2022

United States Lightning Report

In this report

About this report

The 2022 Lightning Report was prepared by our team at AEM using our proprietary Earth Networks Total Lightning Network® (ENTLN). The report includes in-cloud, cloud-to-ground, and total lightning data throughout 2022 from the United States and the surrounding bodies of water. Counts, densities, rankings, Dangerous Thunderstorm Alerts (DTAs), and thunder hours in this report are from January 1, 2022, to December 31, 2022.

Where we get our data

The lightning data in this report is derived from the ENTLN, which monitors the combination of in-cloud and cloud-to-ground lightning in over 100 countries. The ENTLN has been deployed specifically to detect lightning in real time and to provide advanced warnings for severe weather events that could threaten public safety and operational efficiency.

The ENTLN is the most extensive and technologically advanced lightning network in the world. With more than 1,800 sensors, the network provides exceptional baseline lightning detection around the globe. In fact, with recent algorithm changes in 2021, the ENTLN detects 30-50% more lightning worldwide than ever before.

However, in areas where our network is being relied upon to maintain safety and operational efficiency, we understand that the completeness of our network is of the highest importance. That's why we continue to grow the ENTLN around a philosophy that emphasizes completeness over cross-regional evenness of lightning detection. In regions with even higher sensor density, the network's lightning detection efficiency climbs above 95%.

Report terminology

To promote better understanding of the insights contained in this report, we provide definitions of our most frequently used report terminology.

Lightning pulse: A pulse is a surge of electric current in lightning, usually accompanied by a burst of light.

Lightning flash: A lightning flash is a collection of pulses close in space and time that approximate the continuous ionized channels of a complete bolt of lightning.

Pulses and flashes may each be classified as either in-cloud (IC) or cloud-to-ground (CG).

Cloud-to-ground (CG) lightning: Lightning that occurs between opposite charges in a cloud and on the ground.

In-cloud (IC) lightning: Lightning that occurs between opposite charges within a thunderstorm cloud.

Total lightning: The combination of all in-cloud and cloud-to-ground lightning activity.

Flash density: The number of lightning flashes per square mile per year.

Dangerous Thunderstorm Alerts (DTAs): AEM's patented advanced severe weather warnings that notify users of incoming storms up to 45 minutes before storm arrival.

Thunder day: Any given day where lightning was detected within range of a certain location.

Thunder hour: Any given hour where lightning was detected within range of a certain location.

Thunder hour anomalies: Anomalies in thunder hours indicate the amount of variation between our 9-year average and the number of thunder hours observed in the past year.

What this report measures

This report examines in-cloud, cloud-to-ground, and total lightning activity throughout 2022 from the United States and the surrounding bodies of water. However, there is more than one way to think about lightning activity.

Flashes vs. pulses

When comparing lightning activity across geographic regions, we will focus primarily on lightning flashes. There are 3 main reasons for this:

- **Lightning flashes are what tend to be most important to the people and organizations that utilize lightning data to keep students, workers, and communities safe.**
- **Lightning flashes are the scientific quantities that most closely resemble what comes to mind when non-scientists think of lightning bolts.**
- **Lastly, the ENTLN delivers relatively constant flash detection efficiency across the continental United States, even across regions with differing sensor densities.**

Of course, we also recognize that not all lightning flashes are the same; some are comprised of more pulses than others. To provide an additional dimension for understanding lightning activity, we will also report the lightning pulse activity of specific regions.

Density vs. volume

When comparing the amount of lightning activity across different regions, we can look at the volume of activity (e.g., flash counts, pulse counts, etc.), or we can look at the density of that activity (e.g., flashes per square mile, pulses per square mile, etc.).

When considering a single region or two regions of roughly the same size (like Kansas and Nebraska), it makes very little difference which metric we use. There may even be a slight advantage to focusing on lightning volume, since it more intuitively conveys the scale of activity.

However, when two regions have significantly different sizes (like Texas and Maryland), comparing raw counts can misleadingly skew the comparison in favor of the larger region. Density comparisons eliminate this skewing.

When comparing lightning activity across states and counties, we will focus on lightning density (i.e., flashes per square mile). We will look at the volume of activity (i.e., flash counts and pulse counts) only when trying to convey the scale of activity within a single region.

Thunder hours

Since a typical thunderstorm usually lasts for an hour or less, the thunder hour provides an ideal level of granularity for measuring the "storminess" of an area. Other metrics tend to be too sensitive or not sensitive enough.

For example, thunder days are not sensitive enough to distinguish between run-of-the-mill thunderstorms and larger events that can last for 6-12 hours or more. At the other extreme, raw pulse and flash counts are such sensitive metrics that the data from smaller storms can be completely overwhelmed by a single supercell (a type of long-lived severe thunderstorm).

Overall lightning counts

86,547,681

Total lightning flashes

64,247,577

In-cloud | **74%**

22,024,813

Cloud-to-ground | **26%**

Overall, the U.S. experienced nearly 87 million total lightning flashes in 2022, which averages out to about 240 flashes per day or about 1 flash for every 25 square miles.

