Journal of Geoscience and Environment Protection, 2023, 11, 13-27
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Weathering the Storm: Mitigating Hurricanes with Ground-Based CCN and Lightning

Venkata Chaganti, Murali Krishna Cheruvu

Akshara Yantra LLC, Irving, TX, USA
Email: vc@aksharayantra.com

How to cite this paper: Chaganti, V., & Cheruvu, M. K. (2023). Weathering the Storm: Mitigating Hurricanes with Ground-Based CCN and Lightning. *Journal of Geoscience and Environment Protection, 11,* 13-27.
https://doi.org/10.4236/gep.2023.1112002

Received: November 10, 2023
Accepted: December 5, 2023
Published: December 8, 2023

Abstract

This research introduces a groundbreaking methodology aimed at mitigating storm and hurricane intensity through the application of a ground-based, manually operated Cloud Condensation Nuclei (CCN) Generator. To meet the demand for more comprehensive context and rationale, this study explores the escalating challenges presented by the growing intensity of hurricanes, exemplified by Hurricane IAN (2022). The controlled release of environmentally friendly aerosols into the atmosphere, achieved by combusting selected wood pieces and organic edible materials, is a pivotal response to the escalating threat of extreme weather events. By generating CCN, the novel approach seeks to augment positive lightning in the eyewall, providing a potential solution to the intensification of hurricanes. Results illustrate the successful implementation of the methodology, with released aerosols effectively reaching the clouds for seeding, thus contributing to the modification of convection in the outer wall of Hurricane IAN and consequent intensity reduction. Rigorous experiments, incorporating considerations of various parameters such as wind patterns and the experimental location in Sarasota City, emphasize the scientific rigor applied to weakening Hurricane IAN. This comprehensive approach not only holds promise in mitigating hurricane intensity but also sheds light on the potential impact of cloud seeding in reducing the severity of future hurricanes, addressing a critical need for sustainable solutions to climate-related challenges.

Keywords

IAN 2022, Hurricane Mitigation, Lightning, Aerosol, Cloud Condensation Nuclei (CCN)

1. Introduction

It is anticipated that Hurricane IAN's (2022) impact will be on par with or exceed the levels of storms such as Andrew, Charley, Wilma, Irma, and Michael, all of which caused damage costs exceeding $ 20 billion (USD) (source: National Centers for Environmental Information). Researchers at the International Hurricane Research Center (IHRC) have recently conducted a study aimed at mitigating the adverse impacts of hurricanes on residential buildings and other structures (Leatherman et al., 2007). The economic impact of climate-related disasters in the United States of America has exceeded $ 600 billion over the last five years (2016-2020) (Smith, 2021).

David Alexander suggested that the real-time integration of satellites, microcomputers, communication satellites, and other technologies could enhance natural disaster management (Alexander, 1991). According to a report, the behavior of hurricanes can be influenced by atmospheric and oceanic conditions in their surroundings (Merrill, 1988). Furthermore, Laska and Morrow highlighted the influence of social vulnerability on the outcomes of natural disasters, such as hurricanes (Laska & Morrow, 2006). They emphasized the need to consider automated decision support systems utilizing computer technology for hurricane mitigation planning (Berke & Stubbs, 1989). Defu Liu and Fengqing Wang conducted a study on a statistical prediction model for typhoon-induced wave height and wind speed. They emphasized the significance of conducting risk assessments for design codes related to coastal defense infrastructures (Liu & Wang, 2019).

Hurricanes and storms can cause various destructive effects, including tornadoes, heavy rains, winds, thunder, and hail. These disturbances in the environment can result in property damage, harm to lives, and widespread flooding. It was reported that Hurricane Wilma in October 2005 caused $ 16 billion in damages in South Florida, USA (Leatherman, 2011). Additionally, Hutton emphasized the importance of electricity maintenance and restoration after hurricane disasters to preserve the well-being and health of people relying on life-sustaining medical equipment (Hutton & Allen, 2020). To remotely monitor man-made structures during hurricane events, a distributed software system was developed (Otero, 2009).

To effectively mitigate hurricane-induced damages, English, Friedland, and Orooji suggested employing amphibious construction techniques that can reduce flood damage without vulnerability to wind (English et al., 2017). Additionally, a study emphasized the importance of focusing on IT research areas for emergency management and crisis support during extreme events (Jefferson, 2006).

Kerry Emanuel's hypotheses propose that the maintenance and intensification of tropical cyclones depend on self-induced heat transfer from the ocean (Emanuel, 1986). Furthermore, it has been observed that industrial air pollution increases the intensities of storms and hurricanes due to enhanced heat and water condensation (Fritts, 2020). Sarah Gibbens noted that climate change and global warming contribute to the rapid intensification of storms and hurricanes

(Gibbens, 2020).

Various experimental and simulated studies have explored the effects of aerosols on storm systems. Sea-salt aerosols were observed to impact the structure and precipitation of developed tropical cyclones, leading to changes in warm core structure, precipitation distribution, and convective precipitation (Luo et al., 2019). Additionally, anthropogenic aerosols were found to decrease the cloud effective radius, thereby suppressing warm cloud precipitation, and releasing latent heat (Khain et al., 2010; Rosenfeld & Woodley, 2000; Rosenfeld et al., 2008; Andreae et al., 2004). These aerosols act as Cloud Condensation Nuclei (CCN) and facilitate the transport of cloud water to the freezing layer.

Project STORMFURY conducted artificial modification by stimulating convection outside the hurricane/storm eyewall through silver iodide seeding, resulting in decreased wind speeds on certain days. The authors argued that this stimulated convection competes with the convection in the original eyewall, leading to changes in the eyewall's radius and subsequent decreases in wind speed. They emphasized that even a 10% reduction in wind speed can significantly mitigate the damage caused by hurricanes (Willoughby et al., 1985).

