the quality of the record. Source: Google Earth and Jim Lynch.

2022 SURFACE STATIONS SURVEY RESULTS AND FINDINGS

In April and May of 2022, a total of 128 stations were surveyed throughout the contiguous United States. Of those, 80 were USHCN stations, most of which were in the original 2009 report. A total of 528 photographs were taken.[iv] To acquire a sample for the new *n*ClimDiv dataset, 48 GHCN sites were surveyed, with 298 photographs taken. The overall sample is broadly representative of the entire network, as it samples stations in the majority of states. Regional samples comprising many nearby stations were done in the western and southeastern United States, focusing on Alabama, California, Florida, Georgia, Idaho, Montana, Nevada, Oregon, and South Carolina.

- The 2009 report found 89 percent of stations were unacceptable by NOAA's own standards. The 2022 report found an even greater percentage of stations—approximately 96 percent—are sited unacceptably. The official U.S. temperature record, which was shown in 2009 to be heat-biased due to poor siting issues, appears to be even more biased in 2022.
- Of the 128 stations surveyed, only two were found to be a Class 1 (best-sited) station: the Dubois, Idaho Agricultural Experiment Farm, and the St. Joseph, Louisiana Agricultural Experiment Farm.
- Three stations were found to be Class 2 (acceptably sited).
- The remaining 123 stations were found to be Class 3, 4, and 5, and therefore considered unacceptably sited in accordance with Leroy's classification system and NOAA publication 10-1302.
- The 7 percent increase in unacceptably sited stations from 2009 to 2022 seems to be in line with the Gallo and Xian study noting the increase in ISAs near USHCN stations.
- Based on the sample, it appears that waste-water treatment plants (WWTP) comprise approximately 25-30 percent of the entire COOP network. It is difficult to get an accurate count because NOAA / NWS does not discern between WWTPs and other stations in the HOMR database. WWTPs are a poor place to measure data to detect climate change because they grow with population, and the industrial processes they perform (sewage digestion) generate substantial amounts of heat, creating a heat sink effect.
- In some interviews with observers, it became clear NOAA / NWS personnel are aware their station siting does not adhere to NOAA standards, but they do not have the means or the time to take corrective action. A prime example is a Class 5 USHCN station in a radio station parking lot in Grants Pass, Oregon, where the radio station engineer recognized the problem, but the local NWSFO refused to address it—even after multiple requests to relocate the MMTS sensor.
- Based on the 2022 survey sample, it appears that record continuity has been given more importance than accuracy. Even though many stations' sensor locations clearly violate standards, they were placed in sub-optimal locations regardless.
- The majority of USHCN stations that were closed since the 2009 report were stations that received wide publicity for their unacceptable siting. Other equally poor stations that did not receive a similar amount of publicity remain open. For example, compare Tucson, Arizona and Troy, Alabama. This suggests that closures by NOAA / NWS were not done for the purposes of data quality, but rather to save face in the court of public opinion.
- In three stations surveyed (Calhoun, Louisiana; Roseburg, Oregon; and Thompson, Utah) there was a conversion of the wired MMTS sensor to a solar powered wireless reporting sensor. This allowed for placement away from heat sinks in the area, but the solar panel placement directly under the sensor likely negated the value of the siting improvement. Solar panels can reach temperatures of 149°F during the summer, and the heat from them rises to the sensor.[45]

[iv] Before and after results comparing USHCN stations from 2009 to 2022 are provided in Appendix A.

- Several examples of station siting that could be categorized as "absurd" were noted during the survey. These include a GHCN station at Lava Hot Springs, Idaho—a tourist site at which the MMTS sensor was placed into a natural hole in the ground where hot water for bathing and swimming emanates from the ground; a WWTP in Ft. Pierce, Florida—where the MMTS was placed in proximity to a road, a building, and near the warm exhausts of five air conditioning units for WWTP offices; and a station in Virginia City, Nevada—at which the MMTS was not only missing its protective cap, but also placed near asphalt, generators, and air conditioning unit exhausts. Perhaps the most absurd was a USHCN station in Colfax, California, which was recently moved due to a modernization upgrade at the California fire station where it is located. The new station has been placed directly above a 20-foot rock wall that absorbs a massive amount of solar energy during the day, and releases it as LWIR at night, with heated air rising to the sensor.

- Lack of station maintenance was observed throughout the USHCN and GHCN. MMTS sensors were often discolored/yellowed, dirty, and in the case of WWTP placements, often covered in mold. This results in a lower reflectivity albedo and biases temperature readings higher due to increased absorption of sunlight during the day. Some MMTS placements were tilted, allowing solar SW and LWIR to enter the protective slats. For example, the station in Virginia City, Nevada, was missing the top sunshield cap. COOP observers report they have no maintenance schedule for these issues, and that visits from NOAA / NWS personnel can take up to three years.

- Stations using a cotton region shelter often suffered from the greatest non-maintenance issues. Peeling paint, dry rot, missing slats, mold, and other wood deterioration issues were common, such as in Elkton, Oregon.

- Every NWS Forecast Office inspected had a COOP, USHCN, or GHCN station present, and every NWSFO had siting issues that were noncompliant with NWS publication 10-1302. In many cases, MMTS and CRS thermometer shelters were in proximity to concrete and exhaust from air conditioning units. This is likely due to limited real estate and a common theme design for NWSFOs. Pocatello, Idaho and Oxnard, California are prime examples of poor siting at NWS offices. Based on our sampling, the issue likely exists at every NWSFO in the United States.

- The majority of the USHCN and GHCN station networks still use manual recording and transcription to report temperature and rainfall data. Observers must write down these values daily, and then transcribe them onto B91 forms for mailing to NCDC / NCEI in Asheville, North Carolina, which are then manually transcribed into the record. This provides significant potential for human error in the data entry process. Similarly, stations that are set up for reporting data by telephone or web page still must transcribe data from paper to the WxCoder system used by NOAA / NWS.[46]

- Similarly, though stations have thermometers capable of reading to the nearest tenth of a degree Fahrenheit, data are manually rounded by the observer before transcription. This adds potential rounding errors in addition to the potential transcription errors; in the case of reporting record highs or record lows at a station, this may create an inaccurate new record. Oddly, rainfall values at all COOP stations are reported to the nearest tenth of an inch, whereas temperature is reported to the nearest whole degree.

