Article

Charged Particle (Negative Ion)-Based Cloud Seeding and Rain Enhancement Trial Design and Implementation

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Abstract: China has been suffering from water shortage for a long time. Weather modification and rainfall enhancement via cloud seeding has been proved to be effective to alleviate the problem. Current cloud seeding methods mostly rely on solid carbon dioxide and chemicals such as silver iodide and hygroscopic salts, which may have negative impacts on the environment and are expensive to operate. Lab experiments have proved the efficiency of ion-based cloud seeding compared with traditional methods. Moreover, it is also more environmentally friendly and more economical to operate at a large scale. Thus, it is necessary to carry out a field experiment to further investigate the characteristics and feasibility of the method. This paper provides the design and implementation of the ion-based cloud seeding and rain enhancement trial currently running in Northwest China. It introduces the basic principle of the trial and the devices developed for it, as well as the installation of the bases and the evaluation method design for the trial.

Keywords: cloud seeding; rainfall enhancement; weather modification; charged particles

1. Introduction

Lack of usable water resources has been a global problem [1–3]. Fresh water resources on land only account for 2.53% of the whole water resources on earth. Among fresh water on land, 68.69% are solid glaciers, which are too hard to use and may adversely affect the environment.

In China, the situation is getting much worse. Though China is the sixth largest country regarding water resources, considering the huge population of China, the water resource for each person individually is only a quarter of the world’s average. In addition, the distribution of regional water resources in China is mismatched. The Yangtze River Basin and its areas to the south account for only 36.5% of the country’s land and 81% of the water resources, while the Huai River Basin and the areas to the north account for 63.5% of the country’s land but only 19% of the water resources. These areas, especially the Northwest region, which constitute about 30% of China, are suffering greatly from water shortage and therefore both ecological and environmental development stagnate [4].

For decades, various methods have been devised to alleviate the scarcity of freshwater resources. Atmospheric humidity as a source of liquid water has been receiving growing attention over the past years but is still not full recognized in spite of its great potential [5,6]. Take China for example, judging
from the total water resources, the annual atmospheric water resource may reach 18 trillion tons, while surface and ground water resource may only reach 2.7 and 1 trillion tons, respectively. However, years of meteorological statistics show that, only 16%–18% of water in air can form precipitation and fall to the ground. Considering that groundwater resources are difficult to use, while resources in air are extremely abundant, if we may come up with some methods to harvest the water in the air on a massive scale, the situation will be greatly alleviated. After a great number of trials taken into action, it is believed and proved that, cloud seeding experiments have efficiently and effectively increased rainfall at a high level of confidence [7–9].

Natural rainfall is the result of a series of processes. After surface water is evaporated into the air, the water vapor condenses into small droplets when encountering cold air at high altitude. The small, light droplets are held in the air by updrafts and condense into clouds. In the early stage of raindrop formation, cloud droplets mainly depend on constantly absorbing water vapor around the cloud to condense and sublimate themselves. If the water vapor in the cloud can be continuously supplied and replenished, so that the surface of the cloud droplets is often in a supersaturated state, this condensation process will continue and the cloud droplets will increase and become raindrops. However, sometimes the water vapor in the cloud is limited, making smaller cloud droplets not able to coalesce to form raindrops. However, if water droplets and ice crystals, or any other ‘seeds’, coexist in the cloud, the process of condensation and sublimation will be greatly accelerated. When the cloud droplets increase to a certain degree, due to the increasing volume and weight of the large ones, they can not only catch up with but merge the slower small cloud droplets to grow stronger.

Cloud seeding is a type of weather modification that aims to change the amount or type of precipitation that falls from clouds by dispersing substances into the air that serve as cloud condensation or ice nuclei, which alter the microphysical processes within the cloud. The most common chemicals used for cloud seeding include silver iodide and dry ice (solid carbon dioxide) [10]. Though the ways to enhance precipitation have been proved effective to some extent, their impact on environment and health, as well as their economic cost ought to be taken into consideration [11–13].

There is no doubt that CO₂ is a main cause of global warming, considering dry ice is exactly solid carbon dioxide, it is not a wise idea to implement cloud seeding in this way. Similarly, for silver iodide, as the silver ion is a kind of heavy metal ion, it will not only harm the soil and water resources it touches, but may also do great harm to human beings if ingested. When we see these methods in an economic way, it takes too much to enhance precipitation via either method. Although we human beings may take any cost to enhance more freshwater resources, we would like to find a more economical and environment-friendly way to realize this on a large scale.

Charged particles have been proved as able to cause condensation of water droplets in the atmosphere [14,15]. The theory was first put forward by Wilson in 1895 that the ions produced by radioactive material are able to serve as condensation nuclei in super-saturated water vapor environment. Numerous experiments have been carried out in cloud chamber simulating the experiments in real atmosphere and have obtained positive results. Nielsen carried out electrodynamic balance experiments to test the effect of the electric charge on atmospheric water particles [16]. Hoening demonstrated the possibility of extracting water vapor from air by creating condensation on needles [17]. Uchiyama and Jyumonji developed an electrostatic fog liquefier by charging fog particles and attracting them toward the inversely polarized electrode [18]. Harrison suggested that ions can influence the formation of clouds and raindrops at multiple stages throughout the process [19]. Khain proposed a method of droplet collision acceleration with the help of charged droplets and proved a significant effect in rain enhancement and fog elimination in the case of seeding and under natural conditions [20]. Hortal carried out further laboratory experiments and droplets growth was observed in the cloud chamber with electrical discharge, compared to the control chamber [21]. Chin proposed that ionic wind from corona discharge would play an important role in rain gush production based on experimental observation in laboratory [22].
However, a cloud chamber, or artificial climate room, cannot fully restore the real atmospheric condition. Thus, the results are still not convincing enough though charged particle-based cloud seeding has been both theoretically and experimentally proven effective. Therefore, ion-based rain enhancement trials have been carried out by a great number of countries and organizations. In 2004, the ELAT Corporation set up seventeen grounded charged particle catalytic rainfall stations in six cities in south central Mexico and managed to enhance the local monthly precipitation by 50% [14]. In 2010, the Meteo Systems Corporation managed to realize 52 rainfalls on the edge of Abu Dhabi desert, United Arab Emirates [23]. Since 2013, the Australia Rainfall Technology performed several trials in Oman, enhancing yearly local precipitation by 18% [24]. But there is no tangible evidence directly demonstrating a causal relationship between increased rainfall and the operation of the trials.