Drawing from insights gained in the STORMFURY project, Daniel Rosenfeld's findings indicate that simulated numerical models demonstrated the potential for aerosols responsible for cloud condensation to weaken storms. The study encompassed a range of land and ocean aerosols, such as Black Carbon, Organic Carbon, Dust, Sea Salt, and Sulphates, in its simulations (Rosenfield et al., 2011).

Research has shown that anthropogenic aerosols discharged from land can enhance the convective precipitation rate at the periphery of Tropical Cyclones, as supported by research work (Jiang et al., 2016). This finding aligns with our existing research efforts aimed at artificially modifying the convection in the outer wall of hurricanes.

Griffith introduced a ground-based, manually operated Silver Iodide generator for winter cloud seeding to induce snowfall. Their approach utilized a seeding solution composed of a 3% solution of silver iodide complexed with sodium iodide and paradichlorobenzene, dissolved in acetone. This mixture was then burned in a propane flame (Griffith et al., 2009).

It was analyzed that the intense lightning activity during the eruption of Hunga Volcano in Tonga in January 2022, attributing it to the exceptional mass eruption rate that rapidly expanded and entrained abundant seawater, leading to its vaporization through magma-water interaction. The findings show that a sufficiently powerful volcanic plume can create the conditions for electrical activity (Van Eaton et al., 2023).

(Latham & Williams, 2001) reported that the efficiency of lightning fires is less than 0.04 fires per cloud-to-ground flash or approximately one to four flashes in 100 starting fires in much of North America. Wildfires have the capability to generate their own thunderstorms, as noted by AccuWeather Meteorologist

Jordan Root (Schmidt, 2023). He explains, "The hot air generated by a wildfire will rise and create an updraft. As the air rises, moisture will cool and condense into tiny water droplets on the ash creating a cloud".

Chris Vagasky, a meteorologist with Vaisala (Lee, 2022), an environmental measurement company that owns and operates the National Lightning Detection Network, emphasizes the three necessary components for this phenomenon: moisture, instability, and a source of lift.

Laboratory and field experiments (NASA, 2010) have revealed that the core of certain lightning bolts can reach temperatures of up to 30,000 Kelvin (53,540 °F), which is hot enough to instantly melt sand and break oxygen and nitrogen molecules into individual atoms.

Hurricanes with lightning, maximum sustained winds and lightning frequency are significantly correlated (Price et al., 2009).

Through the study of lightning, a team of NASA scientists is striving to develop innovative methods for forecasting the intensity of impending hurricanes (NASA, 2021). Traditionally, an escalation in lightning activity within a storm signifies the likelihood of its strengthening. However, there are instances where even weakening hurricanes experience significant lightning outbreaks, necessitating meticulous analysis of supplementary data for accurate predictions regarding a hurricane's intensity.

Zhang reported that an increase in the percentage of positive lightning in the eyewall during an outbreak may suggest an imminent period of storm weakening (Zhang et al., 2012). They also noted that lightning is observed across all storm intensity change categories: rapid intensification (RI), average intensity change (AIC), and rapid weakening (RW) (Zhang et al., 2015). The differences in Lightning Density (LD) between RI and RW are largest in the inner core, with LD for RI cases being larger than for RW cases in the inner core (0 - 100 km).

Chaganti and Cheruvu, described an experimental methodology to weaken the intensity of storms and hurricanes by utilizing a ground-based manually operated Cloud Condensation Nuclei (CCN) Generator (Chaganti & Cheruvu, 2022).

In this paper we consider the research works (Van Eaton et al., 2023; Latham & Williams, 2001; I; II; III; Price et al., 2009; NASA, 2021; Zhang et al., 2012; Zhang et al., 2015; Chaganti & Cheruvu, 2022) and present our work to show the mitigation of Hurricane IAN (2022) in the Sarasota City, Florida, USA where we performed our experiments.

2. Materials and Methods

The motivation of our experiments is based on the following research factors:

- A sufficiently powerful volcanic plume can create conditions conductive to electrical activity (Van Eaton et al., 2023).
- An increase in the percentage of positive lightning in the eyewall during an outbreak may indicate an impending period of storm weakening (Zhang et al., 2012).

- Employ an experimental methodology aimed at reducing the intensity of storms and hurricanes by utilizing a ground-based manually operated Cloud Condensation Nuclei (CCN) Generator (Chaganti & Cheruvu, 2022).

To achieve these factors, it is necessary to release a substantial quantity of plume before the hurricane arrives in the experiment vicinity. As the hurricane's outer wall and eyewall encounter the plume first, there is a high likelihood of creating conditions conducive to electrical activity and an increase in the percentage of positive lightning in the hurricane's eyewall. Our chosen method, as outlined in (Chaganti & Cheruvu, 2022), involves generating large amounts of ground-based Cloud Condensation Nuclei (CCN) in the form of smoke (plume) using a manual generator, which burns organic materials in significant quantities following a systematic procedure. The process for generating substantial quantities of CCN is detailed below.

2.1. Cloud Condensation Nuclei Generator

In our research endeavors, we have undertaken a series of experiments involving the release of environmentally friendly aerosols into the atmosphere. The primary objective of these experiments is to generate cloud condensation nuclei (CCN) through controlled burning of specific wood pieces from designated trees and certain organic edible materials. This innovative approach aims to mitigate storm intensity by artificially modifying the convection of the hurricane's outer wall and increasing the percentage of positive lightning in the eyewall during an outbreak (Jiang et al., 2016; Griffith et al., 2009; Van Eaton et al., 2023; Latham & Williams, 2001; Schmidt, 2023; Lee, 2022; NASA, 2010; Price et al., 2009; NASA, 2021; Zhang et al., 2012; Zhang et al., 2015; Chaganti & Cheruvu, 2022).

