A proposal to fight tornadoes with multiple connected balloons

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A tornado is an extreme weather condition that can cause enormous damage to human society. In this paper, we propose a low cost, environmentally friendly method to fight against tornadoes using clusters of connected balloons. Deployed over a sufficiently wide area, these large balloons may be able to reduce the wind speed of the tornado, block and disrupt the convective flow of air, and destroy the tornado.

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I. INTRODUCTION

A tornado is an extremely dangerous weather condition with a violently rotating column of air extending from the base of a thunderstorm down to the ground [1, 2]. Through human history, tornadoes have caused many human fatalities, injuries, and massive economic damage throughout the world. For example, on April 26, 1989, a tornado in Bangladesh killed about 1,300 people [3]. The United States has the most tornadoes in the world, nearly four times more than those estimated in all of Europe. In the United States, there are about 1000 tornadoes each year causing about on average 90 fatalities per year in the past 10 years from 2009 to 2018 [4], more than 1000 injuries per year, and several hundred million dollars worth of damage per year [5].

In atmospheric sciences, extensive research was done to understand dynamics and genesis of tornadoes [6–20]. However, there were few studies about mitigation of tornadoes given the challenge of the problem. An old idea that was frequently mentioned is to use nuclear weapons to bomb the tornado [21]. This idea is based on the assumption that the large energy released by a nuclear weapon explosion above a storm would heat the cold air there and disrupt the storm. This idea was dismissed since it would also cause severe damage to surrounding environment, bring about negative effects on human health, and even destroy private properties. Another idea to destroy tornadoes is to use microwave beams from a number of solar-powered space satellites [22]. This idea is based on the assumption that the formation of a tornado needs cold downdraft air. If one can heat the cold downdraft air, this would prevent the tornado from forming. To heat the cold downdraft air, this idea is to use a number of satellites in space to collect solar energy, convert it into microwaves, and send the microwave beams down to Earth to heat the cold downdraft air flow. However, this method would be extremely expensive and was refuted in reference [23]. Recently, three man-made great walls were proposed in references [24, 25] to prevent the formation of tornadoes in the US Tornado Alley. The assumption behind this idea is to use the man-made wall to reduce the wind speed, weaken air mass collisions, and eliminate the major tornadoes in this area. The author proposed building three great walls, each with 300 m height and 50 m width, in this area. The first one is near the northern boundary of the Tornado Alley, maybe in North Dakota. The second one is in the middle, maybe in the middle of Oklahoma and going to east. The third one is in the south of Texas and Louisiana. However, building those great walls or skyscrapers would be a very expensive project by itself and the idea was criticised by the other meteorologists [26]. Another idea to prevent the tornadoes is based on the assumption to change the local climate by cloud seeding. However, there was evidence suggesting that cloud seeding might not help prevent formation of tornadoes, but increase formation of tornadoes in a number of cases [27]. So far, none of the above methods are environmentally and economically practical to mitigate tornadoes.

A tornado is normally associated with the turbulent instability of atmospheric air flow in a storm. In physics, in order to suppress a coherent instability, one can introduce a method to randomize the air flow and to enhance the incoherent motion of atmosphere. In this paper, we propose a low cost, environmentally friendly method to fight tornadoes by using multiple connected large balloons. Each balloon can have a size of about ten meters. A number of these large balloons are connected together to form a cluster that can have a few ten meters across and can cover an area of thousands of square meters. Multiple clusters of these balloons flying into a tornado would cause decoherent motion of air, disrupt the high speed rotating wind, block the warm updraft air flow, and potentially destroy the tornado. Furthermore, these balloons can be reused multiple times for different tornado seasons and can be deflated and stored in a small building when a tornado season is over. There is no modification of the local climate or any other environmental factors.

The organization of this paper is as follows: after the Introduction, we briefly review the life cycle of a tornado in Section II and characteristics of tornadoes in Section III; we then present the proposed multiple connected balloon method in Section IV; discuss potential challenges in Section V; and give some further discussions in Section VI.

