Technische Universität München
Faculty of Civil, Geo and Environmental Engineering
Chair of Hydrology and River Basin Management
Prof. Dr.-Ing. Markus Disse

Let it rain - Weather modification in Europe, USA and with a special focus on China

Wolfgang Gasser, B. Sc.

Study Project

Matr. No.: 03619407

Study Course: Environmental Engineering (Master of Science)

Supervisor: Dr. Christian Rumbaur

Email: wolfgang.gasser@tum.de

Munich, March 2016

Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references. This study project was not previously presented to another examination board and has not been published.

Date, City

Signature

Contents

1. Introduction

Globally, the increase of severe weather hazards such as hailstorms and floods, the strained resources of freshwater and the need to implement a stable agriculture wield many countries into the possibility of conducting weather modification programs. The science of weather modification evolved in the second part of the 20th century and despite the lack of substantial research, many countries have continued to use weather modification techniques to improve the national agriculture and water availability, or to mitigate the adverse outcome of meteorological disasters.

In recent history, the possible alteration and manipulation of weather attracted attention, with the announcement of the Chinese government to secure a rain free opening ceremony of the Olympics in 2008. Eight years later, the Chinese authorities implemented a nationwide weather modification program, which is supposed to prevent meteorological disasters, enhance agricultural yield and secure the freshwater resources in the country. This paper deals with the different techniques of weather modification, their history and possible uncertainties, as well as the implementation of weather modification worldwide with a special focus on the biggest implementer of weather alteration operations, the People's Republic of China.

In the following project, the global weather modification phenomena will be described. First, the history of weather modification, from the first experiments in the 1940s to the modern hail suppression operations, is discussed. Then, it goes into the different techniques of altering the weather, where first, the basic physical concepts behind the formation and transformation of clouds is described. The explanation of the different methods of weather manipulation such as rain enhancement and hail suppression form the next part of the paper. The reflection of weather modification as a technique of warfare and the use of rain enhancement for military utilization in history is the closure of the theoretical chapter 3.

The following chapter 4 deals with the uncertainties and critical issues behind the science of weather modification. Especially the cloud and precipitation microphysics, and the cloud forecast are key issues, which are not fully understood to the day.

The fifth and main part of the paper deals with the history, implementation and authorities of weather modification in different countries. China, as the world’s largest implementer of weather modification projects plays the most important role, whereas the United States of America are chosen as a comparison. Furthermore, the United States were the first to invest and realize weather alteration projects. Lastly, the focus is on weather modification in Europe, especially in the United Kingdom, Germany and Austria. The implementation of weather manipulation in Europe, in comparison to the large rain enhancement programs in China, is more about hail suppression and the mitigation of potentially severe hailstorms. Nevertheless, also in Germany and Austria some see great potential in the implementation of weather modification programs.

2 History

The science of weather modification is a relatively new one compared to the tries of many primitive tribes to change the weather throughout history. Witch doctors and medicine men were supposed to bring rain during long periods of drought or drive away rain clouds in the course of flooding events.

The first specific thoughts to manipulate the weather date back to the 19th century and were mainly of agricultural and military nature. The focus was on the generation of precipitation for the agriculture or on the storm prevention as well as possible methods to make rivers navigably over periods of drought (summer). James Espy (1785-1860) was one of the first, who came up with ideas for precipitation generation. He intended to generate precipitation through enormous forest fires and had already plans to test his thoughts on a relatively big scale. Due to missing political support and without any sponsors, his project, except for some self-paid smaller experiments, was never implemented (Caviezel, et al., 2014).

Another try to influence precipitation was started by Charles M. Hatfield in 1916. He wanted to produce rain through a secret substance introduced in the clouds by high towers. Shortly after his experiments in the spring of 1916, a big flood destroyed big parts of San Diego. This unlucky coincidence showed already one of the big problems of weather modification, namely the difficulty of the correlation of extreme events and weather modification: The city of San Diego denied any correlation between the experiments and the flood and did not pay the originally agreed settlement for refilling a drinking water reservoir (Caviezel, et al., 2014).

