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An Experimental Methodology for Storm Mitigation

Venkata Chaganti, Murali Krishna Cheruvu

Akshara Yantra LLC, Irving, USA
Email: v.chaganti@aksharayantra.com

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Abstract

There are many theoretical explanations for the mitigation of tornados, storms, and hurricanes and one or two known simulation models that address the reduction of the intensities of these forces. We introduce an innovative methodology that releases environmentally friendly aerosol particles responsible for cloud condensation and weakens the intensities of these forces. For the past nine years, we did several experiments and analyzed the results. Experimental results give evidence to this methodology is practical, environment-friendly, cost-effective, and consistent. In this paper, we described our experiments along with results in three different scenarios such as tornado (March 2021, Georgia USA), storm Claudette (June 2021, Georgia USA), and hurricane Elsa (July 2021, Florida USA). Our experimental outcome and subsequent relevant meteorology data support the reason for mitigating the intensity of these destructive forces in and around the experiment locations.

Keywords

Storm Mitigation, Hurricane Mitigation, Tornado Mitigation, Claudette 2021, Elsa 2021, Aerosol

1. Introduction

Storms and Hurricanes can cause tornadoes, heavy rains, wind, thunder, hail, etc., causing a disturbance in the environment and damaging property, harming lives, and producing flooding. The international hurricane research center (IHRC) reported new research to mitigate hurricane-induced effects on residential buildings and other structures [1]. For hurricane mitigation planning, Philip *et al.* [2] have considered automated decision support systems using computer technology. Shirley *et al.* [3] gave evidence that social vulnerability influenced outcomes of natural disasters such as hurricanes. $16 billion in damages were caused by hurricane Wilma in October 2005 in South Florida according to the author Stephen [4]. Nicole *et al.* [5] reported that electricity maintenance and restoration after a hurricane disaster helps preserve the well-being and health of people on life-sustaining medical equipment. A study [6] indicated that in case of extreme events, information on emergency management and crisis support focus should be in the IT research areas.

David Alexander [7] opines that if real-time integration of satellites, microcomputers, communication satellites, etc., is done then it will be useful for natural disaster management. To remotely monitor the man-made structures under the effects of hurricane winds, distributed software was developed [8]. Defu Liu *et al.* [9] studied on statistical prediction model of typhoon-induced wave height and wind speed and regarded that high importance should be given to the risk assessment of some design codes for coastal defense infrastructures. Elizabeth *et al.* [10] suggested that to mitigate hurricane damage, amphibious construction could reduce flood damage without being vulnerable to wind. It was reported [11] that depending on the conditions of their atmospheric and oceanic surroundings hurricanes can be regulated. Kerry Emanuel's [12] hypotheses predict that the maintenance and intensification of tropical cyclones depend on the self-induced heat transfer from the ocean.

Rachel Fritts [13] observed that industrial air pollution would increase the intensities of storms and hurricanes as more pollution will create more heat and condense the water. Sarah Gibbens [14] noted that Climate Change and Global Warming make the intensities of the storms and hurricanes much more rapid as observed in eight of the storms in 2020 had increased wind speeds of 35 mph in less than 24-hour periods. As Adam [15] noted, if we take the last five years (2016-2020) into consideration, climate disasters in the United States of America exceed $600 billion.

Project STORMFURY [16] used an artificial modification of stimulation outside the hurricane/storm eyewall through silver iodide seeding on eight different days in four hurricanes and observed that the winds decreased between 10% - 30% on four of these days. It was argued that the artificially stimulated convection would compete with the convection in the original eye wall. This would cause a change in the radius of the eye wall leading to a decrease in the wind speed. The authors further argued that even a 10% decrease in the wind speed would decrease the damage to a greater extent. As a booster to this project's details, Daniel *et al.* [17] reported that the simulated numerical models showed aerosols responsible for cloud condensation can weaken the storms. The report said that the land and ocean aerosols (Black Carbon, Organic Carbon, Dust, Sea Salt, and Sulphates) were considered in the simulations and this study was based on STORMFURY work.

Huan *et al.* [18] observed the simulation effects of sea-salt aerosols on the structure and precipitation of a developed tropical cyclone and noted that increasing sea-salt aerosol emissions leads 1) to a more obvious warm core structure and more latent heat release, 2) shifts peak precipitation towards the tropical cyclone center, and 3) may increase convective precipitation.

It was found that the cloud effective radius could be decreased by anthropogenic aerosols that subsequently suppress the warm cloud precipitation with the corresponding release of latent heat. These aerosols effectively act as Cloud Condensation Nuclei (CCN) so that more cloud water can reach the freezing layer [19] [20] [21] [22]. Jiang *et al.* [23] found that anthropogenic aerosols discharged from land can promote convective precipitation rate at the periphery of a Tropical Cyclone (TC).

The above experimental and simulated works fall in line with our already existing research work in finding methods to artificially modify the convection of the outer wall of the Hurricane. Griffith *et al.* [24] introduced a ground-based, manually operated Silver Iodide generator (**Figure 1**) for the operation of winter cloud seeding to obtain snow. They used a seeding solution that contained 3% solution of silver iodide complexed with sodium iodide and paradichlorobenzene dissolved in acetone that is burned in a propane flame.

Experimental implementation to mitigating tornadoes, storms, and hurricanes is a scientific challenge and if done, gives a lot of benefits such as decrease in human fatality, and reduced property damage worth billions of dollars.

Research work [23] supports anthropogenic aerosols discharged from land can promote convective precipitation rate at the periphery of Tropical Cyclone. In this paper, we propose the method to weaken the storm/hurricane/tornado

Figure 1. Ground based manually operated Silver Iodide Generator. Courtesy: Griffith *et al.* [24] (Silver Iodide Generator).

intensity by using ground-based manually operated Cloud Condensation Nuclei (CCN) Generator that uses environmentally friendly food materials rather than using Silver Iodide crystals.

2. Method and Materials

2.1. Generating Ground-Based CCN

We conducted several experiments that release environmentally friendly aerosols into the atmosphere. Over the past few years, we conducted these experiments to produce manually ground-based CCN. We arranged 30 inches round and 9 inches depth copper firepit (**Figure 2**) and burned selective wood pieces from certain trees along with selective food materials to produce environmentally friendly aerosols (cloud condensation nuclei) that can reduce the storm intensity. The aerosols are environmentally friendly as these aerosols did not increase the Air Quality Index (AQI) in the area and in fact decreased the AQI within a few hours of the experiment. As the temperature is not sufficient to melt and vaporize the copper in the fire pit negligible amount of copper particles are included in the smoke plume aerosol or particulate matter, $PM_{2.5}$ or PM_{10}. The natural question is how do we know these aerosols made their way into the clouds to be seeded? We have given sufficient evidence in the results section. These CCN will likely grow into cloud drops at the atmosphere's LCL (lifting condensation level).

Parameters such as wind, rain, place, and surroundings were taken into the consideration. We did the experiments in an open space with a high roof to prevent rainwater falling in the firepit (brazier). Also, to prevent winds (if present), we use temporary wooden protective walls.

2.2. Materials

- Ghee (clarified butter): Brooke *et al.* [25] calculated the relative hygroscopicity of atmospheric aerosol organics and concluded that the hygroscopicity of

Figure 2. Firepit releasing environmentally friendly aerosols (Firepit).

Table 1. Aerosols produced by burning food materials—courtesy [27]. (a, b, … k) indicate different references taken by the author [27] (Aerosols by burning food materials).

Material Burnt	$PM_{2.5}$ (g/kg) (Particulate Matter 2.5 micrometer size)	PM_{10} (g/kg) (Particulate Matter 10 micrometer size)
Almond	4.1a, 4.5b	4.3a, 4.8b
Barley	7.4a, b	7.7a, b
Corn	5.0c, 6.0b, 11.7d	6.2b, 10.7c
Rice	2.4c, 3.2b, 13.0g	3.3c, 3.5b, 3.7h
Walnut	4.7b	5.0b
Wheat	0.8 - 4.7e, 3.6k, 4.0c, 4.7g, 5.4a, b, 7.6d	5.7a, b, 7.0c

carbonyls < alcohols < monoacids < diacids. They also reported that individually each of the compounds in pure form take up more water than collectively in a compound. In our experiment we used Ghee (clarified butter) as fuel to enhance the heat in the firepit while the wood is burning to produce less pollution and generate hygroscopic atmospheric organic aerosols. Ghee [26] contains 98.9% lipids with major lipid fraction containing fatty acids. When Ghee is burned it splits into individual compounds and as a result takes up more water as observed by Brooke *et al.*

- Wheat, Rice, Walnut, Corn, Almond, and Barley: **Table 1** gives the weight (grams) of PM2.5 and PM10 aerosols produced due to burning one kilogram each of wheat, walnut, corn, almond, and barley. In the table, the letters (a, b, … k) indicate different references taken by the author. These materials are used for generating environmentally friendly CCN aerosols that may be in the form of molecules/ions/nano particles.
- Pinewood: Environmental Protection Agency (EPA) declared that burning wood is Carbon neutral [28]. Jim Haywood [29] reports from simple conceptual framework of monodisperse distribution of cloud droplets in clouds that anthropogenic aerosols which are active as CCN can increase the optical depth of clouds and increase reflectivity of clouds. Also, if the number of cloud droplets increase along with the decrease in the size of the droplet, there is chance for the clouds not to reach the critical size for precipitation.

3. Process

The selected materials were grains, nuts, ghee (clarified butter), and some aromatic materials such as sandalwood. These materials are burned in specified quantities and at specified intervals for producing efficient results. The materials were manually placed with the help of long spoons (process can be automated for scaling) into the firepit to give time for the materials to properly combust as shown in **Table 2**.

3.1. Quantity of Each Material Used in the Process

Table 2. Materials and quantities used (materials and quantities used).

Material	Approximate Total Quantity (kg)	Approximate Quantity disposed every 10 seconds	Approximate Total Time of Burning
Pinewood	10	NA	2 hours
Ghee	4	5.5 grams	2 hours
Wheat	3	4.1 grams	2 hours
Rice	2	2.75 grams	2 hours
Almond	1	1.35 grams	2 hours
Corn	1	1.35 grams	2 hours
Walnut	0.5	0.65 grams	2 hours
Barley	1	1.35 grams	2 hours
Sandalwood	0.1	NA	NA

3.2. $PM_{2.5}$ and PM_{10} from Burnt Materials

Table 3. $PM_{2.5}$ and PM_{10} produced from burning materials [27] ($PM_{2.5}$ and PM_{10}).

Material	$PM_{2.5}$ (grams)	PM_{10} (grams)
Ghee	Unknown	Unknown
Wheat	12.3 to 13.5	12.9 to 14.4
Barley	7.4	7.7
Walnut	2.35	2.5
Rice	4.8 to 26.0	6.6 to 7.4
Corn	5.0 to 11.7	6.2 to 10.7
Almond	4.1 to 4.5	4.3 to 4.8
Total (Maximum)	65.45	47.5

3.3. Effects of Produced $PM_{2.5}$ and PM_{10}

According to National Aeronautics and Space Administration (NASA)'s Earth Observatory [30], the smoke can rise (forest burning) to a height of 2 to 3 km and spread to 300 km in the wind direction while descending 1 km. Smoke ascends upwards due to low density and increases its volume while it cools as it climbs. While climbing the smoke particles become cloud condensing nuclei if those are hygroscopic and these CCN may form clouds at that height.

Smoke dispersion is affected by [31] Surface winds, Relative Humidity, Temperature, Atmospheric Stability, Mixing Height, Transport Winds, Long-Range Transport, Down Drainage, Plume Rise, and Dispersion Index.

Considering NASA's observations [30], we assume the smoke produced in our experiments could spread to 30 km to 40 km with maximum density to be present within 1 km radius and 100 m depth. Air that was filled with the experimental burning process to contain these $PM_{2.5}$ and PM_{10} within a depth of 100 m (at a height of 1 km) and radius of 1 km, the volume of air would be around.

$$V = 3.14 \times (1000)^2 \times (100)\, m^3 \tag{1}$$

$$V = 3.14 \times 10^8\, m^3 \tag{2}$$

Due to the burning the concentration of $PM_{2.5}$ in the above said volume (see Equation (2)) would increase by (from Table 3 and Equation (2)).

$$C\,(PM_{2.5}) = 65.45 \times 10^6 \text{ (micrograms)/V (cubic meter)} \tag{3}$$

$$C\,(PM_{2.5}) = 0.21 \text{ micrograms per cubic meter} \tag{4}$$

Similarly, the concentration of PM_{10} would be:

$$C\,(PM_{10}) = 47.5 \times 10^6 \text{ (micrograms)/V (cubic meter)} \tag{5}$$

$$C\,(PM_{10}) = 0.15 \text{ micrograms per cubic meter} \tag{6}$$

From the above calculations we can see that the burnt materials do not add to pollution but rather those are useful as CCN.

3.4. Heat Released in the Process

As wood and food burning always release heat and all materials burned/combusted in our experiment was wood and food related, the combustion/burning process release heat as referenced in Table 4.

3.5. Utilization of Heat Released in the Combustion/Burning Process

The released heat will be used to lower the density of burnt material to increase the buoyancy of generated aerosols upon their injection into the troposphere.