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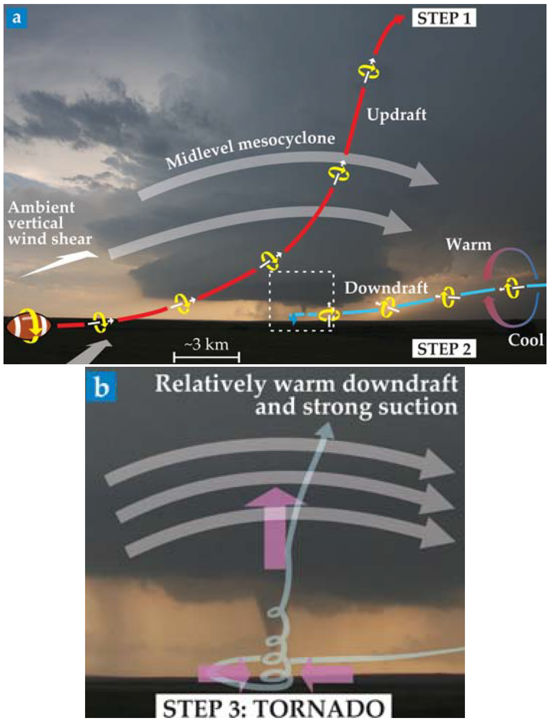

FIG. 1: An illustration of tornado formation from a supercell storm following the three steps in reference [14].

II. LIFE CYCLE OF A TORNADO

A tornado is a dangerous and complex weather phenomenon. Most violent tornadoes are generated from the supercell storm. A thunderstorm can form when the warm humid air collides with the cold air. A supercell is a severe thunderstorm that contains mid-level persistent updrfat rotation (also called mesocyclone). Even though it is still not fully understood how exactly tornadoes form, grow, and stop, some basic understanding of a tornado formation can be illustrated using three steps in Fig. 1 [14].

In step one, the vertical wind shear of the air flow will generate horizontal rolling of air, i.e. horizontal vorticity. Here, the vertical wind shear denotes the change of horizontal wind speed and direction along the vertical altitude. The horizontal vorticity is tilted upward by the warm updraft wind field at the mid-level altitude to become vertical vorticity, i.e. mesocyclone. In step two, the precipitation in the thunderstorm drags with it a region of quickly descending cold air to form the downdraft air flow. This downdraft flow can coexist with the updraft flow since the precipitation normally falls outside the updraft region. This causes a buoyancy gradient at low altitude and generates horizontal vorticity near the ground. These horizontal vorticity is tilted upward by the surrounding wind field to form near ground vertical vorticity as shown in step two of the Fig.1. The near ground rotation by itself will not develop into a strong tornado. In step three, in the region dominated by rotation, the pressure is lower than the outside region. This produces an upward-directed pressure gradient force that sucks the surrounding air into the region. This dynamic updraft suction intensifies the ground level rotation through the conservation of angular momentum and a violent high rotating speed tornado is formed.

Initially, the tornado has a good source of warm, moist air flowing inward to power it. Without surface friction, it grows until the centrifugal force balance the inward pressure-gradient force. As the cold downdraft air flow completely wraps around and cuts off the tornado's air supply, the updraft begins to weaken, the tornado evolves into the dissipating stage. This stage often lasts no more than a few minutes until the tornado ends.

III. CHARACTERISTICS OF TORNADOES

Tornadoes are visualized with strong rotating wind and a cloud of debris. Most tornadoes have a narrow funnel shape except that in the dissipating stage, the tornadoes can resemble narrow tubes or ropes, or can twist into more complex shapes. The size of tornadoes can vary widely from case to case. Some weak or strong dissipating tornadoes can be very narrow and only a few meters across. Some can be as wide as a mile or more. Most tornadoes are about 80 meters across while on average, tornadoes are about 150 m across [2].

Most tornadoes have a rotating wind speed less than 110 miles per hour while some extreme tornadoes can have a speed over 300 miles per hour. Tornadoes are classified into six categories using intensity Enhanced Fujita (EF) scale, EF-0 through EF-5, according to their wind speeds and the damages [28]. EF-0 tornadoes are the mildest with wind speed between 65 and 85 Miles Per Hour (MPH), causing light damage; EF-1 have wind speed between 86 and 110 MPH, causing moderate damage; EF-2 wind speed between 111-135 MPH, causing considerable damage, EF-3 wind speed between 136-165 MPH, causing severe damage; EF-4 wind speed between 166-200 MPH, causing devastating damage; EF-5 wind speed greater than 200 MPH, causing incredible damage. F-5 tornadoes are the most dangerous with wind speed between 261 and 318 MPH and cause violent damage to surroundings.