- NOAA / NCDC / NCEI reports that error correction processes exist for data reported by COOP observers, and that process will catch some but not all transcription errors. For example, a daytime high temperature recorded as 78 degrees might be transposed as 87 degrees during data entry. That error would likely be caught and corrected, provided there were no similar high temperatures in the area. However, a smaller transcription error such as 79 degrees instead of 78 degrees may not be caught, because the computer algorithm checking for such errors would deem it plausible.

- The COOP Network is almost entirely volunteer-operated. The exception is stations placed at airports with Automatic Surface Observing Systems (ASOS) operated by the Federal Aviation Administration, as well as the few MMTS stations that have been converted to wireless operations. There is very little oversight by NOAA / NWS, and the data are entirely dependent on the skill of the volunteer observers.

- There does not appear to be a central authority that oversees any station in the COOP network. Rather, it seems to be an ad hoc collection of competing interests where no central authority exists to determine if the station is properly placed, and producing accurate data. All data quality control appears to be retroactive. While NOAA / NWS are responsible for placement, they clearly do not adhere to their own public standards. This may be due to landowners having the final say on placement for aesthetic or operational reasons. The prime user of the data, NOAA / NCDC / NCEI, has no input into placement and no way to apply quality control to the data before they are recorded.
- Because of the human element in the data collection process, gaps exist in the data due to illness, weekends, vacation time, and holidays. When gaps exist in data, NOAA / NCDC / NCEI try to fill them by interpolating from other nearby station data, creating "data" where none exists. Given approximately 96 percent of stations in the COOP network have siting problems producing a warming bias, such data interpolation nearly guarantees that any well-sited station with data gaps will have those gaps infilled with biased warmer data from surrounding stations.
- Section 515 of Public Law 106-554, known as the Information Quality Act, provides guidelines for the reliability and accuracy of data produced by government agencies.[47] NOAA has acknowledged the IQA, asserting that it "creates and disseminates reliable assessments and predictions of weather, climate, the space environment…[and] works to ensure access to sustained, reliable observations from satellites to ships to radars to data buoys."[48] Yet, given that 96 percent of data generated by the COOP Network appears to be compromised, and because it has been demonstrated by Watts *et al.* that unperturbed stations do not show the same level of warming as stations not in compliance, it is clear that NOAA is producing data that is not in compliance with IQA.

CONCLUSIONS AND RECOMMENDATIONS

The findings of both the 2009 and the 2022 Surface Stations studies clearly demonstrate the COOP network's temperature records—at both USCHN and GHCN stations—have been substantially corrupted. After surveying a comprehensive and representative sample of stations, 96 percent were found to be biased in some way by the heat sink effect, or other heat sources.

Claims by NOAA, NCDC, and NCEI that this data contamination can be statistically adjusted are disingenuous, especially considering the widescale homogenization of good and bad data. Good data exists in the unperturbed stations demonstrated by Watts *et al.* in 2015, but the amount of bad data from poorly sited stations overwhelms the accurate data from well-sited stations.

It is important to note Watts and his fellow authors found a slight warming trend when examining temperature data from unperturbed stations, which cleaved closely to the findings of the University of Alabama-Huntsville's satellite-derived temperature record.[49] This warming trend, however, is approximately half the claimed rate of increase promoted by many in the climate science community.

USCRN was created for the purpose of accurately measuring climatic temperature trends, yet is not being utilized as such. While the state-of-the-art and professionally operated network has only 17 years of data, it represents an uncontaminated climatic record, and should therefore be given preeminence in official reports. The currently utilized *n*ClimDiv data, however, has been adjusted to USCRN data post-2005, but contains no adjustments prior to 2005. This may very well be why warming trends are present in the *n*ClimDiv data. Despite NOAA's assertions to the contrary, climatic temperature increases as measured by *n*ClimDiv cannot be effectively isolated from potential confounds such as heat sinks, urbanization, WWTPs, population growth, and other factors.

In conclusion, the rate of warming as measured by unperturbed surface stations, USCRN, and UAH does not represent a climate crisis.

Based on the project's findings, the following recommendations are suggested:

1. NOAA / NWS has not fully implemented the recommendations of the OIG and GAO reports on the state of the USCHN. They should do so and apply those recommendations to the entire COOP network.
2. NOAA / NWS should immediately cease temperature data collection operations at waste-water treatment plants. These facilities have grown significantly in size and treatment volume over the past century as the U.S. population has grown, adding large heat sink capacity as well as waste heat of sewage digestion to the long-term temperature record. It is unclear if temperatures measured at these facilities reflects population growth or actual climatic changes in temperature. With thousands of reporting stations in the contiguous United States, there is a broad oversampling of temperature and the loss of these stations will not compromise data integrity, but likely improve it by removing stations with century-scale positive biases.
3. A central authority, rather than the ad hoc collection of competing interests, should be created to evaluate stations and determine if they adhere to standards and produce suitable data. The authority should have the power to upgrade or close stations that cannot be brought into compliance.
4. NOAA / NWS should work to modernize the COOP network. NOAA / NWS still inputs most data collection manually with volunteer observers performing data transcription, much like when the network was launched in 1890. Wireless weather station technology—already demonstrated to be effective—will allow placement of stations away from heat sinks and sources, remove data transcription errors, and avoid data gaps.
5. NOAA / NWS should secure funding to continue the modernization program (USHCN-M) that was successfully tested in 2008, but closed for lack of funding. Science has clearly called for a modern climate observing program.[50] Yet, data collection methods by NOAA / NWS remain rooted in manual processes first started in 1890, when the COOP network for formed by the U.S. Weather Bureau.
6. NOAA / NWS / NCEI should make a concerted effort to locate the best, unperturbed Class 1 and 2 stations in the USHCN and GHCN, and classify them as the "gold standard" for long-term climate reporting. Temperatures measured at "gold standard" stations should be reported monthly in *State of the Climate* reports issued by NOAA so the public can see the differences in blended temperature readings from the most well-sited stations.
7. Alternatively, USHCN / GHCN stations should be discontinued altogether for U.S. climate monitoring, and be replaced by the state-of-the-art USCRN stations for determination of climate trends moving forward.
8. NOAA / NWS / NCEI should start reporting the temperature results of the USCRN in monthly and yearly *State of the Climate* reports issued by NOAA. The USCRN provides the most accurate surface temperature record in the United States by design. However, the media and public are not privy to the data it provides, nor are many aware of its existence.