572,995,201

Total lightning pulses

522,483,107

In-cloud | **91%**

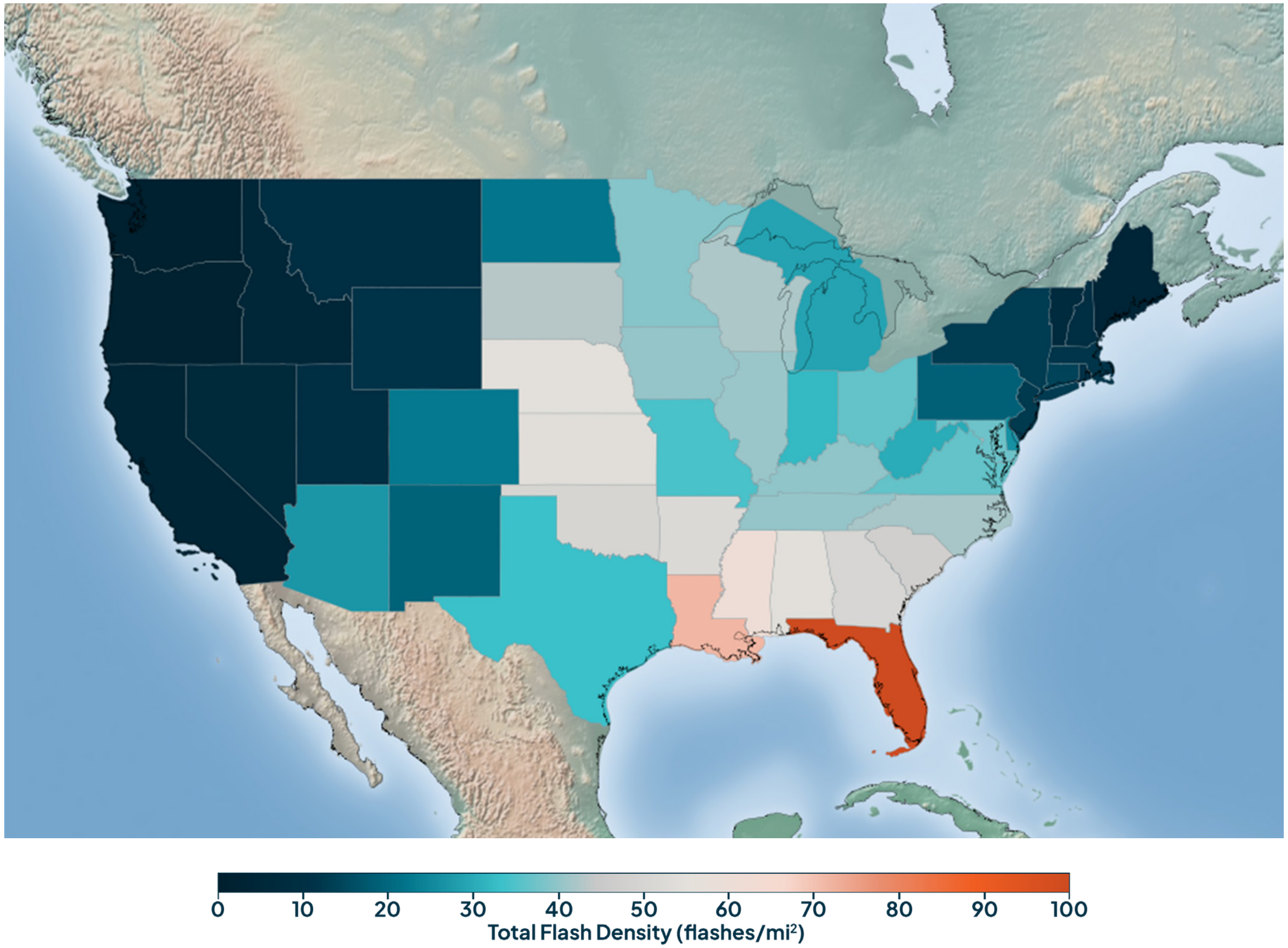
48,391,604

Cloud-to-ground | **9%**

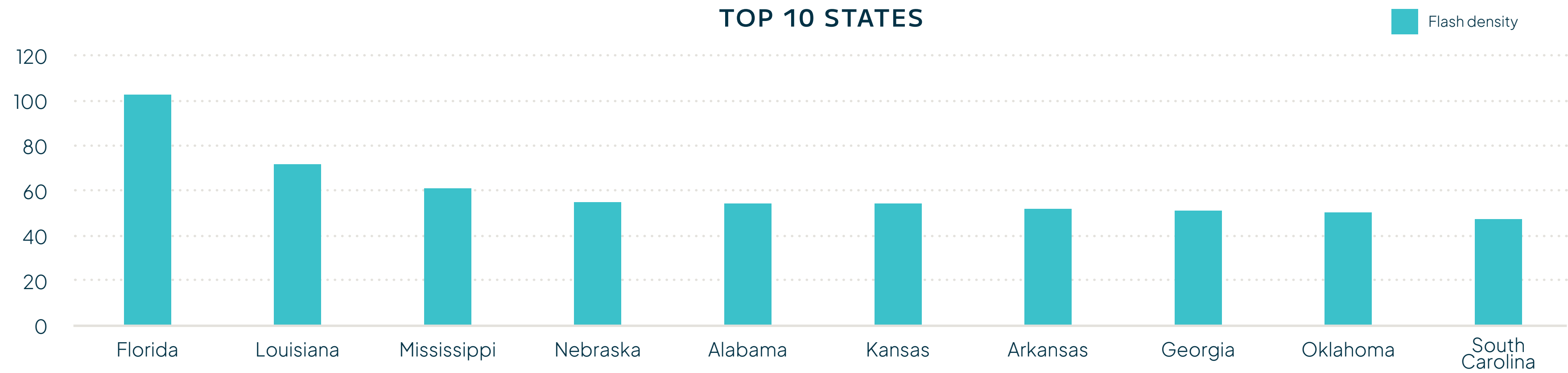
Those flashes were comprised of nearly 573 million lightning pulses, an average of almost 7 pulses per flash of lightning.

Total lightning flash density by state

The map clearly indicates that Florida had the most concentrated lightning activity, followed by Louisiana and Mississippi. From there, lightning activity radiated upward into the Great Plains and the Southeast. Note the near absence of activity in much of the West.



Total lightning flash density rankings by state



	Florida	Louisiana	Mississippi	Nebraska	Alabama	Kansas	Arkansas	Georgia	Oklahoma	South Carolina
FLASH DENSITY	103	72	61	55	54	54	52	51	50	47
TOTAL FLASHES	5,519,321	3,089,147	2,842,370	4,216,455	2,751,821	4,409,099	2,702,451	2,913,681	3,432,347	1,421,092
PULSE: FLASH RATIO	11:1	5:1	5:1	4:1	6:1	7:1	6:1	9:1	8:1	7:1
TOTAL PULSES	62,338,764	14,883,840	13,625,433	17,194,602	16,680,151	28,865,364	15,487,095	24,857,309	28,238,710	9,289,474