As previously described in the research paper (Chaganti & Cheruvu, 2022), we are replicating the same procedure in this study, utilizing a copper fire pit with specific dimensions: 30 inches in diameter, 9 inches in depth, and approximately 2 mm in thickness (refer to **Figure 1**).

Figure 1. Ground based CCN Generator.

2.2. Maintaining the Integrity of the Specifications

We conducted three experiments involving the burning and release of CCN, each lasting approximately 90 minutes. In each session, we introduced a predetermined quantity of material into the fire pit at regular intervals of 10 to 20 seconds. These sessions took place on the evening of September 26, 2022, from 6:00 PM to 7:30 PM; the morning of September 27, 2022, from 7:00 AM to 8:30 AM; and the evening of September 27, 2022, from 6:00 PM to 7:30 PM. Although each experiment was conducted over a 90-minute period, the burning process continued for approximately 24 hours. Consequently, we utilized distinct fire pits for each of the three experiments.

According to the Earth Observatory of the National Aeronautics and Space Administration (NASA), smoke from forest fires can ascend to altitudes of 2 to 3 km and spread up to 300 km in the direction of the prevailing wind, while descending up to 1 km (NASA Earth Observatory, 2018). As the smoke rises, its volume increases due to cooling caused by lower density at higher altitudes. During this ascent, smoke particles can act as cloud condensation nuclei (CCN) if they possess hygroscopic properties, potentially leading to cloud formation at those elevations.

The dispersion of smoke is influenced by various factors, including surface winds, relative humidity, temperature, atmospheric stability, mixing height, transport winds, long-range transport, down drainage, plume rise, and dispersion index (*"Fire Weather Definitions"*, 2023).

Given the substantial number (amount) of materials burned as detailed in (Chaganti & Cheruvu, 2022), an abundant quantity of plumes is generated, ascending to significant heights. The cloud condensation nuclei (CCN) produced in our experiments are highly likely to develop into cloud drops at the atmosphere's lifting condensation level (LCL). This process contributes to our comprehension of cloud seeding and its potential influence on reducing storm intensity.

We have meticulously considered parameters such as wind patterns, the experimental location, and the surroundings during our experiments. To minimize any potential disruptions caused by rainwater, the experiments were conducted in an open space with a high roof, protecting the firepit from direct rainfall. Additionally, to mitigate the influence of winds (if present), we arranged temporary wooden protective walls around the experimental setup.

Initially, there was an estimation that Storm IAN 2022 would intensify into a Category 4 hurricane and make landfall near the Tampa Bay region. However, in a later announcement by the National Hurricane Center at approximately 03:05 PM on September 28th, 2022, Hurricane IAN instead struck Cayo Costa, a barrier island located west of Cape Coral and Fort Myers, 50 miles south of Sarasota City, Florida. It made landfall as a Category 4 hurricane (NOAA, 2022a).

3. Results and Analysis

In Sarasota City, FL, USA, we conducted a series of three experiments. The first experiment took place on September 26th, 2022, from 06:00 PM to 07:30 PM. Subsequently, our second experiment was carried out on September 27th, 2022, from 07:00 AM to 08:30 AM. The final experiment was conducted later that day, on September 27th, 2022, from 06:00 PM to 07:30 PM.

On September 26th, 2022, between 06:00 PM and 07:30 PM the wind direction as shown in **Figure 2** was blowing from SE but for the rest of the night it was from East to West.

On September 27th, 2022, between 07:00 AM and 08:30 AM the wind direction as shown in **Figure 3** is blowing from East to West.

On September 27th, 2022, between 06:00 PM and 07:30 PM the wind direction as shown in **Figure 3** was blowing from ENE and most of the night it was blowing from ENE.

On September 28th, 2022, from **Figure 4**, we can deduce that the entire day the wind was almost blowing from NNE.

It is evident from (Van Eaton et al., 2023; Latham & Williams, 2001; I) that rising plumes can create the conditions for electrical activity. If an increase in the percent of positive lightning (Zhang et al., 2012) in the eyewall during an outbreak, it may suggest a coming period of storm weakening. From (Zhang et al., 2015) we understand that if the Lightning Density difference is large between inner core (<100 km) and outer core, then Rapid intensification is more and if it is the other way round then Rapid weakening is possible.

On September 26th and 27th, 2022 we did our experiment and released ground

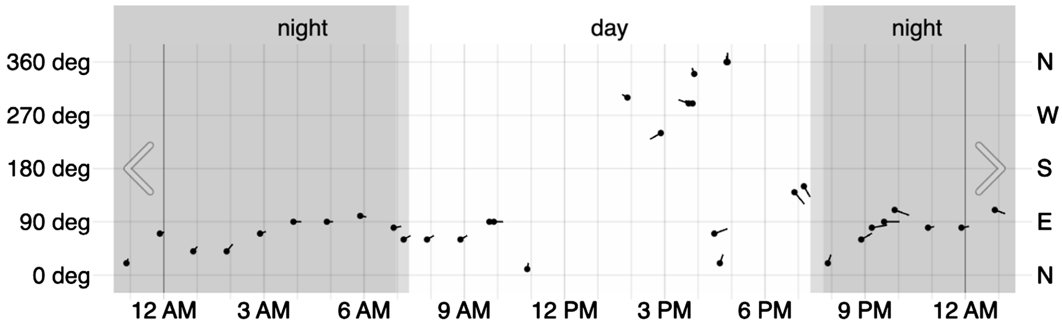

Figure 2. Direction of wind flow in Sarasota City, FL on September 26, 2022 (Courtesy: Sept 26th, 2022, Weather Spark, 2022a).

