The Expected Intensity of Summer Thunderstorms along the Florida Panhandle

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The Florida Panhandle is a 16-county region of Florida known for its white-sand beaches and blue-green waters of its barrier islands along the Gulf of Mexico, making it a popular summer vacation destination. However, the warmer months do not only attract tourists but also bring about afternoon thunderstorms. The combination of heat, humidity, and Gulf winds along the Florida Panhandle makes it an ideal breeding ground for thunderstorms, especially during the summer months. Afternoon thunderstorms are nothing out of the ordinary for residents of the Florida panhandle. Florida is notorious for its high numbers of thunderstorms and lightning fatalities in the United States. Figure 1 shows the average number of thunderstorm days per year throughout the United States. The most occur along the northern and eastern Gulf coast, with the state of Florida having the highest number of average thunderstorm days. "Thunderstorms occur about 70 days per year in the Florida Panhandle," according to Fuelberg and Beggar, "with most occurring during the warm season in the afternoon and early evening" (Fuelberg and Biggar, 1994). Data suggests that afternoon thunderstorms could intensify as the climate warms due to increasing anthropogenic greenhouse gas emissions. Coastal beach community residents on the panhandle should expect more dangerous storms in the summertime and will need mitigation efforts to combat increasing storm intensity. As beach communities along the Panhandle experience a surge in tourists during the summer months, efforts should be made to educate those unaware of thunderstorm hazards to reduce fatalities.

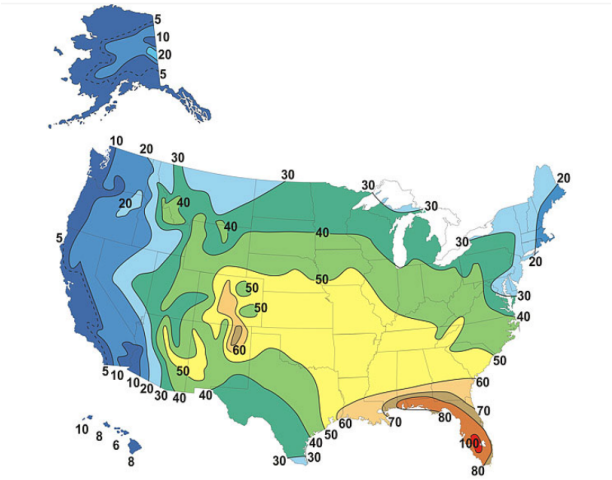

Figure 1: The figure above shows the average number of thunderstorm days each year throughout the United States (NOAA).

According to the National Weather Service (NWS), a thunderstorm is defined as "a rain-bearing cloud that also produces lightning" and is usually associated with heavy rainfall and strong winds (NWS,

2015). The most severe thunderstorms can produce severe weather conditions, including damaging winds, lightning, hail, and tornadoes. "Thunderstorms typically develop in the warmer months of spring, summer, and fall, but they can occur at any time of year over most of the United States," according to the National Oceanic and Atmospheric (NOAA) National Severe Storms Laboratory (NOAA National Severe Storms Laboratory). Several conditions or "ingredients" must be met for a thunderstorm to form.

The three main ingredients for thunderstorm production are moisture, an unstable environment, and a lifting mechanism. The maritime tropical (mT) air that forms over the Gulf of Mexico provides ample moisture levels across the panhandle. The second requirement is instability. Warm, wet air near or at the surface, and cold, dry air above, describes an ideal unstable atmosphere. The heating of the ground, which causes the air to become buoyant due to convective uplift, is one of the leading causes of the air instability found in the panhandle. The instability of the atmosphere is also referred to as convective available potential energy or CAPE is described by the National Weather Service (NWS) as "the amount of fuel available to a developing thunderstorm. More specifically, it describes the instability of the atmosphere and provides an approximation of updraft strength within a thunderstorm. A higher value of CAPE means the atmosphere is more unstable and would therefore produce a stronger updraft" leading to a more severe storm (NWS, 2015).