Even though the first US- patent for rainmaking was introduced in 1891 (Gathmaistn, 1891), the first step for weather modification into modern science began with the discovery of an employee of the General Electric Research Laboratory in 1946. Vincent Joseph Schaefer introduced dry ice (solid CO_2) into a freezer containing cloud droplets cooled below 0°C (super cooled droplets), which resulted in the formation of ice crystals. (Cotton, et al., 2007)

2.1 Scientific Breakthrough

In the mid 1940’s the General Electric Research Laboratory, under the direction of Irving Langmuir, launched a project studying ways to prevent airplanes from icing. During research for the project, Vincent Schaefer discovered a technique to form a super cooled cloud by blowing moist air into a freezer lined with black velvet. The temperature inside the freezer was not allowed to fall below -23°C, as ice crystals failed to form in the cloud, Schaefer discovered. He experimented with several substances to introduce into the cloud, but only after introducing dry ice, crystals began to form. He then showed that only small grains of dry ice or even a needle cooled in liquid air could trigger the formation of millions of ice crystals (Cotton, et al., 2007).

Soon after Schaefer’s discovery, his colleague Bernard Vonnegut systematically searched for elements that consist of a similar crystallographic structure as dry ice, so it could be used as artificial ice nuclei. At that time, it was already known that under conventional conditions for the nucleation of ice crystals the existence of a foreign substance is crucial. This substance called nucleus or mote would then promote the formation of ice crystals in the super cooled cloud.

Vonnegut’s search for a potential nucleus material revealed three potential substances, which displayed the favored crystallographic structure: lead iodide, antimony and silver iodide (Cotton, et al., 2007). Whereas a simple dispersion of powder of these substances into a cold chamber showed little effect, Vonnegut decided to vaporize the materials. The smoke of silver iodide particles then produced numerous ice crystals in the cold box similar to the dry ice experiment of Schaefer.

Previous experiments in the 1930’s by the Swedish meteorologist Tor Bergeron, the German meteorologist Walter Findeisen and the German geophysicist and meteorologist Alfred Wegener proposed a mechanism for the formation of precipitation in clouds. The so-called Wegener-Bergeron-Findeisen process (1935) describes the nucleation of ice particles in super cooled clouds followed by their growth by vapor diffusion into snow particles (National Research Council, 2004).

This effect is a result of the saturation vapor pressure with respect to ice being lower than the saturation vapor pressure with respect to water at temperatures colder than 0°C. With temperatures decreasing below 0°C, the supersaturation with respect to ice increases linearly. Therefore, an ice crystal in a cloud that is water saturated finds itself in an environment, which is supersaturated with respect to ice and can grow quickly by deposition of vapor. This leads to a depletion of the vapor in the cloud and the vapor pressure lowers to below water saturation. Hence, cloud droplets evaporating provide a reservoir of water vapor for growing ice crystals. Therefore, the ice crystals grow on the expense of the cloud droplets (Cotton, et al., 2007).

Based on the Wegener-Bergeron-Findeisen effect Vonnegut hypothesized that the addition of silver iodide or dry ice into a super cooled cloud would start the nucleation of ice crystals, which would then grow by vapor deposition. Consequently, precipitation could be triggered artificially in such clouds.

On November 13, 1946, Schaefer would test his results in real super cooled clouds and released about 1.4 kg of dry ice pellets from an airplane flying over a super cooled stratus cloud near Schenectady, New York. Analogous to his labor experiments in the cold box the cloud droplets transformed to ice crystals and fell out as snow. (Cotton, et al., 2007)

Already in the time of these first experiments, it was well known that the water content in the clouds being used for the experiments was not enough to be relevant for significant precipitation. Meteorologists were aware that useful amounts of precipitation needed a continued inflow of moist air and profound cloud layers with updrafts (National Research Council, 2004).

Even though the results of the first experiments did not show abundant precipitation, the director of the General Electric Research Laboratory Irving Langmuir disseminated the idea of successful cloud harvesting in the near future.

2.2 Project Cirrus

In 1947, the possible potential in cloud seeding and the possible future legal liability implications led Irving and the General Electric Company to stop practical experiments on real clouds. A contract with the military stated that further field experiments were now carried out by the military with Langmuir and Schaefer as technical consultants. These projects came to be called Project Cirrus (National Research Council, 2004).

Under Project Cirrus Langmuir and Schaefer executed numerous cloud seeding experiments with different types of clouds, including cumulus clouds, cirrus clouds, super cooled stratus clouds and even hurricanes.