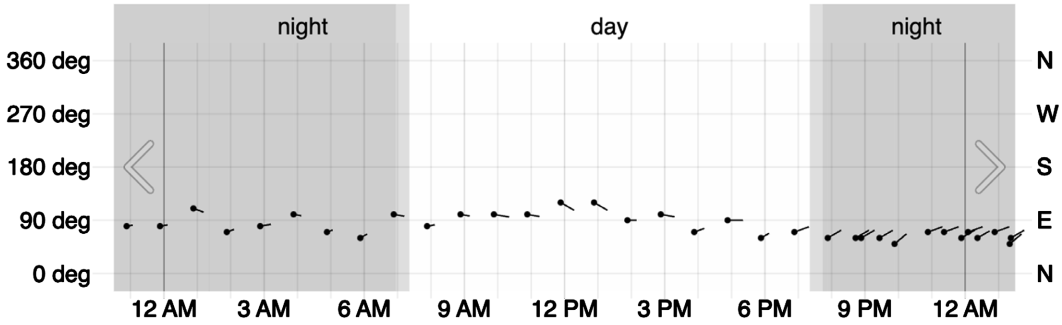

Figure 3. Direction of wind flow in Sarasota City, FL on September 27, 2022 (Courtesy: Sept. 27th, 2022, Weather Spark, 2022b).

based CCN in Sarasota City, FL, USA. The plume was continuously released for 90 minutes in each session with a total of 3 sessions. According to (NASA Earth Observatory, 2018) the smoke can rise (forest burning) to a height of 2 km to 3 km and spread to 300 km in the wind direction while descending 1 km. We expect the burning of the material in our experiment must have reached a similar distance and height.

From **Table 1** we observe that on September 27, 2022, wind speed average was about 10.2 miles per hour and the average direction was ENE. Considering 24 hours of time the plume must have spread from zero to 300 km. As we can see from **Figure 4**, the direction of wind flow on September 28th, 2022, was almost NNE making the plume to be directed to the incoming Hurricane. From (Schmidt, 2023) we understand that the hot air generated by a wildfire will rise and create an updraft. From (Van Eaton et al., 2023) we understand that the particles in the plume cause intense lightning due to a downdraft. An updraft and downdraft cause weakening of the Hurricane's horizontal winds and this causes the Hurricane to weaken.

According to NOAA Hurricane IAN was at the location shown in **Figure 5**. Also, from **Figure 6**, and **Figure 7** we can observe the lightning is present only in the outer wall and the core does not have lightning. Therefore, we see that the difference in the Lightning Density is negative in the core and positive in the eyewall of Hurricane IAN. Also, lightning causes the release of extreme heat and the air expands (NASA, 2010). This causes stimulated convection in the Eyewall/Outer wall of the Hurricane and further weakens the Hurricane (Willoughby et al., 1985).

Table 1. Daily Wind Speeds in Sarasota City, September 2022 (Weather Underground, 2022).

	Wind Speed Max (mph)	Wind Speed Avg (mph)	Wind Speed Min (mph)
Sep 26, 2022	17	6.6	0
Sep 27, 2022	15	10.2	5
Sep 28, 2022	48	31.7	10

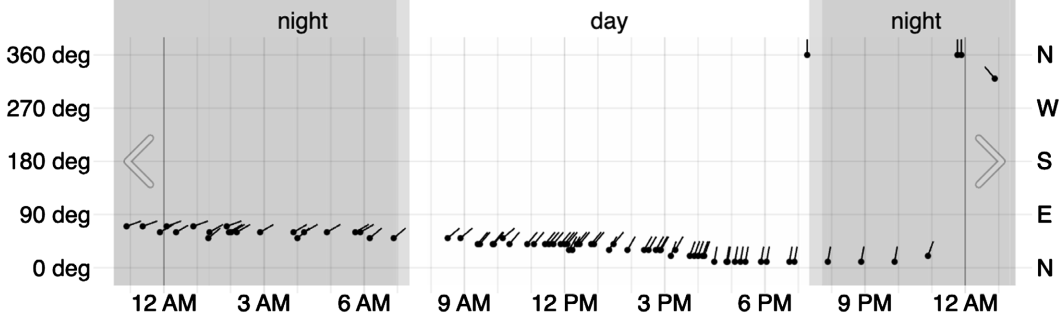

Figure 4. Direction of wind flow in Sarasota City, FL on September 28, 2022 (Courtesy: Sept 28th, 2022, Weather Spark, 2022c).

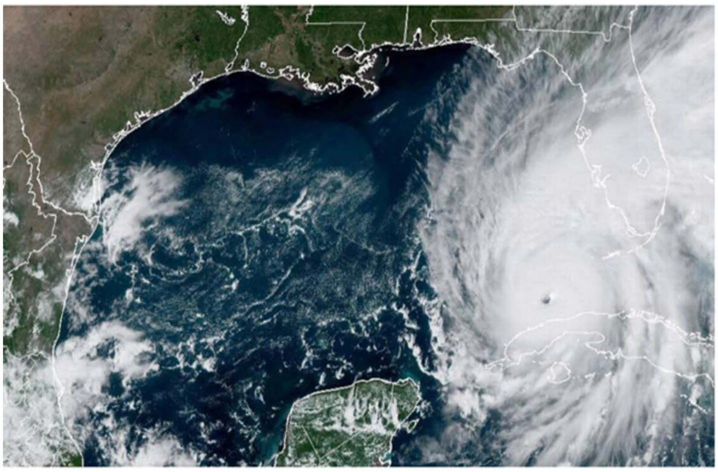

Figure 5. Hurricane IAN has an eye that was 40 miles wide (Karacostas, 2022) and hurricane force winds that extend another 100 miles beyond that (Courtesy NOAA).