4. Experiments

We would like to present our experiments conducted on three different occasions

Table 4. Heat released during the combustion/burning process (Heat released during the combustion process).

Material	Heat of Combustion kJ/kg	Experimental Quantity in kg	Total Heat re-leased kJ	Reference
Pine Wood	20,003	10	200,003	[32]
Wheat	14,476	3	43,428	[33]
Almonds	25,982	1	25,982	[34]
Rice	15,397	2	30,794	[35]
Corn	15,564	1	15,564	[36]
Barley	14,700	1	14,700	[37]
Walnut	27,400	0.5	13,700	[38]
Ghee	37,700	4	150,800	[39]

in 2021. The first was conducted on 17th March 2021 at McDonough, Georgia USA when severe storm warning was issued by national weather channel that tornados and severe weather would affect areas near McDonough, Georgia USA early morning of 18th March 2021. Second experiment was conducted on 19th and 20th June 2021 at McDonough, Georgia USA before Storm Claudette passed through Georgia. Third experiment was conducted on 5th and 6th July 2021 at Sarasota Springs, Florida USA to mitigate the intensity of the hurricane/storm Elsa.

4.1. Experiment 1

Saint Patrick's Day tornado outbreak of 2021 [40], that lasted about three days from March 16th to 18th 2021. On 16th and 17th March National Weather Channel gave Tornado and severe Storm warnings that could damage parts of Georgia (GA) on 18th March 2021. The damage predicted was so severe that many schools were given virtual classes on 18th March 2021 so that students would not attend the in-person classes. On learning this message on 17th March from news channels, we did the experiment at McDonough, GA on 17th March 2021 between 6:00 PM and 7:30 PM (EDT USA) that released environmentally friendly aerosols into the atmosphere to analyze the effects of these aerosols on the Tornado.

4.2. Experiment 2

On learning that Tropical Storm Claudette (18th June 2021) caused severe damage in the state of Alabama and would pass through Georgia as Tropical Depression, we repeated the experiment when storm Claudette was about to pass Georgia on 20th June 2021. Our experiment at McDonough, GA released environmentally friendly aerosols on the evening of 19th June between 7:00 PM and 9:00 PM (EDT USA), and on the morning of 20th June 2021 between 10:00 AM and 12:00 noon (EDT USA) at McDonough, GA. Storm Claudette passed through Georgia on 20th June 2021.

4.3. Experiment 3

On learning about Tropical Storm Elsa that would turn into a Hurricane on the west of Florida, and could damage Tampa Bay region and west Florida, we conducted our experiment in the premises of hotel Super 8 by Wyndham near Sarasota Springs, FL (**Figure 3**) and released environmentally friendly aerosols on the evening of 5th July between 6:00 PM and 8:00 PM (EDT USA), and on the morning of 6th July 2021 between 7:00 AM and 9:00 AM (EDT USA). Experimental results give evidence to this methodology to be practical, environment friendly, cost-effective (significantly less expensive when compared to cloud seeding with silver iodide), and consistent.

5. Results

Mainly the following scientific parameters and their values published by EOSDIS

Figure 3. Experiment at Sarasota Springs, FL (Firepit at experiment location).

WORLD VIEW [41] was used for analyzing our results.

- Aerosol Index [41]: The Aerosol Index layer (PyroCumuloNimbus) indicates Ultraviolet (UV) absorbing particles (aerosols) in the air such as desert dust and soot particles in the atmosphere. It is related to both the thickness of the Aerosol layer located in the atmosphere and to the height of the layer. The measurement is unit less range from 0 to 50 and the Aerosol Index measures unit less range from 0 to 5. Values greater than 5 indicates dense smoke and if the value is greater than 10, indicates the smoke has reached upper troposphere and into stratosphere. This parameter is used to check the increase in aerosols in the atmosphere.
- Effective Radius [41]: It is a measure of cloud particle size in microns during daytime for water phase and ice phase. Generally, the smaller the particle size, brighter and more effective are the clouds. The smaller cloud particles tend to reflect and scatter more sunlight back into space. This parameter is used to check if the cloud effective radius has decreased or not. If decreased, then we can confirm that more aerosols have been introduced and the clouds are more effective. Moreover, if newly water phase CCN are formed, we can consider there is a release of heat.
- Cloud Top Temperature [41]: It indicates the atmospheric temperature at the top of the cloud measured in Kelvin. It can be used to infer tropical convection and precipitation. This parameter is an indication of heat released if the temperature is increased.
- Cloud Phase Infrared [41]: It indicates the phase of the cloud particles inferred from the infrared wavelengths (8.5 to 11 microns). The three cloud particle phase categories received are ice, liquid, and uncertain.

5.1. Experiment 1: Results and Discussion (Experiment on 17th March 2021)

From Table 5, the aerosol index indicates that on 16th March 2021 there are few aerosols when compared to 17th March 2021. This indicates that excess aerosols have been produced on the 17th of March indicating either the aerosols were released from our experiment or from some other sources. 16th, 17th, and 18th of March happened to be Tuesday, Wednesday, and Thursday, all aerosols producing sources (like factories, vehicles etc.) should be regular. We see that on 16th Aerosol Index is less than 0.5 and expect about the same on the next days. But an increase in the aerosol quantity indicates that some additional sources of aerosols have been injected into the atmosphere that have risen to a good height of 1.5 km or so. This confirms the release of aerosols from our experiment on 17th March 2021.

We see from **Table 6** the Ice Phase Cloud Effective Radius is the collection of the data during daytime. We did the experiment before Sunset and the data for night is not available. As we can see the Cloud Effective Radius has decreased on 18th March. This indicates the bigger size IN (Ice Nuclei) have become small due to excess aerosols arriving at the clouds. Also, if we include the **Table 7** data, we see that the Cloud Top Temperature has increased on 17th of March indicating release of heat. The heat release could be due to the water vapor condensation. Therefore, it can be inferred that the extra aerosols that were released by our experiment caused artificially invigorated convection [16] [17], decrease in wind speeds, and subsequent mitigation of the Tornado.

According to National Weather Service [42] as was reported on 19th March

Table 5. Aerosol Index Layer above McDonough, GA [41] (Aerosol Index Layer above McDonough, GA).

Date	UV Aerosol Index (Pyro Cumulo Nimbus) Suomi NPP/OMPS	Aerosol Index Suomi NPP/OMPS
16th March 2021	Unknown	<0.500
17th March 2021	1.400 to 1.425	1.500 to 1.525
18th March 2021	Unknown	Unknown

Table 6. Cloud Effective Radius [41] (Cloud Effective Radius).

Date	Ice Phase (microns)	Water Phase (microns)	Appendix A
16th March 2021	36	NA	Figure A1
17th March 2021	12.5	NA	Figure A2
18th March 2021	NA	15.5	Figure A3

Table 7. Cloud Top Temperature [41] (Cloud Top Temperature).

Date	Night	Appendix A
16th March 2021	220 K to 225 K	Figure A4
17th March 2021	225 K to 230 K	Figure A5
18th March 2021	225 K to 230 K	Figure A6

2021, "the tornado has either dissipated or was in the process of doing so". This may be considered as the result of our tornado mitigation experiment since the tornado predictions given few hours before were downgraded in the experiment location—McDonough, GA.

5.2. Experiment 2: Results and Discussion (Experiment on 19th June 2021 Evening and 20th June 2021 Morning)

From Table 8 we can check that the Aerosol Index on 20th June 2021 is almost double that on 18th June 2021. 19th and 20th June 2021 happened to be a weekend (Saturday and Sunday), we expect a smaller number of aerosols due to absence of regular aerosol sources (factories, vehicles etc.) on these days. On the contrary, there is an increased activity of aerosols, and we attribute it to our experiments conducted on 19th evening and 20th morning of June 2021.

From Table 9, we can see that the Cloud Effective Radius during daytime on 20th of June 2021is considerably less than the Cloud Effective Radius during daytime of 18th and 19th June 2021. From Table 10 we can see the temperature during the daytime has increased on 20th of June 2021 when compared to 19th of June 2021 indicating heat release. This could be due to the water vapor condensing on the new aerosols that arrived due to our experiment.

Therefore, from the above discussion based on the data in Tables 8-10, we can safely say that the extra aerosols that were released by our experiments caused artificially invigorated convection [16] [17], decrease in wind speeds, and

Table 8. Aerosol Index Lyaer above McDonough, GA [41] (Aerosol Index Layer).

Date	UV Aerosol Index Aura /OMI	Aerosol Index Aura/OMI	Appendix A
18th June 2021	<0.500	0.150 to 0.175	Figure A7
19th June 2021	Unknown	Unknown	Figure A8
20th June 2021	<0.500	0.300 to 0.325	Figure A9

Table 9. Cloud Effective Radius [Aqua/Modis] [41] (Cloud Effective Radius).

Date	Ice Phase (microns)	Water Phase (microns)	Appendix A
18th June 2021	33	NA (not available)	Figure A10
19th June 2021	40.5	NA	Figure A11
20th June 2021	NA	15.8	Figure A12

Table 10. Cloud Top Temperature [41] (Cloud Top Temperature).

Date	Night	Day	Appendix A
18th June 2021	290 K to 350 K	290 K to 350 K	Figure A13
19th June 2021	235 K to 240 K	225 K to 230 K	Figure A14
20th June 2021	280 K to 285 K	285 K to 290 K	Figure A15

subsequent mitigation of the storm Claudette.

From Table 11 and Figure 4, we can see the complete track of Tropical Storm (TS) Claudette as it passed Alabama, Georgia, South, and North Carolina, and into the Atlantic Ocean where it dissipated. TS Claudette entered Georgia around 7:00 AM EST (1100 UTC) on 20th June 2021 and left Georgia around 5:00 PM EST (2100 UTC) on 20th June 2021. During this time the speed of the storm had increased to 17 mph and the maximum sustainable wind speed had fallen to 30 mph. After that the speed continued to increase but the maximum sustainable wind speed slowly picked up. No noticeable damages were reported in Georgia, South, and North Carolinas. It was dissipated earlier than it was predicted and by deviating from its original path in the Atlantic Ocean.

From Table 11, we can check the coordinates and time at which the speed of the winds had dropped to 30 mph (least speed during the existence of storm Claudette). Between 0300 UTC on 20th June (11:00 PM EDT USA on 19th June) and 0000 UTC on 21st June (8:00 PM EDT USA on 20th June), the speed of the winds had dropped to 30 mph when the storm was within a radius of 200 miles from McDonough, GA where the experiment was conducted.

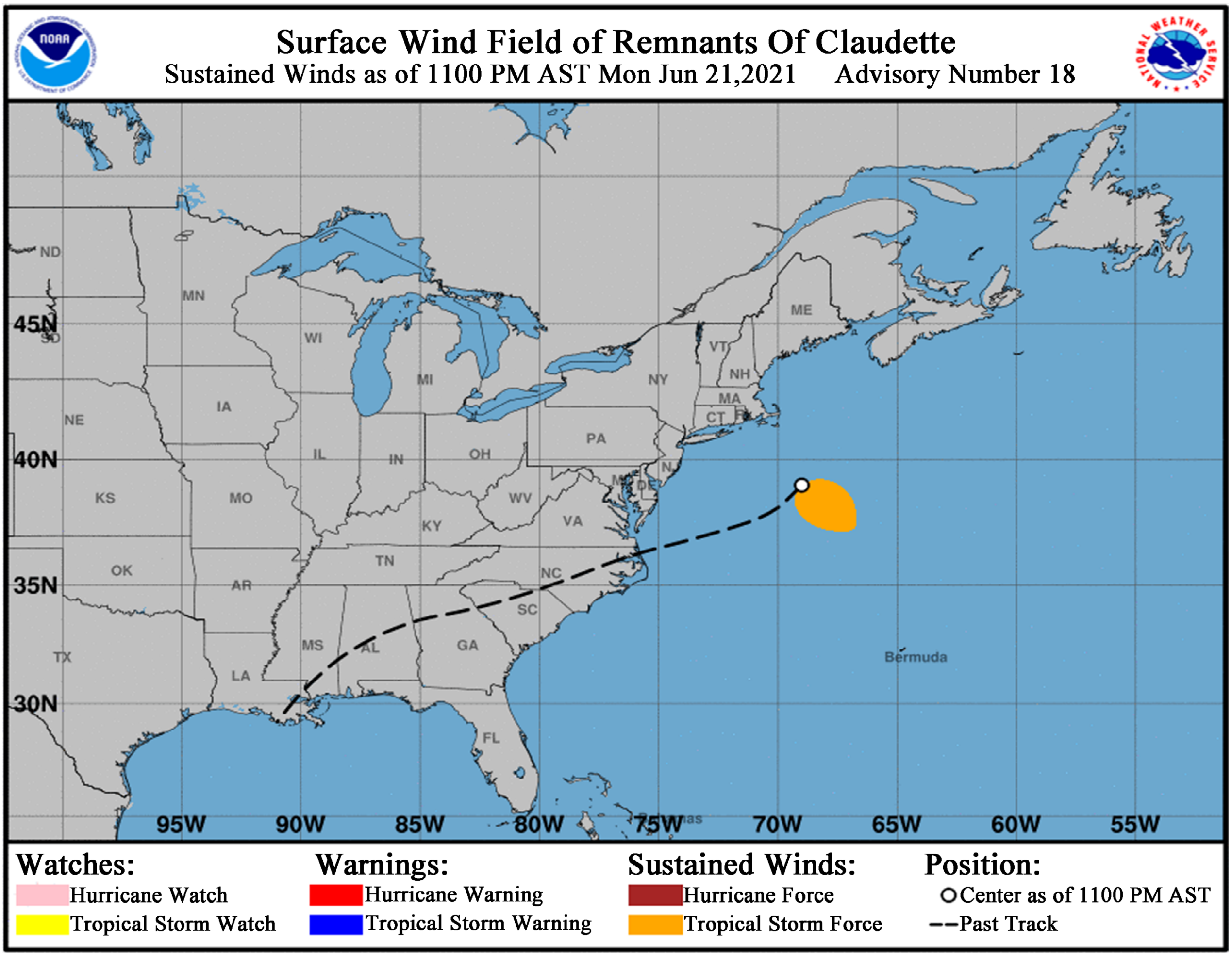

Figure 4. Path of Tropical Depression Claudette 2021 (Image Courtesy: NWS National Hurricane Center).