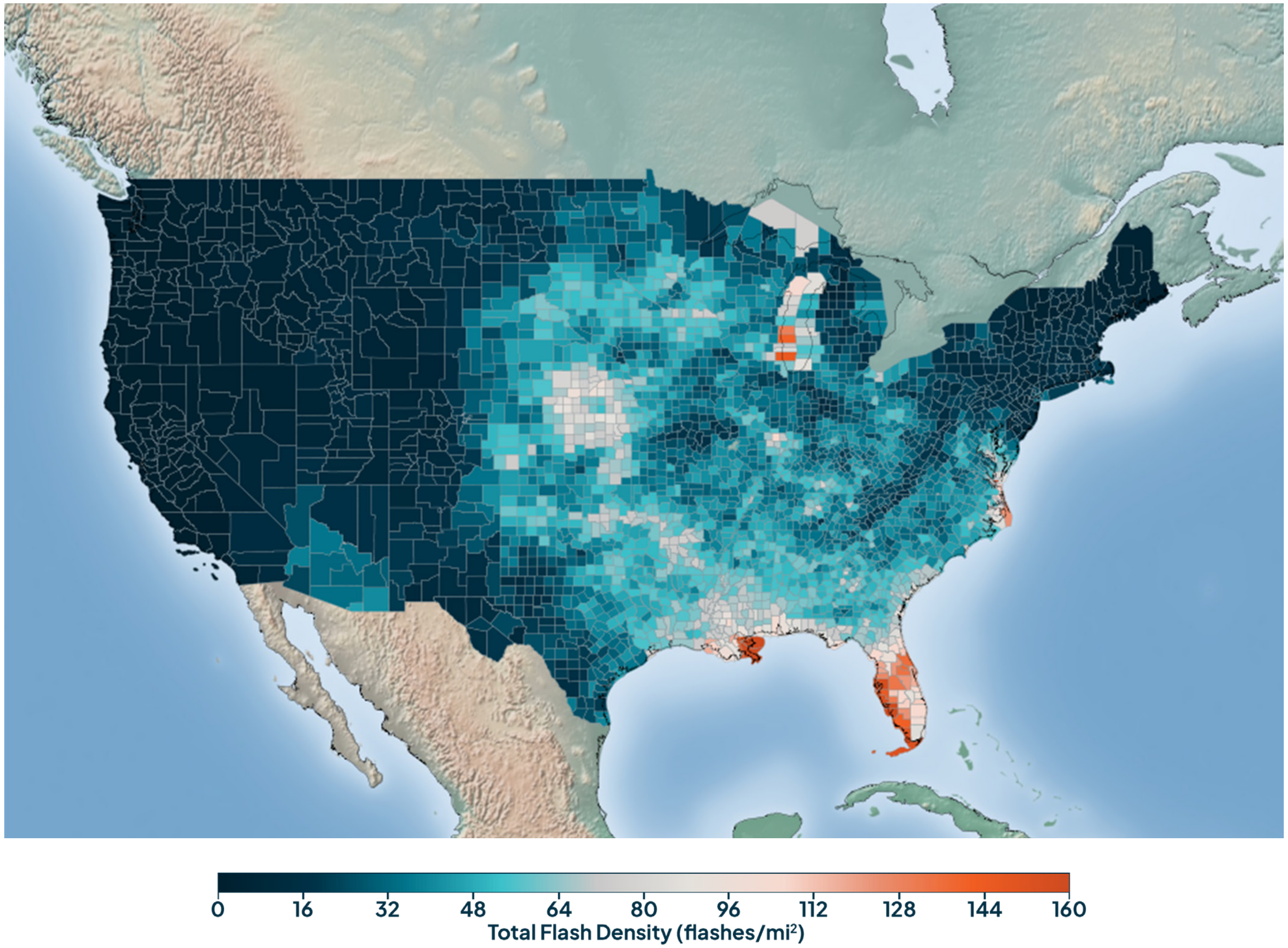
A note on picking the right metrics

The data clearly shows how volume comparisons can be skewed by differences in regional size. Although the lightning flash densities of Nebraska and Kansas trail far behind those of Mississippi and Louisiana, Nebraska and Kansas experienced significantly greater total volumes of lightning pulses.

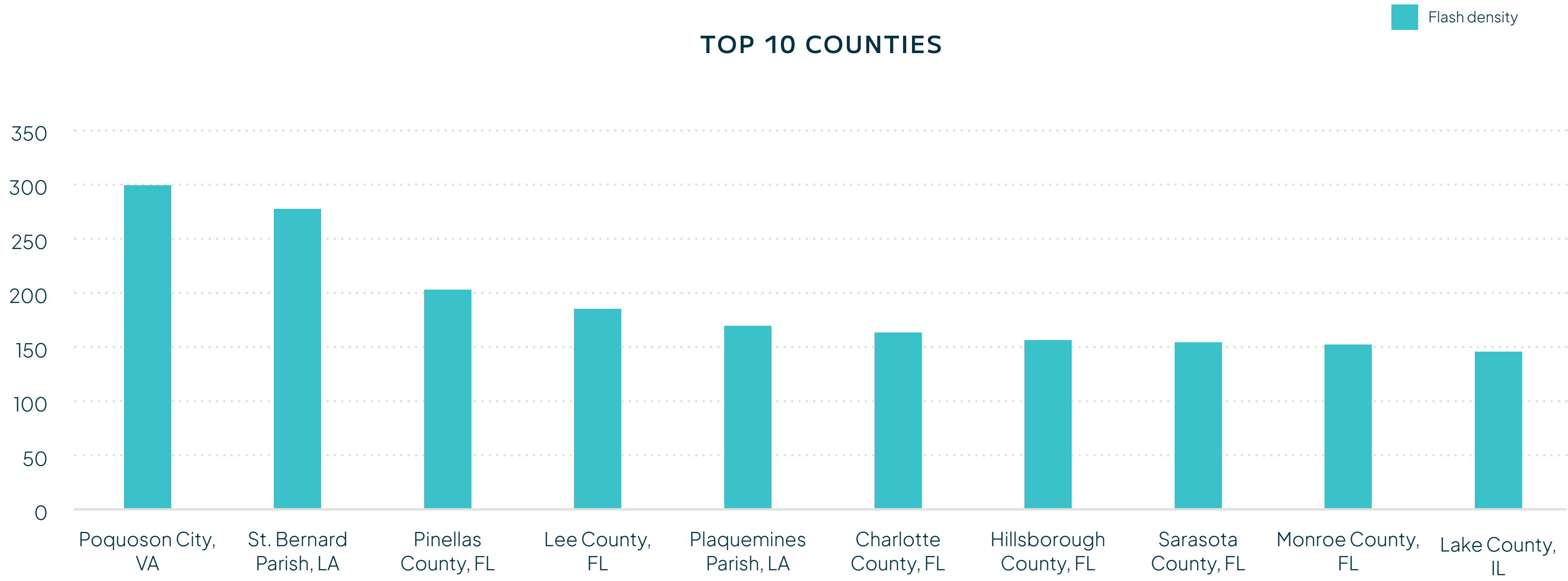
It also shows how pulse counts can be skewed by regional differences in the extent and energy of lightning flashes. Although Louisiana had significantly more flash density and flash volume than Georgia, it experienced fewer lightning pulses because its average lightning flash was less extensive and/or less energetic (i.e., comprised of fewer pulses).

Total lightning flash density by county

When we take a more granular look at the county level, we can see that most counties in the U.S. experienced relatively low concentrations of lightning activity in 2022. However, there were a few hotbeds of activity along the Gulf Coast of Florida, the mouth of the Mississippi River, the Chesapeake Bay, and the southwest coast of Lake Michigan. Beyond the main hotbeds of activity, the counties that experienced the densest lightning activity were along the Gulf Coast, the southeast Atlantic Seaboard, and parts of Tornado Alley.