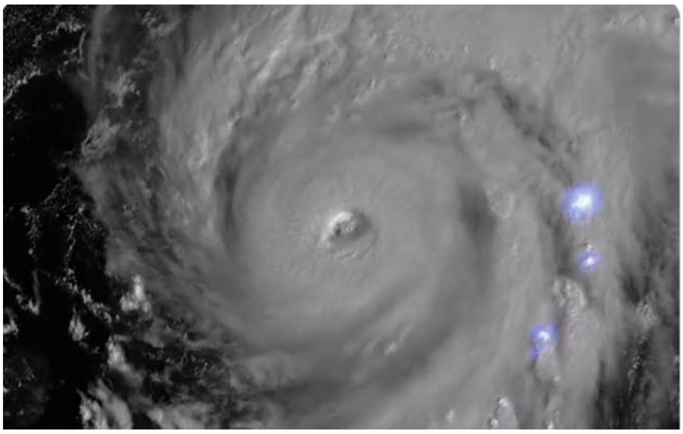

Figure 6. Lightning in the outer walls of Hurricane IAN (courtesy NOAA).

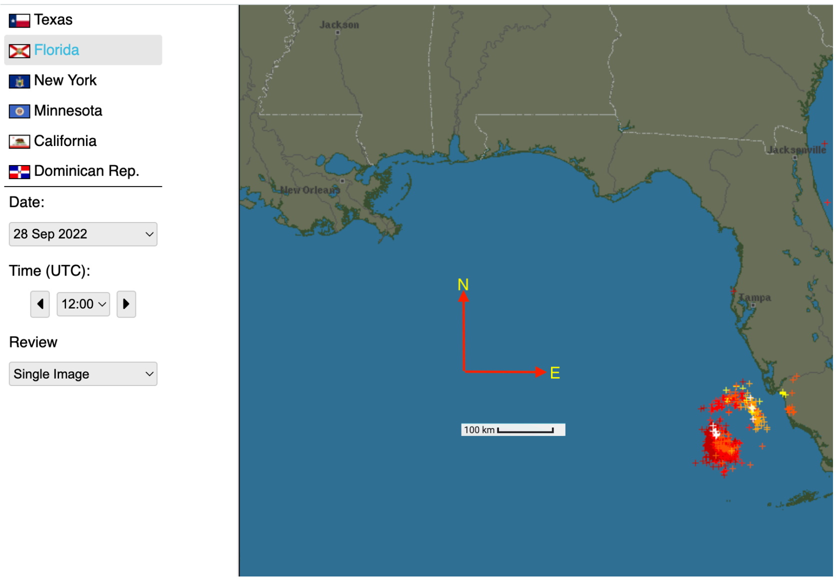

Figure 7. Lightning in the Eyewall of Hurricane IAN on 28th September 2022. (Courtesy: Blitzortung.org, 2022).

This indicates that Hurricane IAN had weakened due to the lightning in the eyewall. This lightning is a definite cause due to the plume that we released in our experiment on September 26th and 27th, 2022 in Sarasota City, FL, USA.

The additional aerosols released by our experiment potentially triggered artificial stimulation outside the hurricane/storm eyewall (Willoughby et al., 1985; Rosenfield et al., 2011; Chaganti & Cheruvu, 2022), resulting in reduced wind speeds and subsequent mitigation of Hurricane IAN in Sarasota City.

We can see the Lightning in the Eyewall (**Figure 6**) and on September 28, 2022, the Eye of the Hurricane (WFLA News Channel 8, 2022) was at about 153 km (**Figure 8**). According to (Zhang et al., 2012), an increase in the percent of positive lightning in the eyewall during an outbreak may suggest a coming period of storm weakening. From (Zhang et al., 2015) we understand that the differences in Lightning Density (LD) between Rapid Intensification (RI) and Rapid Weakening (RW) are largest in the inner core and the LD for RI cases is larger than for RW cases in the inner core (0 - 100 km).