Table 11. Claudette System Track—Courtesy National Hurricane Center [43] (Claudette 2021).

Path of Tropical Depression Claudette 2021 (Image Courtesy: NWS National Hurricane Center).												
Remnants of Claudette System Track (2021)					Advisory Name: Potential Tropical Cyclone							
Advisory #	Date (UTC)				Advisory Name	Lat	Lon	Direction	Speed (mph)	Pressure (mb)	Winds (mph)
1	2100	THU	JUN	17	Three	22.9N	92.4W	N	9	1008	30
1A	0	FRI	JUN	18	Three	23.2N	92.3W	N	9	1007	30
2	300	FRI	JUN	18	Three	23.5N	92.2W	N	9	1007	30
2A	600	FRI	JUN	18	Three	24N	92W	N	9	1007	35
3	900	FRI	JUN	18	Three	25.2N	91.5W	N	14	1007	35
3A	1200	FRI	JUN	18	Three	26N	91.5W	N	14	1007	35
4	1500	FRI	JUN	18	Three	26.5N	91.1W	NNE	14	1007	35
4A	1800	FRI	JUN	18	Three	27.3N	91.1W	N	14	1007	45
5	2100	FRI	JUN	18	Three	27.9N	91.2W	N	16	1006	45
5A	0	SAT	JUN	19	Three	28.3N	91.1W	N	16	1007	45
6	300	SAT	JUN	19	Three	28.9N	90.9W	N	13	1007	45
6A	600	SAT	JUN	19	Three	29.1N	91W	N	10	1006	45
7	900	SAT	JUN	19	TS Claudette	29.6N	90.7W	NNE	12	1006	45
7A	1200	SAT	JUN	19	TS Claudette	30.4N	90.1W	NNE	12	1006	45
8	1500	SAT	JUN	19	TS Claudette	31N	89.7W	NNE	14	1007	40
8A	1800	SAT	JUN	19	TS Claudette	31.8N	88.6W	NNE	14	1007	40
9	2100	SAT	JUN	19	TS Claudette	32.2N	87.9W	NE	16	1007	35
9A	0	SUN	JUN	20	TS Claudette	32.4N	87.7W	NE	15	1005	35
10	300	SUN	JUN	20	TS Claudette	32.6N	87W	NE	14	1005	30
10A	600	SUN	JUN	20	TS Claudette	32.9N	86.7W	NE	13	1006	30
11	900	SUN	JUN	20	TS Claudette	33.3N	85.8W	ENE	13	1006	30
11A	1200	SUN	JUN	20	TS Claudette	33.7N	84.8W	ENE	13	1007	30
12	1500	SUN	JUN	20	TS Claudette	33.8N	84.2W	ENE	17	1009	30
12A	1800	SUN	JUN	20	TS Claudette	33.9N	83.5W	ENE	17	1009	30
13	2100	SUN	JUN	20	TS Claudette	34.2N	82.5W	ENE	0	0	
13A	0	MON	JUN	21	TS Claudette	34.4N	81.3W	ENE	17	1008	30
14	300	MON	JUN	21	TS Claudette	34.7N	80.4W	ENE	20	1008	35
14A	600	MON	JUN	21	TS Claudette	35.1N	79.1W	ENE	20	1008	35
15	900	MON	JUN	21	TS Claudette	35.6N	77.6W	ENE	25	1007	40
15A	1200	MON	JUN	21	TS Claudette	36.4N	76.3W	ENE	28	1007	40
16	1500	MON	JUN	21	TS Claudette	37N	75W	ENE	28	1007	40
17	2100	MON	JUN	21	TS Claudette	37.5N	72.1W	ENE	29	1004	45
18	300	TUE	JUN	22	Remnants of Claudette	39N	69W	ENE	29	1004	45

5.3. Experiment 3: Results and Discussion (Experiment on 5th July 2021 Evening and 6th July 2021 Morning)

Table 12 clearly indicates that the number of aerosols has increased on 6th and 7th, of July 2021. This is plausible due to re-leasing aerosols on the evening of 5th July 2021 and Morning of 6th July 2021. In any case the number of aerosols has in-creased from 5th to 7th, and it is an indication that there is a chance for CCN formation. Cloud Effective Radius is a measure of cloud particle size in microns.

Cloud Phase Infrared

Cloud Phase infrared layer indicates the phase of cloud particles inferred from the infrared wavelengths 8.5 microns to 11 microns. Changes in the cloud phase affect the climate feedback mechanism.

Table 13 gives the Cloud Effective Radius obtained during the daytime. The Cloud Effective Radius transformation between daytime of 6th July 2021 and daytime of 7th July 2021 indicated that the size of the Ice Nuclei (IN) has decreased. This indicates there were additional aerosols that decreased the Cloud Effective Radius. We can see from the Table 14 to get the status of these IN that matches with the Table 13. Storm Elsa turned into Hurricane at about 8:00 PM (0000 UT) on 6th of July 201 and fallen back to Storm status between midnight of 6th July 2021 and 1:00 AM of 7th July 2021.

Therefore, a lot of heat must have been released from conversion of water vapor to IN (Ice Nuclei), and it was plausible that the extra aerosols that were released by our experiment caused artificially invigorated convection [16] [17], decrease in wind speeds, and subsequent mitigation of the Hurricane Elsa.

Table 12. Aerosol Index Value [41] (Aerosol Index Value).

Date	Aerosol Index Value	Appendix A
5th July 2021	<0.0	Figure A16
6th July 2021	0.250 < Aerosol Index < 0.275	Figure A17
7th July 2021	0.400 < Aerosol Index < 0.425	Figure A18

Table 13. Cloud Effective Radius (Aqua/MODIS) [41] (Cloud Effective Radius).

Date	Ice Phase	Water Phase	Appendix A
5th July 2021	Unknown	Unknown	Figure A19
6th July 2021	39.5 to 39.8	NA	Figure A20
7th July 2021	18.6 to 18.9	NA	Figure A21

Table 14. Cloud Phase Infrared [41] (Cloud Phase Infrared).

Date	Night	Day	Appendix A
5th July 2021	Liquid Water	Unknown	Figure A22
6th July 2021	ICE	ICE	Figure A23
7th July 2021	ICE	ICE	Figure A24

From Table 15 and Figure 5, we can see the complete track of Tropical Storm (TS) Elsa as it passed Florida, Georgia, South, and North Carolina, and into the Atlantic Ocean where it dissipated. TS Elsa entered Key West, FL around 8:00 AM EST (1200 UTC or 8AM EDT USA) on 6th July 2021 and landfall in FL around 10:00 AM EST (1400 UTC or 10AM EDT USA) on 7th July 2021.

From Table 15, we can see that TS Elsa turned to Category-1 Hurricane at about 8:00 PM EDT (6th July 2021) or (0000 UTC) on 7th July 2021and is located about west of Fort Myers, FL and about 62 miles South-west of Sarasota Springs, FL and maintained to a Hurricane status for about 3 hours till 11:00 PM of 6th July 2021 (0300 UTC 7th July) when it came closest (about 42 miles) to Sarasota Springs, FL. While crossing this point hurricane Elsa dropped its status to TS Elsa with wind speeds falling to 70 mph.

On the 4th, 5th, and 6th July weather reports from different agencies predicted that TS Elsa would turn into a Hurricane and bring storm surge of 5 ft or more and heavy rains to Tampa Bay and other areas in Florida. On 6th July 2021 TS Elsa crossed Key West and caused storm surge and heavy winds. TS Elsa brought storm surge and heavy rains to Naples, FL, and Fort Myers. Even though the

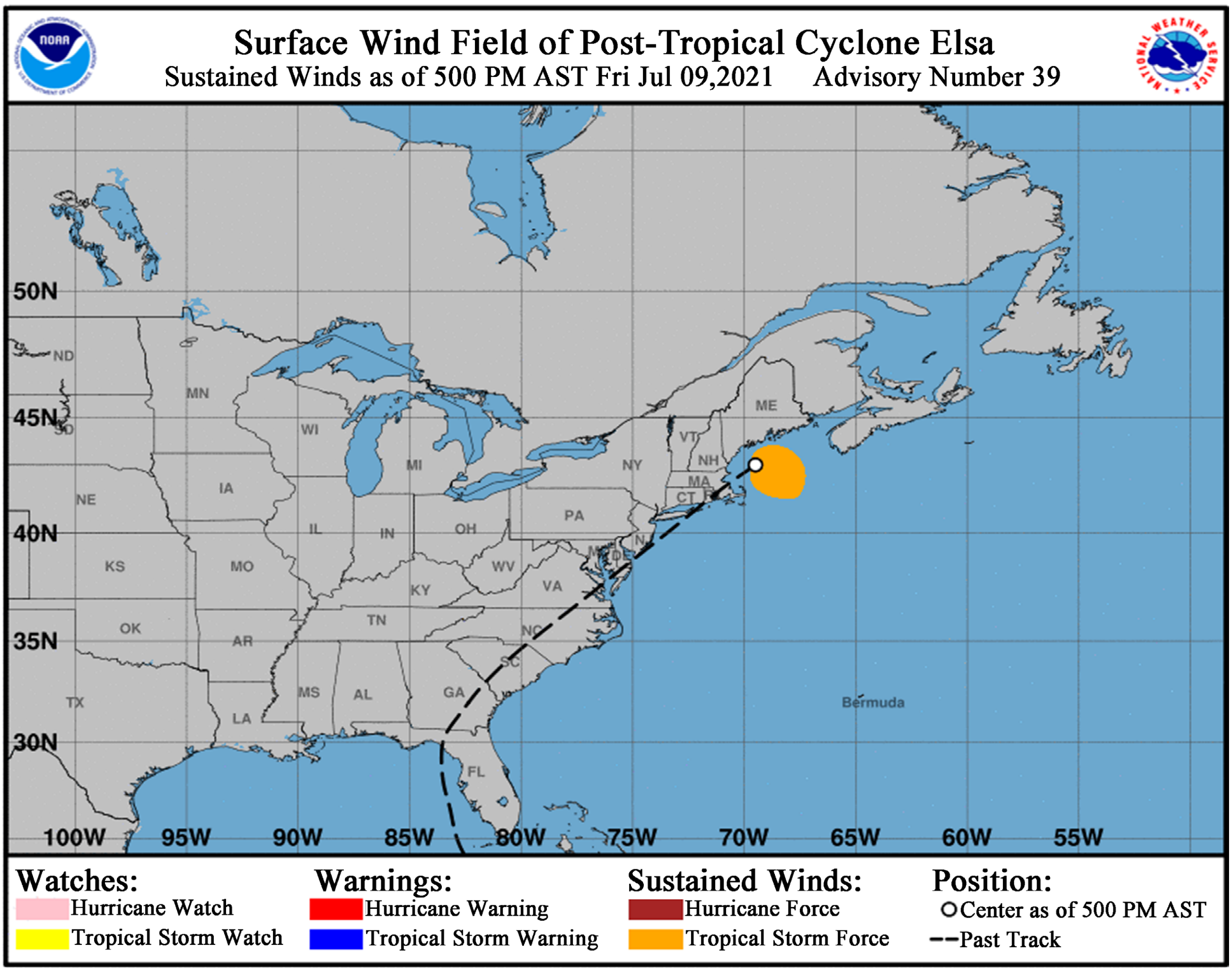

Figure 5. Tropical Storm Elsa 2021. Image Courtesy: NWS National Hurricane Center (Elsa 2021).

Table 15. Elsa System Track—Courtesy National Hurricane Center [44] (Elsa Track).