The results of Project Cirrus were contentious already at the publication, though. The group of Langmuir performed for example a periodic seeding experiment on a 7-day periodic schedule and was carried out from December 1949 to July 1951. The analysis after the time period over the Ohio river basin showed a significant 7-day periodicity, which brought Langmuir to the conclusion the seeding experiments were the trigger for the rainfalls. Other scientists were not convinced (Lewis, 1951; Wahl, 1951). They claimed that 7-days periodicities in rainfall and other meteorological parameters had happened in the period of 1899-1951 and therefore the rainfall periodicity was due to natural variability. (Cotton, et al., 2007)

Although the results of these tests were highly controversial among scientists, the group of Langmuir and his colleagues even tried to alter the course of a hurricane on October 10, 1947, with about 102 kg of dry ice. (Cotton, et al., 2007) After the experiment, the hurricane changed direction from a northeasterly to a westerly course, which brought him into the coast of Georgia. Even without any evidence of the connection of the seeding and the course alteration, General Electric Corporation became the target of hundreds of lawsuits for damage claims.

Project Cirrus was the scientific start for the science of cloud seeding, cloud physics research and atmospheric science, and its impact on those scientific fields is comparable to the launch of Sputnik on the US aerospace industry.

3 Techniques

In weather modification history, several types of precipitation phenomena (rain, hail, snow) have been tried to alter. The most common technique worldwide is the so-called cloud seeding, where small particles of dry ice or silver iodide are injected into the cloud. Cloud seeding is performed in order to increase the amount of natural precipitation and thus support agriculture or bring precipitation to drought- endangered regions.

This chapter discusses first the basic physical concept of the formation of clouds and the different types of clouds. Then, the concept of cloud seeding for precipitation enhancement purposes and hail suppression is explained. At last, the use of weather modification for military purposes is discussed.

3.1 Basic concept of a cloud

A cloud is a visible saturation of air in the homosphere, when air gains water vapor or cools. Homosphere includes the troposphere, stratosphere, mesosphere and the lowest part of the thermosphere. It needs two ingredients for clouds to become visible: water and nuclei.

Water is always present in the atmosphere, but water molecules are too small to bond together for the formation of cloud droplets. In order to form cloud droplets they need an object with a radius of at least one micrometer (10^{-6} m) on which they can form a bond (Figure 1). Those objects are called nuclei. Nuclei are small solid or liquid particles found in great quantity in the atmosphere. They are made up of such things as smoke particles from fires or volcanoes, ocean spray or tiny fragments of wind-blown soil. These nuclei are 'hygroscopic', which means they attract water molecules (NOAA, National Oceanic and Athmospheric Administration, 2013)

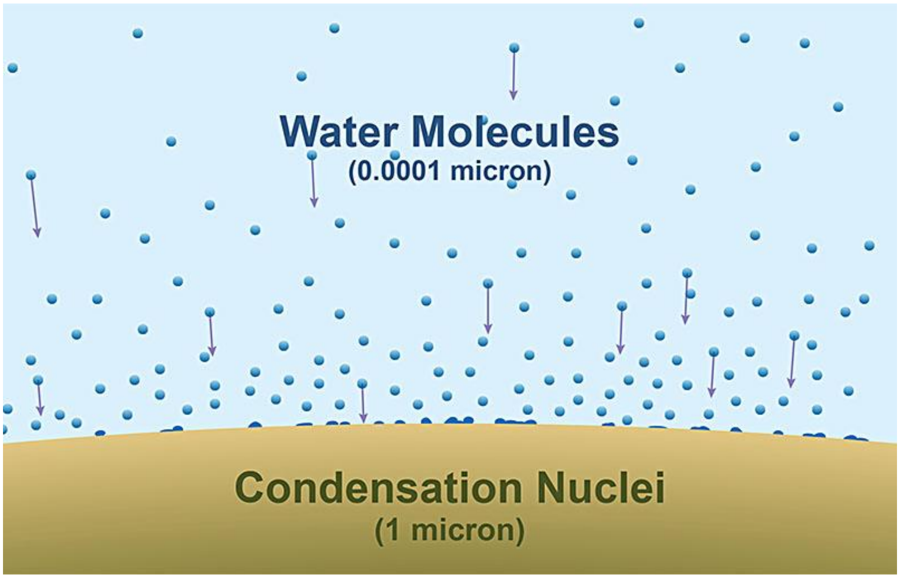

Figure 1: Relative size of water molecules to condensation nuclei (NOAA, 2013)

The particles that attract water molecules are called cloud condensation nuclei (CNN) and are about 1/100th the size of a cloud droplet. Consequently, every cloud droplet has a fleck of dust or dirt at its core.