A lifting mechanism is the third component needed to develop a thunderstorm. The National Weather Service (NWS) defines a lifting mechanism as "any mechanism that causes the uplift of air in the atmosphere" (NWS, 2019). In the summer afternoons, convective lifting of air happens when parts of the surface become warmer than the surrounding air due to intense solar radiation. Uplift can also be caused by the convergence of gulf and pacific sea breezes over the Florida panhandle. A sea breeze, described by senior Meteorologist of AccuWeather, Alex Sosnowski, "is simply a push of air from the ocean that

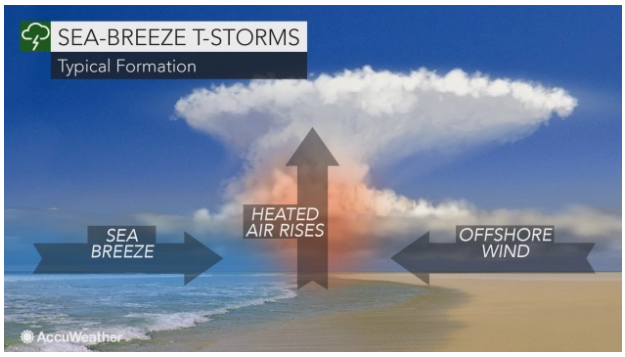

Figure 2: The figure above demonstrates how the convergence of sea breezes and offshore winds lead to the development of afternoon thunderstorms along the Florida panhandle (AccuWeather, 2019).

usually brings a drop in temperature or humidity level during the daytime" (Sosnowski, 2019). Figure 2 illustrates how sea breezes converge to create uplift and aid in the development of afternoon thunderstorms. Sonsnowki states that sea breezes “enhance showers and thunderstorms across inland areas as clouds, showers, and thunderstorms tend to focus along the temperature boundary between the cool ocean air and the warm air well inland" (Sosnowski, 2019). The Florida Panhandle is an ideal environment for thunderstorm production due to the abundance of CAPE and sea breezes available in the summer months.

Thunderstorm development is categorized into three developmental stages. The developing, mature, and dissipating stages are the three stages of thunderstorm development, as shown in Figure 3. The combination of moisture, instability, and uplift begins to form a cumulus cloud. A rising column of air known as an updraft pushes the cumulus cloud upward. As the updraft develops, the cumulus cloud grows taller, called a cumulus congestus cloud. There is usually light or no precipitation during this stage, although lightning is possible. As the updraft continues to fuel the storm and precipitation begins to fall out of the now cumulonimbus cloud, a downdraft is formed. A downdraft is a column of air sinking downward and where precipitation occurs. At this point, the thunderstorm has entered the mature stage. Hail, heavy rain, frequent lightning, strong gusts, and tornadoes are all likely during the mature stage, making it the most dangerous stage. As precipitation continues to fall, the updraft is eventually overcome by the downdraft, marking the beginning of the dissipating stage. The warm moist air fueling the thunderstorm on the ground has been cut off, and rainfall intensity is decreasing, although still possible.

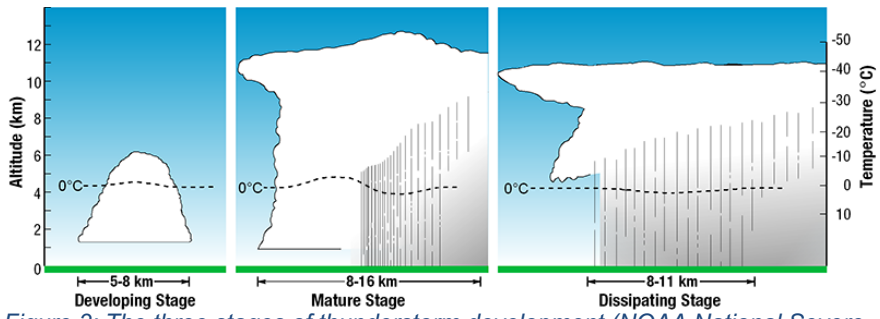

Figure 3: The three stages of thunderstorm development (NOAA National Severe Storms Laboratory)