APPENDIX A: BEFORE (2009) AND AFTER (2022) SITE PHOTOS

This appendix contains before and after photos from the original Surface Stations publication in 2009 compared to photos taken for the 2022 publication. In those cases where site access was unattainable, Google Earth satellite and street view imagery is relied upon. Many of these NOAA / NWS weather stations are now inaccessible due to their status as government facilities.

In addition to the photos and descriptions, an estimate of site quality is provided. A rating of CRN5 represents the “worst” sites, with CRN1 representing the “best” sites. Ratings of CRN1 and CRN2 are considered to be acceptably sited; CRN3, CRN4, and CRN5 are not. According to the published standards for station siting provided by NOAA / NWS,[51] the vast majority of these USHCN stations have not met these standards in 2009 or 2022.

Note that many of the worst examples of USHCN station siting from 2009 have now been closed. Determination of station closure has been sourced from NOAA’s HOMR database.[52]

Amherst, MA, sited on gravel bed near driveway at WWTP. RATING = CRN4

No change. RATING = CRN4

Ardmore, OK, between city hall and sidewalk, main street. RATING = CRN5

2022

CLOSED

Ashland, OR, patch of green, sea of concrete. RATING = CRN5

Moved, converted to MMTS, better siting. RATING = CRN4

Atchison, KS, near corner of large stone buildings. RATING = CRN4

Location unchanged, but on 2009-06-01, site was removed from USHCN network and now is COOP "B" network (not climate). RATING = CRN4

Baltimore, MD, sited on red platform on city rooftop. RATING = CRN5

2022

CLOSED

Bartow, FL, nearby building, road, parking lot. RATING = CRN5

2022

CLOSED

(Moved to private residence, unable to survey new location)

Blacksburg, VA, at NWSO, nearby concrete platforms, satellite dish. RATING = CRN4

No change. RATING = CRN4

Block Island, RI, adjacent to parking lot and aircraft parking area. RATING = CRN4

No change. RATING = CRN4

Brinkley, AR, nearby building with 3 air blowers, dirt mound, raw sewage at WWTP. RATING = CRN3

No change. RATING = CRN3

Brookville, IN, nearby driveway, building. RATING = CRN4

No change. RATING = CRN4

Buffalo Bill Dam, WY, sited on concrete, between two buildings. RATING = CRN5

Moved, converted to MMTS. Next to a asphalt parking lot and vehicle. RATING = CRN5

Bunkie, La, too close to sidewalk and Building at WWTP. RATING = CRN4

No change. RATING = CRN4

Champion, MI, nearby road, parking area, house. RATING = CRN4

2022

CLOSED

Conway, SC, near large asphalt area, building. RATING = CRN4

2022

CLOSED

Cornwall, VT, nearby residence, road approximately 50 feet away. RATING = CRN3

No change. RATING = CRN3

Crosby, N.D, nearby building, patio.
RATING = CRN4

2022

CLOSED

(Private residence, unable to survey new location)

Dayton, WA. Water plant, over cinder.
RATING = CRN5
rock, near vents, buildings.

No change. RATING = CRN5

Detroit Lakes, MN, nearby air-conditioning unit, building, gas tank.
RATING = CRN5

Moved 70 feet west away from building and A/C unit. RATING = CRN2

Dillon, MT, at power plant building, sited on concrete border of sidewalk 6’ from brick wall. RATING = CRN5

No change. RATING = CRN5

Durham, N.H, nearby building, parking lot. RATING = CRN4

Moved to new location, siting similar.
RATING = CRN4

Ennis, MT, nearby building, trailer, assorted junk. RATING = CRN4

2022

MOVED TO ACCOMMODATE CONSTRUCTION

(Unable to survey)

Enosburg Falls, VT, adjacent to driveway, nearby building. RATING = CRN4

2022

CLOSED

Falls Village, CT, nearby building and parking lot. RATING = CRN4

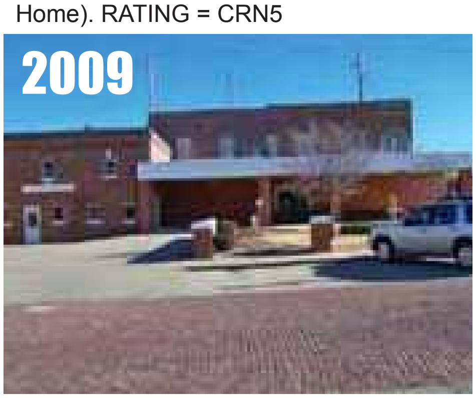
2022

CLOSED

Fort Morgan, CO, huge industrial building, parking lot. RATING = CRN4

Moved, but new station is compromised by addition of mailbox and solar panel. RATING = indeterminate, there is no formula for mailboxes.

Fort Scott, KS, overwhelmed by large paved area, nearby building (Funeral Home). RATING = CRN5



Closed, moved 1.8 miles southeast to an improved location at private residence. RATING = CRN3

Gainesville, GA, between two driveways. RATING = CRN4

No change. RATING = CRN4

Grace, ID, CRS over concrete, industrial nightmare. RATING = CRN5

No change to location, but MMTS added improperly to the roof of the CRS, resulting in warmer temperature. RATING = CRN5

Greenville, TX, nearby building, satellite dish, two air-conditioning units. RATING = CRN4

No change in location, but MMTS is now tilting due to lack of maintenance. RATING = CRN4

Greenwood, DE, sited on concrete platform. RATING = CRN5

2022

CLOSED

Gunnison, CO, nearby parking lot. RATING = CRN4

Location unchanged, but note new two-story construction nearby. RATING = CRN4

Haskell, TX, between road and parking lot, nearby building. RATING = CRN4

Location moved, but now near sidewalk and A/C unit, building. RATING = CRN4

Hay Springs, NE, next to building, narrow sidewalk, telephone pole. RATING = CRN4

2022

CLOSED

Hendersonville, NC, nearby parking lot, satellite dish, building. RATING = CRN5

Location unchanged, but MMTS moved about 15 feet away from parking lot. Improved siting. RATING = CRN4

Heppner, OR, MMTS in a sea of dark crushed rock, at city WWTP. RATING = CRN5

No change in location. Unable to ground survey. RATING = CRN5

Hillsdale, MI, near large paved area at WWTP. RATING = CRN4

No change in location. Unable to ground survey. RATING = CRN4

Hopkinsville, KY, adjacent residence, driveway, accumulated junk, BBQ. RATING = CRN5

Same location, but MMTS moved 126 FEET SW to front yard, for better siting. RATING = CRN4

Hot Springs, SD, partially obscured by foliage. RATING = CRN3

MMTS remains partially obscured by foliage, but new generator has been installed nearby. RATING = CRN3

Kennebec, SD, sited on gravel path, nearby Shed at private residence. RATING = CRN4

Same location, but NWS reports: "moved MMTS 35 feet to the northwest due to bad location." Unable to ground survey. RATING = CRN4

Lampasas, TX, next to sidewalk, near satellite dish, road, parking lot, building. RATING = CRN5

2022

CLOSED

(NWS reports: "DATA AT THIS LOCATION IS NO LONGER REPRESENTATIVE DUE TO CONSTRUCTION AND URBANIZATION.")