Beside the presence of nuclei, the air temperature has to be below the saturation point. Hence, a cloud forms when a parcel of air containing water vapor has cooled below the point of saturation. In order to reach the dew point temperature, air is being lifted from the surface up into colder layers. As a parcel of air rises, it moves into areas of lower pressure and expands in size. This process is in need of heat energy to be removed from the parcel. This so called adiabatic process describes the cooling of air as it rises and expands. Once the pack of air reaches saturation temperature (100% relative humidity), water vapor will condense onto the CNN resulting in the formation of a cloud droplet. (NOAA, National Oceanic and Athmospheric Administration, 2013)

As the atmosphere is consistently in motion, the rising air is mixed with dryer air, which leads to both condensation and evaporation happening at the same time and cloud droplets are constantly forming and dissolving. Clouds grow when there is more condensation on the nuclei than evaporation from the nuclei and dissipate when evaporation prevails, leading the cloud to constantly change its shape.

3.1.1 Cloud Classification

The current international system of Latin-based cloud classification dates back to amateur meteorologist Luc Howard. Howard, in 1803, wrote an essay titled “The Modification of Clouds”, in which he named three categories of clouds as well as several compound modification. The World Meteorological Organization (WMO) currently recognizes ten different cloud genera (Figure 2), depending on the location of their formation and their appearance (WMO, World Meteorological Organization, 2015).

- High clouds (CH): Cirrus, Cirrocumulus, Cirrostratus;
- Middle clouds (CM): Altocumulus, Altostratus, Nimbostratus
- Low clouds (CL): Stratocumulus, Stratus, Cumulus,
- Cumulonimbus

These four cloud genera are subdivided into 14 species (secondary classification), which refer to shape and internal structure, and nine varieties (tertiary classification), which describe the transparency and arrangement of clouds.

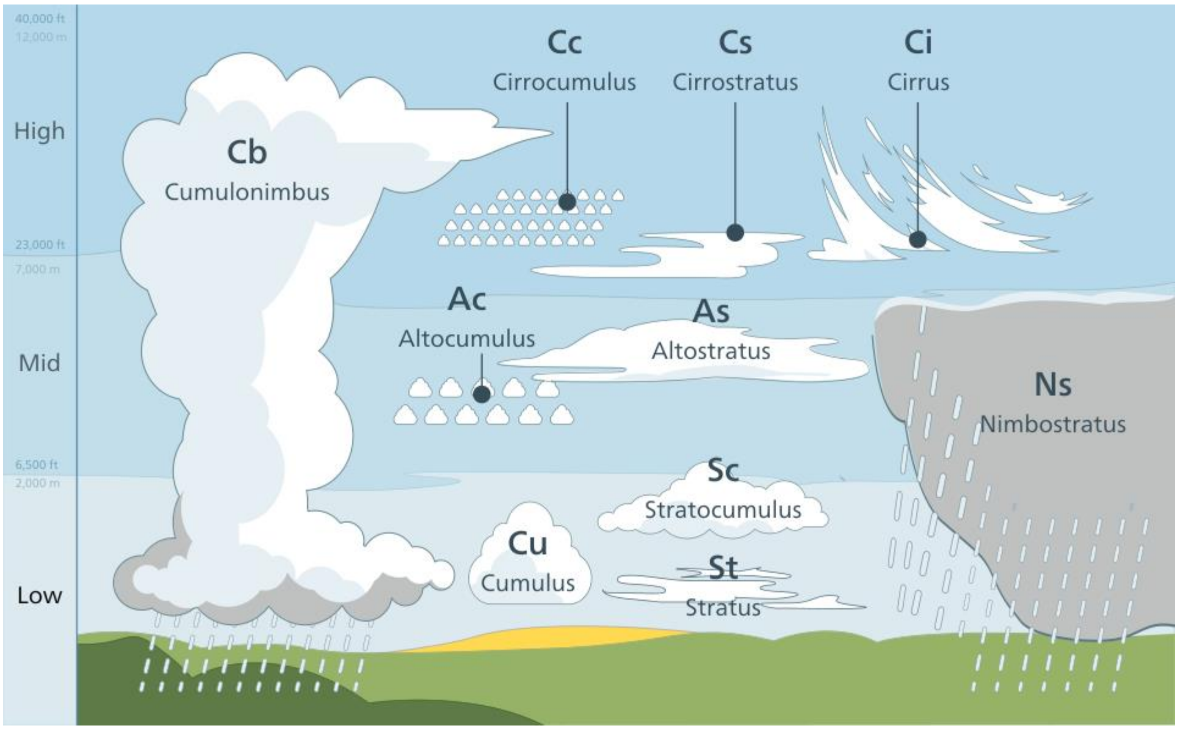

Figure 2: Classification of clouds by altitude (Bruyn, 2012)

The most important genera for the weather modification projects are the Nimbus-clouds (lat. precipitation).