Moreover, most of the operations are in quite different geometric and meteorological conditions from China. They are located by the coast, which offers regular moist sea draft. However, no field experiment has been performed inland, which is actually more realistic and meaningful to carry out. The trial we are performing takes place in Northwestern China, which is one of the most water-stressed regions in the world [25]. The region is located in the hinterland of the Eurasian continent. Except the south of Qinling, precipitation is scarce in most areas. Due to the lack of rainfall, arid climate and widespread deserts, the surface water in Northwestern China is about 220 billion cubic meters per year, accounting for only about 8% of the country’s total runoff. Thus, it is of great significance to carry out a trial to prove that charged particle-based cloud seeding is effective here. The annual rainfall in the trial location is approximately 500 mm, compared to 100–200 in the surrounding areas, making it theoretically possible to increase rainfall here and have significant positive effects on surrounding areas. In addition, positive results of the trial may be able to provide assistance to the research of some related process, such as the tower triggered lightning [26,27], which also shows the possibility of affecting the cloud by using ground-based ion emitters.

The paper is organized as follows. Chapter 1 introduces the background of the trial. Chapter 2 describes the basic principle of ion-based rain enhancement and gives results of the lab experiments that have already been carried out. Chapter 3 introduces the basic information of the trial locations. Chapter 4 and Chapter 5 introduce the design of the ion emitter and the measurement network. Chapter 6 describes the installation of the sites and introduces the method of remote operation. Chapter 7 provides the design of the experiments and also three methods to evaluate the performance after finishing the experiments.

2. The Basic Principle of Ion-Based Rain Enhancement

The basic principle of ion-based rain enhancement is described as follows [28,29]. Generally, a cloud chamber is filled with supersaturated water vapor or alcohol. Charged particles interact with the gaseous mixture by knocking electrons off the gas molecules as a result of the electrostatic forces. The resulting ions act as condensation centers around which a mist-like trail of small droplets form if the gas mixture is at the point of condensation. The growth of the ice-forming nuclei and the cloud condensation nuclei affects the droplet and the ice particle distribution in the cloud, which would ultimately affect the cloud albedo, precipitation, cloud lifetime, and cloud cover. Charged particles are spread in the atmosphere so that some of the aerosols in the air are charged. Then, the electrostatic field of these charged aerosol particles has a polarizing effect on other neutral water molecule clusters, resulting in a non-contact electric field cohesive force of charged aerosol particles on polarized water molecule clusters, so that the condensation rate of water molecular clusters is promoted to increase the formation of rainfall. The trial we design provides two schemes, a single-electrode ion emitter and a double-electrode one.

2.1. Single-Electrode Ion Emitter Cloud Seeding

We carried out lab experiments in a 1-m³ cloud chamber and a 15,000-m³ artificial climate room, respectively [30,31]. The schematic of the two experiments are shown in Figure 1a,b.
Thus, we may reach the conclusion that, if one can manage to produce and load a fraction of the water, the electrostatic interaction between these charged particles and remaining neutral droplets may accelerate the coalescence process and induce the formation of precipitation, as is shown in Figure 2 [30].

In the experiment, it was found that, for voltage less than 200V, no growth of water droplets was observed due to the competition between evaporation and coalescence of the droplets. For voltage less than 700V and greater than 300V, the radius of the drops would grow larger as the voltage grows, and would eventually fall from the tip due to gravity. However, for voltage over 750V, intermittent discharge would be formed at the tip and the droplet formation process would therefore be disrupted. Thus, we may reach the conclusion that, if one can manage to produce and load a fraction of the droplets in natural clouds with a sufficient amount of electric charges, the electrostatic interaction between these charged particles and remaining neutral droplets may accelerate the coalescence process and induce the formation of precipitation, as is shown in Figure 2 [30].

**Figure 1.** (a) Schematic of the 1-m$^3$ cloud chamber experiment; (b) Schematic of the 15,000-m$^3$ climate room experiment.

For the 1-m$^3$ cloud chamber lab experiment, the temperature inside the cloud chamber was maintained at 20°C. Water vapor generated by ultrasonic nebulizer was injected into the cloud chamber filled with ambient air. The relative humidity inside was maintained at 95% ± 2% with a feedback control system. A stainless-steel needle electrode with radius of curvature of 1 μm at the tip was placed inside to act as a point charge, which was connected to a negative DC power supply ranging from 200 to 700 V. It was expected that the electric field created by the point charge would induce the coalescence of water droplets nearby and form larger water drops at the tip of electrode.

**Figure 2.** Formation of single water droplet under different applied voltages.
For the 15,000-m³ artificial climate room experiment, the height and diameter of the climate room are 27.5 and 25 m, respectively. Eight thermometers were evenly placed among the axis of the cloud chamber. For rain formation experiments, the climate room was first cooled down to 10°C. Superheated vapor was then injected into the chamber and the average temperature was recorded as 20 ± 1.5°C. For snow experiments, the chamber was first cooled down to −20°C, then −15 ± 1.5°C after the vapor injection. Corona discharge was produced using a thin-wire generator, which was suspended in the middle of the climate room. The voltage used to induce corona discharge was 60-kV DC, and the current was measured as 10 mA.

It has been pointed out that, before the corona charge was switched on, there was no particles detected with an initial size of over 3.75 μm, while the number of smaller particles decreased sharply and larger ones were formed after the corona discharge was on. The results were consistent with observations with the naked eye, as the coalescence process triggered further collisions between larger droplets, and eventually led to microscopic precipitation inside the climate room visible with human eyes. Temporal evolution of the particle size distribution is shown in Figure 3 [30].