Total lightning flash density rankings by county

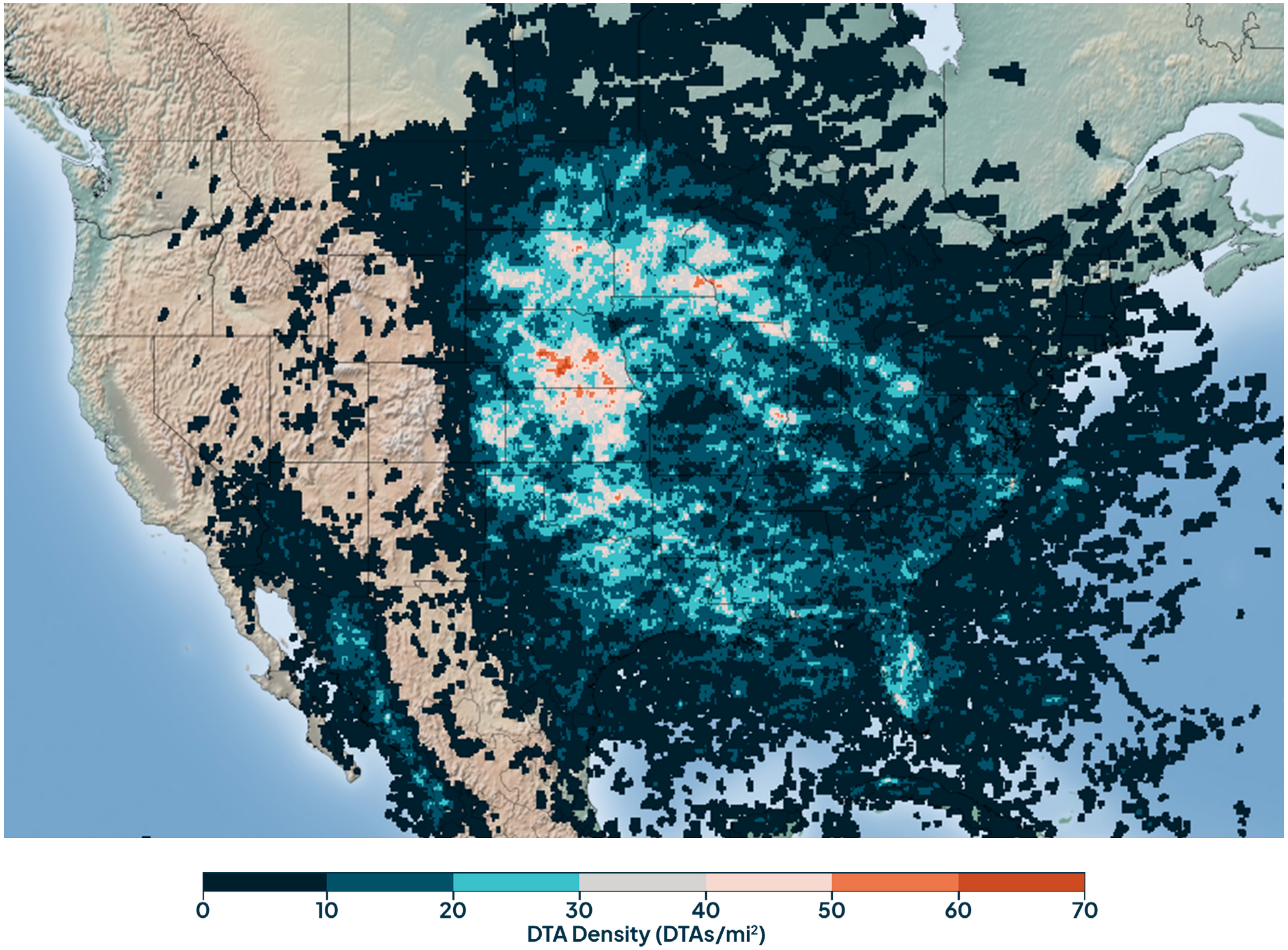


	Poquoson City, VA	St. Bernard Parish, LA	Pinellas County, FL	Lee County, FL	Plaquemines Parish, LA	Charlotte County, FL	Hillsborough County, FL	Sarasota County, FL	Monroe County, FL	Lake County, IL
FLASH DENSITY	300	278	203	184	169	162	156	154	153	145
TOTAL FLASHES	4,602	104,926	55,576	143,896	131,763	110,182	158,916	85,864	150,277	64,374
PULSE: FLASH RATIO	16:1	4:1	11:1	13:1	4:1	15:1	12:1	13:1	12:1	11:1
TOTAL PULSES	75,464	466,257	614,206	1,837,956	508,333	1,616,949	1,896,427	1,120,762	1,823,474	721,737

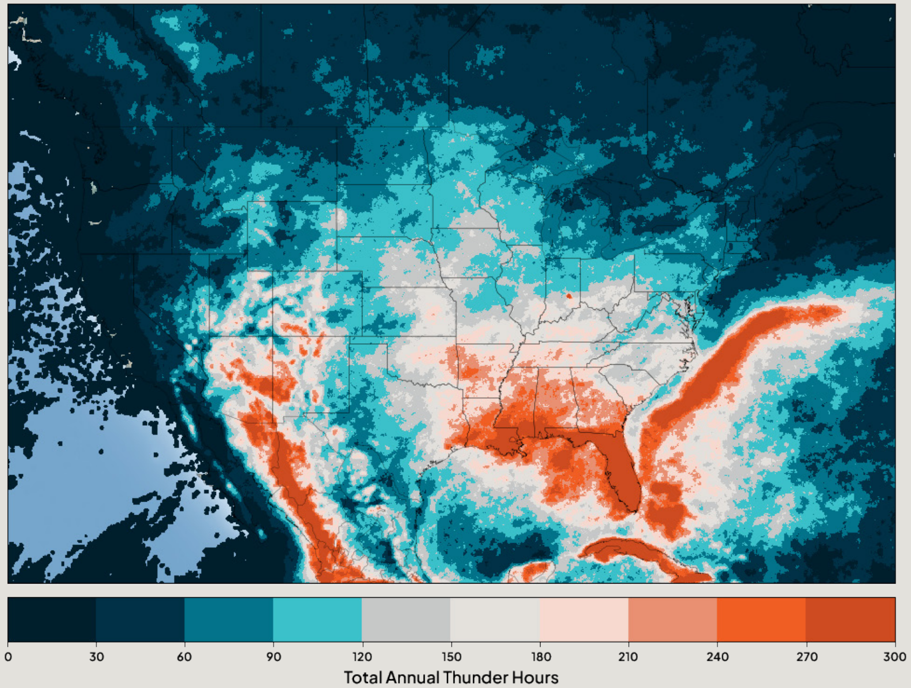
Dangerous Thunderstorm Alerts in the U.S.