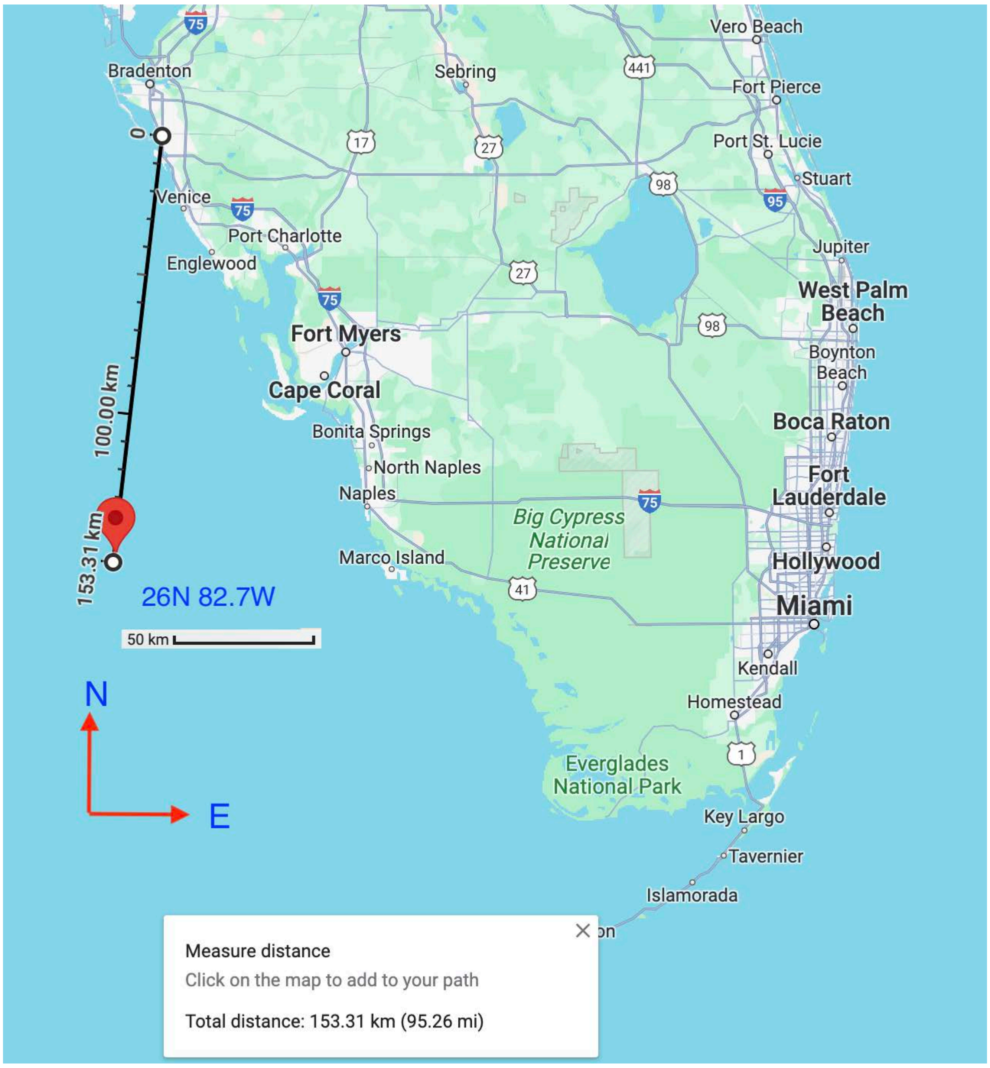

Figure 8. 28th September 2022 at 12 noon UTC (NOAA, 2022b) Hurricane IAN Location Map.

4. Discussion

Our experiments in Sarasota City, FL, USA, instigated an evaluation of the consequences of Hurricane IAN 2002 on the region. Reports indicate minimal damage in Sarasota City, with downed trees and utility lines reported but limited compared to nearby cities (XVII) as depicted in **Figure 9**. Wind speed and precipitation data as shown in **Table 2** further suggest that Sarasota City experienced relatively lower wind speeds and moderate precipitation compared to Punta Gorda, Bradenton, and Tampa.

While these preliminary findings imply a potential correlation between our experiments and reduced damage in Sarasota City, a comprehensive assessment

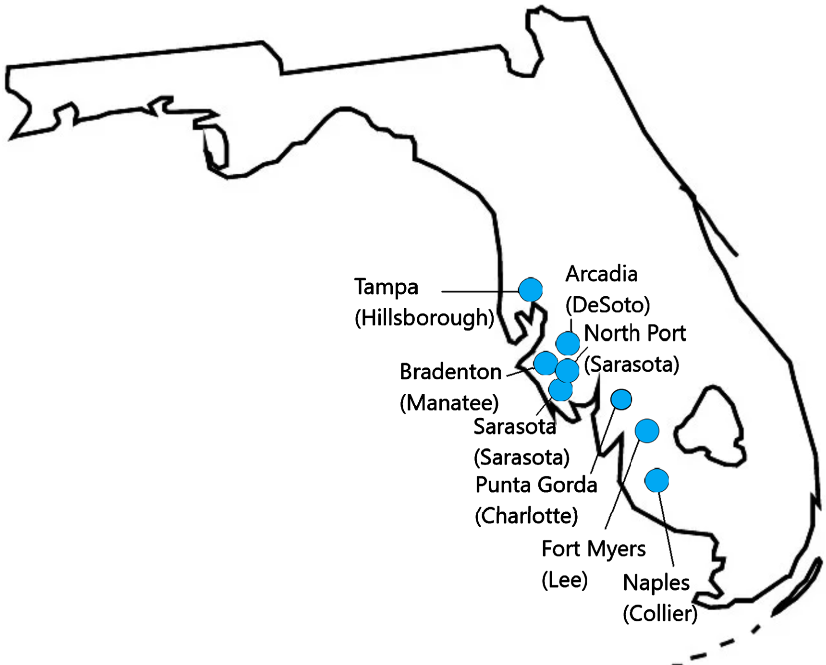

Figure 9. Sarasota and nearby Cities on Florida Map, USA (Courtesy: Florida Map Image by Vectorportal.com).

Table 2. Wind Speed and Precipitation at Sarasota and nearby Cities, September 28, 2022 (Borresen & Procell, 2023).

County	City	Wind Speed (mph)	Precipitation (inch)
Charlotte	Punta Gorda	145	23
Lee	Fort Myers	most damage	-
Collier	Naples	most damage	-
Manatee	Bradenton	86	10
DeSoto	Arcadia	-	16.8
Hillsborough	Tampa	75	-
Sarasota	North Port	-	21
Sarasota	Sarasota	50	-

requires considering local infrastructure, preparedness, and additional factors beyond weather conditions. Further investigation into cities with missing data is essential for drawing comprehensive conclusions about the overall impact.

5. Conclusion

In conclusion, the groundbreaking experimental methodology employing a ground-based Cloud Condensation Nuclei (CCN) Generator has demonstrated promising results in mitigating Category 4 Hurricane IAN (2022)'s intensity in and around Sarasota City, FL, USA. Through controlled burning of selected wood pieces and organic edible materials in the CCN Generator, environmentally friendly aerosols were released into the atmosphere, effectively seeding the clouds during Hurricane IAN. The aerosols' successful integration into the hurricane's eyewall was evidenced by the observed increase in positive lightning during the hurricane's outbreak. This was substantiated by comparing lightning density patterns, indicating that the plume's introduction contributed to the weakening of Hurricane IAN. Our experiments must have potentially reduced the wind speeds subsequently mitigating Hurricane IAN via induced convection in Sarasota City. This novel approach showcases the potential of CCN Generation to influence hurricane dynamics, resulting in a weakening effect on catastrophic hurricanes. The experiment's careful consideration of various parameters including the wind patterns emphasizes the significance of a well-designed approach for future hurricane intensity reduction strategies. Subsequent reports on the aftermath of Hurricane IAN in Sarasota City reinforced the idea that the experiment had lessened the hurricane's impact, as evidenced by the limited damage in the city compared to the substantial destruction observed in nearby cities. This research contributes to our understanding of environmentally friendly cloud seeding and its impact on hurricane intensity, further studies are warranted to refine the technique and enhance our preparedness for dealing with future hurricanes with the potential to protect widespread destruction and economic losses.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