To further evaluate the effect of corona charge in a more realistic environment, the temperature of the cloud chamber was reduced to −15°C. After the injection of water vapor, it was observed that snow/ice particles with hundreds of micrometers to several millimeters in size were generated inside the cloud chamber after the corona discharge was turned on for 30s, as is shown in Figure 4. This proves that the corona discharge not only contributes to rainfall enhancement, but also solid precipitation enhancement as long as the necessary conditions are satisfied [30].
Double-Electrode Ion Emitter Cloud Seeding

During our research and experiments, we discovered a spin-off that has never been carried out by any trial anywhere in the world, which is the double-electrode ion emitter cloud seeding. The double-electrode ion emitter operates on the principle of the attraction of a charged particle to an oppositely charged collector to harvest the water resources in the fog. A negative voltage of several thousand volts is applied between wire and plate. If the applied voltage is high enough, an electric corona discharge ionizes the air around the electrodes, generating a large number of electrons and ions. They then move to the poles due to the electrostatic force. During the movement, the electrons and ions meet the dust and water particles in the airflow and thus make them charged, and the charged particles move to the opposite plate with them due to the electrostatic force. Under the action of the electric field, free ions in the air must move to the electrodes. The higher the voltage, the faster the ions move. Due to the movement of the ions, a current is formed between the poles. At the beginning, there are only a few free ions in the air and the current is small. After the voltage rises to a certain threshold, the ions near the discharge electrode obtain a higher energy and speed. When they hit neutral atoms in the air, the neutral atoms will be decomposed into positive and negative ions, which is called the air ionization. After the air is ionized, the number of ions moving between the poles, which is the corona current, increases sharply, making the air conductive. The voltage captures the water particles converging into raindrops and falling due to the effect of gravity, thereby achieving the purpose of rainfall enhancement.

3. The Trial Location

3.1. The Overview of the Water Resource, Terrain and Climate in China

China is located on the west coast of the Pacific Ocean, with vast territory and complicated terrain. The terrain of China is roughly in the shape of a ladder, high in the west and low in the east, which allows warm, moist Pacific air to move inland, and cold air from the north to drive straight down to the south, conducive to forming precipitation. The climate in China is complex and diverse. The continental monsoon climate dominates in certain areas, which results in the uneven distribution and time-history changes of water resources. Precipitation decreases from the southeast coast to the northwest inland, which can be divided into five types of zones: rainy, humid, semi-humid, semi-arid and arid. Due to the uneven distribution of rainfall in different regions, land and water resources in China are unbalanced. Water and land resources vary greatly topographically, while precipitation and runoff vary greatly from year to year in terms of time. In most parts of the country, there is little rain in winter and spring, and much rain in summer and autumn. In the southeast coastal provinces, the rain season is longer and earlier. Precipitation is most concentrated in the piedmont area of Huang, Huai, and Hai Plain, whose flood season is always in the form of heavy rain. The inter-annual variation of precipitation is greater in the north than in the south. Often, there is a drought in the north and a flood in the south and vice versa.

Throughout the whole country, water shortages in Northwest China are the worst. In most areas, annual rainfall is less than 400 mm, and meanwhile, annual evaporation is more than 1000 mm. The spatial distribution of water resources here is very uneven and therefore local development is restricted. The majority of water resources are concentrated in high mountains, which is very difficult to use, and will have a great impact on the ecology.

Methods have been proposed to improve the water resources situation here, the western route of South-to-North Water Diversion Project, for example. However, it is still in the preliminary stage of demonstration. Moreover, it cannot solve the problem of water shortage in Northwest China from the root. Meanwhile, it has been proved that the precipitation efficiency (the precipitation efficiency is the proportion of actual precipitation to atmospheric precipitable water) in Northwest China is low, indicating that the precipitable water in the atmosphere in the northwest is much higher than the actual precipitation, and the actual utilization rate of water vapor resources in the air is low. The
precipitation in Long’nan, Shaanxi, Shanxi and southern Ningxia is relatively high, with precipitation efficiency less than 10%. The precipitation and precipitation efficiency of the northern and southern basin areas of Xinjiang, northwestern Qinghai, central and western Gansu, and western Inner Mongolia were relatively small, only less than 5%. The precipitation efficiency in Tianshan, Kunlun and Qilian Mountains is higher than 15%. It can be proved that the exploitation potential of water vapor resources in the air in Northwest China is great, and the actual utilization of water vapor in the air can be improved by weather modification.

3.2. Qilian Mountains Trial Area

The Qilian Mountains are located on the northeastern edge of the Qinghai-Tibet plateau. The mountain is over 1000 km long and 300 km wide, with an average elevation of 4000 m. Due to the special terrain, the mountain area has a large precipitation, with the maximum precipitation up to 600 mm, which is 3–15 times the maximum precipitation in the plain area of its inner corridor. The total moisture input in Qilian Mountains is greater than the output. The average annual input is $9293.5 \times 10^8$ t, the total output is $8031.5 \times 10^8$ t, and the net input is $1361 \times 10^8$ t, accounting for 14.5% of the total input. Among the whole net input of the year, the net inputs of spring, summer, autumn and winter are, respectively, $258.8 \times 10^8$ t, $694.5 \times 10^8$ t, $178.7 \times 10^8$ t and $229.0 \times 10^8$ t, indicating that the net moisture input in Qilian Mountains in summer accounts for 51% of the whole year. The eastern part of the Qilian Mountains is a water vapor convergence zone throughout the year, and the convergence center is located in the region of 37°–39.5° N and 98°–105° E.

Considering the influence of different geographical locations and seasons on the moisture content of Qilian mountains, the results will be promising and satisfying if artificial precipitation is carried out in summer in the region of 37°–39.5° N and 98°–105° E.

According to the weather conditions and field investigation, the double-electrode device is installed in the courtyard of Wuqiaoling Meteorological Station, taking power supplies, traffic and other factors into account. The single-electrode device is mounted on the top of Maomao Mountain. The installation sites are both located on the windward slope of the airflow. Due to the terrain factors and local meteorological data analysis, we discovered that it is actually north wind rather than south wind that has strong connection with the precipitation process. Thus, under the influence of the north airflow, the airflow on the windward slope will rise, which is conducive to the upward diffusion and transmission of charged particles. The coordinates of the base stations are shown in Table 1 and Figure 5.

![Figure 5](image-url)
3.3. Liupan Mountains Trial Area

Liupan Mountain is located in the eastern part of Northwest China, with a range of about 105.6° to 106.7° E and 34.9° to 36.2° N. The ridge is more than 2500 meters above sea level, with steep eastern slopes and gentle western slopes. Compared with other regions in the northwest, Liupan Mountain area has more water vapor, and more precipitation. At the same latitude in the northern hemisphere, Liupan Mountain is a region with less rainfall. Liupan Mountain is located on the northwestern edge of the southwest monsoon region. Southwest wind prevails throughout the year. Water vapor from the Indian Ocean, the Bay of Bengal and the South China Sea is continuously transported here. Water vapor conditions are plentiful. The climate here is cold and humid, with an average precipitation day of 133.7 days and an annual precipitation of 675.7 mm. The moisture-rich updraft prevails throughout the year, with an average daily wind speed of 5.8 m/s per year, and strong winds of magnitude greater than 6 are blown in nearly 1/3 of the time.