Lebanon, MO, nearby radio station building. RATING = CRN4

No change in location. Unable to ground survey. RATING = CRN4

Lenoir, NC, nearby sidewalk, road, building. RATING = CRN4

Location unchanged. RATING = CRN4

Lexington, VA, sewage plant, near building, sidewalks, road, parking lot at WWTP. RATING = CRN4

2022

CLOSED

(Moved to private residence. Unable to ground survey.)

Logan, IA, nearby building, concrete slabs. RATING = CRN4

2022

CLOSED

Lovelock, NV, nearby residence, U-Haul unit. RATING = CRN4

Closed, then moved to an industrial area, worse location. RATING = CRN5

Marengo, IL, nearby buildings, parking lot at WWTP. RATING = CRN4

2022

CLOSED

Miami, AZ, sited on dark gravel, next to building. RATING = CRN5

2022

CLOSED

Midland, MI, next to concrete and a vent at WWTP. RATING = CRN5

Same location at WWTP, but moved and converted to MMTS. Slightly better siting compared to original location. RATING = CRN4

Milwaukee, WI, nearby road. RATING = CRN4

2022

CLOSED

Mohonk Lake, NY, much too close to ground, shading issues, nearby building, chimney. RATING = CRN4

2022

UNCERTAIN FATE

(NWS reports: REMOVING TEMPERATURE, 24-HOUR PRECIPITATION, AND SNOW ELEMENTS TEMPORARILY DUE TO NON-NWS EQUIPMENT BEING USED. OBSERVER UNABLE TO USE OFFICIAL NWS EQUIPMENT TO REPORT TEMPERATURE AND MANUAL PRECIPITATION/SNOW DATA.)

Monticello, MS, between two buildings, nearby sidewalk. RATING = CRN4

Moved to new location at city offices on lawn. Improved location, but still too close to buildings. RATING = CRN3

Morrison, IL, sited on concrete, between open wastewater tanks at WWTP. RATING = CRN5

Same location at city WWTP, but moved away from tanks when converted to MMTS. RATING = CRN3

Mount Vernon, IN, nearby road, building, ironwork. RATING = CRN4

Location unchanged, but ironwork has been removed and replaced by chain-link fence. RATING = CRN4

Napoleon, OH, over concrete, near wastewater Tank at WWTP. RATING = CRN5

2022

CLOSED

Neosho, MO, nearby driveway and house. RATING = CRN4

Moved MMTS. NWS reports: SOMETIME IN THE SUMMER OF 2010 THE SRG AND MMTS WERE MOVED 556 FT TO THE NE, CLOSER TO THE NEW VISITOR CENTER. Siting is slightly better at new location. RATING = CRN3

Northfield, VT, nearby driveway, building. RATING = CRN4

2022

CLOSED

Okemah, OK, sited on edge of driveway, nearby street. RATING = CRN4

2022

CLOSED

Orangeburg, SC, nearby metal coverings, parking lot, building at WWTP. RATING = CRN4

Uncertain. Surveyor in 2022 reports that readings are coming from non-standard weather station (shown) but NWS reports in HOMR that official NOAA MMTS is being used. RATING = CRN4

Orono, ME, sited on roof of powerplant building with parking lot. RATING = CRN5

2022

CLOSED

Panguitch, UT, former location (screen removed) on concrete, by parking lot. RATING = CRN5

Station closed, moved to private residence. Siting is better than a parking lot, but has issues with shading and irrigation. RATING = CRN4

Paris, IL, adjacent brickwork and rooftop at city waterworks. RATING = CRN4

MMTS was moved to a somewhat better location at city WWTP. NWS reports: "RELOCATED STATION 2 MILES SOUTHEAST OF PREVIOUS SITE, TO THE PARIS SEWAGE TREATMENT PLANT." RATING = CRN3

Paso Robles, CA, sited on concrete slab next to sidewalk, nearby road, interstate. RATING = CRN5

Location unchanged, but wooden slat/chain-link fence to the north has been removed. RATING = CRN5

Pocahontas, AR, fairly well sited. RATING = CRN2

Updated to MMTS and moved to a new location, now closer to buildings and more wind sheltered than before. RATING = CRN4

Racine, WI, between building and road. RATING = CRN4

No change. RATING = CRN4

Red Cloud, NE, on premises of city power plant. Nearby brick wall, structures. RATING = CRN4

Same location, but MMTS moved in 2010, improved siting. NWS reports on HOMR: “MMTS RELOCATED 282 FT SW”. RATING = CRN3

Richardton Abbey, ND, at edge of sidewalk, nearby road, building. RATING = CRN5

No change. RATING = CRN5

Rock Rapids, IA, nearby building, sidewalk, driveway. RATING = CRN4

No change. RATING = CRN4

Salisbury, MD, nearby building, air-conditioning unit. RATING = CRN4

2022

CLOSED

Sandpoint, ID, heavy gravel base, near road. RATING = CRN4

MMTS was relocated to even worse site 0.31 miles away to the airport parking lot, sandwiched between airport tarmac and airport parking. Note vehicle radiator is directly under the sensor.
RATING = CRN5

Santa Rosa, NM, exposed cabling, nearby metal boats, burn barrel, junk. RATING = CRN4

2022

CLOSED

Searchlight, NV, in Department of Transportation parking lot, heavy equipment. RATING = CRN5

Same location, but CRS updated to MMTS. Still close to building and asphalt parking lot. RATING = CRN4

Spanish Fork, UT, sited on gravel, near concrete wall at power station. RATING = CRN4

No change. RATING = CRN4

Spooner, WI, nearby parking lot and building. RATING = CRN4

Same location, but CRS upgraded to MMTS and moved to front lawn. Better siting, but still only 25' from brick building. RATING = CRN4