Tornadoes can last from several seconds to more than an hour [21]. Most tornadoes last less than 10 minutes and move at speeds of about 10 to 20 miles per hour. The average distance tornadoes have traveled is about three and half miles. In addition to strong winds, tornadoes also show changes of temperature, moisture, and pressure of surrounding air. Temperature tends to decrease and moisture content to increase around a tornado. From the outside of the tornado to the center of the tornado, there could be about 100 mbar pressure difference [29]. Accompanying the strong wind of tornadoes, there can be very heavy rain, frequent lightning, and hail in the storms.

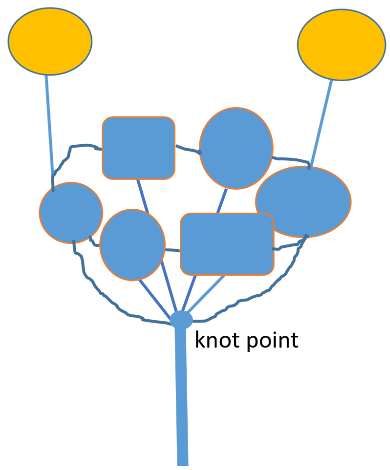

FIG. 2: A schematic plot of a cluster of multiple connected balloons. Here, the balloons inside the cluster can have different sizes and shapes to enhance the random irregular motion of air. Two extra balloons (yellow) filled with light gas such as helium are used as lifting balloons.

IV. MITIGATION OF TORNADOES USING MULTIPLE CONNECTED BALLOONS

From the life cycle of a tornado, we know that the formation and the survival of the tornado depends on the downdraft and the updraft air flow. Without the updraft warm air flowing into the tornado, it would become weak and dissipate quickly. From the characteristics of tornadoes, we know that even though the area affected by a thunderstorm can be quite large (∼miles), the size of a typical tornado is relatively small (∼100 meters). This suggests that if one could block the updraft warm air flowing into a tornado, the tornado might be stopped quickly.

In this section, we discuss fighting tornadoes using multiple connected balloons. This method is to use multiple connected balloon clusters to block the updraft and the swirl air flow of a tornado and to divert the convective air flow into the disordered air flow to achieve the goal of slowing down and even destroying the tornado. A schematic plot of a connected balloon cluster is shown in Fig. 2. In this cluster, multiple balloons (six balloons in this example), each with individual string (this string by itself can consist of multiple strings), are tied together with roughly the same distance from the balloon to the knot point to form a star like structure. Then those balloons are connected side by side with a string to form a polygon like structure. Using the string connection between balloons is to enhance the random interaction among balloons and to cause the disordered motion of air. Extra balloons (two in this example), each connecting to one of these six balloons, are used to help lift the balloon cluster. The different sizes and shapes (round, rectangular box, and ellipsoid) of balloons are included there to illustrate that those balloons can have irregular shapes instead of just the round shape. This could even enhance the random motion of balloons after collisions, helps disrupt the coherent convective air flow, slows down the wind speed of the tornado. These balloons also block the inflow warm updraft air from the tornado suction. This leads to the dissipation of the tornado and eventually destroys the tornado.

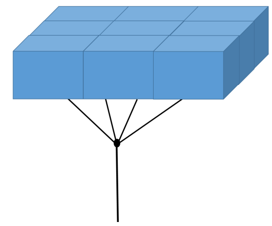

FIG. 3: A schematic plot of a single multi-chamber rectangular shape balloon.

Figure 3 shows a rectangular shape balloon that consists of multiple chambers. There are total nine chambers in this example. Using multiple chambers in a balloon helps it to float inside the tornado after being penetrated by high speed flying debris. It also reduces the time to pump the balloon through multiple inlets. The size of the balloon can be on the order of ten meters in the two horizontal dimensions and on the order of meters in the vertical dimension. Such a rectangular shape balloon might be more efficient to block the updraft air flow in the tornado than the round shape balloon. The length of the string connecting two balloons in a cluster can be on the order of 20 to 30 meters. The string from the balloon to the knot point of the cluster can have similar length. A cluster of these connected balloons has an across of about 20 to 50 meters and covers an area of thousands square meters. A dozen of clusters will cover the size of a football field, which is about the size of a typical tornado. Each balloon can be made of materials such as air bed vinyl with a rough soft surface. The rough soft surface helps slow down the wind speed at the surface of the balloon. The balloon can be electrically pumped with air or with helium or with cheaper hydrogen (if fire is not a problem). The lifting balloons can be filled with helium or with hydrogen so that they will get into the tornado storm first and drag the entire cluster into the tornado with the help of updraft suction force of the tornado. Each balloon consists of multiple independent air chambers so that even one is broken, the balloon can still fly. The altitude of these balloons in the tornado will be relatively low (e.g. maybe less than 30 meters) and can be made lower or higher by adjusting the length of the large rope connecting the cluster using a remote controller. Varying the altitude of the balloon cluster inside a tonorado might help enhance the random motion of air flow inside the tornado. As the tornado moves, the large nylon rope is released and becomes longer so that the balloon cluster can move together with the tornado (like fishing).