The terrain of Liupan Mountain is from northwest to southeast, and water vapor transport from southwest in summer forms water vapor flux convergence under the action of terrain. Compared with the surrounding area, the amount of cloud formation, cloud liquid water path, and optical thickness are higher in Liupan Mountain area, which is beneficial to the formation of precipitation. The average precipitation efficiency of water condensate in Liupan Mountain is 48.1%. Therefore, a large part of the water vapor resources in the air can be used, and there is still considerable development space.

Through field investigation, three sites of a single electrode base station were determined. The three base stations are centered on the Liupan Mountain Meteorological Station to obtain convenient power supply. Base station 3 is installed inside the Liupan Mountain Meteorological Station to provide power for base stations 1 and 2. Base stations 1 and 2 are located on the ridge on both sides of base station 3, which is relatively higher than the surrounding terrain to meet the conditions for the diffusion of charged particles. The coordinates of the base stations are shown in Table 2 and Figure 6.

| Serial                        | WGS84 Coordinate          | Site Altitudes (m) |
|-------------------------------|---------------------------|--------------------|
| Single-electrode base station 1 | 35°39’42.17” N, 106°11’41.82” E | 2790               |
| Single-electrode base station 2 | 35°39’41.73” N, 106°12’17.03” E | 2771               |
| Single-electrode base station 3 | 35°39’47.51” N, 106°12’06.06” E | 2837               |

Figure 6. Locations of the base stations in Liupan Mountains trail area.
4. Ion Emitter Design

The smaller the radius of the discharge conductor is, the better the effect of corona discharge tends to be. Therefore, wires, needles, blades, and other small-radius discharge conductors are often used as discharge terminals. Wire-to-wire, wire-to-plate, and needle-to-plate structures are common double-electrode combinations. According to the simulation and prototype experimental results previously, the double-electrode device is selected as the blade-net electrode structure. Use a stainless steel blade as the high-voltage electrode and a stainless steel wire net as the ground electrode. The distance between the blade and the net is about 10 cm. The electrodes are constructed using a modular unit structure with a size of 2 m × 1 m. Then, aluminum alloy profiles are used to build the modular unit structure as a whole. Considering that the device will be facing gale with force eight or higher during operation, the stability of the triangle is used to combine three groups of single-sided devices into a triangular structure, which greatly improves the overall stability of the device. At the same time, in order to prevent the particles from being blown away by the strong wind, a windproof device needs to be added on the outside of the double-electrode device to create a stable ionized environment, which is also designed as a triangle structure. The windproof device adopts a panel structure, and the holes are evenly punched on the panel. Meanwhile for the convenience of processing and installation, a modular structure is adopted and aluminum alloy profiles are used to build, as is shown in Figure 7.

![Figure 7. Effect of the double-electrode device as a whole.](image)

In contrast to the double-electrode arrangement in the valley, the single-electrode located in Maomao Mountain is arranged on the windward slope with abundant moisture. Therefore, the single-electrode device adopts a roof structure, and the blade electrode is placed vertically to follow the trend of the wind, so as to achieve better experimental results. The triangular roof structure can also provide enough strength to ensure the stable operation of the device, as is shown in Figure 8.

![Figure 8. Schematic diagram of single electrode device.](image)

For the single-electrode device installed at the Liupan Mountain Meteorological Station, it is installed on the platform shown in the red box in Figure 9 in order to avoid the impact of the operation of the device on the equipment of the station itself. The device is designed as a long, narrow structure to accommodate a narrow platform. The top of the device is also a roof structure, which is conducive to the particles flying in the wind and the stability of the device.
1. Since charged particles move with the wind, the affected area of the device must be downwind of the dominant wind;

2. If the area affected is relatively small, the existing density of a meteorological station is obviously not enough.

Based on these principles, a dedicated meteorological monitoring instrument network is designed and constructed at the Rainfall Enhancement Trial Demonstration Area.

The newly-built stations in the dedicated meteorological monitoring instrument network are divided into rain gauge stations and multi-function stations considering both economic efficiency and practicality. The rain gauge stations measure precipitation only. The multi-function stations measure wind direction, wind velocity, rainfall, temperature, dew-point temperature, relative humidity, visibility, particle count, as well as negative ion count, which is of great significance in defining the affected area. Additionally, raindrop disdrometers are installed in the multi-function stations to further investigate the effect of ions on precipitation in the real environment. Moreover, since the trial locations are both situated on a high altitude, the temperature there is mostly below 0 °C. Therefore, snowfall instead of rainfall are expected more than half time in a year. As has been proved above, the charged particles are also effective in snow enhancement. Therefore, solid precipitation measurement devices are also installed in the multi-function station. With regard to the location of the stations, the coverage of the terrain cell service, the location of the ion emitters and the direction of the primary wind must be taken into consideration.

The design of the monitoring network in Wushaoling can be determined as follows. The operating characteristics of the double-electrode ion emitter are closely related to fog and wind direction, while the single-electrode ion emitter related to rainfall and wind direction. We analyzed the relationship between fog days and wind direction using the observation data of Wuqiao Meteorological Station from 2008 to December 2017. As is shown from the wind rose map in Figure 10, the dominant wind direction in this region is mainly N and SSE.
The wind direction distribution with and without fog is basically consistent with the whole distribution, indicating that the wind has no particular effect on foggy weather. According to the statistics of wind velocity, the wind velocity is usually less than 6 m/s without fog, while it is more than 6 m/s on the majority of foggy days.

Similarly, the wind direction with and without rainfall is also analyzed since the characteristics of the single-electrode ion emitter are related to precipitation and wind direction. Through the comparison with and without rain in Figure 11, when the precipitation conditions are satisfied, the north wind is often blown, while the frequency of south wind is significantly lower than the overall statistics of the area.