St. George, UT, between building and raised parking lot, car radiator level. RATING = CRN5

2022

CLOSED

(Moved to private residence. Unable to ground survey)

St. Joseph, LA, well-sited station. RATING = CRN1

No change. However, CRS is in serious need of maintenance and peeling paint/dirt/missing slats will make it warmer than normal. RATING = CRN1

State College, PA, nearby concrete path, building, construction. RATING = CRN4

No change, but construction has ended. RATING = CRN4

Staunton, VA, at WWTP, between tank wall and paved road. RATING = CRN4

No Change. RATING = CRN4

Thompson, UT, nonstandard equipment, over asphalt, nearby building. RATING = CRN4

Site moved, new wireless MMTS provided. Better location. NWS reports: “SITE MOVED 1.99 MILES EAST SOUTHEAST” RATING = CRN2

Tifton, GA, nearby air-conditioning units, sidewalk, road. RATING = CRN5

No Change. However, MMTS is dirty/ discolored and needs maintenance. RATING = CRN5

Titusville, FL, at city WWTP. Mounted near sewage digester, near air-conditioning unit, generator. RATING = CRN5

Same location at WWTP, but NWS reports: “MMTS MOVED 102 FEET SOUTHEAST.” However, new site on rooftop is just as bad if not worse than original siting. Note exhaust fan nearby. RATING = CRN5

Troy, AL, nearby parking lot, MMTS at rear of satellite dish. RATING = CRN4

Same location, but MMTS was moved to top of brick wall, closer to building and parking lot. Worse siting than original. NWS seems unaware of move, no mention in HOMR. RATING = CRN5

Troy, NY, nearby parking lot, sidewalk, building. RATING = CRN4

No change. RATING = CRN4

Tuckerton, NJ, unshielded sensor attached to building. RATING = CRN5

2022

CLOSED

Tucson, AZ, sited on concrete in a parking lot. RATING = CRN5

2022

CLOSED

Tularosa, NM, at edge of gravel road. RATING = CRN3

2022

CLOSED

Tullahoma, TN, at city WWTP, electrical transformer, cement path. RATING = CRN5

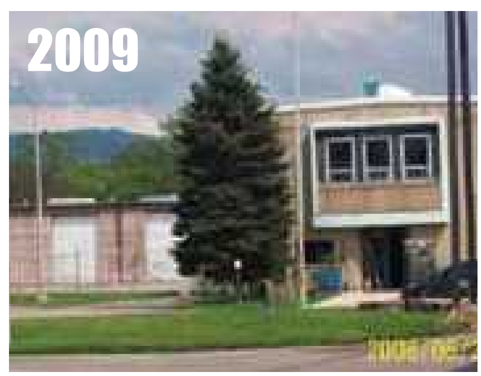
No change. Unable to get access for ground survey. RATING = CRN5

Union Springs, AL, nearby building. RATING = CRN4

2022

CLOSED

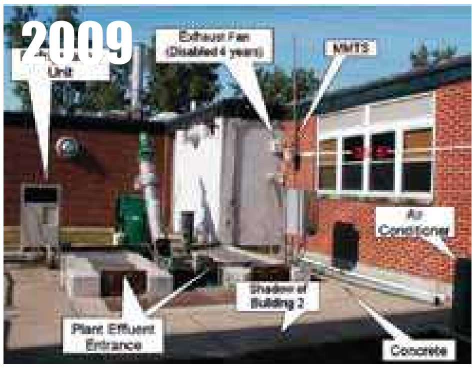
Uniontown, PA, nearby building, road, parking areas. RATING = CRN4



2022

CLOSED

Urbana, OH, at city WWTP, mounted on brick wall, other multiple violations (see labels). RATING = CRN5



Same location at city WWTP, but MMTS moved to a better location over grass in front of office. Better site, but still too close to road and the building. See markers. RATING = CRN4

Vale, OR, next to road, CRS facing wrong direction per NWS standards. RATING = CRN5

2022

CLOSED

Waterville, WA, over cinder rock, adjacent to sidewalk, parking lot. RATING = CRN5

2022

CLOSED

West Point, NY, sited on edge of paved path, nearby stone building. RATING = CRN4

2022

NO CHANGE

(Unable to get access to re-survey)

Wickenburg, AZ, adjacent building, parking lot, accumulated junk. RATING = CRN5

2022

CLOSED

Williamsburg, KY, next to brick building (note the adjacent exhaust vent). RATING = CRN4

2022

CLOSED

Winfield Locks, WV, MMTS is up on the roof. RATING = CRN5

2022

NO CHANGE

Unable to resurvey due to locks/dam now a “restricted area.”
NWS notes in HOMR on 2/6/20: “THIS EQUIPMENT HAS BEEN ON THE ROOFTOP SINCE THE BEGINNING OF SERVICE AT THIS SITE AND HAS NOT BEEN MOVED...”
Siting is in direct violation of NOAA/NWS siting standards.
RATING = CRN5

Winnebago, MN, at city WWTP, nearby sewage tanks, concrete pad. RATING = CRN4

NWS notes in HOMR: “UPDATED DUE TO MAJOR CONSTRUCTION AT WWTP. MOVED EQUIPMENT FROM WWTP BACK TO VERY CLOSE TO ORIGINAL REND 8 LOCATION.” Now located between street and brick building. Siting not improved. RATING = CRN4

Woodville, MS, nearby building. RATING = CRN4

2022

CLOSED

Worland, WY, nearby sidewalk, brick sign mount, gravel at base, outbuilding. RATING = CRN4

No change. RATING = CRN4

Yreka, CA, CRS sited on cinder rock, nearby concrete driveway, parking lot, road. RATING = CRN5

CRS converted to MMTS, but moved next to building, parking lot, sidewalk, and A/C unit. Very slight improvement in siting but could go either way RATING = CRN4/5