In the United States, Florida has the highest frequency of thunderstorms per year due to heat, moisture, and constant convergence of sea breezes over the peninsula. The Florida Climate Center

reported that "central Florida's frequency of summer thunderstorms equals that of the world's maximum thunderstorm areas: Lake Victoria region of equatorial Africa and the middle of the Amazon basin" (Florida Climate Center). Many of these thunderstorms, however, are single-cell thunderstorms. A single cell thunderstorm has one main updraft and one main downdraft. These thunderstorms are also commonly referred to as "ordinary," "pop-up," or "pulse thunderstorms." Pop-up thunderstorms are generally not severe and only last for about an hour, commonly occurring on summer afternoons. Although the afternoon thunderstorms are short-lived, hail and wind gusts can develop. According to the National Weather Service (NWS), “If atmospheric conditions are right and the ordinary cell is strong enough, there is the potential for more than one cell to form and can include microburst winds (usually less than 70 mph/112 km/h) and weak tornadoes" (NWS). The greater availability of ingredients to produce thunderstorms, increases the possibility of more hazardous storms.

There are many hazards associated with thunderstorms. Lightning, torrential rain, wind gusts, hail, tornadoes, derechos, downbursts, and flash flooding are associated with thunderstorms. The most severe storms can result in a variety of hazardous weather conditions.

Lightning, however, is the one of the most concerning hazards produced by thunderstorms in the Florida Panhandle. Lightning is a powerful electrostatic discharge that is produced during a thunderstorm and is defined by the American Meteorological Society (AMS, 2012) as "a transient, high-current electric discharge with path lengths measured in kilometers" (AMS, 2012). Figure 4 shows areas where lightning is most prone within a single year. According to the map, lightning densities within the Florida panhandle in the year 2021 were extremely high, making the possibility for lightning induced injuries or deaths to

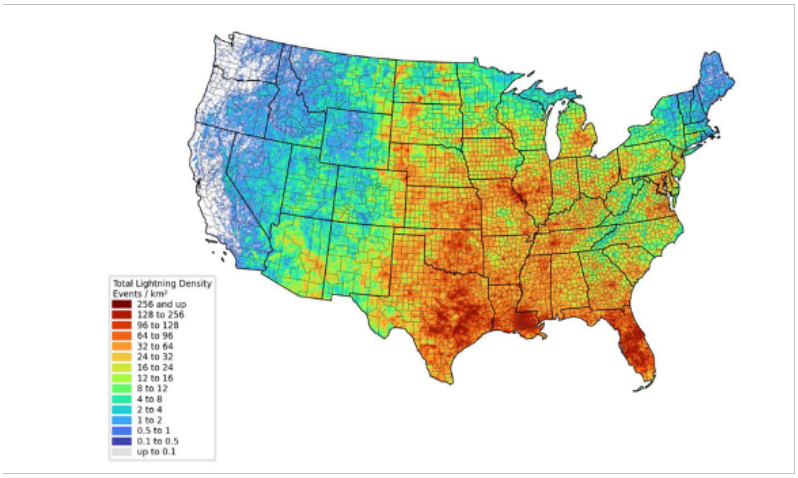

Figure 4: Total lightning density gridded map of 2021: cloud-to-ground lightning strokes plus cloud pulses (Vaisala, 2022).

increase. John S. Jensensius, a lightning safety specialist, reported that "beach-related activities were the second most significant contributor to lightning deaths" (Jensensius, 2020). Due to a dense population and a large amount of leisure activities that take place outdoors during the summer within the Florida panhandle, lightning poses a significant risk to those unaware of what is happening in the sky around them. Jensensius continues to state that "in some cases, the sounds of the surf may have masked the sound of thunder, which could have provided an earlier awareness that thunderstorms were developing or approaching. In other cases, victims had walked or run along the beach due to a lack of situational awareness and may have been far from safety when the storm approached" (Jensenius, 2020). Lightning fatalities and injuries are common to the panhandle population due to outdoor activities; however it is not the only severe weather hazard that can potentially cause harm.