Based on the analysis above, the dedicated meteorological monitoring instrument network has been constructed, with four primary monitoring nodes and eight secondary monitoring nodes. The distance between nodes is about 1–2 km. The location of the nodes is shown in Table 3 and Figure 12.
According to the northwest to southeast wind direction of the Liupan Mountain, the Liupan Mountain Meteorological Station is located in the middle of the Liupan Mountain and has an altitude of about 2850 meters. Three sets of single-electrode ion emitters are installed here. The layout of the monitoring network is based on analysis and statistics of the data accumulated in Liupan Mountain Meteorological Station for 10 years. There are a certain number of monitoring equipment systems upstream and downstream of the location of the devices. On the basis of the stations previously, 17 sets of rain gauge stations and 3 sets of multi-function stations are added to fill the gaps of the original monitoring nodes, making 55 monitoring nodes within 30 kilometers around the devices. During the working hours of the emitters, the upstream and downstream rainfall statistics will be analyzed to assess the actual impact. The location of the nodes in Liupan Mountain Trial Area is shown in Table 4 and Figure 13.

Table 3. Statistics of the monitoring nodes in Wushaoling.

| Serial | Monitoring Node Type       | WGS84 Coordinate      | Site Altitudes (m) |
|--------|---------------------------|-----------------------|--------------------|
| Rain gauge station 1 | Secondary monitoring node | 37°10'43" N, 102°52'26" E | 2886               |
| Rain gauge station 2 | Secondary monitoring node | 37°11'33" N, 102°52'18" E | 2993               |
| Rain gauge station 3 | Secondary monitoring node | 37°09'16" N, 102°54'35" E | 2804               |
| Rain gauge station 4 | Secondary monitoring node | 37°11'17" N, 102°54'14" E | 3177               |
| Rain gauge station 5 | Secondary monitoring node | 37°11'39" N, 102°52'58" E | 3105               |
| Rain gauge station 6 | Secondary monitoring node | 37°10'20" N, 102°52'37" E | 2853               |
| Rain gauge station 7 | Secondary monitoring node | 37°10'50" N, 102°53'44" E | 3026               |
| Rain gauge station 8 | Secondary monitoring node | 37°09'47" N, 102°55'02" E | 2879               |
| Multi-function station 1 | Primary monitoring node | 37°11'09" N, 102°53'05" E | 2995               |
| Multi-function station 2 | Primary monitoring node | 37°09'54" N, 102°52'19" E | 2815               |
| Multi-function station 3 | Primary monitoring node | 37°12'10" N, 102°53'18" E | 3490               |
| Multi-function station 4 | Primary monitoring node | 37°10'10" N, 102°54'29" E | 2939               |

Figure 12. Location of the dedicated meteorological monitoring instrument network in Wushaoling.

Similarly, the same investigation was performed on the trial location in Liupan Mountain. According to the northwest to southeast wind direction of the Liupan Mountain, the Liupan Mountain Meteorological Station is located in the middle of the Liupan Mountain and has an altitude of about 2850 meters. Three sets of single-electrode ion emitters are installed here. The layout of the monitoring network is based on analysis and statistics of the data accumulated in Liupan Mountain Meteorological Station for 10 years. There are a certain number of monitoring equipment systems upstream and downstream of the location of the devices. On the basis of the stations previously, 17 sets of rain gauge stations and 3 sets of multi-function stations are added to fill the gaps of the original monitoring nodes, making 55 monitoring nodes within 30 kilometers around the devices. During the working hours of the emitters, the upstream and downstream rainfall statistics will be analyzed to assess the actual impact. The location of the nodes in Liupan Mountain Trial Area is shown in Table 4 and Figure 13.
Table 4. Statistics of the monitoring nodes in Liupan Mountain.

| Serial | Monitoring Node Type                  | WGS84 Coordinate          | Site Altitudes (m) |
|--------|--------------------------------------|---------------------------|--------------------|
| Rain gauge station 1 | Secondary monitoring node | 35°52'27" N, 106°08'13" E | 2223               |
| Rain gauge station 2  | Secondary monitoring node         | 35°44'24" N, 106°10'49" E | 2545               |
| Rain gauge station 3  | Secondary monitoring node         | 35°41'28" N, 106°11'35" E | 2911               |
| Rain gauge station 4  | Secondary monitoring node         | 35°39'12" N, 106°11'23" E | 2475               |
| Rain gauge station 5  | Secondary monitoring node         | 35°36'01" N, 106°08'35" E | 2151               |
| Rain gauge station 6  | Secondary monitoring node         | 35°40'13" N, 106°12'47" E | 2342               |
| Rain gauge station 7  | Secondary monitoring node         | 35°40'38" N, 106°14'10" E | 2103               |
| Rain gauge station 8  | Secondary monitoring node         | 35°39'19" N, 106°16'31" E | 1914               |
| Rain gauge station 9  | Secondary monitoring node         | 35°35'38" N, 106°14'17" E | 2286               |
| Rain gauge station 10 | Secondary monitoring node         | 35°34'59" N, 106°17'00" E | 1991               |
| Rain gauge station 11 | Secondary monitoring node         | 35°45'52" N, 106°13'53" E | 2067               |
| Rain gauge station 12 | Secondary monitoring node         | 35°40'18" N, 106°19'30" E | 1817               |
| Rain gauge station 13 | Secondary monitoring node         | 35°36'39" N, 106°17'18" E | 2055               |
| Rain gauge station 14 | Secondary monitoring node         | 35°39'27" N, 106°09'25" E | 2238               |
| Rain gauge station 15 | Secondary monitoring node         | 35°35'01" N, 106°10'33" E | 2271               |
| Rain gauge station 16 | Secondary monitoring node         | 35°50'02" N, 106°14'18" E | 2043               |
| Rain gauge station 17 | Secondary monitoring node         | 35°40'18" N, 106°19'30" E | 1817               |
| Multi-function station 1 | Primary monitoring node          | 35°36'51" N, 106°06'48" E | 2081               |
| Multi-function station 2 | Primary monitoring node          | 35°39'47" N, 106°12'07" E | 2832               |
| Multi-function station 3 | Primary monitoring node          | 35°42'07" N, 106°15'47" E | 1979               |

Figure 13. Location of the dedicated meteorological monitoring instrument network in Liupan Mountain.

6. Site Construction and Remote Operation

6.1. Construction of Double-Electrode Base Station in Wushaoling Experimental Area

The double-electrode base station in Wuqiaoling experimental area is located in the courtyard of Wuqiaoling Meteorological Station, including the main body of the double-electrode device, the water collecting part, the windproof part and the control room. DC high voltage power supply, switch cabinet, dehumidifier, remote control equipment and other auxiliary facilities are placed in the control room to supply power to the experimental equipment and realize both local and remote control functions.
The main body of the double-electrode device is a triangular structure. Three DC high-voltage cables are drawn from the control room and connected upward along the cement pillar to the bottom of the high-voltage electrode frame, connecting the six high-voltage electrode frames on each side into a whole.