- *Cumulonimbus clouds (*Figure 3*)*

  Height of base: 400 – 2000 m

  Latin: *cumulus* - pile; *nimbus* - rainy cloud

  Precipitation: Heavy rain and thunderstorms

Cumulonimbus clouds are low-level clouds, which have a dense and heavy appearance. Their characteristic shape is a high-extension into the sky in plumes or tower shaped peaks. Generally known as thunderclouds, the base is often very dark and flat and can be only a few hundred meters above the Earth's surface. Cumulonimbus clouds are linked with extreme weather such as hailstorms, heavy torrential drenches, thunderstorms and tornados. (MOUK, 2014).

Cumulonimbus form when a vertically enormous and humidity-unstable lamination of the troposphere takes place. The top of the cloud can reach as high as 12 km (DWD, Deutscher Wetter Dienst, 2015).

Figure 3: Cumulonimbus cloud (MOUK, 2014)

- *Nimbostratus clouds (*Figure 4*)*

  Height of base**:** 650 - 3500 m

  Latin**:** *nimbus* - rainy cloud; *stratus* - flattened or spread out

  Precipitation**:** Continuous rain or snow likely

Nimbostratus clouds are mid-level clouds, which are dark grey or bluish grey featureless layers of clouds, thick enough to block out the sun. These type of clouds are linked with continuous heavy rain or snow and cover most of the sky.

Nimbostratus clouds will often bring long lasting precipitation, lasting for several hours until the front passes over (MOUK, 2014).

Figure 4: Nimbostratus cloud (MOUK, 2014)

3.2 Cloud Seeding

Cloud seeding is the most common form of weather modification. In the years after Langmuir and Schaefers experiments, as the science of weather modification developed, two different schools of cloud seeding methodology emerged. On one hand the so-called static mode of seeding, on the other the dynamic mode.

3.2.1 Static Mode

The Bergeron-Findeisen concept is the base for the static mode of cloud seeding. It states that ice nuclei, which are nucleated either naturally or through artificial seeding in a water-saturated supercooled (temperatures below 0°C) cloud, will grow by *vapor deposition* at the cost of cloud droplets. A naturally inefficient cloud containing supercooled cloud droplets, can thus be converted into an effective one, using the precipitation in the form of vapor-grown ice crystals or raindrops formed from melted ice crystals. (Cotton, et al., 2007). Hence, the success in seeding a cloud is dependent on the availability of supercooled water in the targeting cloud.

Experiments in laboratory cloud chambers showed that on one hand the quantity of natural ice nuclei increased exponentially with the degree of super cooling, and on the other hand that the amount of water vapor available for condensation increases with temperature. Because of these understandings, the availability of supercooled water is generally believed to be greatest at temperatures between 0°C and -20°C. (Cotton, et al., 2007)

This simple concept of static seeding is only valid for a limited variety of clouds, though. The primary natural precipitation process in clouds is not the growth of ice crystals by vapor deposition but growth of precipitation by *collision and coalescence (*Figure 5*)* (Cotton, et al., 2007). Cloud seeding experiments on the basic physical concepts of cloud formation in the 1950s until the early 1980s showed, that clouds containing a relatively low amount of cloud condensation nuclei (CCN) were more probable to produce precipitation by collision in contrast to those with a higher concentration of CCN. In a cloud containing fewer cloud droplets, the average size of the droplets will be bigger and fall faster than a cloud containing many, slowly settling droplets. Since these bigger droplets will settle through a fair amount of smaller droplets by collision, clouds with a low amount of CCN are more likely to initiate precipitation. In general, clouds formed over maritime regions have a much lower concentration of CCN than clouds forming in a continental air mass, differing by an order of magnitude or even more. Polluted air masses contain up to 40 times more CCN, than found in clean maritime air masses (Cotton, et al., 2007).