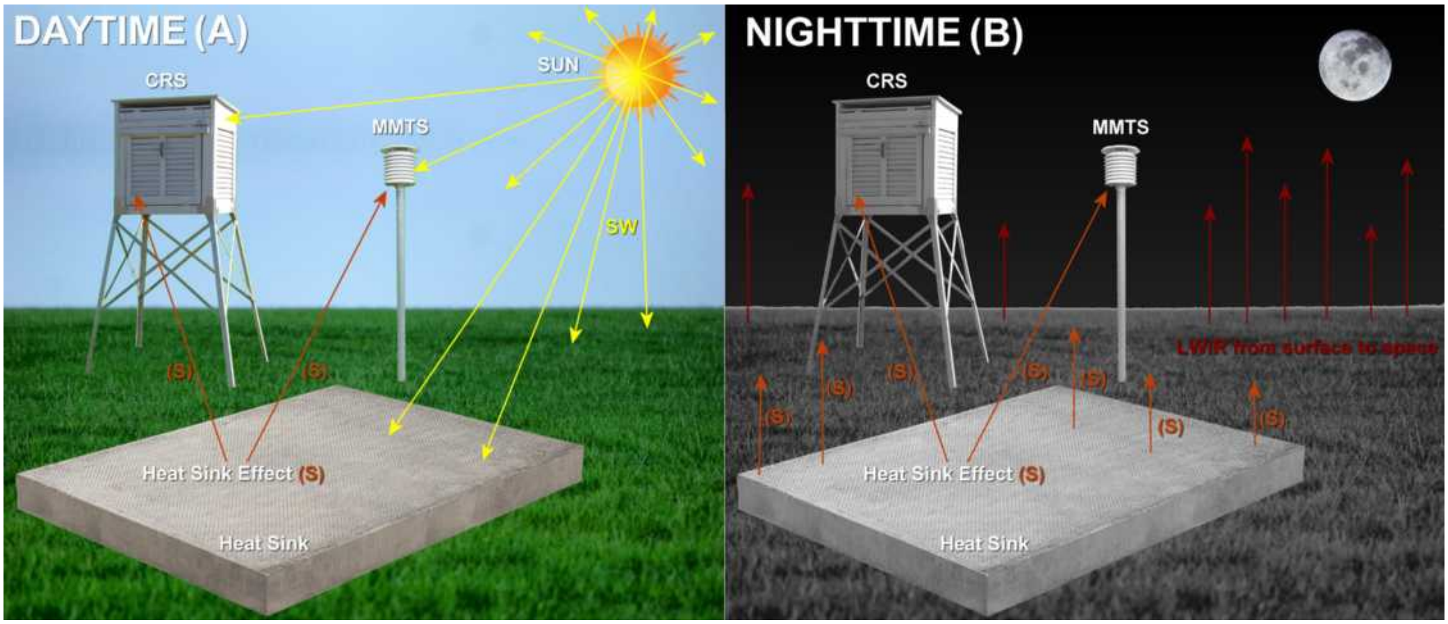
Photo Credits:

Photos in this appendix and in the body of the report have been obtained from a variety of sources, including SurfaceStations.org volunteers, and associates of The Heartland Institute including H. Sterling Burnett, Linnea Lueken, Tim Benson, and Anthony Watts. A special thanks to Doug Lynch who worked with the author for almost a month to locate the mislabeled NOAA USHCN station in Sandpoint, ID.

Some photos are satellite and/or street view images sourced from Google Earth, and are used with their fair use licensing, with the required attributions: Map data ©2022 Google, Street View ©2022 Google. Some imagery provided by Google may not be from 2022, but earlier. Care was taken to be certain earlier photos are still valid in 2022 for the purpose intended.

APPENDIX B: THE SCIENCE OF HEATSINKS AND THERMOMETERS

To provide an understanding of how both distance and surface area affect temperature near a NOAA / NWS thermometer used to measure long-term climate change, Figure 1 illustrates what happens in the environment around the thermometer between daytime and nighttime.



Figures 1A and 1B: During daytime (Figure 1A), visible sunlight known as shortwave light (SW) heats the earth, the NOAA / NWS thermometer shelters (CRS and MMTS), and a nearby concrete slab. A minimal amount of the SW light is redirected from the heat sink effect (S) towards the thermometer. During nighttime (Figure 1B), the accumulated SW light from the sun during the day is radiated from the surface, grass, soil, and the concrete slab as long-wave infrared light (LWIR). The concrete slab has a greater ability to retain SW light energy and emit it at night as LWIR energy, thus making the heatsink effect (S) greater. The closer the concrete slab is to the thermometers, and the greater the surface area of the concrete slab, the greater the heatsink effect. The LWIR energy from the heat sink effect warms the air near the surface locally and biases the nighttime temperature near the thermometers to a higher number than would exist in the absence of a heat sink. Source: Anthony Watts.

The issue with artificial surfaces such as asphalt, brick, and concrete near thermometers has to do with the heat sink effect. During the day, sunlight impacts these surfaces and heats them. According to NASA, the average irradiance value measured on the edge of space and outside the Earth's atmosphere on a flat surface positioned perpendicular to the sun is about 1,360 watts per square meter (or 1.36 kilowatts per m^2).[53] By the time the sun's rays pass through the Earth's atmosphere and reach the surface at sea level, the maximum solar irradiance across a $1m^2$ flat surface at ground level can be measured. At an equatorial location on a clear day around solar noon, the amount of solar radiation that is approximately 1000 watts per square meter (or 1.0 kW/m^2).