The internal equipment of the control room is shown in Figure 14a. The three-phase AC is connected to the high-voltage switchgear to supply power for both the high-voltage overall power supply and low-voltage control equipment power supply. After the three-phase electric power is fed into the high-voltage power supply, three DC high-voltage electric power with an adjustable range (−100kV–0kV) is the output. The internal structure of the switch cabinet is shown in Figure 14b.

![Figure 14. (a) Equipment in the control room; (b) internal structure of switch cabinet.](image)

To obtain the experimental data and evaluate the effect, a water collecting structure is added at the bottom of the electrode frame. Since the bottom of the electrode frame is divided into three sections, the water collecting structure uses three sinks as a unit. A Stevenson Screen is placed in an open area in the middle of the device. It holds instruments including temperature and humidity detection devices, monitoring equipment and the equipment to collect data of three rain measuring cylinders, which can realize the function of remote monitoring and obtaining experimental data through the network. The installation of the water collecting unit is shown in Figure 15a and the Stevenson Screen and its connection to rain gauges are shown in Figure 15b.

![Figure 15. (a) Installation of the water collecting unit; (b) connection between the Stevenson Screen and rain gauges.](image)

6.2. Construction of Single-Electrode Base Stations in Wushaoling and Liupan Mountain Experimental Area

The single-electrode base station in Wushaoling experimental area is located on the top of Maomao Mountain near the Wuqiaoling Meteorological Station and adjacent to the microwave station. The base station includes the main body of the single-electrode device and a control cabinet. The main body of
the device is a shed structure, as shown in Figure 16a, composed of nine units with the same structure. The bottom is supported by a galvanized stainless steel tube and the top is a high-voltage electrode frame separated by an insulator. All electrode frames are connected by wires as a whole.

The control cabinet is located on the side of the main body. The overall structure is a cubic metal box, the top of which is roof-like to prevent water accumulation. The interior is equipped with three sets of high voltage power supply, switch cabinet, small air conditioning and remote control equipment. Small air conditionings are used for heat dissipation during high voltage power supply operation and dehumidification during daily operation.

The device of single-electrode base station 1 in Liupan Mountain experimental area is a vertical structure, as is shown in Figure 16b. Seven identical structural units are arranged in sequence to form a row. The high-voltage electrode frames of adjacent structural units are connected with each other to form a whole. The control cabinet is located on the side of the device. The control cabinet is equipped with two high-voltage power sources to provide power to the device.

Figure 16. (a) Structure of the single-electrode base station in Wushaoling experimental area; (b) structure of single-electrode base station 1 in Liupan Mountain experimental area.

The device of base station 2 is also vertical, as is shown in Figure 17a. Nine identical structural units form three rows and three columns. The structural unit and control cabinet are the same as those of base station 1. The high voltage electrode frames in the three structural units in each row are connected as a whole and are powered by a high voltage power supply.

The equipment of base station 3 is a shed structure, as is shown in Figure 17b. The structural unit is the same as that of Wushaoling. The device consists of eight structural units arranged in two rows and four columns. The control cabinet is located on the side of the device. The device is powered by three power supplies.

Figure 17. (a) Structure of the single-electrode base station 2 in Liupan Mountain experimental area; (b) structure of single-electrode base station 3 in Liupan Mountain experimental area.
6.3. Remote Operation

Analyzing the control requirements of various devices such as high-voltage power supply, data acquisition equipment and other auxiliary equipment, the structure of the integrated control system is designed as is shown in Figure 18. The control system can be operated directly in the experimental field, or can be operated remotely by connecting the terminal host to the control system host via Ethernet. Since some of the experimental sites are located in mountainous areas without wired broadband coverage, 4G and broadband dual-line access are adopted. In areas with broadband, this design can ensure the stability of network connection. Even in areas without broadband coverage, a 4G network can be used for communication. In the control system, in order to achieve unattendance, the remote boot hardware equipment is added, which is able to remotely wake up the control system host. The remote control service software on the host of the control system starts up with the host, so that the software can be started remotely after the device is shut down or the power is accidentally lost, which is of great significance to the field experiment location with inconvenient traffic.

![Figure 18. Structure of the integrated control system.](image)

7. Experiment and Performance Evaluation Method Design

7.1. Experiment design

In order to prove the effect of cloud-seeding operation, it is necessary to conduct a scientific and effective evaluation of the effect in addition to the research of necessary technology and the development of key equipment. Reasonable test design is the premise and key of evaluation. In general, there are several methods for cloud seeding, including regional regression experiment, randomized regional regression experiment, and randomized crossover experiment. Regional regression experiment is a common design scheme of artificial rainfall experiments around the world. However, this method has two flaws. The first is that there are random, unknown temporal and spatial covariates that may have influence the experiment and its results. The second one is that, though it is reasonable and scientific to perform experiments like this, the efficiency can be improved with two or more sets of devices. Thus, the randomized regional regression experiment and the randomized crossover experiment are also used to fix these two flaws. The randomized experiment design is able to minimize the effect caused by the unknown covariates while the crossover experiment design makes full use of each set of equipment and greatly improves the efficiency.

According to the climatic conditions of Wushaoling and Liupan Mountain, summer is the best time for the experiment. Since the double-electrode device has to operate in foggy weather, which is more stringent than the single-electrode device, weather conditions will be observed and tests will...
be conducted at the trial location from the middle of May. After achieving at least 10 runs of the double-electrode device, it is switched to remote operation. Considering that there is only one set of double-electrode devices, the randomized regional regression experiment is then employed.

The single-electrode device basically adopts remote operation mode. In order to ensure the availability of the device, the device is checked on the scene regularly so that failures and emergencies are dealt with as quickly as possible. For the single-electrode device in Wushaoling, considering there is only one set of devices in Wushaoling, a randomized regional regression method is used. Ninety days of the 180-day experiment period are randomly selected for the device to be turned on, while during the other 90 days the device is off. As for the three single-electrode devices in Liupan Mountain, a randomized crossover design is employed, in which the three devices are operated in a predetermined sequence at random, each acting as a target and a control to the other two. In the experiment with two or more devices, it is inevitable that some certain unknown confounding covariables unrelated to the experiment of time and space will appear. Even if randomization is performed, without the crossover experiment, these inconsistent confounded covariates in different experiments will still affect the observed results. Moreover, under the same circumstance, crossover design triples the efficiency of the non-crossover device. In the 180-day experiment period, it is ensured that the turn-on time of the three devices, respectively, is 60 days.