Advisory # (UTC)	Advisory Date				Name	Position		Direction	Speed (mph)	Pressure (mb)	Winds (mph)
24	900	TUE	JUL	6	TS Elsa	24.1N	82.4W	NNW	12	1007	60
24A	1200	TUE	JUL	6	TS Elsa	24.5N	82.6W	NNW	12	1007	60
25	1500	TUE	JUL	6	TS Elsa	24.9N	82.8W	NNW	10	1007	60
26	1800	TUE	JUL	6	TS Elsa	25.4N	83W	N	9	1000	70
27	2100	TUE	JUL	6	TS Elsa	25.8N	83W	N	10	998	70
27A	0	WED	JUL	7	Cat1 Hurricane Elsa	26.6N	83.1W	N	14	996	75
28	300	WED	JUL	7	Cat1 Hurricane Elsa	27.3N	83.2W	N	14	997	75
28A	600	WED	JUL	7	TS Elsa	27.9N	83.5W	N	14	1004	70
29	900	WED	JUL	7	TS Elsa	28.5N	83.5W	N	14	1004	65
29A	1200	WED	JUL	7	TS Elsa	29.2N	83.6W	N	14	999	65
30	1500	WED	JUL	7	TS Elsa	29.9N	83.6W	N	14	999	65
30A	1800	WED	JUL	7	TS Elsa	30.3N	83.5W	N	14	1002	50
31	2100	WED	JUL	7	TS Elsa	30.8N	83.4W	N	14	1003	45
31A	0	THU	JUL	8	TS Elsa	31.4N	82.7W	NNE	14	1006	45
32	300	THU	JUL	8	TS Elsa	32.1N	82.3W	NNE	16	1006	45
32A	600	THU	JUL	8	TS Elsa	32.7N	82W	NNE	16	1007	45
33	900	THU	JUL	8	TS Elsa	33.4N	81.3W	NE	18	1007	40
33A	1200	THU	JUL	8	TS Elsa	34.2N	80.5W	NE	18	1006	40
34	1500	THU	JUL	8	TS Elsa	35N	79.7W	NE	20	1006	45
34A	1800	THU	JUL	8	TS Elsa	35.6N	79W	NE	20	1007	45
35	2100	THU	JUL	8	TS Elsa	36.3N	78.3W	NE	21	1006	50
35A	0	FRI	JUL	9	TS Elsa	36.8N	77.4W	NE	21	1004	50
36	300	FRI	JUL	9	TS Elsa	37.6N	76.5W	NE	25	1002	50
36A	600	FRI	JUL	9	TS Elsa	38.3N	75.7W	NE	25	1002	50
37	900	FRI	JUL	9	TS Elsa	39.4N	74.3W	NE	31	1000	50
37A	1200	FRI	JUL	9	TS Elsa	40.2N	73.1W	NE	31	1000	50
38	1500	FRI	JUL	9	TS Elsa	41N	72.1W	NE	31	1000	50
38A	1800	FRI	JUL	9	Post-Tropical Cyclone Elsa	42N	71W	NE	31	999	50
39	2100	FRI	JUL	9	Post-Tropical Cyclone Elsa	43N	69.5W	NE	35	999	50

storm Elsa passed closest to Sarasota Springs, Clearwater, and Tampa Bay, it did not cause storm surge and did not pour heavy rains in these areas.

At 2:00 AM EDT USA (0600 UTC) on 7th July, TS Elsa was placed at about 69 miles from Sarasota Springs, FL as a Storm with maximum sustained wind speeds of 70 mph. From this point TS Elsa's wind speed decreased gradually to 65 mph and after landfall at around 10:00 AM. From then onwards the speed of TS Elsa increased gradually from 14 mph to 31 mph and wind speeds decreased gradually from 65 mph to 45 mph.

From **Table 15**, we can see that when the eye of the hurricane was between (27.3N, 83.2W) and (27.9N, 83.5W) it was close to the location of the experiment—Sarasota Springs, FL (27.3N, 82.5W). During this time the hurricane dropped its status to a Tropical Storm (TS) and we can observe that the pressure increased from 996 mb to 1004 mb. Since the location Sarasota Springs, FL is in the wall (>30 miles from the eye) of the hurricane, we can conclusively say that our experiment caused artificially invigorated convection [16] [17], a decrease in wind speeds, an increase in pressure and subsequent mitigation of the Hurricane Elsa.

Table 16 gives the average rainfall over a period of 30 hours starting at 6:00 AM on 6th July 2021 and ending at 12:00 PM on 7th July 20. We can clearly see that the average rainfall in Sarasota Springs, Tampa, and Clearwater did not cross 2.16 inches. Whereas if it were to be a hurricane, it should have been at least 10 inches of rainfall as predicted. We can see the rainfall in Fort Myers was about 4.62 inches which is more than double that in Sarasota Springs. This clearly indicates that the intensity of Storm Elsa has been mitigated to a good extent due to our experiment.

Table 16. A 30-hour Average Rainfall starting 6AM on 6th July 2021 ending 12 PM 7th July 20. Courtesy: NOAA's NWS [45] (Elsa Rainfall).

Place	Average Rainfall (inches)
In and around Sarasota Springs	2.16
In and around Tampa	1.94
In and around Clearwater	1.69
In and around Fort Myers	4.62

6. Conclusion

Advanced tools and methods may help in tracking the storm intensities and rate of conversions to hurricanes. Fatality rates have significantly come down with continuous communication and relocating the people. However, the reactive nature of addressing storms and hurricanes is not effective in controlling the risks and potential property damages. Our methodology and experiments bring hope of establishing a new yet effective way to reduce the intensities of tornadoes, storms, and hurricanes if done in advance in the path of the storm or hurricane path locations. Our methodology releases (ground-based) environmentally friendly aerosol particles that are responsible for cloud condensation and weaken the intensities of these forces. Results from our recent experiments focused on tornado (17th March 2021), storm Claudette (19th and 20th June 2021), and hurricane Elsa (5th and 6th July 2021) indicate that the methodology of releasing ground-based aerosols by burning prescribed materials in a prescribed method to be effective in mitigating intensities (including rainfall where applicable) of tornadoes, storms, and hurricanes.

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Conflicts of Interest

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

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Appendix

The following figures are collected from EOSDIS WORLD VIEW [41].

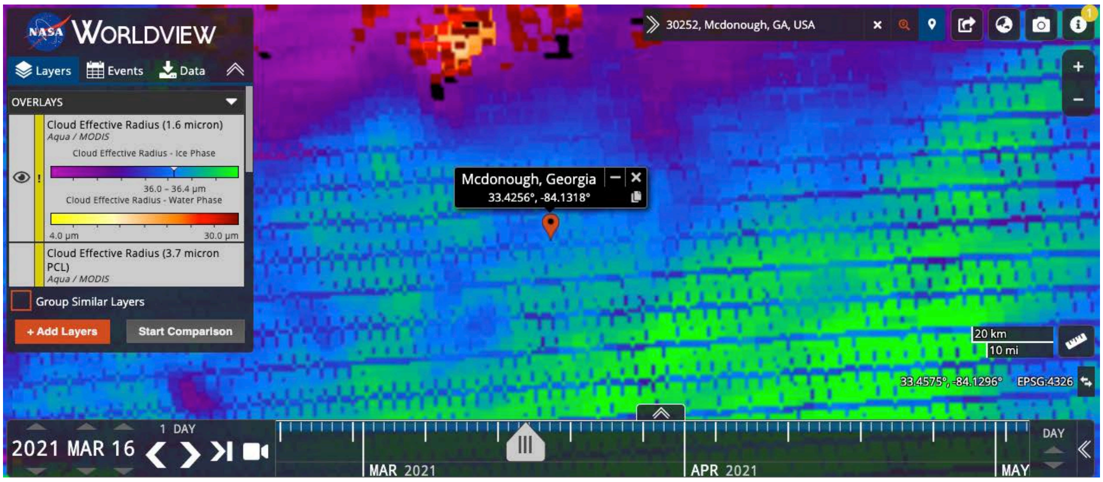

Figure A1. Cloud Effective Radius: March 16th, 2021, McDonough, GA, USA.

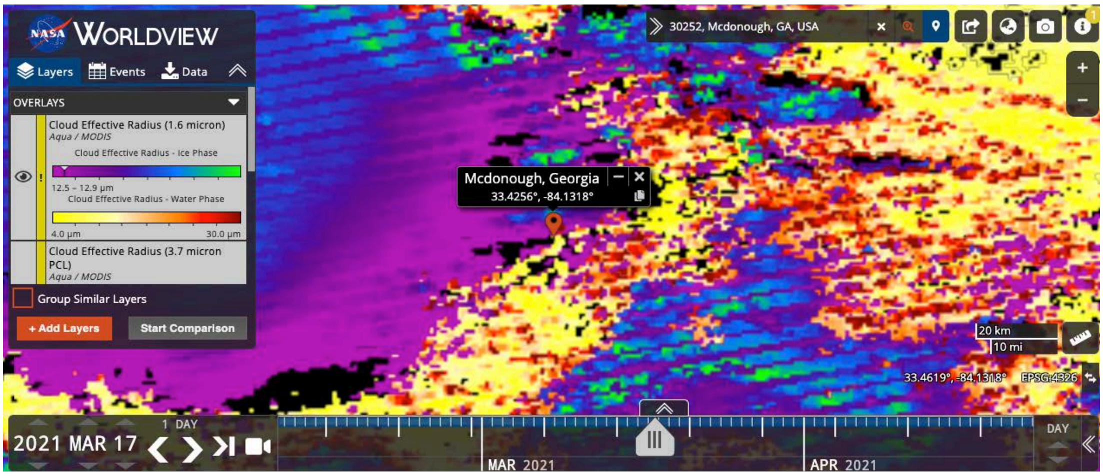

Figure A2. Cloud Effective Radius: March 17th, 2021, McDonough, GA, USA.

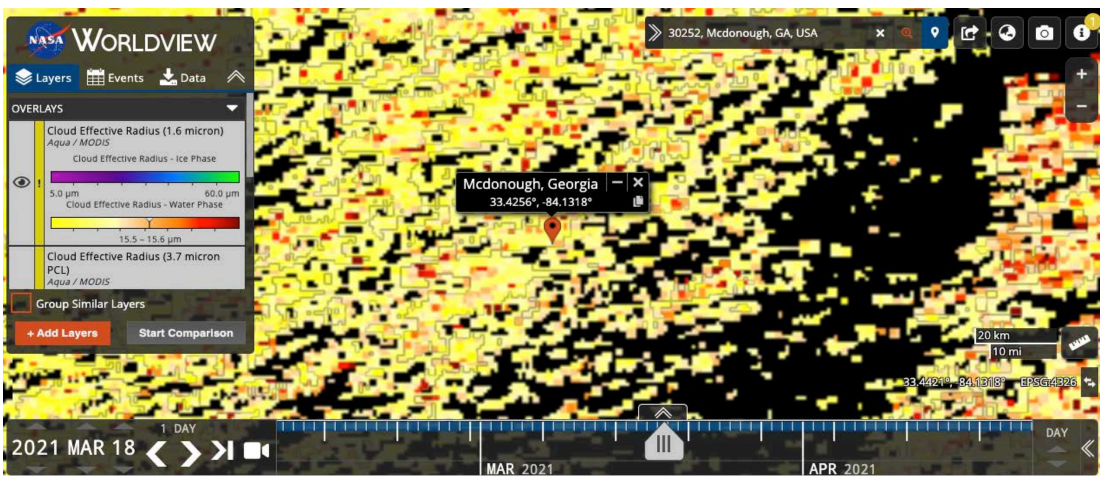

Figure A3. Cloud Effective Radius: March 18th, 2021, McDonough, GA, USA.

Figure A4. Cloud Top Temperature: March 16th, 2021, McDonough, GA, USA.

Figure A5. Cloud Top Temperature: March 17th, 2021, McDonough, GA, USA.

Figure A6. Cloud Top Temperature: March 18th, 2021, McDonough, GA, USA.

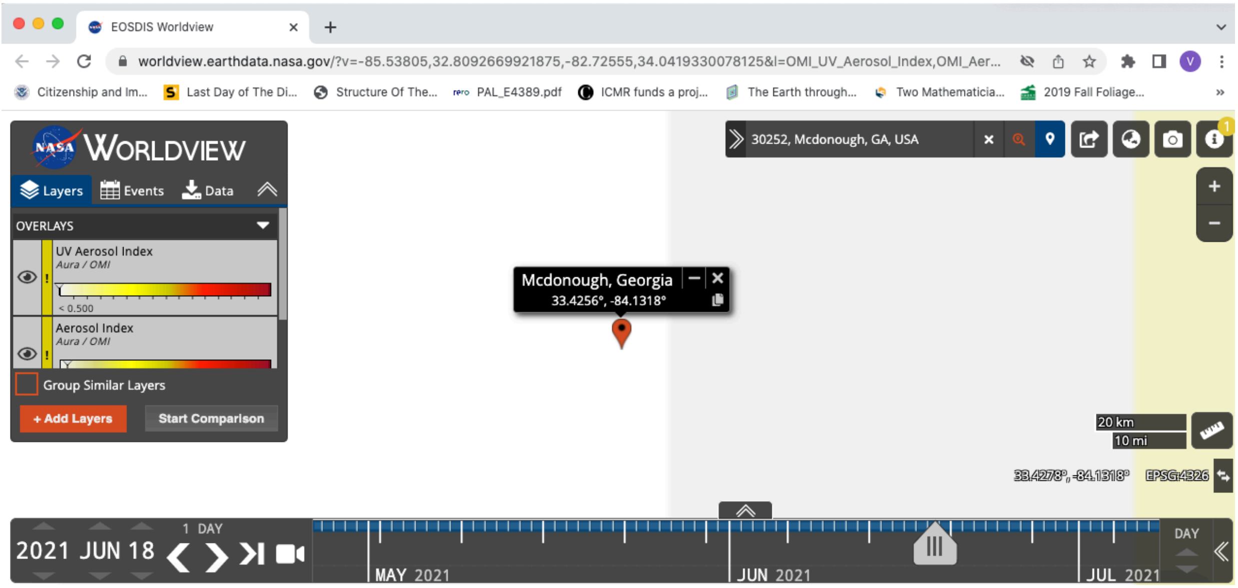

Figure A7. UV Aerosol Index: June 18th, 2021, McDonough, GA, USA.