Due to the availability of heat, moisture, and lift, thunderstorms represent a significant threat to the heavily populated Florida panhandle throughout the summer months. However, a change in average weather patterns, referred to as climate change, could potentially further increase this risk. The National Aeronautics and Space Administration (NASA) defines global warming as "the long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere" (NASA, 2022). As anthropogenic gasses continue to be released into the atmosphere, they will continue to increase surface temperatures. NOAA recently announced that "despite pandemic shutdowns of 2020, anthropogenic greenhouse gasses are continuing to increase" (Stein, 2021). NOAA reported that "the atmospheric burden of carbon dioxide (CO_2) is comparable to during the Mid-Pliocene Warm Period around 3.6 million years ago when carbon dioxide concentrations ranged from about 380 to 450 parts per million. During that time, sea level was about 78

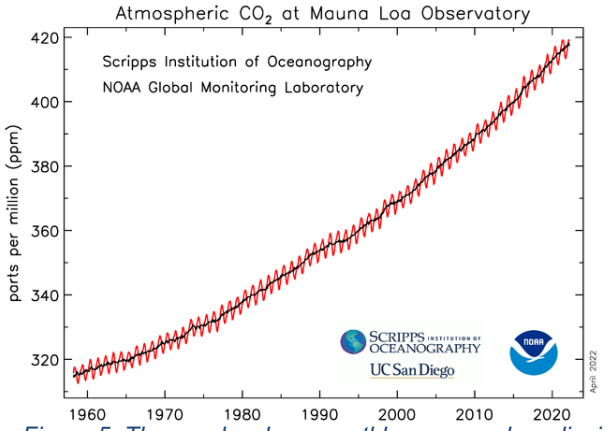

Figure 5: The graphs show monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii starting in 1958 (NOAA Global Monitoring Laboratory, 2022)

feet higher than today, and the average temperature was 7 degrees Fahrenheit higher than in pre-industrial times" (NOAA, 2022). Figure 5, known as the Keeling Curve, represents monthly the overall global increase of CO_2 since the first recording of 1958. As greenhouse gases such as CO_2 continue to increase, results in climbing average global temperatures. Figure 6, created by NASA's Goddard Institute for Space Studies illustrates the change in global surface temperature relative to 1951-1980 average temperatures, with the year 2020 tying with 2016 for warmest on record. Global surface temperatures are increasing, and the state of Florida is noticing these warming temperatures. In fact, in 2016, The Environmental Protection Agency reported that "the Florida peninsula has warmed more than one degree Fahrenheit during the last century (EPA, 2016).

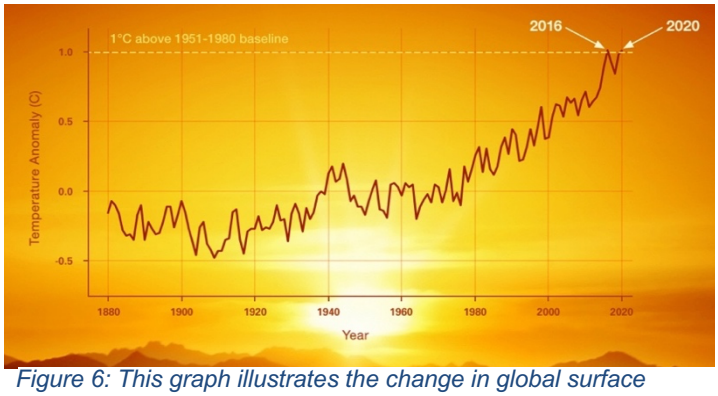

Figure 6: This graph illustrates the change in global surface temperatures relative to 1951-1980 average temperatures, within the year 2020 (NASA, 2022)

Though thunderstorms are familiar to Florida Panhandle residents, due to the changing climate, these 30-minute pop-up thunderstorms have the potential to become more severe. As temperatures increase along the Florida panhandle, more energy is provided for storms, resulting in the potential for more intense thunderstorms to build. A study by Trapp et al. (2007) suggested that global warming should increase convective available potential energy (CAPE) by warming the Earth's surface and therefore increasing the amount of moisture in the air through evaporation (Trapp et al. 2007). "CAPE can provide storms with the raw fuel to produce rain and hail, and vertical wind shear can pull and twist weak storms into strong, windy ones," explained Harold Brooks, a meteorologist at NOAA's National Severe Storms Laboratory (Brooks, 2013). Figure 7 demonstrates how convective potential energy environments in the United States are expected to significantly