"Fire Weather Definitions". https://www.weather.gov/gum/fireweatherdefinitions

Alexander, D. (1991). Information Technology in Real-Time for Monitoring and Managing Natural Disasters. *Progress in Physical Geography, 15,* 238-260. https://doi.org/10.1177/030913339101500302

Andreae, M. O., Rosenfeld, D., Artaxo, P., Costa, A. A., Frank, G. P., Longo, K. M., & Silva-Dias, M. A. F. (2004). Smoking Rain Clouds over the Amazon. *Science, 303,* 1337-1342. https://doi.org/10.1126/science.1092779

Berke, P., & Stubbs, N. (1989). Automated Decision Support Systems for Hurricane Mitigation Planning. *Simulation, 53,* 101-109. https://doi.org/10.1177/003754978905300304

Blitzortung.org (2022). *Network for Lightning and Thunderstorms in Real Time*. https://www.blitzortung.org/en/historical_maps.php?map=32

Borresen, J., & Procell, C. (2023). Ian's Deadly Path: A Visual Look at How the Hurricane Devastated Florida Region by Region. *USA Today*. https://www.usatoday.com/in-depth/graphics/2023/01/09/hurricane-ian-destruction-in-florida/10938513002/

Chaganti, V., & Cheruvu, M. (2022). An Experimental Methodology for Storm Mitigation. *Atmospheric and Climate Sciences, 12,* 648-678. https://doi.org/10.4236/acs.2022.124037

D. Latham, & E. Williams (2001). Chapter 11. Lightning and Forest Fires. In E. A. Johnson, & K. Miyanishi (Eds.), *Forest Fires* (pp. 375-418). Academic Press. https://doi.org/10.1016/B978-012386660-8/50013-1

Emanuel, K. A. (1986). An Air-Sea Interaction Theory for Tropical Cyclones. Part I: Steady-State Maintenance. *American Meteorological Society, 43,* 585-604. https://doi.org/10.1175/1520-0469(1986)043<0585:AASITF>2.0.CO;2

English, E. C., Friedland, C. J., & Orooji, F. (2017). Combined Flood and Wind Mitigation for Hurricane Damage Prevention: The Case for Amphibious Construction. *Journal of Structural Engineering, 143,* Article ID: 06017001. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001750

Fritts, R. (2020). *To Make Better Hurricane Models, Consider Air Pollution*. EOS. https://doi.org/10.1029/2020EO153044

Gibbens, S. (2020). *Did Climate Change Drive 2020's Epic Hurricane Season? It's Complicated*. National Geographic. https://www.nationalgeographic.com/environment/article/did-climate-change-drive-2020-historic-hurricane-season

Griffith, D. A., Solak, M. E., & Yorty, D. P. (2009). 30+ Winter Seasons of Operational Cloud Seeding in Utah. *Journal of Weather Modification, 41,* 23-37.

Hutton, N. S., & Allen, M. J. (2020). Challenges in Upgrading Emergency Power in Florida Nursing Homes following Hurricane Irma. *Weather, Climate, and Society, 12,* 805-814. https://doi.org/10.1175/WCAS-D-19-0064.1

Jefferson, T. L. (2006). Evaluating the Role of Information Technology in Crisis and Emergency Management. *VINE, 36,* 261-264. https://doi.org/10.1108/03055720610703542

Jiang, B., Huang, B., Lin, W., & Xu, S. (2016). Investigation of the Effects of Anthropogenic Pollution on Typhoon Precipitation and Microphysical Processes Using WRF-Chem. *Journal of the Atmospheric Sciences, 73,* 1593-1610. https://doi.org/10.1175/JAS-D-15-0202.1

Karacostas, C. (2022). *How Big Is Hurricane Ian? The Massive Storm Is Twice as Wide as the Florida Peninsula*. Bradenton Herald. https://www.bradenton.com/news/weather-news/article266451551.html

Khain, A., Lynn, B., & Dudhia, J. (2010). Aerosol Effects on Intensity of Landfalling Hurricanes as Seen from Simulations with the WRF Model with Spectral Bin Microphysics. *Journal of the Atmospheric Sciences, 67,* 365-384. https://doi.org/10.1175/2009JAS3210.1

Laska, S., & Morrow, B. H. (2006). Social Vulnerabilities and Hurricane Katrina: An Unnatural Disaster in New Orleans. *Marine Technology Society Journal, 40,* 16-26. https://doi.org/10.4031/002533206787353123

Leatherman, S. P. (2011). Hurricane Wind Damage Mitigation: Research and Outlook. *Natural Hazards Review, 12,* 202-206. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000048

Leatherman, S. P., Chowdhury, A. G., & Robertson, C. J. (2007). Wall of Wind Full-Scale Destructive Testing of Coastal Houses and Hurricane Damage Mitigation. *Journal of Coastal Research, 23,* 1211-1217. https://doi.org/10.2112/07-0829.1

Lee, J. (2022). *Lightning Is Extremely Rare in the Bay Area. But Here's Why It Can Be So Dangerous When It Strikes*. https://www.sfchronicle.com/projects/2022/weather-lightning/