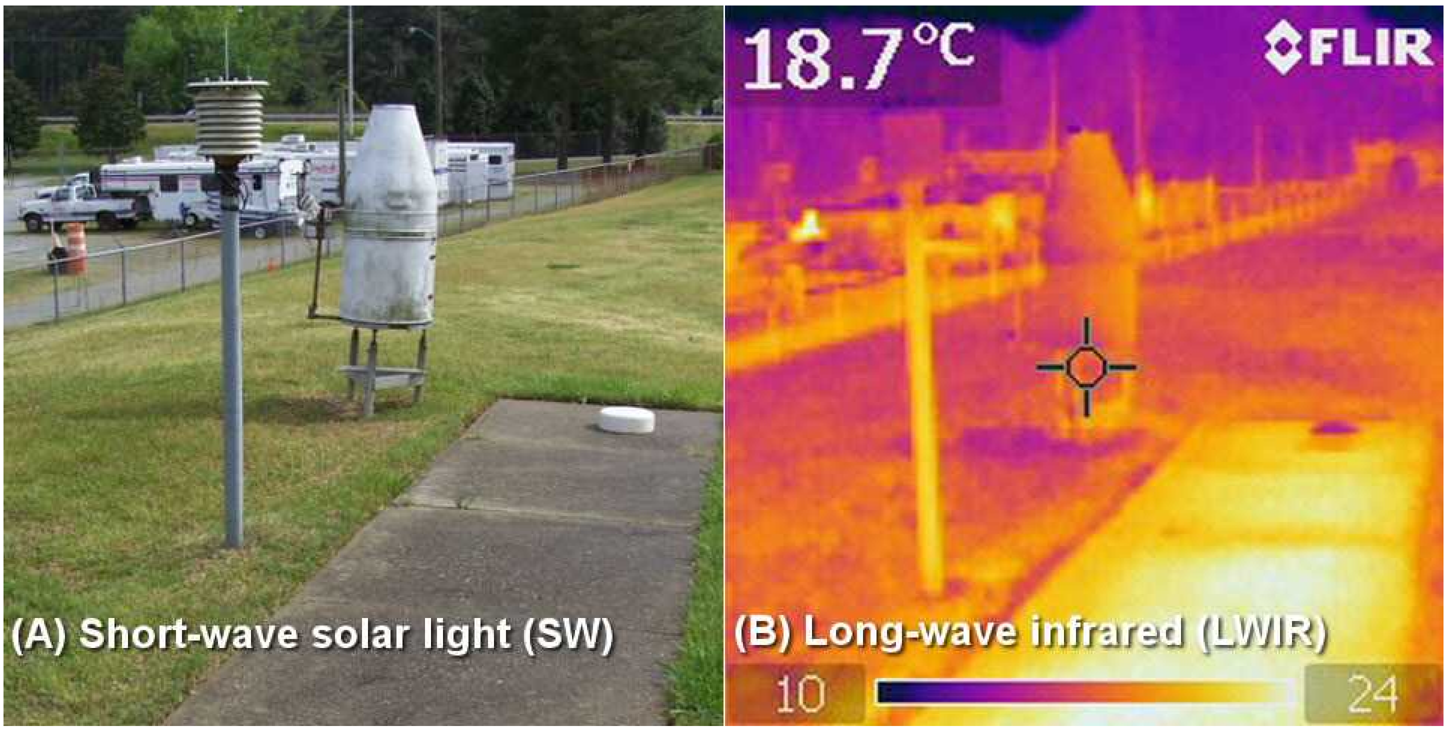
Solar irradiation values will vary by season, latitude, and weather. As an example, if the average solar energy reaching the surface during the summer months is 800 watts per square meter and the weather is clear for a full eight hours, daily solar irradiance would equal:

800 W/m2 x 8 hours = 6400 Watt-hours/m2 or 6.4 kWh/m2 (6.4 kilowatt hours)

6.4 kilowatt-hours are comparable to the amount of electricity an average home might use during a summer daytime hour when air-conditioning is running. As indicated, a section of asphalt, brick, and concrete near an official thermometer will absorb quite a large amount of solar energy during the day. At night, that energy will be released as long-wave infrared light (LWIR).[54]

One can see this process for themselves by simply standing next to a brick or concrete wall—that has been illuminated by the sun during the day—just after sunset. The heat emanating from the wall is LWIR. Alternatively, one can observe LWIR as the "shimmer" effect from a heated road during a hot summer day.

Nightly emissions of LWIR into space are a primary reason for night-time temperatures being cooler, as the Earth sheds its energy absorbed from the sun during the day. Figure 2 illustrates these effects.



Figures 2A and 2B: Figure 2A (left) shows the USHCN station at Fayetteville, NC in visible light (SW - shortwave daytime solar) versus Figure 2B (right), the same station viewed in long-wave infrared (LWIR). Note the concrete slab is significantly warmer. The MMTS temperature sensor on the pole will "sense" the warmer air at night due to the emission of LWIR. Source: Anthony Watts.

In the paper "Determination of temperature differences between asphalt concrete, soil and grass surfaces of the City of Erzurum, Turkey," the authors illustrate via experiment that temperature differences of 7.54 degrees C existed between asphalt/concrete and grass surfaces.[55] That heat-sink experiment clearly demonstrated that significant divergences in air temperature measurement exist across different surface types.

APPENDIX C: GLOSSARY AND ACRONYMS

A/c: Abbreviation for an outside Air Conditioner unit, sometimes called a heat exchanger.

Albedo: Albedo is an expression of the ability of surfaces to reflect sunlight. Light-colored surfaces (high albedo) return a large portion of the sun's rays back to the atmosphere. Dark-colored surfaces (low albedo) absorb the sun's rays and tend to heat up more than lighter colored surfaces.

ASOS: The Automated Surface Observing Systems (ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities. However, due to many of these installations being located at airports, the substantial heat sink volume associated with tarmacs and runways may be upwardly biasing temperature readings, especially with the growth of air travel in recent decades necessitating further airport expansion.

Average Air Temperature: The mathematical average of the daily high and low temperature recorded daily from a USHCN or COOP weather station. Daily average temperatures are amalgamated to create monthly and yearly average temperatures, which are used to track changes in climate temperature over a 30-year period.

COOP: The Cooperative Observer network (COOP) is comprised of thousands of volunteer-operated weather stations in the United States, managed by the National Weather Service (NWS), with data reported to the National Climatic Data Center (NCDC) for dissemination. COOP stations exist at airports, police stations, fire stations, ranger stations, dams/locks, newspaper offices, TV/radio stations, college campuses, National Weather Service offices, agricultural experiment stations, waste-water treatment plants, and in the yards of U.S. citizens.

CRS: A Cotton Region Shelter (CRS)—also known as Stevenson screens or instrument shelters—is used to shield meteorological instruments against precipitation and direct heat radiation from outside sources, while still allowing air to circulate freely around them. A CRS forms part of a standard COOP weather station and typically holds two thermometers (ordinary, plus a maximum/minimum recording thermometer), and sometimes other weather instruments.

Their purpose is to provide a standardized environment for measuring temperature, humidity, dewpoint and other variables. Typically, a CRS is a box made of wood with slats for ventilation and is placed about 5 feet above ground. It is painted white to reflect direct solar radiation. The CRS design is being phased out of use in the COOP network because of maintenance issues with paint, dry rot, and other exposed wood related problems. The MMTS is the replacement for the CRS.

GHCN: The Global Historical Climatology Network (GHCN) is a data set of temperature, precipitation and pressure records managed by the National Climatic Data Center (NCDC). The data are collected from many continuously reporting fixed stations at the Earth's surface. In 2012, there were 25,000 stations within 180 countries and territories, including several thousand as part of the United States COOP network. GHCN stations are intended to report both the total daily precipitation and the maximum and minimum temperature, though stations that measure both are predominantly located in the United States. Overall, 66 percent of GHCN stations report only the daily precipitation and not temperature.