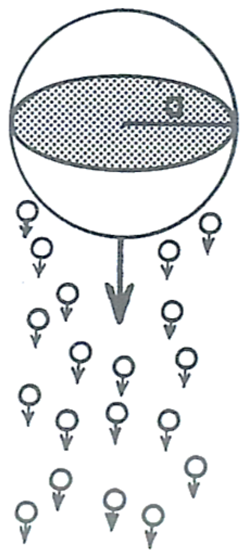

Figure 5: Growth of a drop by colliding and coalescing with smaller cloud droplets (Cotton, 1990)

Another result of the early cloud physic experiments was the finding that clouds with a relatively warm base temperature were richer in water content than clouds with a colder base temperature. This is because saturation vapor pressure increases exponentially with temperature. Therefore, clouds having a warm base temperature have much more water vapor in the base available to be condensed in the upper parts of the cloud.

The precipitation process of collision and coalescence is not only happening between liquid droplets. If ice crystals become large enough to settle through a cloud of supercooled droplets, the ice crystals grow by collecting those droplets to form what is called graupel particles. Frozen raindrops can form hailstones or large graupel particles this way. The precipitation process in a natural cloud is dependent on the water content in the cloud. The larger the amount of liquid water, the more likely the precipitation will form by collision or coalescence. (Cotton, et al., 2007)

The static mode of seeding focuses on the artificial introduction of cloud condensation nuclei (dry ice or silver iodide) into the cloud to start the precipitation processes. This injection is accomplished either with stationary rocket launchers shooting into the cloud or airplanes releasing the artificial nuclei while flying through the potential target.

However, the potential of precipitation enhancement by cloud seeding is much smaller than initially thought. Clouds with a warm base and of maritime air masses have a higher natural potential of precipitation. Therefore, clouds, which are cold-based and continental, show a much higher potential of precipitation enhancement, although the absolute water amount in the cloud is much lower than in a warm-based cloud. Field experiments, such as the Isreali I and II experiments[1], showed promising success in seeding clouds with a relatively cold basis (5-8°C) (Gagin, et al., 1981).

Physical experiments and studies, as well as statistical seeding experiments show that there is a limited range of opportunity for precipitation enhancement by the static mode of cloud seeding. The window of opportunity seems to be limited to

- Clouds, that are cold-based and formed in continental regions
- Clouds, that have temperatures on the top in the range of -10°C to -25°C
- A timeframe, limited by the obtainability of supercooled water before reduction by natural precipitation processes

This limited range of opportunities for precipitation enhancement by the static mode of cloud seeding possibly explains the wide scope of outcomes of seeding experiments. A successful experiment in one region does not guarantee the same success in another region, unless all meteorological and environmental conditions as well as the seeding approach are identical (Cotton, et al., 2007).

Furthermore, the implementation of a seeding experiment, which operates only in exactly these conditions mentioned above, is extremely difficult. The successful operation of a cloud seeding project is highly dependent on a cloud forecast skill that is far greater than in use nowadays. The forecast has to be aware of not only the temperature spectra in the cloud, but the content of broad droplet spectra and an active warm-rain process as well. In addition, a considerate time window for the seeding operation complicates the process even more. Seeding material has to be targeted at the right time in a cumulus cloud before natural precipitation processes deplete the available liquid water. Beside the expensive airborne delivery, it would require, a prediction of the timescale of liquid water availability in clouds is necessary. (Cotton, et al., 2007).

3.2.2 Dynamic Mode

The main concept of the *static mode* of cloud seeding describes the improvement of the precipitation efficiency in clouds. The *dynamic mode* on the other hand, is focusing on the

[1] Cloud seeding experiments in Israel in the late 1970s to reverse desertification

enhancement of the vertical air currents in clouds, which thereby processes more water through the cloud resulting in increased precipitation. The process states that as ice crystals grow by vapor deposition the released latent heat would warm the seeded part of a cloud and cause upward motion and turbulence. During the growth by vapor deposition, a phase transition takes place in which water vapor molecules deposit on an ice crystal matrix. This process releases the latent heat of sublimation (2.83 x10^6 J/kg), warming the immediate surrounding of the ice crystals. (Cotton, et al., 2007)

However, if the cloud contains liquid cloud droplets, the growth of ice crystals causes the cloud saturation pressure to lower below water saturation. This results in the evaporation of cloud droplets to restore the cloud to water saturation. The evaporation absorbs most of the latent heat of vaporization (2.50 x10^6 J/kg), resulting in a net warming of 0.33 x10^6 J/kg. After all condensed liquid water is evaporated and deposited on ice crystals the cloud will be exposed to the full warming effects of the latent heat of sublimation.