Dangerous Thunderstorm Alerts (DTAs), available exclusively from AEM, warn clients of severe storms with up to 45 minutes of lead time.

AEM issued 54,242 Dangerous Thunderstorm Alerts in 2022. This map, which shows the density of this year's DTAs, draws attention to the significant amount of severe storm activity that took place across the Great Plains and into the Upper Midwest.



Total thunder hours



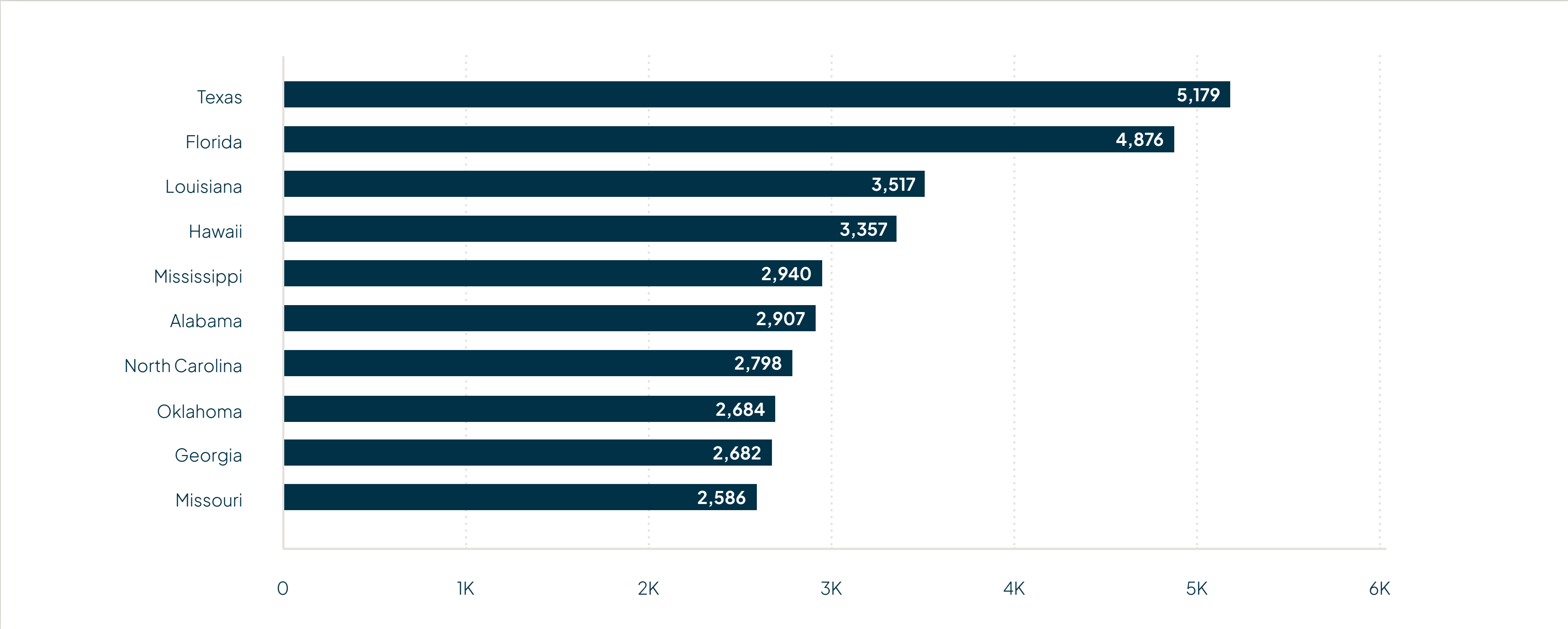
In addition to the usual hotbeds of activity in the Southeast, the map shows concentrated storm activity that radiates from Mexico into the American Southwest. This activity is associated largely with the North American Monsoon and could easily be missed by looking only at flash and pulse data.

THE NORTH AMERICAN MONSOON

A phenomenon known as the North American Monsoon occurs each year in the southwestern United States. As the continental air mass in the Southwest warms throughout the spring and early summer months, it triggers an influx of (relatively) cooler, moister air from the Gulf of Mexico and Gulf of California. As a result, there is a shift in the prevailing winds. Instead of blowing from the west (as they normally do), they begin to blow from the south and southeast. This change in air flow and the influx of moisture brings much-needed rain to the region from June to early September.

It's worth noting that there are many more thunder hours than lightning flashes recorded for the American Southwest; that's because thunderstorms caused by the North American Monsoon don't produce very much lightning, even though they can happen every day for up to 3 months.

Thunder hour rankings by state



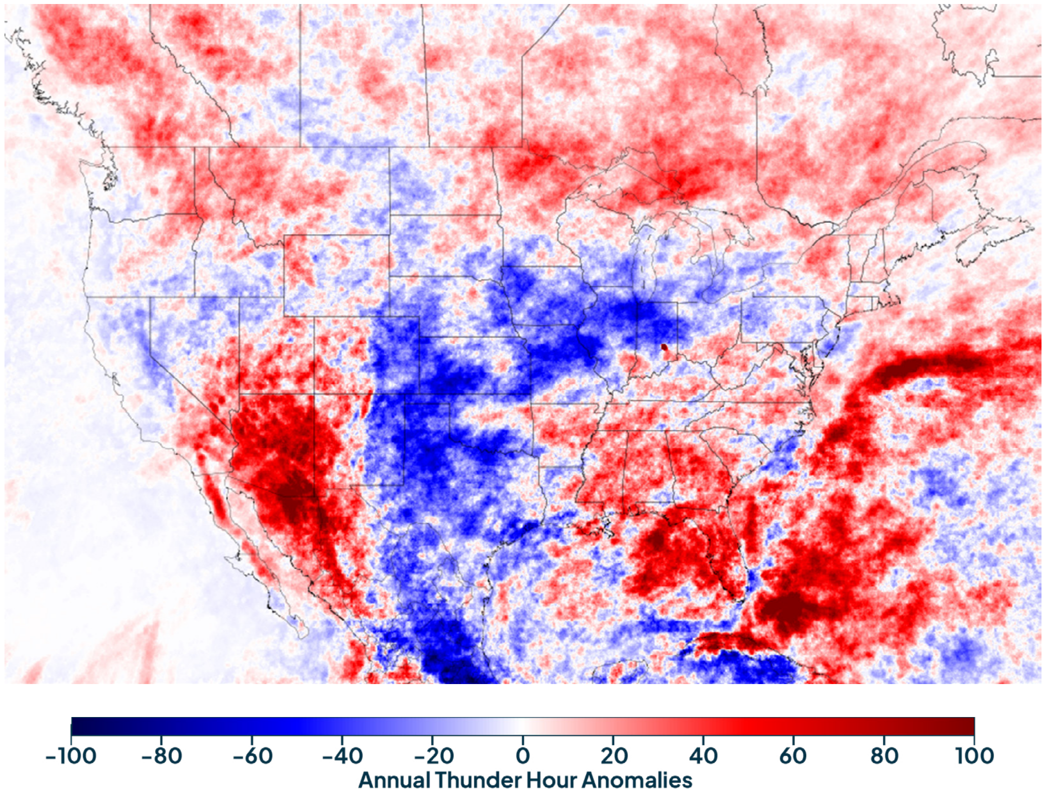
Gulf Coast States like Florida, Texas, Louisiana, and Alabama are natural candidates for the greatest number of thunder hours. Even states like Missouri and Oklahoma, located in Tornado Alley, are not all that surprising. But, based on lightning data, it may be surprising to see a state like Hawaii in the top 10. This illustrates why thunder hours are a useful supplemental data point to flash density and volume.

