Evaluation of the First Negative Ion Based Cloud Seeding and Rain Enhancement Trial in China

**Abstract**

**1 Introduction**

The concept of cloud seeding was first put forward by Louis Gathmann in 1891, suggesting that shooting liquid carbon dioxide into rain clouds might accelerate the raining process. During the 1930s, the Bergeron–Findeisen process theorized that supercooled water droplets present while ice crystals are released into rain clouds would cause rain. In the 1940s, multiple researches and experiments were performed with the discovery of the artificial ice nucleation by both dry ice and silver iodide.

Traditional weather modification methods mostly rely on solid carbon dioxide or silver iodide and other hygroscopic salts. While positive results have been acquired over years of experiments and implementations, there are still serveral issues to be mentioned. Whether cloud seeding is effective in producing a statistically significant increase in precipitation is still a matter of academic debate, with contrasting results depending on the study in question. In addition, traditional weather modification usually delivers catalyst via aircraft or rockets, which would too costful and complex to perform. Negative impact on environment and health is also a contension.

With all the concerns mentioned above, cloud seeding by charged particles seems to be a solution. The cloud chamber 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. The theroy was at first used for visualizing the passage of ionizing radiation. It took a long time before its connection with weather modification was found. Nielsen conducted an electrodynamic balance experiment to test the effect of electric charge on atmospheric water particles [16]. Hoenig demonstrated the possibility of extracting water vapor from the air by forming condensation on the needle [17]. Uchiyama and Jyumonji developed an electrostatic fog liquefier, which charged fog particles and attracted them to the reverse polarization electrode [18]. Harrison suggested that ions can affect the formation of clouds and raindrops at multiple stages throughout the precipitation process [19]. Khain proposed a method of accelerating droplet collision with the help of charged droplets, and proved its remarkable effect on enhancing rainfall and defogging under sowing and natural conditions [20]. Hortal conducted further laboratory experiments and observed droplet growth in the chamber with electrical discharge [21]. Chin proposed that, based on laboratory observations, the ionic wind generated by corona discharge will play an important role in the generation of precipitation [22]. Tan also proved the growth of a single droplet would be enhanced with the help of charge on it, and further investigated the formation of corona discharge–induced rain and snow in a 15,000 m2 artificial climate room.

Ion–based precipitation enhancement trials have also been carried out by a few countries and organizations, and proved positive. ELAT Corporation constructed 17 ground–based charged particle catalytic stations in Mexico and claimed to enhance local monthly precipitation by 50%. The Meteo Systems Corporation realized 52 rainfalls on the edge of the Abu Dhabi desert applying the technique. The Australia Rainfall Technology performed serveral trials in Oman since 2013 and enhanced local yearly precipitation by 18%. These field experiments suggest that ion–based cloud seeding has the potential to enhance precipitation under certain well–constrained conditions. In addition, most trials are located by the coast, offering abundant moist sea draft. Northwest China is one of the most water–stressed regions in the world, located inland. Various cloud seeding attempts have been carrying out to increase rainfall and mitigate projected future reduction. New technique to cloud seeding in China, coupling research in ion–based cloud seeding performance inland, led to first negative ion based cloud seeding and rain enhancement in China.

The paper is organized as follows. Chapter 1 introduces the background and significance of the trial. Chapter 2 gives a whole overview about the trial, including trial schedule and location, experiment design, as well as the seeding procedures and facilities. Chapter 3 offers the analysis methodology. Chapter 4 provides the results of the trial.

**2 Trial overview**

The equipment used in this experiment is a ground–based negative ionization system, and the hypothesis is to enhance the microphysical process of precipitation formation in multiple stages, which ultimately leads to an increase in rainfall on the ground downwind of the emitter. There is one device in Wushaoling, and three other independent devices in Liupan Mountain. Meanwhile, dedicated meteorlogical monitoring instrument networks are designed and constructed for the trial, surrounding the negative ionization system, mostly downwinds.

**2.1 Principle and seeding procedures of the ion–based rain enhancement**

The principle of the ion–based cloud seeding can be described as follows. Water vapor condenses into small droplets when encountering cold airflow at high altitude. With abundant vapor in the cloud, the condensation process will continue and thus droplets accumulate until precipitation is formed. With the help of ice-forming nuclei(IFN) and cloud condensation nuclei(CCN), the condensation process will be accelerated and easier to reach the condition to form precipitation. Presence of space charge enhances both contact ice nucleation and population of particles effective as condensation nuclei. Thus both cases will play an important role in droplet condensation and thus eventually result in precipitation enhancement.