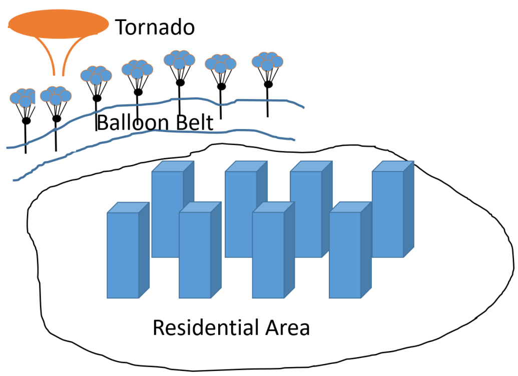

FIG. 4: A schematic plot of deploying a balloon belt near a residential area to fight against the tornado.

Figure 4 shows a schematic plot of the deployment of these balloon clusters in front of a residential area. An open space near the residential area can be used to deploy those balloon clusters. Using an open space has the advantage of reducing the amount of debris in a tornado. A number of electric pumping spots and cluster rope holders can be installed in the open space. On an ordinary day without tornadoes, the area is open to the general public. On a tornado day, multiple clusters of balloons will be quickly pumped and released into the air to form a balloon belt. The width of the balloon belt can be about one hundred meters and the length of the belt can be a couple of hundred meters. Once a tornado moves into the balloon belt, it will interact with the balloon clusters inside the belt. These clusters block and disorder the convective air flow in the tornado through the random motion of balloons and cause the tornado to lose its high wind speed before reaching the residential area. This would protect the residential area from the damage of strong wind and flying debris of the tornado. If possible, these balloon clusters might also be installed on a strong mobile device (e.g. a tank-like low weight center heavy automobile) and be carried directly into the path of the tornado to fight against the tornado.

V. POTENTIAL CHALLENGES OF THE PROPOSED METHOD

There are some potential challenging questions for the above proposed method.

Firstly, are these balloons large enough to affect a tornado? As mentioned in Section III, the size of a storm that helps form the tornado can be large (on the order of miles), but the size of a tornado that touches the ground can be much smaller. A typical tornado has a width of about hundred meters and a size of about a football field. Using multiple clusters of balloons might not be able to affect the local weather. However, a number of clusters that contain a few hundred large balloons will cover an area greater than a football field and should be able to affect the local air flow inside and around the tornado. Some past studies of debris loading in a tornado suggested that under some conditions, the debris loading could have substantial impact on the tornado dynamics, causing 50% or more reduction of near-surface wind speeds [30, 31]. Given the much larger size of the balloon compared with the debris, the impact of these balloons on the tornado dynamics should be more significant.

Secondly, will the balloons be strong enough to survive the strong wind of a tornado? The strong wind of the tornado can break down trees and destroy houses. It might also break a balloon. However, the difference between the flying balloon and a tree or a house is that the latter is still while the former moves together with a wind. The relative speed between the wind and the tree or the house is large for a strong wind. On the other hand, the relative speed between the strong wind and the moving balloon might not be very large since the balloon moves and rotates together with the wind. This reduces the impact of the strong wind on the balloon. Each balloon can be tied by multiple nylon strings at several locations. These strings are braided together to form a single nylon string as shown in Fig. 3. In case that a single string is broken, the other strings can still hold the balloon. Such a balloon is further bundled and connected with the other balloons to form a balloon cluster. This cluster will rotate with the swirl wind inside the tornado. The balloons inside the cluster interact with each other due to different rotating speeds. These moving balloons would disrupt the convective air flow, reduce the rotating speed of air inside the tornado, and block the updraft air flowing into the tornado.