It's worth nothing that Hawaii has such high thunder hour counts compared to its annual flash density because there are many thunderstorms over the water immediately adjacent to the island chain, and ocean thunderstorms tend to produce very little lightning.

Thunder hour anomalies

We look specifically at thunder hour anomalies to provide a better sense of how the past year deviated from the climatological trend. Simplistic year-over-year comparison of thunder hours can introduce extraneous noise because each year in the comparison (not just the most recent year) can deviate to a greater or lesser extent from the overall trend.

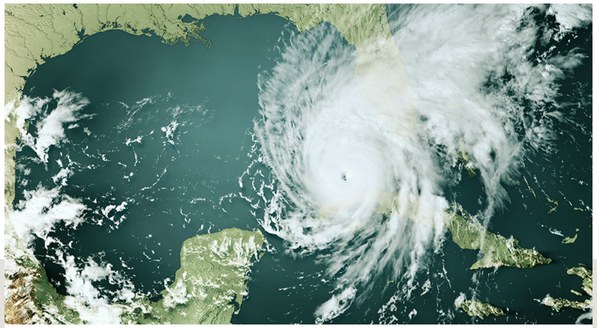
The map shows above-average storm activity throughout the southeast, across Arizona, and along most of the Canadian border. However, storm activity was well below average throughout Texas, the southern Great Plains, and into portions of the Midwest. Positive anomalies throughout the Southwest were tied to a very active monsoon season in 2022. Negative anomalies in the Great Plains were related to drought conditions that were partly caused by a persistent La Niña pattern.



2022 lightning recap

CASE STUDIES

California escapes disaster after exceptional dry lightning storm ignites fires



Why Hurricane Ian's unusual lightning activity was a bad omen

Great Lakes thundersnow buries Buffalo

Lightning data provides important insights into weather and climate across the United States. In this portion of the report, we will focus on the close relationships between lightning and some interesting meteorological events. The following case studies discuss several interesting weather events from 2022 and their noteworthy lightning activity.

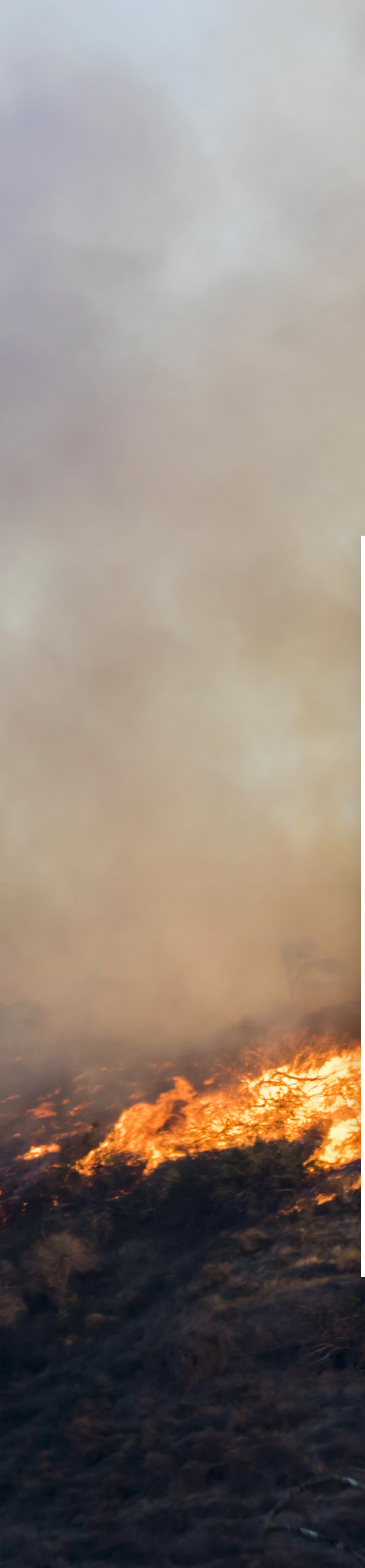
CALIFORNIA ESCAPES DISASTER AFTER EXCEPTIONAL DRY LIGHTNING STORM IGNITES FIRES

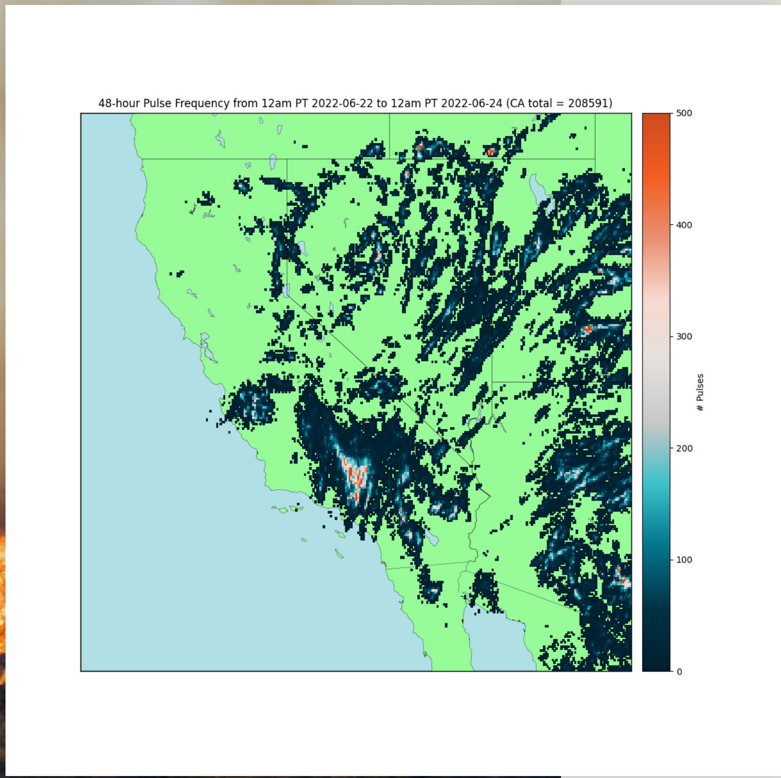
As Californians awaited the first day of summer, they were also bracing for a significant storm system to roll through the state, fueled partly by monsoonal moisture and partly by a disturbance in the jet stream moving across the region. Although the thunderstorms in the forecast were expected to produce very little rain, **meteorologists warned** they could still produce dangerous lightning.