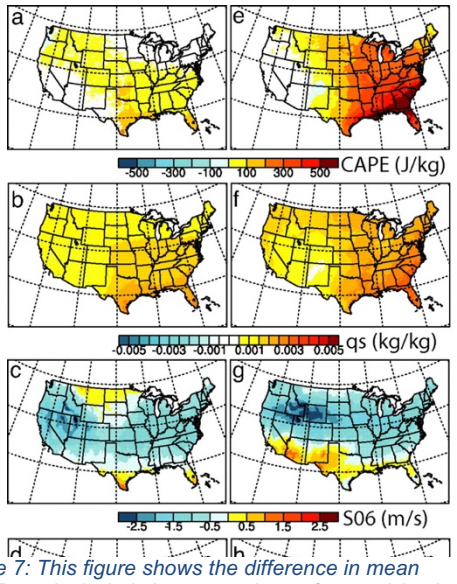

Figure 7: This figure shows the difference in mean CAPE, vertical wind shear over the surface to 6 km layer (S06), mean surface specific humidity (qs), and severe thunderstorm environment days (NDSEV) The RF integration period is 1962–1989, and the A2 integration period is 2072–2099 (Trapp et al. 2007).

increase in the future and how it directly correlates to an increase in severe thunderstorm environment days. A study by Jacob Steeley and David Romps concluded that with a warming climate "the growing consensus that there will be more annual severe-thunderstorm-favorable combinations CAPE and wind shear in a warm future United States (Seeley and Romps, 2015). As the Florida panhandle already has thunderstorm favorable conditions, a warming climate will further increase the potential for thunderstorm development that are more severe.

Research conducted by Trenberth et al claims that global warming directly influences precipitation. (Trenberth et al. 2003). An anticipated increase in atmospheric water vapor is coupled with warming temperatures, leading to intensified precipitation and a higher frequency of extreme precipitation events. Trenberth et al. state that "the water holding capacity of air increases by about 7% per 1°C warming, which leads to increased water vapor in the atmosphere (Trenberth et al. 2003). Therefore, this leads to the conclusion that individual thunderstorms with more moisture produce more extreme precipitation events" (Trenberth et al. 2003). The Florida panhandle is already considered a very wet environment due to the maritime tropical air from the Gulf of Mexico. According to Rick O'Connor a Sea Grant Extension Agent in Escambia, reported that the western Florida panhandle has "a mean annual rainfall of 64.4 inches" (O'Connor, 2021). Figure 8 shows the total rainfall for Pensacola, FL from 2007 to 2020. According to the table, the annual mean rainfall for this panhandle city over 14 years is 70.72 inches, which is 6.32 inches higher. O'Connor continues to state that since "most of the panhandle areas are developed and an increase in rainfall will bring an increase in stormwater issues for the area" (O'Connor, 2021). As air temperatures rise within the Florida panhandle, residents and visitors should expect that individual thunderstorms with more moisture will produce more extreme precipitation events" (Trenberth et al. 2003). Furthermore, as precipitation increases along with

Total Rainfall Pensacola, FL	
Year	Inches of Rainfall
2007	57.76
2008	56.69
2009	88.33
2010	62.96
2011	48.68
2012	66.63
2013	74.61
2014	83.17
2015	75.69
2016	64.62
2017	91.91
2018	90.01
2019	52.56
2020	76.49
MEAN	70.72

Figure 8: The annual mean rainfall and total annual rainfall in inches (in) for Pensacola, FL (NOAA, 2020)

development as beach communities continue to grow and surface temperatures rise, residents are at higher risk for flooding.

As thunderstorms along the Panhandle are expected to intensify, coastal communities should protect themselves and their property through mitigation. The Federal Emergency Management Agency (FEMA) defines mitigation as "a sustained action to reduce or eliminate risk to people and property from hazards and their effects" (FEMA, 2021). As afternoon summer thunderstorms are predicted to intensify means Florida panhandle residents are at greater risk for experiencing severe weather hazards.