Thirdly, will the flying debris break the balloon? The flying debris inside the strong wind of a tornado can have a very high speed and a large momentum. It would penetrate into or through the balloon. However, this would not prevent the balloon from flying since the balloon is driven by both the updraft inflow wind from the suction of the tornado and the dragging force of the lifting balloons. Also, the balloon consists of multiple independent chambers. If one chamber is broken, the other chambers can still function. Moreover, the balloon can be made of air bed like material or multi-layer material (including a special layer). Even after the balloon is pierced through by a flying object, it would still hold sufficient air to be able to float in the strong wind (like a kite). On a rainy storm day, the soft surface of the balloon can soak water and increase the balloon weight. The heavier weight of the balloon helps dissipate more convective wind energy of the tornado.

Fourthly, will the pressure drop inside a tornado blow up the balloon? The pressure drop from the region outside of the tornado to the region inside the tornado is about 100 mbar. This corresponds to about 10% decrease of the usual atmosphere pressure. A balloon made of the air-bed material or other type of materials should be able to withstand this pressure difference.

Fifthly, what if a tornado moves through these balloons? The tornado will move with a relatively slow speed (a typical speed is about ten to twenty miles per hour). The length of the nylon rope connecting to the balloon cluster can be made automatically adjustable (with a remote controller) so that the cluster moves together with the tornado. This is similar to fishing. Once the balloon cluster is caught by the tornado, it would move with the tornado until the end of the tornado.

VI. FURTHER DISCUSSIONS

After a tornado storm is over, balloons hit by flying debris can be repaired and reused for another tornado. The cost of a balloon can be a few hundred US dollars. The cost of a cluster of connected balloons can be a few thousand dollars. A dozen of clusters of balloons would cost on the order of ten thousand dollars. Compared with the multiple million dollar damage and even life lost caused by the tornado, the cost of these balloons is much less. Also, these balloons would not affect the local weather condition, neither cause any environmental problem. After the tornado storm, these balloons can be deflated electrically and folded into a small volume and stored in a convenient place. On a tornado day, these balloons can be quickly pumped using electric devices, set up, and released into the air within a couple of minutes. Given the current warning time of the tornado (more than ten minutes) it should be sufficient to set up the balloon system within the warning time. In practice, it will be safer to set up the balloon system somewhat earlier so that people can still have time to find a safe shelter after that.

Besides the star like cluster structure, these large size balloons can also be connected into a mesh like structure to form a protecting balloon wall. A schematic plot of such a balloon wall is shown in Fig. 5. Again, the shape and the size of individual balloon can be different from each other. Such a wall in front of a residential area helps slow down the strong wind blowing from a severe storm and protects the people and properties behind it. Such a balloon wall can also be used test the great wall idea proposed in references [24, 25] with a much lower cost. For a 300 meter high and 50 meter wide wall, it will use about 100 (25×4) ten meter size balloons. Assuming that the cost of each balloon is between 500 and 1000 US dollars, the cost of such a great balloon wall will be between $50,000$ to $100,000$ US dollars. This is much cheaper than the similar size skyscraper. Even one uses a two-plane, three-dimensional structure as shown in Fig. 5 by doubling the number of balloons in the wall, it is still much less expensive than a skyscraper great wall.

In this paper, we propose a method to use multiple connected balloons to fight against tornadoes. This method is environmentally friendly and economically practical. However, a number of further studies probably need to be done in real applications. These studies include the optimal choice of size and shape of the balloons, of the length of string connecting the balloons, of the number of balloons in a cluster, of the material used to make the balloons, of the weight of the balloons, of the gas used to fill the balloons, of the altitude of the balloons, and of the way to deploy the balloons. This method can be tested with the experimentally simulated tornadoes and if possible with the numerically simulated tornadoes.

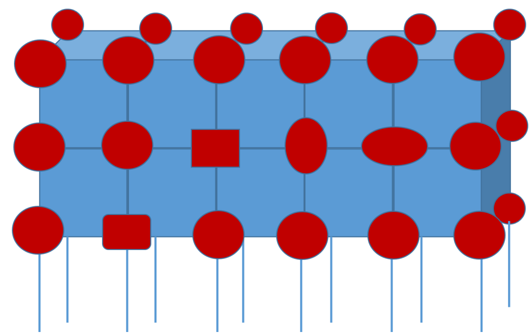

FIG. 5: A schematic plot of a multiple connected balloon wall.

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