The seeding procedures can be conceptualized with the ground–based negative ionization system as follows. Aerosols with negative ions are created via applying high voltage DC to the device so that particles close to the electrode will be negatively charged. As the plume of charged particles drifts with the updraft to the cloud layer which may form precipitation, it is lifted orographically and dispersed by mechanical mixing, atmospheric electric field and possibly other turbulent processes to fill a relatively large volume of cloudy air. The particles act as condensation centers as a result of electrostatic forces. The charged aerosols have a polarizing effect on other neutral water molecule clusters, so that the nucleation of the cloud droplets and ice crystals will be accelerated over what would happen naturally. In a water–saturated condition, these cloud droplets and ice crystals will eventually grow until they are large enough to fall to the ground, leading to precipitation in the target area.

**2.2 Trial Location**

Two trial locations, Wushaoling and Liupan Mountain, have been chosen, considering local synoptic and wind flows, cloud types, terrain, moisture availablity and widespread uplift. Such features affect the delivery of charged particles or aerosols to cloud layer and potential subsequent rainfall enhancement.

Wushaoling is located in the middle of Tianzhu Tibetan Autonomous County, Wuwei City, Gansu Province, southeast end of the northern branch of Qilian Mountains. Topographically, Wushaoling is located at the intersection of the Loess Plateau, the Qinghai-Tibet Plateau and the Inner Mongolia Plateau, with a length of 17 kilometers and an average elevation of 3,562 meters. Climatically, the three major climate zones of plateau sub-arid zone, mid-temperate sub-arid zone, and mid-temperate arid zone intersect in Wushaoling. The east of Wushaoling is the monsoon and the outflow area, and the west is the non-monsoon and the inflow area. Main source of surface runoff replenishment are precipitation and melting ice and snow, with great interannual variation. Abundant moisture input is provided compared with surrounding area. Precipitation has increased in recent years, presumably due to cloud seeding operations. Taking power supplies, traffic and other factors into account, the site in Wushaoling is located on the top of Maomao Mountain, relatively close to local meteorological station. The site is installed on the windward slope of the airflow, indicating that the charged particles would be transported easier to the cloud layer.

Liupan Mountain ranges in northern China extending southward from Hui Autonomous Region of Ningxia across the eastern panhandle of Gansu province and into western Shannxi province, with a general elevation of 2,000 meters and individual peaks that reach 2,995 meters. The mountain is located on the northwestern edge of the southwest monsoon region, with southwest wind prevailing throughout the year. The area has an average of 133.7 days of precipitation and an annual precipitation of 675.7mm. The amount of cloud formation and water vapor is much higher than surrounding areas and based on previous study. The trend and extent of the convergence zone of the water vapor flux produced by the Liupan Mountain topography are consistent with that of the mountainous area. The dynamic effect of the low-level convergence and high-altitude divergence configuration in mountainous areas is conducive to the occurrence and development of precipitation. There is still considerable development space for precipitation enhancement. Three sites are located in Liupan Mountain, centered on local meteorological station. The distances between the three sites are relatively close, while they are all constructed on different tuyeres so that the catalytic effect of charged particles is expected to be more obvious.

Locations and construction of the sites are shown as follows.

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| --- | --- |
|  |  |
| (a) | (b) |
|  |  |
| (c) | (d) |

Figure 1. (a) The ground–based negative ionization system in Wushaoling (W1); (b) The 1st ground–based negative ionization system in Liupan Mountain (L1); (c) The 2nd ground–based negative ionization system in Liupan Mountain (L2); (d) The 3rd ground–based negative ionization system in Liupan Mountain (L3).

Table 1. Locations and elevations of the ground–based negative ionization systems

|  |  |  |  |
| --- | --- | --- | --- |
| System Serial | Latitude(N) | Longtitude(E) | Elevation(m) |
| W1 | 37°12’03.40” | 102°53’29.40” | 3529 |
| L1 | 35°39’42.17” | 106°11’41.82” | 2790 |
| L2 | 35°39’41.73” | 106°12’17.03” | 2771 |
| L3 | 35°39’47.51” | 106°12’06.06” | 2837 |

**2.3 Ionization system and meteorological monitoring instrument network design**

The smaller the radius of the electrode is, the better effect of the corona discharge tends to be. According to the simulation and prototype experimental results, blade electrode was finally adopted as the discharge terminal. As all the sites are located on the windward slopes, the devices adopt a roof structure to make it easier for charged particles to spread with the wind. However, L1 and L2 are located in the nature reserve in Liupan Mountain. At the request of relevant department, a board structure is adopted to reduce the floor space they take. The roof structure itself is strong enough to resist the strong wind on the top of the mountain. The board structure is reinforced for better stability.