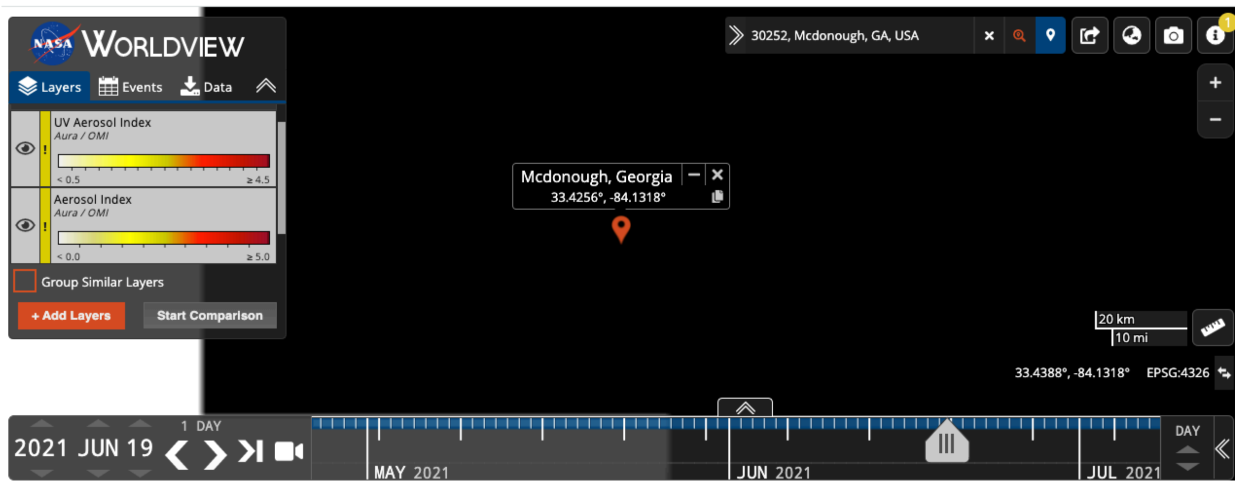

Figure A8. UV Aerosol Index: June 19th, 2021, McDonough, GA, USA.

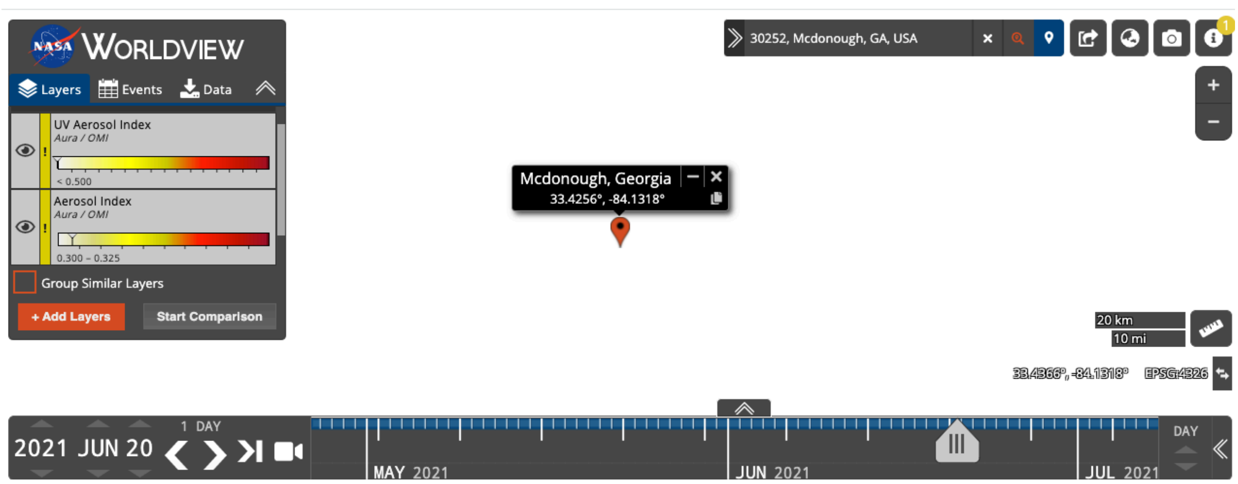

Figure A9. UV Aerosol Index: June 20th, 2021, McDonough, GA, USA.

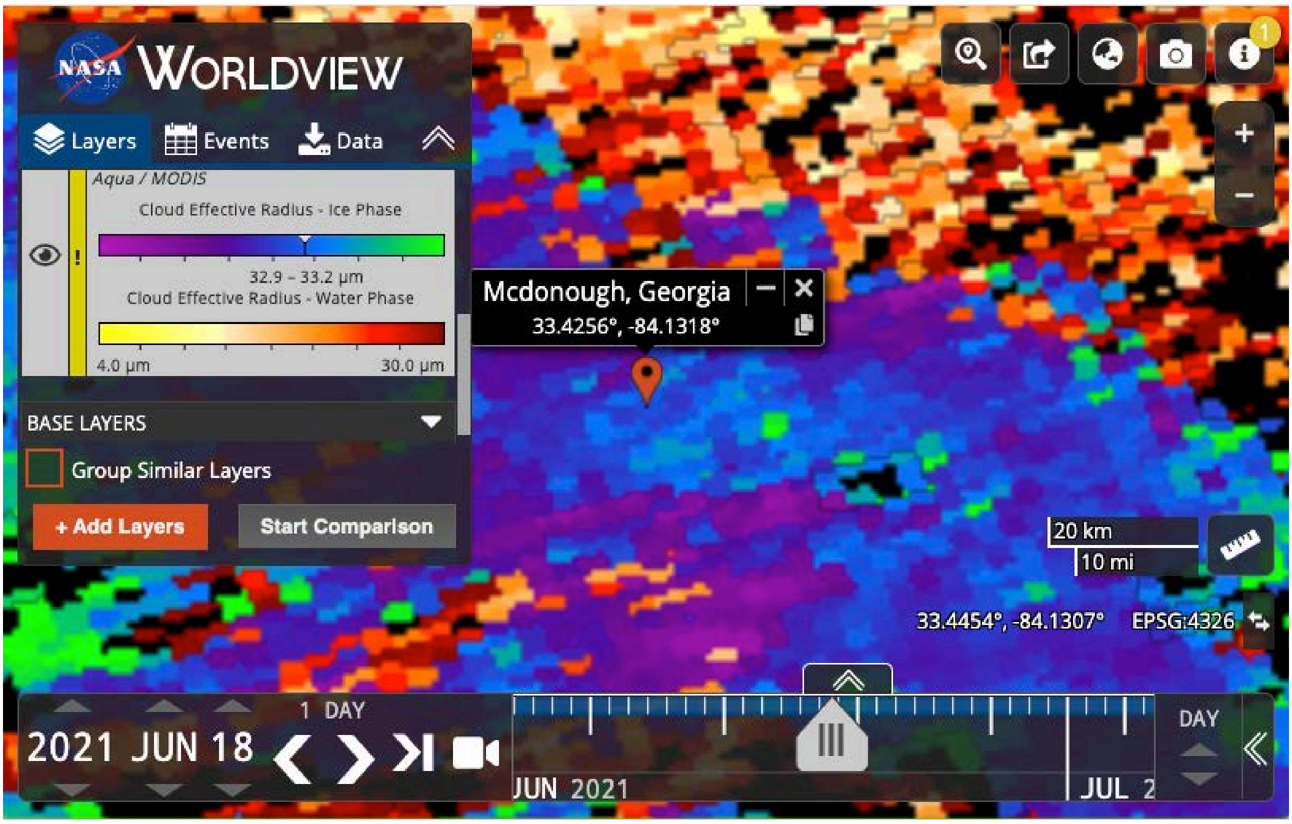

Figure A10. Cloud Effective Radius: June 18th, 2021, McDonough, GA, USA.

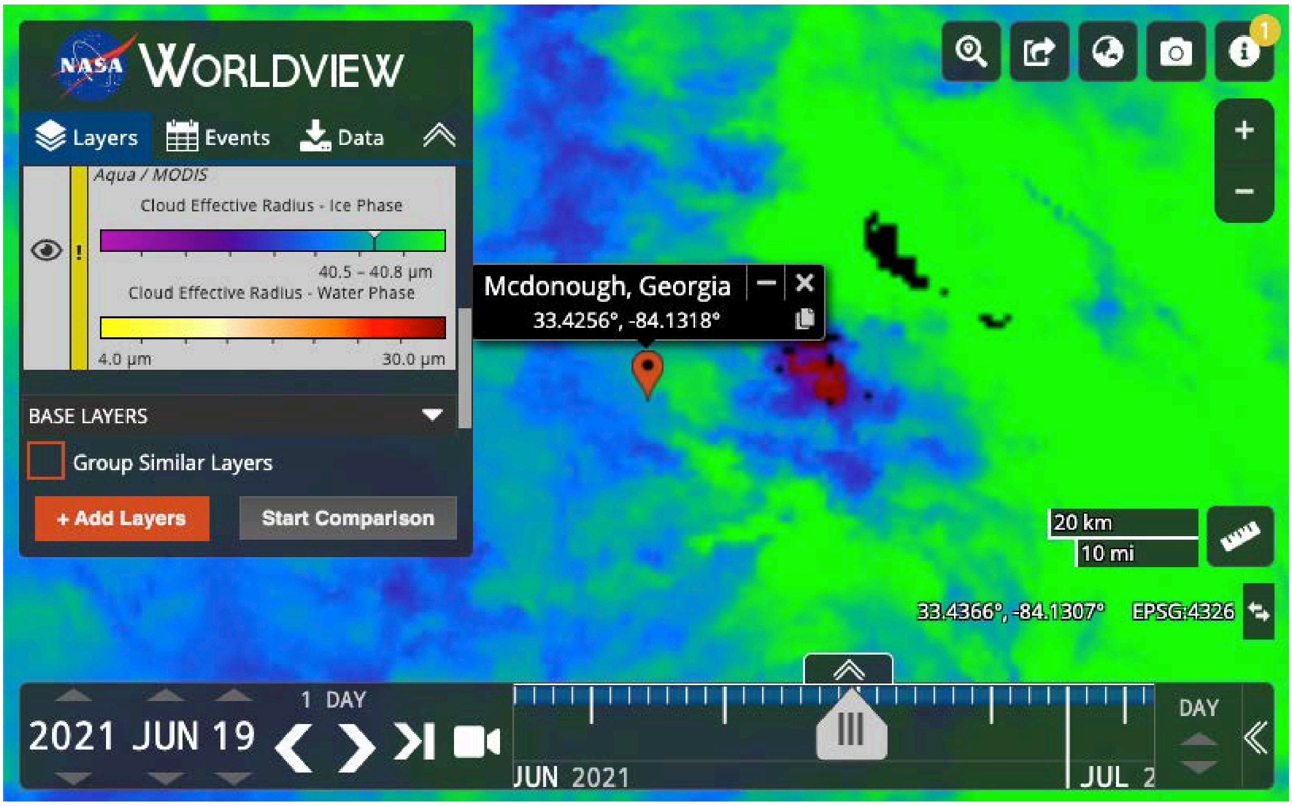

Figure A11. Cloud Effective Radius: June 19th, 2021, McDonough, GA, USA.

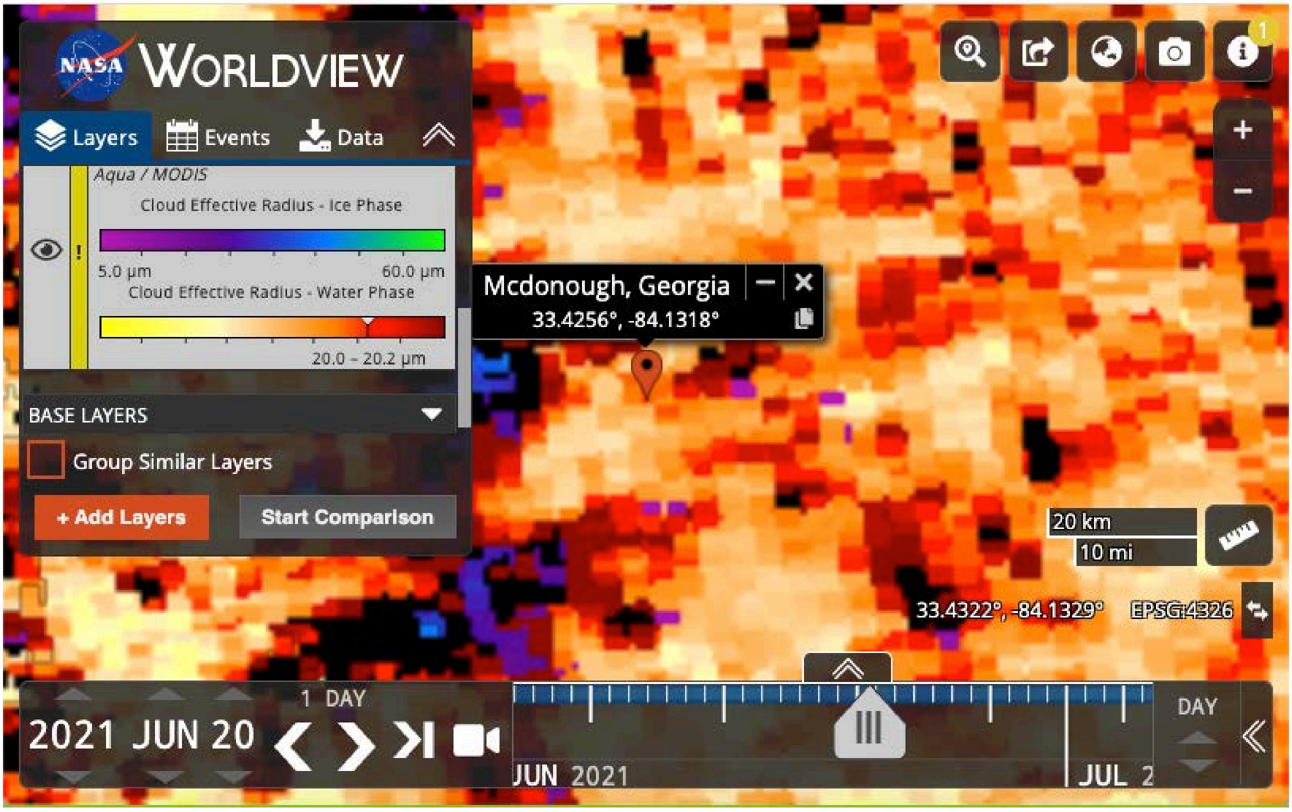

Figure A12. Cloud Effective Radius: June 20th, 2021, McDonough, GA, USA.