Heat Sink: In the context of this report, a heat sink is a solid surface such as asphalt, brick, or concrete absorbing visible sunlight energy during the day, raising the temperature of the surface. At night, the heat sink surface cools by radiating or releasing that stored energy as infrared heat, warming the air near the heat sink surface.

HOMR: The Historical Observing Metadata Repository (HOMR) is an online database tracking detailed information for a variety of weather stations throughout their lifespans, including identifiers, names, locations, observation times, reporting methods, and equipment modifications and siting. Station histories are most extensive for the National Weather Service COOP network, including officially documented station changes that adhere to an NWS approval process.

HOMR is used in this report to verify equipment placement and station status. HOMR did not exist prior to the original 2009 Surface Stations report. It is possible the 2009 report was the impetus for HOMR's creation in 2013, as the previous database was unwieldy, incomplete, and error-ridden.

Maximum Temperature: Also referred to as "Tmax," maximum temperatures in the context of this report consist of the highest temperature recorded in a 24-hour period at a USHCN or COOP weather station. Typically, this occurs in the afternoon or early evening. Under certain weather events, this may change.

Minimum Temperature: Also referred to as "Tmin," minimum temperatures in the context of this report consist of the lowest temperature recorded in a 24-hour period at a USHCN or COOP weather station. Typically, this occurs in the early morning, just before or a few minutes after sunrise. Under certain weather events, this may change.

MMTS: The Maximum Minimum Temperature System (MMTS) is an electronic thermometer, similar to what one might find at a local electronics store. The MMTS enclosure houses an electronic thermistor. A thermistor converts air temperature values into electrical values, typically by varying electrical resistance. The MMTS shelter appears very similar to a beehive. They require a cable to connect the sensor with a display, which is often located within an indoor office or residence. The display records and stores the maximum and minimum temperatures recorded each day. The internal display is often called the "Nimbus," due to the name given by the manufacturer. Introduction of the MMTS in the COOP network began in the late 1980s and has gradually replaced the CRS system.

NCDC: The National Climatic Data Center (NCDC), previously known as the National Weather Records Center (NWRC), was the world's largest active archive of weather data. Starting as a tabulation unit in New Orleans, Lousiana in 1934, the climate records were transferred to Asheville, North Carolina in 1951, and renamed the National Weather Records Center (NWRC). It was later renamed the NCDC in 1993. In 2015, NCDC merged with the National Geophysical Data Center (NGDC) and the National Oceanic Data Center (NODC) to create the National Centers for Environmental Information (NCEI).

NCEI: The National Centers for Environmental Information (NCEI) is the new name for the NCDC, with the two acronyms often used interchangeably in literature.

nClimDiv: The U.S. Climate Divisional Dataset (*n*ClimDiv) replaced the previous U.S. Historical Climatology Network (USHCN) in March 2014. Compared to USHCN, *n*ClimDiv uses a much larger set of stations—more than 10,000—and a different computational approach to calculate the average temperature of the United States.

NOAA: The National Oceanic and Atmospheric Administration (NOAA) is the scientific and regulatory agency within the United States Department of Commerce that forecasts weather, monitors oceanic and atmospheric conditions, charts the seas, conducts deep-sea exploration, and manages fishing and protection of marine mammals and endangered species in the United States. It has several sub-agencies including the National Weather Service (NWS) and the National Climatic Data Center (NCDC).

NWS: The National Weather Service (NWS) is tasked with providing "weather, hydrologic and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy." This is done through a collection of national and regional centers, 13 river forecast centers (RFCs), and more than 120 local weather service forecast offices (WSFOs).

Temperature Anomaly: Temperature anomalies measure the departure from the average temperature, positive or negative, over a certain period (day, week, month, or year). They use a 30-year average baseline temperature for positive or negative departure. In standard use, the normal average temperature would be calculated over a period of at least 30 years over a homogeneous geographic region, such as the contiguous United States.

USHCN: The U.S. Historical Climatology Network (USHCN), sometimes also referred to as simply "HCN," is a hand-picked collection of 1,218 long-record COOP stations in the United States that were once assumed to be of "high quality." However, the USHCN dataset was discontinued in March 2014 after severe criticism of station siting quality was published by The Heartland Institute, and independent investigations were carried out by the U.S Inspector General and the U.S. General Accounting Office.

USHCN-M: USHCN-M was a failed modernization program of the USHCN. This program was to have installed 1,000 modernized state-of-the-art stations throughout the United States that would have enhanced the capability of the USCRN by providing additional observations of temperature and precipitation of the same quality but with more dense spatial coverage, thus enabling detection of regional climate trends with greater confidence. The program included a few dozen stations as a test in 2008 but was later discontinued due to lack of funding.

USCRN: The U.S. Climate Reference Network (USCRN) consists of 114 stations in the contiguous United States, 29 stations in Alaska, and 2 stations in Hawaii. These stations have been developed, deployed, managed, and maintained by NOAA for the express purpose of detecting climate change.

The vision of the USCRN program is to maintain a sustainable high-quality climate observation network that can decisively answer how the national climate changes over a long periods. The USCRN has state-of-the-art sensors, with triple redundancy to reduce errors. The stations are located far away from human urbanization influences so that the type of issues found in the USHCN and COOP networks do not influence the temperature and precipitation data they record. The data produced by USCRN does not need any of the corrective adjustments that the USHCN and COOP networks necessitate.

WSFO: The Weather Service Forecast Office (WSFO) is comprised of more than 120 local weather service forecast offices in the United States.

WWTP: Waste-Water Treatment Plants (WWTP) house a substantial number of GHCN, USHCN and COOP network stations, as treatment plants are constantly manned and can provide continuity of daily records. In the early days of the COOP network, all data were recorded on paper called a B91 form, and mailed into the NWRS / NCDC, where they were transcribed.[56] Station placement at facilities such as WWTPs has become a preferred option to facilitate a continuous record of daily weather data.

ACKNOWLEDGMENTS

The author would like to express thanks to the following individuals for inspiration and their scientific contributions: James D. Goodridge, former California State Climatologist (deceased) and Roger Pielke, former Colorado State Climatologist.

The author would also like to express special thanks to the many surfacestations.org volunteers and to the readers of wattsupwiththat.com for their time-intensive efforts in locating, photographing and documenting these stations.

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