With predicted increased rainfall, cities should expect a greater flood risk. To combat flooding, FEMA suggests a multitude of suggestions. One of them includes improving stormwater drainage system capacity (Baxter et al., 2013). An abundance of rainwater can cause flooding and erosion in developed areas. Increasing the water capacity of stormwater drains will help alleviate water buildup. FEMA also suggests elevating or retrofitting structures and utilities. Elevating utilities and buildings decrease the risk of coastal flooding damage and flash flood damage. FEMA recommends that communities protect and restore natural flood mitigation features, such as sand dunes (Baxter et al., 2013). Restoring sand dunes along the panhandle's barrier islands will aid in the prevention of erosion and coastal flooding of beach communities. The chief financial officer of Florida, Jimmy Patronis, recommends that property owners adopt a regimen of cleaning gutters. He shares that clearing debris out of gutters is important to ensure water can flow away from properties and prohibit flooding and damage (Patronis).

Lighting, notorious for fatalities in Florida, is also expected to increase as storms more intense storms increase. Lightning strikes cause fatalities to humans, but they can also cause significant damage to buildings, critical facilities, and infrastructure. The Federal Emergency Management Agency (FEMA) recommends protecting critical facilities and infrastructure from lightning damages by installing lightning protection devices such as lightning rods and surge protection electronic equipment. To prevent future fatalities from lightning during leisure activities, public beaches and parks should consider installing a lightning horn to warn those outdoors of approaching lightning, indicating to take shelter inside.

Severe wind is another hazard associated with thunderstorms that threaten lives, property, and community utilities. Most wind damage is caused by flying debris, downed trees, and fallen power lines due to strong winds. FEMA recommends adopting regulations that govern residential construction sites to reduce flying debris. As well as ensuring regular maintenance of powerlines and upkeep of utilities to prevent possible damage from severe wind (Baxter et al., 2013). Property owners should also consider installing shutters as a protection feature to add to windows and doors. Shutters can help reduce damage caused by wind gusts from storms, such as broken glass and wind entering structures. For new constructions, FEMA encourages the use of hip roofs due to their wind resistance ability as well as roof-to-wall connections that will help protect homes and other structures (Baxter et al., 2013). Figure 9 shows visual examples of wind mitigation for residential homes that insurance companies recommend. If expecting a storm, The Florida Chief Financial Officer, Jimmy Patronis suggests tying down loose items to prevent flying objects during storms, especially beach chairs, umbrellas, and other equipment frequently brought to the beach (Plan prepare protect). Strong winds can pick up objects which may cause damage to buildings and potentially injure or cause death to those in an object's path.

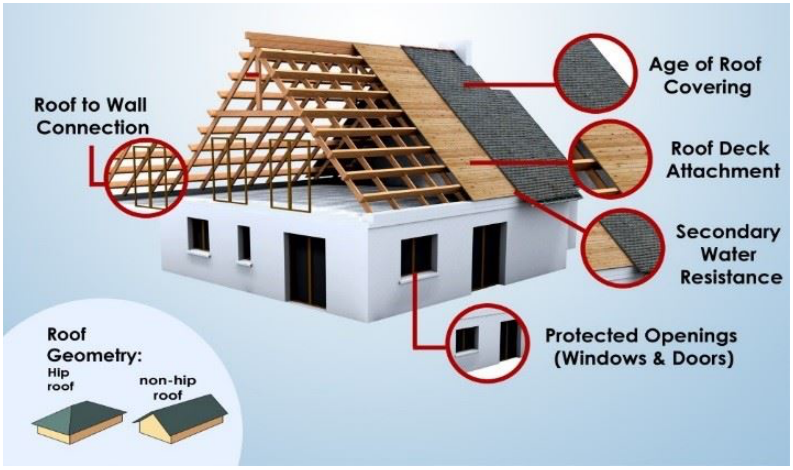

Figure 9: Severe wind mitigation efforts applied to residential home (Tallahassee Real Estate Inspections LLC)

Hailstorms are another potentially dangerous hazard accompanying thunderstorms that Floridians must prepare for with increasing storm strength. To prevent hail-induced building damages, FEMA suggests implementing structural bracing, shutters, laminated glass in windowpanes, and hail-resistant roof coverings (Baxter et al., 2013).