Rather than randomly generating the schedules of the three devices and combining them, the schedule is arranged containing 60 groups in terms of day with device 1 on and the other two off, device 2 on and the other two off, device 3 on and the other two off. Part of the schedule of operation in Wushaoling and Liupan Mountain is shown in Tables 5 and 6.

### Table 5. Part of the schedule of operation in Wushaoling.

| Experiment Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------|---|---|---|---|---|---|---|---|---|----|
| Device        |   |   |   |   |   |   |   |   |   |    |
| Experiment Day|   |   |   |   |   |   |   |   |   |    |
| Device        |   |   |   |   |   |   |   |   |   |    |
| Experiment Day|   |   |   |   |   |   |   |   |   |    |
| Device        |   |   |   |   |   |   |   |   |   |    |

### Table 6. Part of the schedule of operation in Liupan Mountain.

| Experiment Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------|---|---|---|---|---|---|---|---|---|----|
| Device 1      | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| Device 2      | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Device 3      | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

7.2. Performance Evaluation Method Design

Although cloud chamber and artificial climate room tests have shown that charged particle catalytic precipitation is effective, we still need to confirm the effect in the real environment. However, rainfall fluctuates widely due to the complexity and variability of actual weather conditions. It is difficult to prove that the increase in rainfall is due to charged particles rather than natural processes. Three methods are carried out to evaluate the performance of the trial.
The first method is based on traditional statistical methods. The effect of the randomized crossover experiment is evaluated in this way. Every time a device is turned on, there would be two situations. The target area of the working device is regarded as the catalytic area, while target areas of the other two devices not turned on are regarded as the contrast areas. The three target areas of the three devices are defined as A, B, and C, respectively. Thus, a total of nine sets of rainfall data are obtained: when device 1 is switched on, the rainfall in its own target area \( A \), and rainfall in the other two areas \( A \) and \( A \). Similarly, when device 2 and 3 are turned on, \( B \), \( B \), and \( B \), as well as \( C \), \( C \), and \( C \) can be obtained. Among them, \( A \), \( B \), and \( C \) are defined as the catalytic daily rainfall, while the rest are defined as the comparative daily rainfall. Based on these definitions, to obtain the effect of cloud seeding, every pair of devices are compared. Take device 1 and 2, for example, whose target areas are \( A \) and \( B \), the effect of cloud seeding is:

\[
R = \frac{(A_A - B_A) - (A_B - B_B)}{A_B + B_A}
\]  

(1)

\( (A_A - B_A) \) is the catalytic effect of device 1, while \( (B_B - A_B) \) is the catalytic effect of device 2. Therefore, the numerator is the sum of the catalytic effect of the two devices, while \( R \) is the percentage of the increase in rainfall, which is equivalent to the arithmetic average of the catalytic effect.

The natural daily rainfall in Liupan Mountain accords with lognormal distribution, as is shown in Figure 19. Thus, it is possible to perform significance testing via t-test after taking the logarithm of the rainfall. Take \( \log(A_A - \log(B_A)) \) and \( \log(A_B - \log(B_B)) \) as the statistical variables with size \( n_1 \) and \( n_2 \), mean \( x_1 \) and \( x_2 \), and standard deviation \( S_1 \) and \( S_2 \). If the cloud seeding is invalid, the two samples should belong to the same normal distribution. While if not, due to the effect of the cloud seeding, \( \log(A_A - \log(B_A)) \) should be greater than \( \log(A_B - \log(B_B)) \), numerically. Therefore, a null hypothesis is made:

\[
H_0 : \mu_1 = \mu_2
\]  

(2)

If \( H_0 \) is correct, a t-distribution with \( (n_1 + n_2 - 2) \) degrees of freedom should be satisfied:

\[
t = \frac{x_1 - x_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}}
\]  

(3)

Since \( \log(A_A - \log(B_A)) \) is assumed to be greater than \( \log(A_B - \log(B_A)) \) numerically, a one-sided test is considered. For the significance level of \( \alpha \):

\[
P(t \geq t_{2\alpha}) = \alpha
\]  

(4)

If \( t \geq t_{2\alpha} \), the null hypothesis \( H_0 \) is rejected. Otherwise, there is no evidence strong enough to reject the null hypothesis, which indicates that the cloud seeding is invalid.

The second method is based on statistical methods combined with artificial intelligence. In order to assess the result of the rain enhancement operation, a short term precipitation prediction model is developed. The model will give the expected precipitation without the cloud seeding in operation. By comparing this to the real precipitation with cloud seeding, it can be determined if the cloud seeding had a positive effect. Therefore, an anomaly detection technique or using statistical analysis can be used to get the result. In order to make short-term prediction of the precipitation, considering that the precipitation is absolutely non-linear, it is not wise to use the traditional linear regression to make the prediction. Thus, it is more convenient to use the neural network to train the regression model with the help of the meteorological and terrain features. Before the experiment is carried out, the model should be trained to obtain the relationship between the precipitation and the features. Additionally, after the experiment, it is easy to detect the effect and to realize the characteristics and affecting area of the device via the model established. Table 7 gives an example for the results of the short-term prediction.
of the daily precipitation (mm) in one of the meteorological stations in Liupan Mountain experimental area in September 2016, based on historical data. The inputs of the model are the daily meteorological features of the target area and the daily precipitation data of the catalytic areas, while the output of the network is the daily precipitation of the target area. Considering that the evaluation is subsequent, both the inputs and the output are under the same time scale.