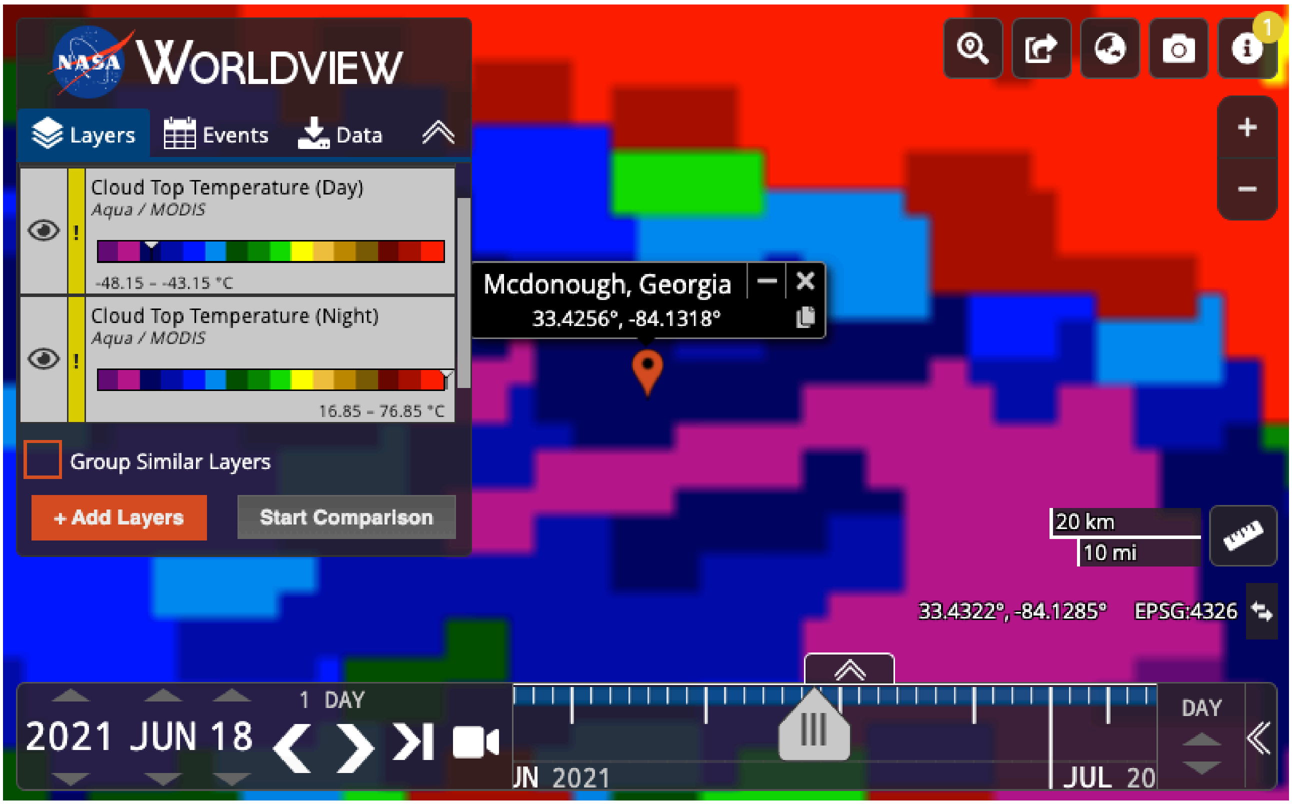

Figure A13. Cloud Top Temperature: June 18th, 2021, McDonough, GA, USA.

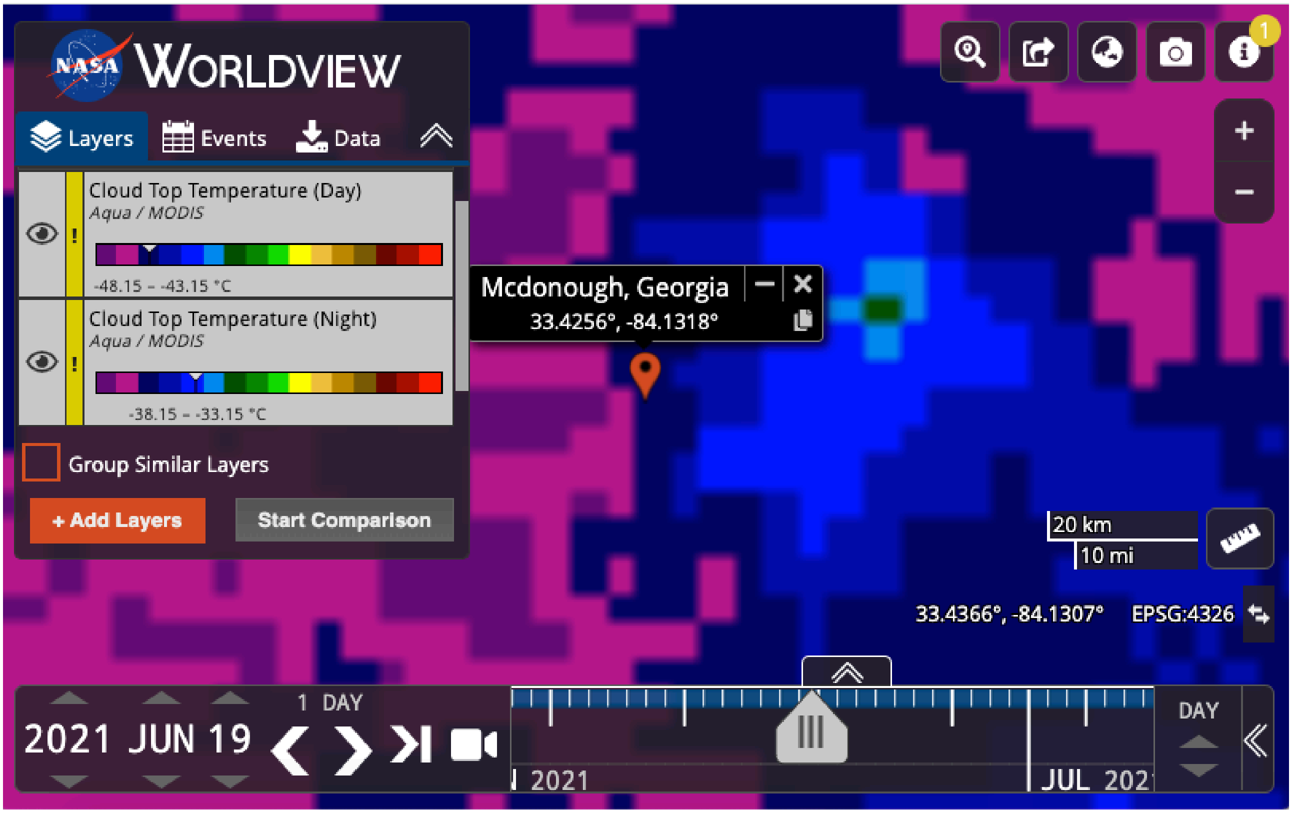

Figure A14 Cloud Top Temperature: June 19th, 2021, McDonough, GA, USA.

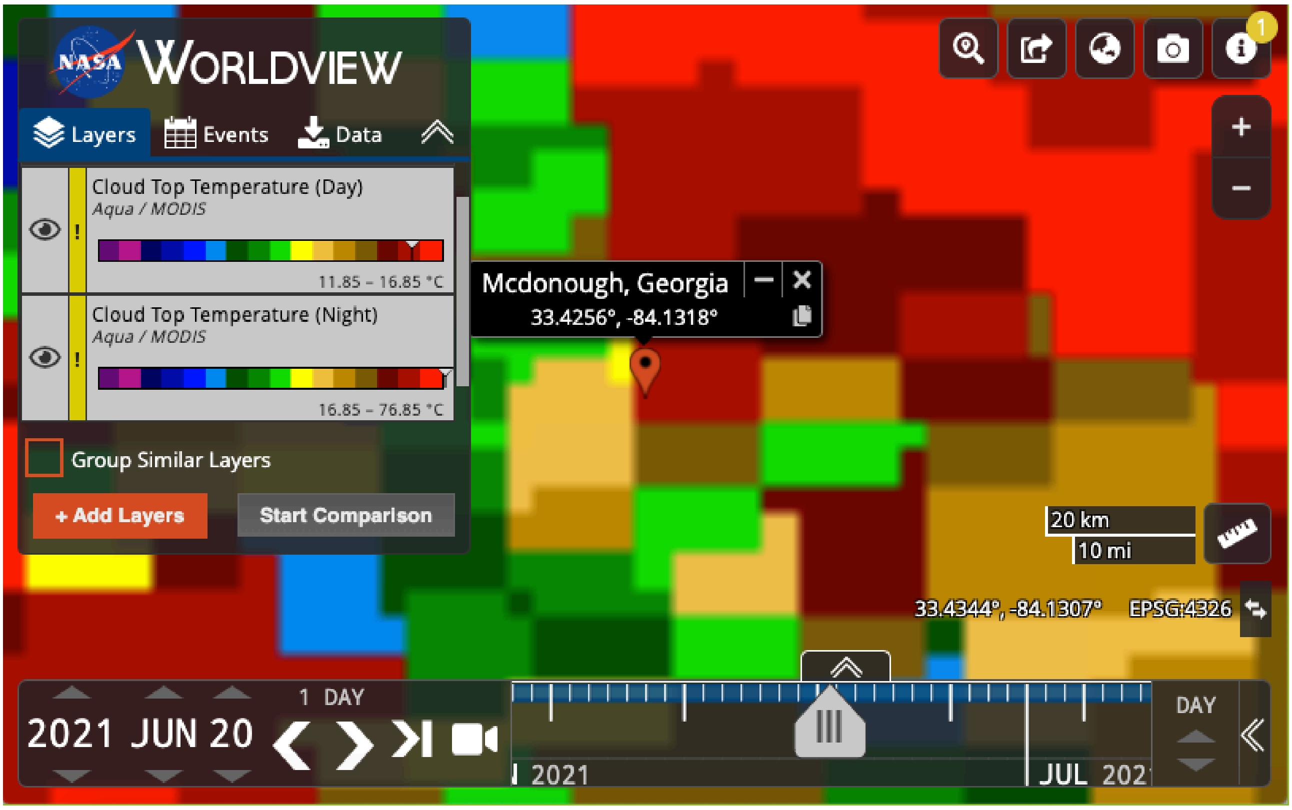

Figure A15. Cloud Top Temperature: June 20th, 2021, McDonough, GA, USA.