Although hail may not be a thunderstorm hazard that is familiar to state of Florida, tornadoes are. The National Weather Service defines a tornado as "a violently rotating column of air touching the

ground, usually attached to the base of a thunderstorm (NWS, 2015). The expected increase of severe storms means a possibility for more tornadoes to occur. According to FEMA, tornadoes typically cause the most significant damage to structures of light construction, including residential dwellings and mainly manufactured homes" (Baxter et al., 2013). FEMA recommends and encourages the building of safe rooms, however, in coastal communities' safe rooms are at high risk of flooding. Residents should follow severe wind mitigation efforts to protect building from tornadoes and hail formed within severe thunderstorms.

There are several safety concerns for locals, and especially tourists during the warm months in the Florida panhandle. Each year, beach communities experience an increase in population and tourists. Dani Travis, a multimedia journalist for Panama City Beach, reported that in 2021, tourism numbers were up 50% over pre-pandemic numbers, which was an overall record-breaking tourism year for Panama City Beach (Travis, 2022). Not only are there frequented visitors, but the panhandle is also experiencing a surge in residents, despite high market values. Johnathan Truma et al. conducted research to determine the impact of climate change on the Florida Panhandle. They concluded that "as temperatures continue to warm up more and more population will move to Florida and especially the panhandle as southern Florida has reached built-up status and become overpopulated" (Truma et al. 2011). Figure 10 estimates projected population of residents with Florida panhandle counties. Due to the high population and the "many outdoor activities taking place during the afternoon and evening, a prime time for summer thunderstorms, it is easy to see why [thunderstorms] can be so dangerous," according to the National Weather Service of Melbourne, FL (NWS Melbourne Lighting Rules, 2015). Because storms are predicted to become more intense, lightning fatalities and other injuries induced by thunderstorm hazards will increase if education and mitigation strategies are not implemented.

POPULATION IN 2002 AND PROJECTED (2010 THROUGH 2030) (IN THOUSANDS)

COUNTY	Estimate 2002	2010	2015	2020	2025	2030
ESCAMBIA	299.5	347.2	375.4	404.7	434.9	465.5
OKALOOSA	177.0	219.6	245.7	273.2	301.7	330.8
SANTA ROSA	61.1	80.9	93.5	107.1	121.4	136.2

Figure 10: Population in 2002 and projected population 2010 through 2030 in thousands (Truma et al. 2011)

Florida's panhandle should brace itself for stronger and perhaps deadly afternoon thunderstorms. The summer months are when panhandle population is at its peak and engaged in outdoor activities. Property rentals in beach communities should educate their renters about thunderstorm dangers and safety precautions before visiting the Florida panhandle. Many tourists come from places in the United States where thunderstorms are uncommon, therefore, visitors may be unaware of the possible dangers associated with summer thunderstorms. As coastal cities expand to accommodate a growing population, thunderstorm mitigation and education must be addressed to raise public awareness and education about thunderstorms. Education is particularly important as the environment continues to warm and thunderstorms have the potential to intensify in the future.

Each year, I visit beach towns with my family and have observed the population growth and the expansion of beach communities. I propose that large hotels or resorts implement the lightning horn to give tourists time to pack their belongings and prepare to seek shelter from an approaching storm. Tourists visiting the panhandle's stunning beaches must frequently monitor weather forecasts and the sky around them when participating in outside activities. The weather forecast is difficult to predict along the coast due to the environment's fluctuation; yet it aids in awareness and can assist beachgoers in understanding the possibility of thunderstorms. Additionally, coastal towns must initiate education campaigns on thunderstorm threats and safety measures. My favorite vacation destination is the Florida panhandle, and I want to ensure that beaches remain safe in the future.

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