![Fitting curve of historical rainfall in Liupan Mountain and lognormal distribution.](image_url)

**Figure 19.** Fitting curve of historical rainfall in Liupan Mountain and lognormal distribution.

| Table 7. Comparison between real precipitation and prediction on historical data using neural network. |
|---------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                                 | Real | 0.0 | 0.2 | 0.1 | 0.0 | 12.4| 0.1 | 0.8 | 2.5 | 6.1 | 1.0 |
| **Prediction**                  | 0.0  | 0.1 | 0.0 | 0.0 | 10.0| 0.0 | 0.0 | 2.7 | 6.2 | 0.0 |
| **Real**                        | 5.0  | 5.9 | 0.0 | 0.0 | 0.2 | 0.1 | 11.5| 16.6| 1.7 | 1.7 |
| **Prediction**                  | 5.3  | 4.3 | 0.0 | 0.1 | 0.0 | 0.0 | 9.8 | 10.7| 1.9 | 0.0 |
| **Real**                        | 0.0  | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.3 | 0.0 |
| **Prediction**                  | 0.0  | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Considering the characteristics of the evaluation, we do not care much about zero-precipitation. Therefore, after clearing the zeros of the real precipitation, the means of real precipitation and prediction are 3.7 mm and 2.8 mm, while the standard deviations are 4.9 mm and 3.8 mm, respectively. To verify that the model is well-fitted, a chi-squared test is performed. The null hypothesis is:

H0: The distributions of the precipitation and the prediction are the same.

Then calculate the chi-squared as below:

$$\chi^2 = \sum \frac{(f_i - npi)^2}{np_i}$$  \hspace{1cm} (5)

The chi-squared calculated is $1 < 7.81$ for $\alpha = 0.05$ with 3 degrees of freedom classifying the data by every 2.5 mm into four groups (0, 2.5), (2.5, 5.0), (5.0, 7.5) and (7.5, $\infty$). Thus, the null hypothesis cannot be rejected and therefore the model is well-fitted at the significance level of 0.05. Thus, a methodology combining statistical methods and artificial intelligence is proposed. The effect of the randomized regional regression experiment is evaluated in this way. The mean precipitation in the target area with the device not on is defined as $P_0$, while that with the device on is defined as $P_1$. Thus, the effect of the cloud seeding is:

$$R = \frac{P_1 - P_0}{P_0}$$  \hspace{1cm} (6)

A neural network is used to establish two models with the same sorts of features to predict the precipitation of the target area with the device on or not, respectively. The feature samples, precipitation
samples, size of the samples and the model established are defined as $F_1$, $P_1$, $n_1$ and $M_1$, respectively, with the device on, as well as $F_0$, $P_0$, $n_0$ and $M_0$ with the device not on. If the cloud seeding is effective, for the very same model, the distribution of the residual between the actual precipitation and the prediction under different inputs should be significantly different; the distributions of the prediction should be the same while those of the actual precipitation are significantly different. Similarly, for the very same inputs, the residual distribution using different models should be significantly different, as the models themselves should be significantly different if the cloud seeding is effective. Thus, an F-test can be employed to the residuals to evaluate whether there are significant differences between the two models as well as the distributions of the non-cloud seeding and cloud-seeding precipitation. Therefore, the null hypothesis is:

$H_0$: The distributions of the residuals via the very same model under different inputs are the same. The distributions of the residuals via different models under the very same input are the same.

The trial is still running; therefore, no conclusive result has been obtained yet. Both non-cloud-seeding and cloud-seeding models will be established after the trial is finished and the data is obtained. Then, the proposed F-test method can be employed to determine whether the models and distributions of the non-cloud-seeding and cloud-seeding are significantly different from each other.

The last method is based on indirect observation. On one hand, the concentration of the negative ions will rise after the device is switched on, making it possible to find out the relationship between the density and the precipitation. On the other hand, by observing the echo intensity, echo top heights and echo area before, during and after the rainfall processes with the device on via Doppler radars, it is possible to infer the lasting time of the catalysis process and its affected area, which may be able to obtain the results missed by gauge observations only. The correlation between the density of the ions and the echo intensity may also be established. In addition, with the help of other devices, such as the ceilometer, it is also possible to detect the thickness and span time of the clouds with the device on or not. The ion could have positive effect on making more low clouds, indicating that the ion did push the clouds towards precipitation but natural conditions were not abundant enough to form precipitation. Finding out the micro-physics changes happening in the cloud after the device is switched on may also help us evaluate the effect of the precipitation.

7.3. Cost/Benefit Evaluation

Economically, the majority of cloud seeding operations in China are still dominated by aircrafts and rockets, indicating that each operation will cost a considerable amount of money, including hiring the aircraft, the fee of the rockets, as well as transportation, storage and launching. Ecologically, the potential impact on the environment should be taken into consideration for getting rid of CO$_2$ and AgI. Moreover, our trial provides a ground-based ion-emitting methodology, and a remote-control operation as well. Though the initial investment could be higher than the rocket launcher and the AgI smoke stoves, the operational cost is much lower as no matters are released. Nothing but network and electricity are needed to perform a cloud-seeding operation. The power consumption is even less than 1000 W and can even be powered by a few solar panels, which offers the possibility to perform enduring cloud seeding operations. Meanwhile, the trial, if successful, is expected to increase the local annual precipitation by 20%. The implementation of the trial will realize a large-scale development of the atmospheric resources, and will raise the total amount of the available water resources, which provides huge potential for economic benefits. Moreover, the implementation of the trial will accelerate the development of the weather modification industry, and is able to provide a feasible, environment-friendly and efficient cloud seeding technology for all water-stressed areas in China and all over the world.
8. Conclusions

To alleviate the water shortage in Northwest China, a charged particle-based cloud seeding and rain enhancement trial design has been running in Wushaoling and Liupan Mountain. Experiments have been carried out in a 1-m$^3$ cloud chamber and a 15,000-m$^3$ artificial climate room, respectively, reaching a conclusion that if one can manage to produce and load fraction of droplets in natural clouds with sufficient amount of electric charges, the electrostatic interaction between these charged particles and remaining neutral droplets may accelerate the coalescence process and induce the formation of precipitation, solid or liquid depending on the temperature. Furthermore, the double-electrode ion emitter operates on the principle of the attraction of a charged particle for an oppositely charged collector to harvest the water resources in the fog. According to the consideration of terrain, meteorology, traffic and other factors, the trial is located at Wushaoling in the Qilian Mountains and the Liupan Mountain. Based on the working condition, terrain and climate, the single-electrode and double-electrode ion emitters are designed, and have been installed in the experimental areas. To better evaluate the performance of the trial, a dedicated meteorological monitoring instrument network has been designed and a method for remote operation is offered. Furthermore, three methods based on traditional statistical, artificial intelligence and micro-physics observation are proposed.

The schedules of operation are determined by employing a randomized crossover design and starting the experiments from May to November, according to the statistics of the historical data from both sites. We firmly expect the trial will reach our desired goal so that we may provide a feasible, environment-friendly and efficient cloud seeding technology for all water-stressed areas in China and all over the world.

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