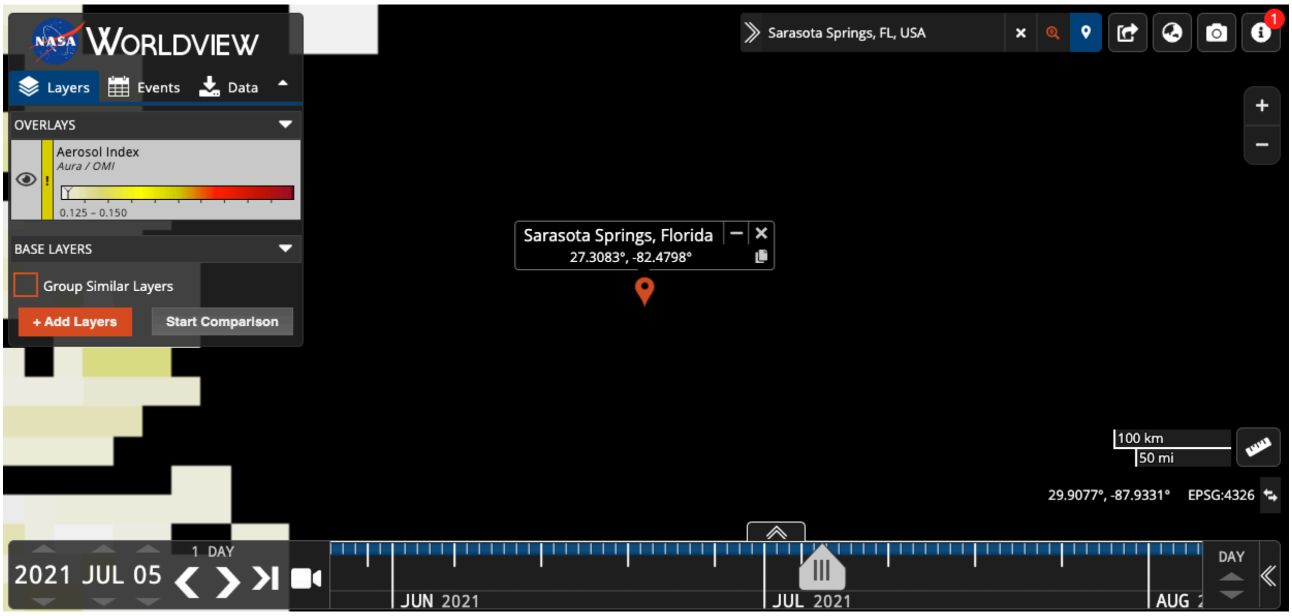

Figure A16. Aerosol Index: July 5th, 2021, Sarasota Springs, FL, USA.

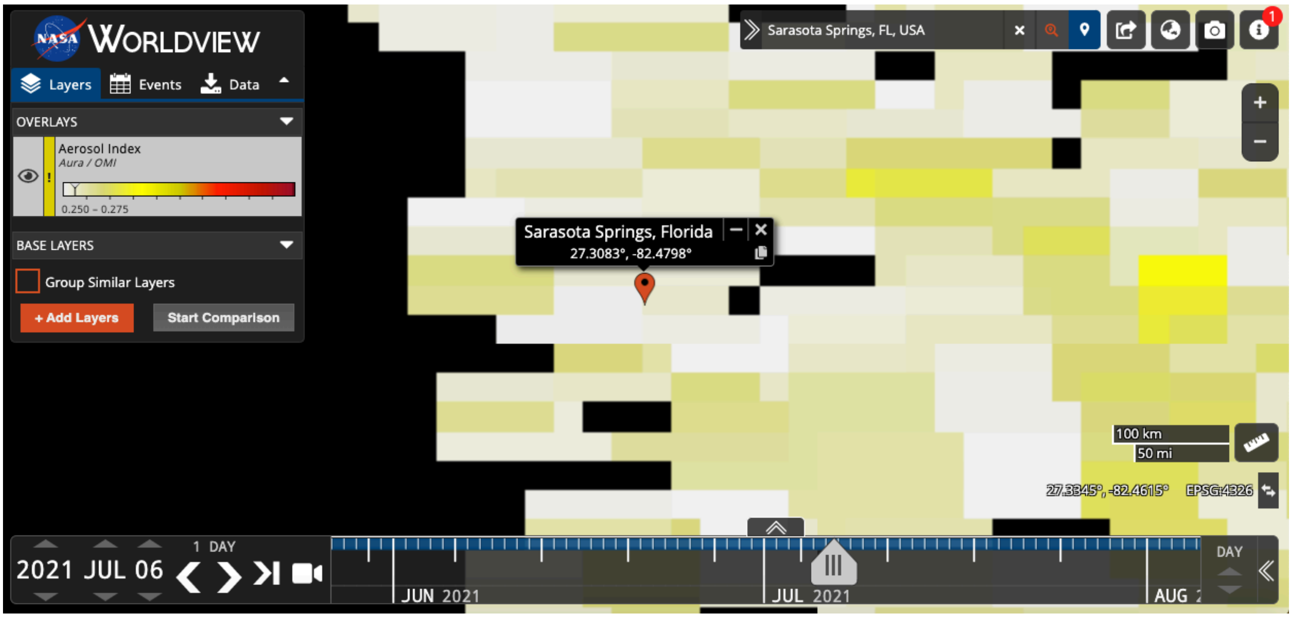

Figure A17. Aerosol Index: July 6th, 2021, Sarasota Springs, FL, USA.

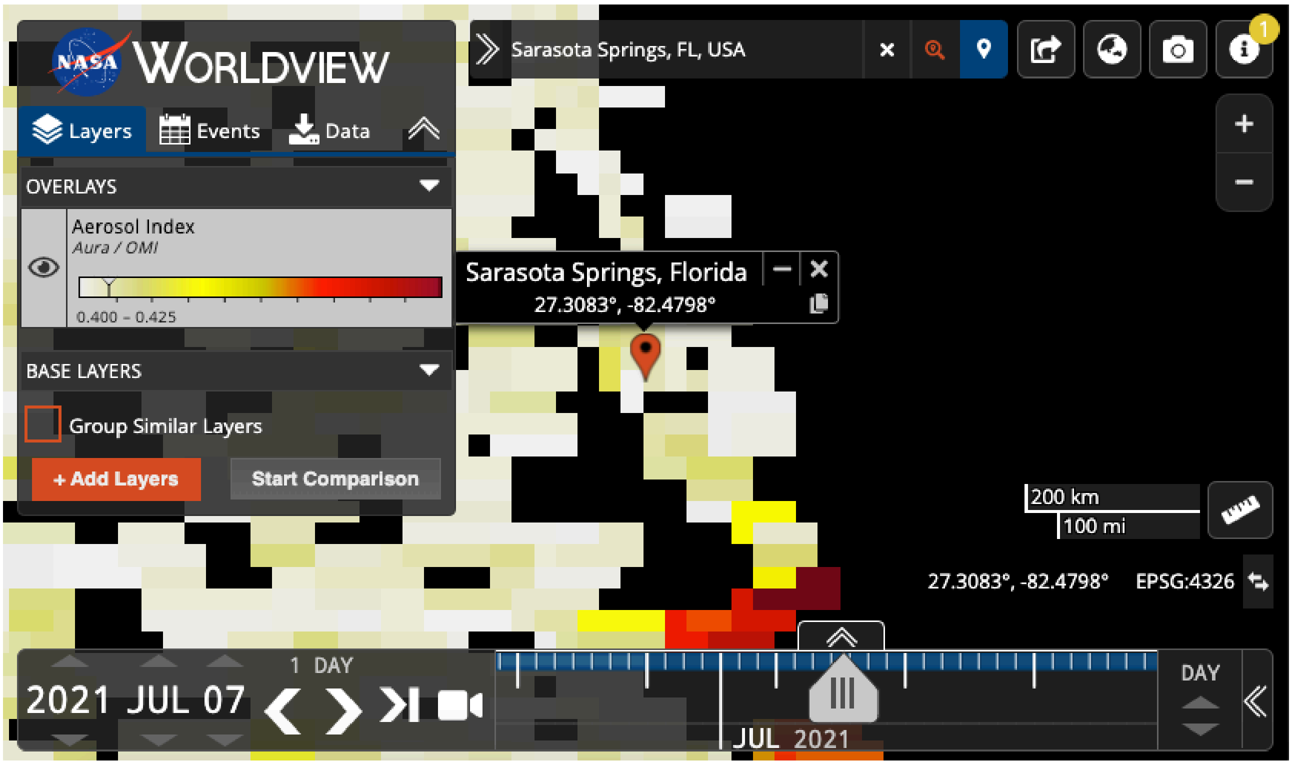

Figure A18. Aerosol Index: July 7th, 2021, Sarasota Springs, FL, USA.

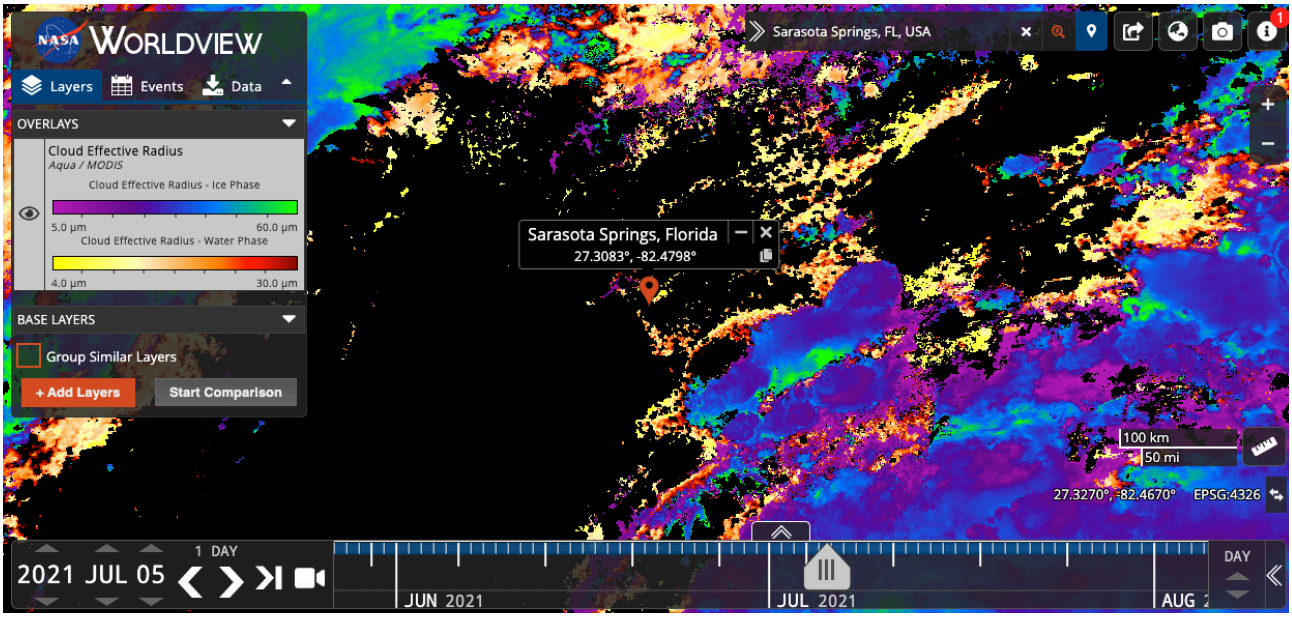

Figure A19. Cloud Effective Radius: July 5th, 2021, Sarasota Springs, FL, USA.

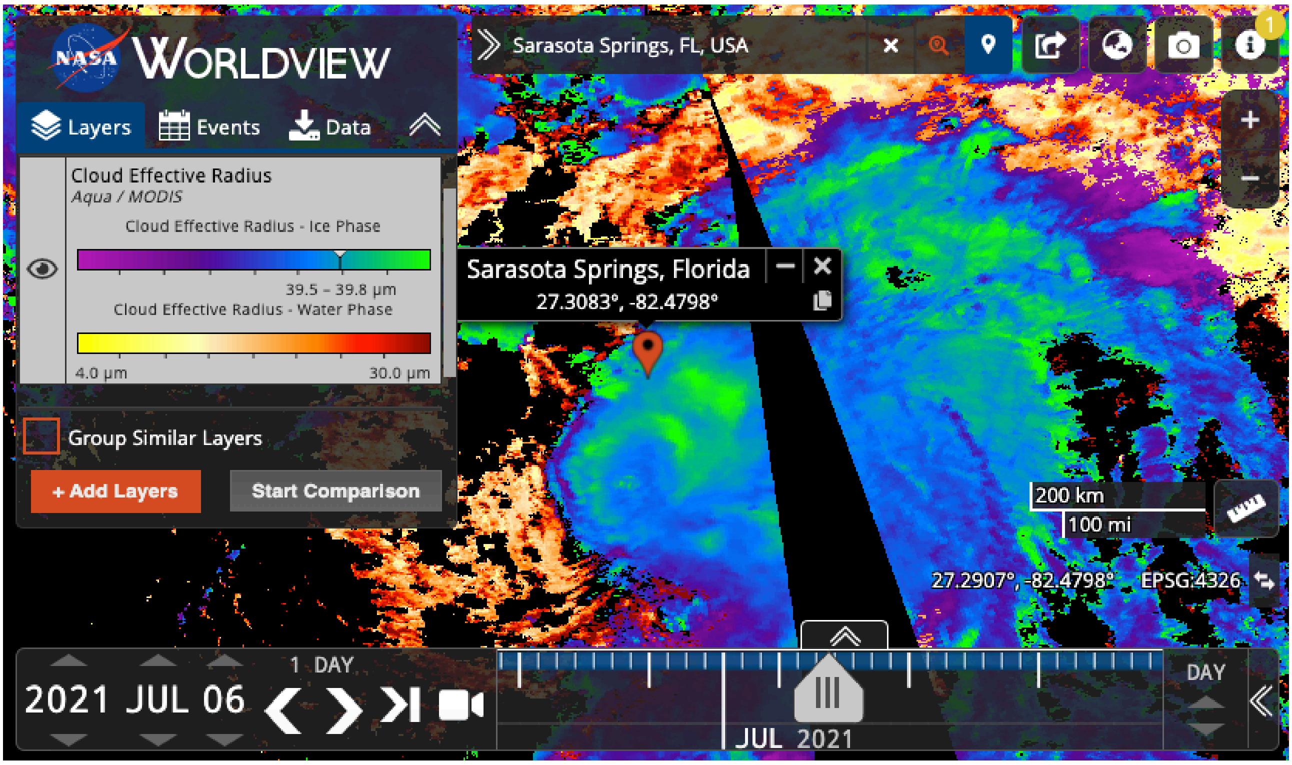

Figure A20. Cloud Effective Radius: July 6th, 2021, Sarasota Springs, FL, USA.