While there is no such thing as safe lightning, so-called "dry lightning" (i.e., lightning accompanied by rain that evaporates before it hits the ground) is especially dangerous because it brings heightened wildfire risk. And, in drought-stricken California, that risk is already high enough without lightning.

When the storm system finally hit, from June 22 to June 23, it produced more than 208,000 total lightning pulses across the state, including more than 33,000 cloud-to-ground pulses. It was the **most lightning** the state had seen in a single day in nearly five years.

Wildfire Today reported that the storm did, in fact, ignite a number of small fires. The largest of these was the Thunder Fire, which burned about 2,500 acres before being fully contained. Fortunately, firefighters were able to contain most of the fires without too much difficulty, limiting the **total burn area** to less than 4,000 acres.





While no amount of destruction is ever good, Californians were fortunate that this incredible amount of lightning did not produce a more incredible amount of fire. For comparison, **in August** 2020, a similar "dry lightning" storm ignited more than 650 wildfires across northern California, including the August Complex Fire, which became the largest fire in state history. Together, those fires burned an estimated 1.5-2.1 million acres (about the area of Connecticut).

Three factors combined to prevent the outcome of the June 2022 lightning storm from being much worse:

1. Rain is thought to have reached the ground along with some of the strikes, especially at higher elevations.

2. The active North American Monsoon winds brought high relative humidity to the region, making fuels less receptive to ignition.

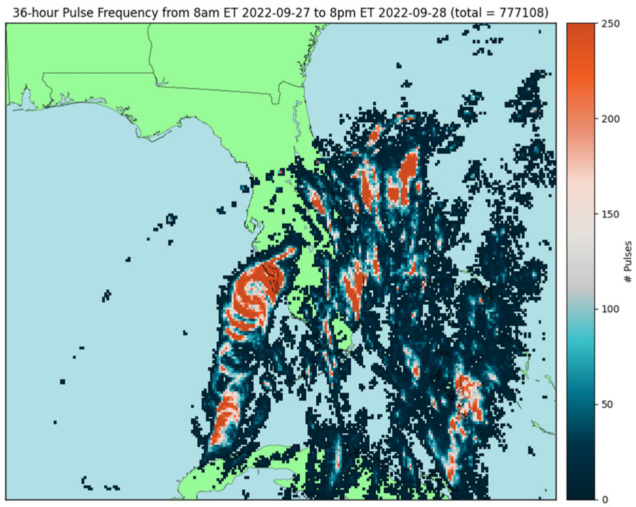
3. June is still early in the fire season, before fuel moisture drops to critically low levels.

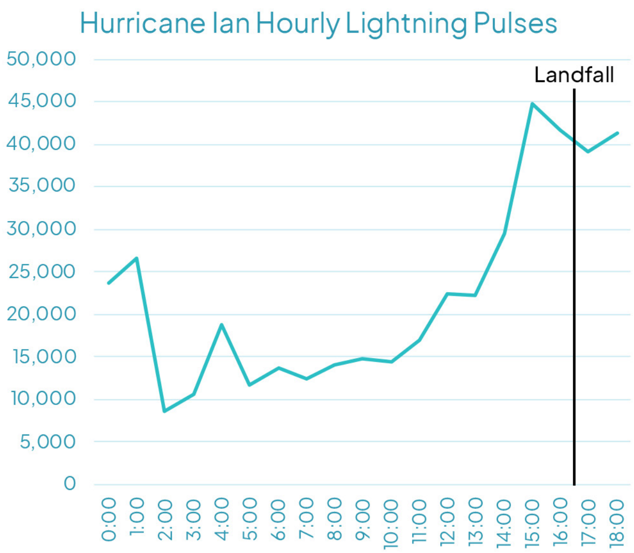
WHY HURRICANE IAN'S UNUSUAL LIGHTNING ACTIVITY WAS A BAD OMEN

After striking the Florida coastline on September 28, Hurricane Ian took the lives of more than 100 Floridians, making it the **deadliest tropical storm** to hit the state since the Great Labor Day Hurricane of 1935.

The devastation was made worse by the fact that Ian went through a period of rapid intensification only hours before hitting the coastline. Over a three-hour period, **Ian's wind speeds increased** from 120 mph to 155 mph as measured by AEM's weather network – leaving it only a few miles per hour short of the most dangerous Category 5 classification on the Saffir-Simpson scale.

Hurricane eyewall: The central ring of wind and rain around the clear, calm eye of the storm, where the storm produces its strongest wind speeds.





Ian was unusual in other ways too. Hurricanes typically don't produce prolonged lightning activity in and around their eyewalls. Ian did. As the storm approached and struck Florida, AEM's network of weather stations and lightning sensors recorded no less than 98,176 lightning flashes and 839,858 lightning pulses over 48 hours.

There's an interesting connection between Ian's unusual lightning activity and its exceptional strength. Both are tied to a process called eyewall replacement.

It's a natural part of the hurricane lifecycle for the eyewall to weaken over time. As this happens, a new ring of wind and rain will sometimes contract inward and surge upward to replace the old eyewall. This upward surge can enable the clouds to get tall enough at a fast enough rate to temporarily develop ice crystals in them, and those colliding crystals can generate the static charge needed to produce lightning. Unfortunately, this inward and upward movement also causes the new eyewall to spin even faster (**like a figure skater pulling their arms inward**).