Each site is powered by three individual DC power supplies with a maximum voltage output of -100kV. The power supplies can be remotely controlled by connecting the terminal host to the control system via the Ethernet. The time of power–on and power–off, voltage, current and error log are storaged local automatically and are backed up in database.

To better evaluate the actual effect of cloud seeding, meteorological monitoring instrument networks were designed and constructed in both experimental areas to provide a higher temporal and spatial resolution of the precipitation and other meteorological characteristics. Previous study based on historical meteorological data indicated dominant wind direction of the experimental area. It is assumed that the charged particles spread with the airflow. Thus the meteorologcial monitoring instrument network is mainly constucted downwind the ionization system. The meteorological monitoring instrument networks consist of rain gauges and multi–function stations. Since both trial areas are located on a high altitude, the temperature is often below 0°C. Therefore, solid precipitation measurement gauges have also been installed with the multi–function stations. Data collected by the meteorological monitoring instrument networks can be obtained through web or directly from the database. Meteorological characteristics and their resolution are shown in Table 2. Location of the network is shown in Figure 2.

Table 2 Meteorological elements and their resolution of the multi–function stations.

|  |  |
| --- | --- |
| Meteorological Element | Resolution |
| Wind direction | 1° |
| Wind velocity | 0.1m/s |
| Precipitation | 0.1mm |
| Solid Precipitation | 0.1mm |
| Temperature | 0.1°C |
| Relative Humidity | 1% |
| Number of Negative Ions | 1 |

**2.4 Supplementary data**

The meteorological monitoring instrument network was completely established in 2019 and therefore hasn't accumulated enough data to support historical contrast. Thus supplementary data from local meteorological stations has been acquired, with temporal resolution of 1 hour. The time span of data from local meteorological data is from 2008 till present.

In addition, to observe possible micro–physical process take place in clouds during the cloud seeding, ceilometer and total sky imager have also been constructed next to the device.

**2.5 Experiment Design**

The seeding procedures are relatively tremendous and uncontrollable in both time and space scale with great uncertainty. The speed and directions of the diffusion of charged particles, as well as response of different cloud layers are all greatly affected by natural conditions and few research have been carried out so far. Thus it is necessary to design a a variety of comparative experiment methods, using time, space, and natural conditions such as the wind direction and velocity to establish various experimental and control groups to perform the whole experiment.

The trial employs a regional regression design as the basic principle. Based on this principle, to minimize the effect caused by random and unknown temporal and spatial covariates that may influence the effect and result of the experiment, a randomized design is employed. In addition, regional regression experiments often take a fixed control and target area, and precipitation of both areas are summed up by all the rain gauges within a certain range. In this way, it is more convenient for statistics, but the spatial resolution is lost, therefore reducing the sensitivity of the statistical test greatly. Considering the effect area and the operation characteristics of the device are still unknown, a dynamic control and target area based on wind direction is taken. Based on this, the spatial resolution of the resolution can be improved and it is more likely to determine the scope of the influence. Meanwhile, with the help of neural network for regression, meterological characteristics and precipitation data can be made full use of and forecast accuracy and temporal resolution will be improved.

The ion plume generated by the device will be diffused and transported by the airflow. Considering the time that the ion plume exists in the atmosphere,though it is uncertain how long it takes for the ions to diffuse and take effective, it takes approximately 12 hours to reduce the concentration of the ions disturbed by the device to normal levels. Thus according to the randomized trial design mentioned above, the time interval of the experiment can be divided into control and target groups. Define temporal target group as the duration that counts from switching on the device to 12 hours after switching off, and control group as the rest of the experiment.

Geographically, the scope of the influence of the charged particles is downwind of the device. Thus the trial area can be divided into control and target groups according to the terrain, wind speed and velocity. Define spatial target group as a device-centered arc and the rest of the experimental area as the control group.

**2.6 Trial Schedule**

Due to the COVID–19, experiments could not be carried out as planned and thus the devices were left unused for quite a long time. In addition, weather condition on both trial locations were extreme and led to minor damage to the device. Both factors delayed the experiment and thus, the rain enhancement operation phase was postponed until midyear of 2020. The trial operation ran for 122 days from 1st July to 31st October 2020 in Wushaoling, and 91 days from 1st Augest to 31st October 2020 in Liupan Mountain. This period was chosen to capture the water vapor transported by the monsoon with consistently suitable conditions for cloud seeding operations, while the temperature was still warm enough so that the devices would not be frozen.

**3 Analysis methodology**

**3.1 Trial Schedule**

**4 Results**

**5 Conclusions**