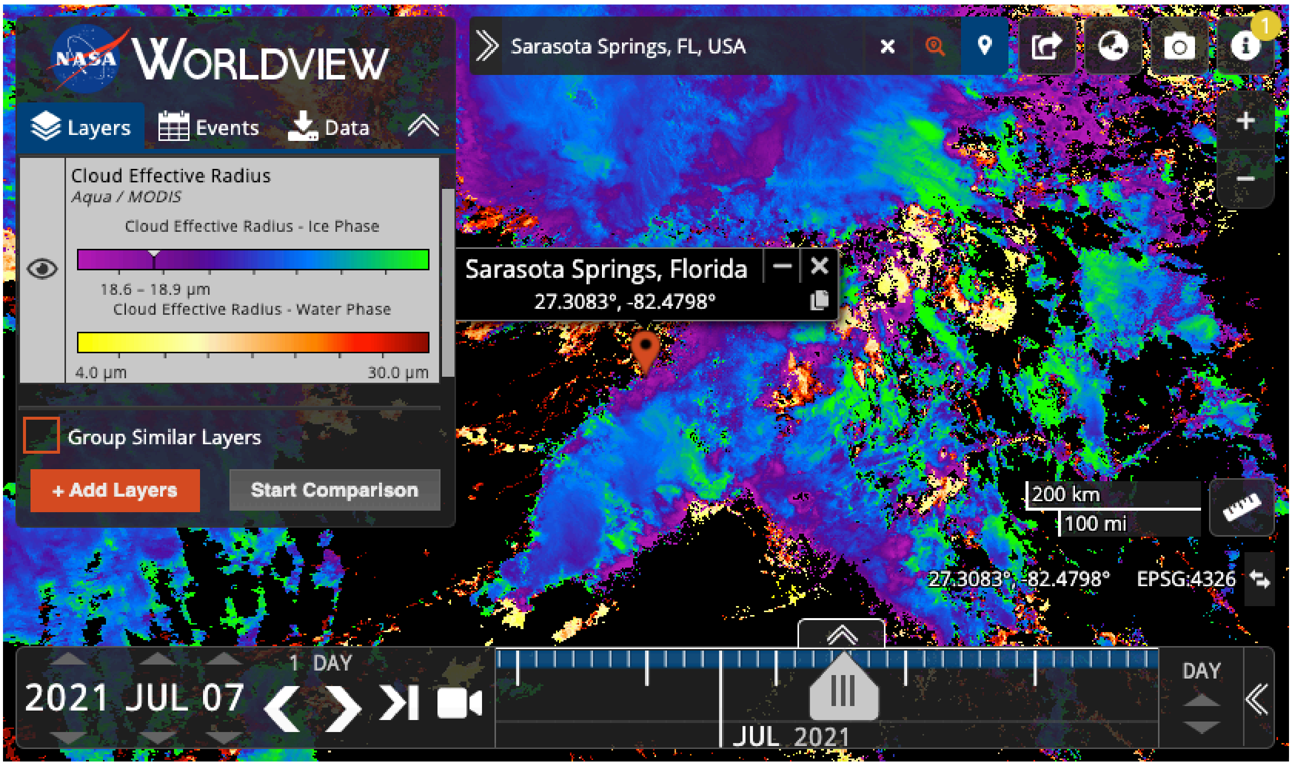

Figure A21. Cloud Effective Radius: July 7th, 2021, Sarasota Springs, FL, USA.

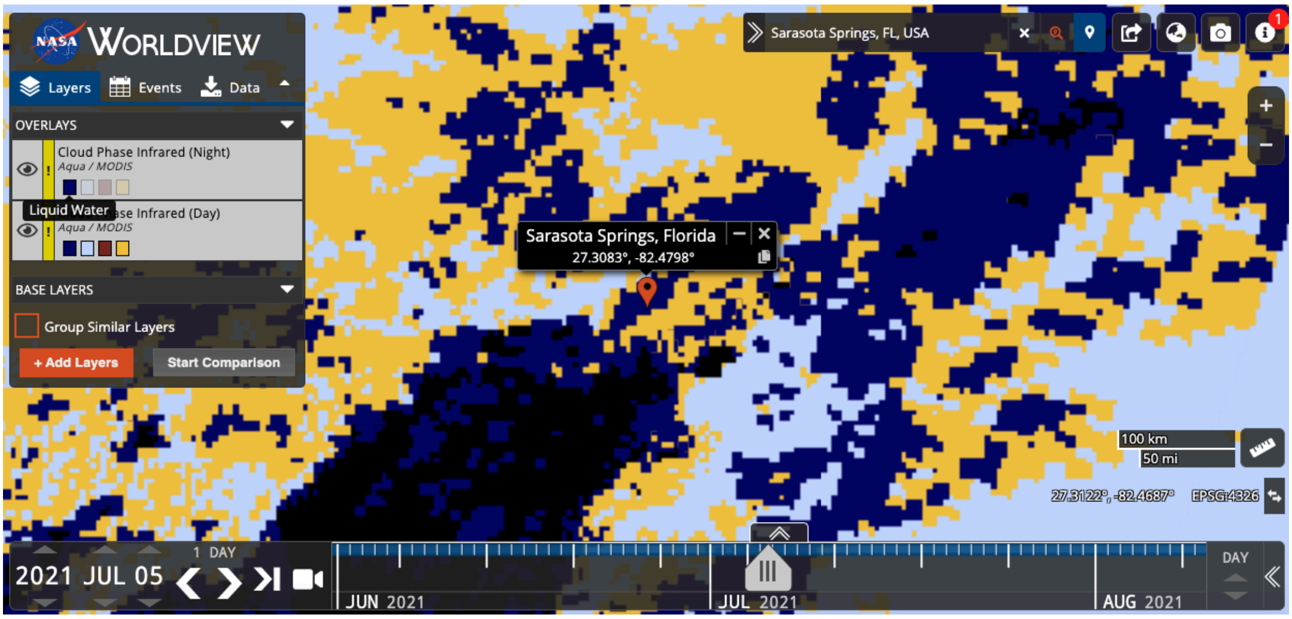

Figure A22. Cloud Phase Infrared: July 5th, 2021, Sarasota Springs, FL, USA.

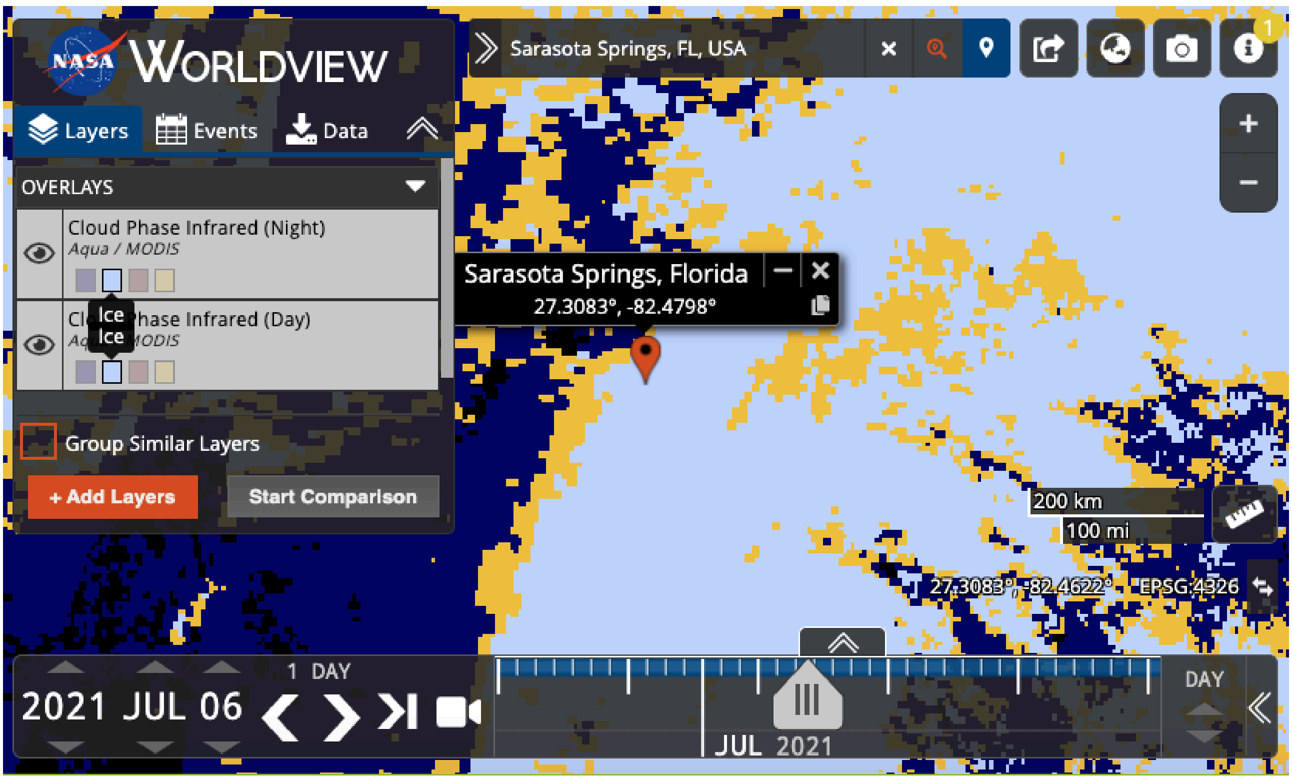

Figure A23. Cloud Phase Infrared: July 6th, 2021, Sarasota Springs, FL, USA.

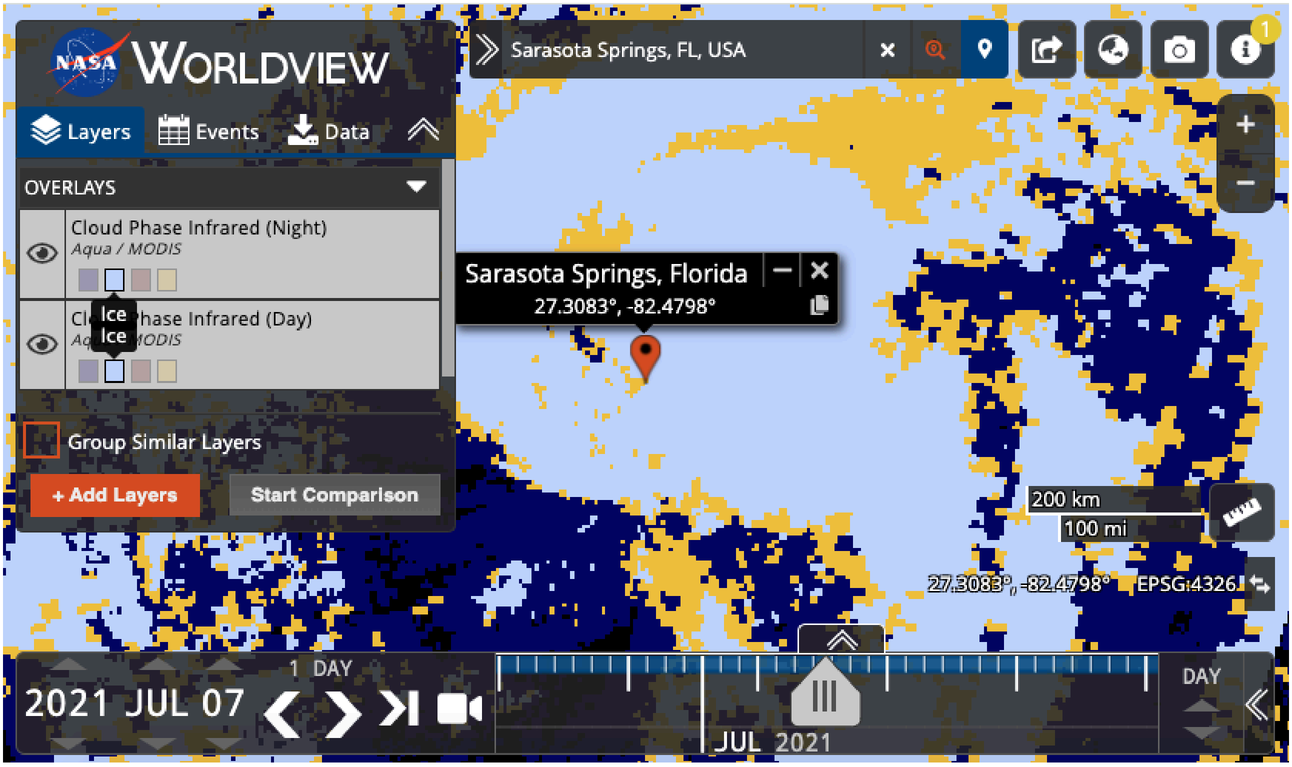

Figure A24. Cloud Phase Infrared: July 7th, 2021, Sarasota Springs, FL, USA.