Liu, D. F., & Wang, F. Q. (2019). Typhoon/Hurricane/Tropical Cyclone Disasters: Prediction, Prevention, and Mitigation. *Journal of Geoscience and Environment Protection, 7,* 26-36. https://doi.org/10.4236/gep.2019.75003

Luo, H., Jiang, B. L., Li, F. Z., & Lin, W. S. (2019). Simulation of the Effects of Sea-Salt Aerosols on the Structure and Precipitation of a Developed Tropical Cyclone. *Atmospheric Research, 217,* 120-127. https://doi.org/10.1016/j.atmosres.2018.10.018

Merrill, R. T. (1988). Environmental Influences on Hurricane Intensification. *Journal of Atmospheric Sciences, 45,* 1678-1687. https://doi.org/10.1175/1520-0469(1988)045<1678:EIOHI>2.0.CO;2

NASA (2010). *Laboratory for Atmospheres 2009 Technical Highlights* (p. 124). https://ntrs.nasa.gov/api/citations/20100033215/downloads/20100033215.pdf

NASA (2021). *Scientists Use Lightning to Help Predict Hurricane Intensity.* https://www.weathernationtv.com/news/nasa-scientists-use-lightning-to-help-predict-hurricane-intensity

NASA Earth Observatory (2018). *How the Smoke Rises*. https://earthobservatory.nasa.gov/images/144658/how-the-smoke-rises

National Centers for Environmental Information. *September 2022 National Climate Report*. https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202209/supplemental/page-5

NOAA (2022a). *Hurricane Ian Tropical Cyclone Update. Sept. 28, 2022, 1200 PM.* https://www.nhc.noaa.gov/archive/2022/al09/al092022.update.09281557.shtml

NOAA (2022b). *Hurricane Ian Tropical Cyclone Update. Sept. 28, 2022, 310 PM.* https://www.nhc.noaa.gov/archive/2022/al09/al092022.update.09281909.shtml

Otero, C. E. (2009). Real-Time Monitoring of Hurricane Winds Using Wireless and Sensor Technology. *Journal of Computers, 4,* 1275-1285. https://doi.org/10.4304/jcp.4.12.1275-1285

Price, C., Asfur, M., & Yair, Y. (2009). Maximum Hurricane Intensity Preceded by Increase in Lightning Frequency. *Nature Geoscience, 2,* 329-332. https://doi.org/10.1038/ngeo477

Rosenfeld, D., & Woodley, W. L. (2000). Convective Clouds with Sustained Highly Supercooled Liquid Water Down to 37˚C. *Nature, 405,* 440-442. https://doi.org/10.1038/35013030

Rosenfeld, D., Lohmann, U., Raga, G. B., O'Dowd, C. D., Kulmala, M., Fuzzi, S., Reissell, A., & Andreae, M. O. (2008). Flood or Drought: How do Aerosols Affect Precipitation? *Science, 321,* 1309-1313. https://doi.org/10.1126/science.1160606

Rosenfield, D., Clavner, M., & Nirel, R. (2011). Pollution and Dust Aerosols Modulating Tropical Cyclones Intensities. *Atmospheric Research, 102,* 66-76. https://doi.org/10.1016/j.atmosres.2011.06.006

Schmidt, A. (2023). *How Destructive Wildfires Create Their Own Weather*. https://www.accuweather.com/en/weather-news/how-destructive-wildfires-create-their-own-weather/346337

Smith, A. B. (2021). *2020 U.S. Billion-Dollar Weather and Climate Disasters in Historical Context*. Climate.gov.

Van Eaton, A. R., Lapierre, J., Behnke, S. A., Vagasky, C., Schultz, C. J., Pavolonis, M. et al. (2023). Lightning Rings and Gravity Waves: Insights into the Giant Eruption Plume from Tonga's Hunga Volcano on 15 January 2022. *Geophysical Research Letters, 50,* e2022GL102341. https://doi.org/10.1029/2022GL102341

Weather Spark (2022a). *September 26, 2022 Weather History in Sarasota*. https://weatherspark.com/h/d/16875/2022/9/26/Historical-Weather-on-Monday-September-26-2022-in-Sarasota-Florida-United-States#Figures-WindDirection

Weather Spark (2022b). *September 27, 2022 Weather History in Sarasota*. https://weatherspark.com/h/d/16875/2022/9/27/Historical-Weather-on-Tuesday-September-27-2022-in-Sarasota-Florida-United-States#Figures-WindDirection

Weather Spark (2022c). *September 28, 2022 Weather History in Sarasota*. https://weatherspark.com/h/d/16875/2022/9/28/Historical-Weather-on-Wednesday-September-28-2022-in-Sarasota-Florida-United-States#Figures-WindDirection

Weather Underground (2022). *Sarasota, FL Weather History*. https://www.wunderground.com/history/monthly/us/fl/sarasota/KSRQ/date/2022-9

WFLA News Channel 8 (2022). https://www.facebook.com/watch/?v=815849529437898

Willoughby, H. E. et al. (1985). Project STORMFURY: A Scientific Chronicle 1962-1983. *Bulletin of the American Meteorological Society, 66,* 505-514. https://doi.org/10.1175/1520-0477(1985)066<0505:PSASC>2.0.CO;2

Zhang, W. J., Zhang, Y. J., Zheng, D., & Zhou, X. J. (2012). *Lightning Distribution and Eyewall Outbreaks in Tropical Cyclones during Landfall*. American Meteorological Society. https://doi.org/10.1175/MWR-D-11-00347.1

Zhang, W., Zhang, Y., Zheng, D., Wang, F., & Xu, L. (2015). Relationship between Lightning Activity and Tropical Cyclone Intensity over the Northwest Pacific. *Journal of Geophysical Research: Atmospheres, 120,* 4072-4089. https://doi.org/10.1002/2014JD022334