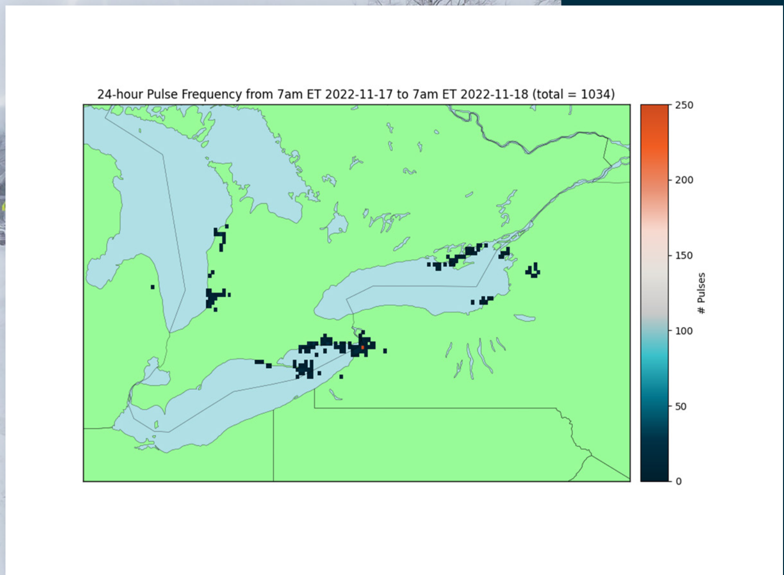
As a result, surges in lightning activity in the storm's inner core and eyewall tend to be associated with periods of rapid intensification. And that's exactly what we saw happen with Hurricane Ian. Just before the storm made landfall in Florida, we saw a spike in lightning activity accompanied by a period of rapid intensification.

GREAT LAKES THUNDERSNOW BURRIES BUFFALO

On the afternoon of November 17, residents of northwestern New York found themselves pummeled by snowfall – at some points, **more than three inches per hour**. By the time the clouds finally cleared on November 18, some areas had been blanketed with **more than six feet**. The city of Buffalo more than doubled its previous record for maximum snowfall in a day, and the town of Orchard Park broke the state record for most snowfall in a 24-hour period.

But this storm delivered more than just record-breaking snowfall. It delivered a rare lightshow of more than 1,000 lightning pulses in 24 hours.

Thundersnow, as it is called, is a relatively rare occurrence. It's been estimated that thundersnow accounts for **less than 0.1%** of all U.S. snowstorms. The reason for the rarity is that lightning and snowstorms are generally caused by very different atmospheric conditions.



Lightning is caused by **conditions of atmospheric instability** in which warm air rises rapidly into the cooler air above it. In contrast, most snowfall is generated under conditions that tend to produce atmospheric stability, namely, the air near the ground being almost as cold as the air above it. For comparison, a typical thunderstorm has air rising at **more than ten miles per hour**, while the most severe snow bands tend to have air rising at only two miles per hour.

However, **some snowstorms**, such as lake effect snowstorms, can form when cold air near the surface is heated while moving over relatively warm waters. If the air above the surface is cold enough, the newly warmed layer of air can rise rapidly, producing a tall column that looks more like a thunderstorm cloud than a flat snow cloud. That same scenario can produce the atmospheric instability needed to generate lightning; that's when our snowstorm becomes thundersnow.

Unfortunately, the **same atmospheric instability** that gives rise to thundersnow also tends to result in heavier snow and higher snowfall rates. Wherever you see thundersnow, there's a high probability for **significant snow accumulation** – just as they experienced in northwestern New York.

Appendix

This table ranks all U.S. states by total lightning flash density (including in-cloud and cloud-to-ground) from highest to lowest. We also include the total number of flashes, the total number of pulses, and the total number of thunder hours in each state. The period covered is January 1, 2022, to December 31, 2022.

STATE	ANNUAL TOTAL FLASHES PER SQ MILE	ANNUAL TOTAL FLASHES	ANNUAL TOTAL PULSES	ANNUAL THUNDER HOURS
Florida	103.00	5,519,321	62,338,764	4,867
Louisiana	71.59	3,089,147	14,883,840	3,517
Mississippi	60.65	2,842,370	13,625,433	2,940
Nebraska	54.95	4,216,455	17,194,602	2,029
Alabama	54.40	2,751,821	16,680,151	2,907
Kansas	53.99	4,409,099	28,865,364	2,142
Arkansas	52.00	2,702,451	15,487,095	2,431
Georgia	50.54	2,913,681	24,857,309	2,682
Oklahoma	50.10	3,432,347	28,238,710	2,684
South Carolina	47.33	1,421,092	9,289,474	2,304
District of Co-	44.64	2,726	52,705	192
South Dakota	43.10	3,263,283	10,877,734	1,724
Wisconsin	42.32	2,289,803	11,976,216	1,682
North Carolina	42.11	2,045,029	14,172,966	2,798
Illinois	40.77	2,260,609	23,482,084	2,188
Tennessee	40.39	1,663,551	11,341,744	2,040
Iowa	40.37	2,251,967	11,686,470	1,646
Kentucky	40.12	1,582,510	11,835,929	2,056
Minnesota	39.10	3,109,534	10,143,384	1,932
Maryland	37.37	362,495	8,631,546	1,183
Ohio	36.50	1,489,530	14,346,163	1,724
Virginia	36.44	1,436,987	19,047,342	2,072
Missouri	34.45	2,365,433	16,523,949	2,586
Texas	33.59	8,765,528	61,537,173	5,179
Indiana	32.34	1,157,280	13,481,570	1,669
West Virginia	30.20	725,100	7,637,140	1,654

STATE	ANNUAL TOTAL FLASHES PER SQ MILE	ANNUAL TOTAL FLASHES	ANNUAL TOTAL PULSES	ANNUAL THUNDER HOURS
Michigan	29.03	1,640,962	9,621,082	2,183
Arizona	26.98	3,061,140	11,922,308	2,076
Delaware	26.46	51,486	1,135,761	479
Colorado	23.04	2,384,775	8,038,461	2,191
North Dakota	22.44	1,546,637	4,737,571	1,230
New Mexico	19.47	2,358,975	8,526,336	2,370
Pennsylvania	18.96	847,457	13,670,644	1,588
Connecticut	14.22	68,758	1,426,124	448
New York	12.93	608,625	6,604,962	1,873
New Jersey	12.51	91,875	2,593,112	772
Massachusetts	11.92	92,875	1,438,051	671
Wyoming	11.67	1,131,796	5,545,704	1,656
Rhode Island	11.31	11,675	241,522	233
New Hampshire	9.67	86,509	576,350	451
Montana	9.64	1,401,478	5,749,758	1,703
Utah	9.63	790,874	4,099,065	1,664
Vermont	7.80	71,800	425,387	459
Nevada	6.24	684,095	2,533,626	1,481
Idaho	5.35	441,216	1,721,982	1,460
Maine	4.03	124,095	376,649	681
California	3.86	601,205	2,225,743	1,912
Oregon	1.81	173,798	814,401	817
Washington	1.55	103,187	557,965	535
Hawaii	1.08	6,931	14,279	3,357
Alaska	0.06	36,394	51,650	1,132

Thank you

For additional insights or permission to use data or graphics from this report, please contact us at:

info@aem.eco