Many clouds are driven by buoyancy. Therefore, when a part of the cloud becomes warmer than its environment it expands and shifts a volume of environmental air equal to the weight of the warm part. The warmed air will be buoyed up with a force that is equal to the weight of the displaced environment air, causing a vertical growth of the cloud. The anthropogenic part of this concept is the artificial freezing of the cloud water near the cloud top through glaciogenic seeding (Cotton, et al., 2007). The artificial glaciation is performed through intensive, on- top seeding of the updraft region using a glaciogenic agent, mostly AgI.

The seeding converts most of the supercooled water to ice nuclei during the clouds growth phase. This results in the formation of numerous small ice crystals and frozen raindrops, which releases fusion heat. In this way, the environment warms and increases the updraft and buoyancy and possibly the height of the cloud.

Nevertheless, the buoyancy of the cloud is not only determined by how warm the air is with respect to its surroundings, but also on how much water is condensed in a cloud. If there is much water condensed in the cloud, it causes a negative buoyancy (Cotton, et al., 2007). The air is too “heavily loaded” to become buoyant. Cumulus clouds (precipitation clouds) often unload the upper part of the cloud from the condensed water, causing the unleashed top part of the cloud to rise higher. The water however, transfers to the lower levels, causing a weakening of updrafts at lower levels (Figure 6 (a)).

When the liquid drops settles in subsaturated regions, they start to evaporate. The evaporation absorbs latent heat from the surrounding air, cooling the air. The denser colder air sinks towards the ground and spreading horizontally as it approaches the surface. The colder air undercuts the moist, warm air, elevating it into cloud base. Hence, the settling of raindrops below cloud base can activate the development of new cumulus clouds by lifting warm, moist air into the cloud base (Figure 6 (b)) (Cotton, et al., 2007).

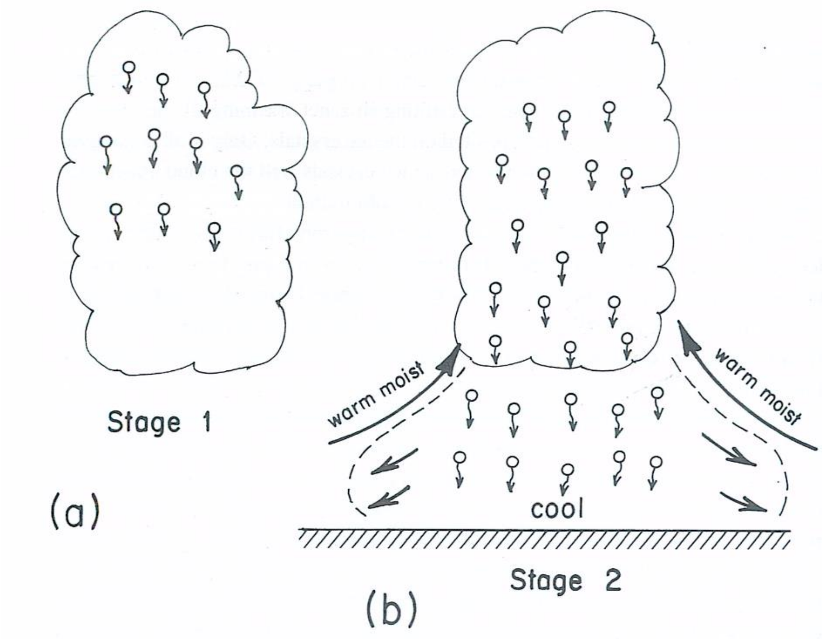

Figure 6: Stages of droplets setting from upper levels of a cloud and formation of evaporatively chilled layer near surface (Cotton, 1990)

Another important step for a cumulus cloud to transform into a thunderstorm or cumulonimbus cloud is the merger of two cumulus clouds due to the interaction cool outflows from neighboring clouds (Figure 7). During the merger process, several smaller cumulus clouds form between the two clouds, which eventually fill the gap and often result in a wider and mostly taller cloud. Clouds emerging from a fusion generally last longer, are bigger and produce more rainfall. The amount of rainfall produced from merged clouds is a factor of ten greater than the sum of rainfall of similar, non-merged clouds (Simpson, et al., 1980).

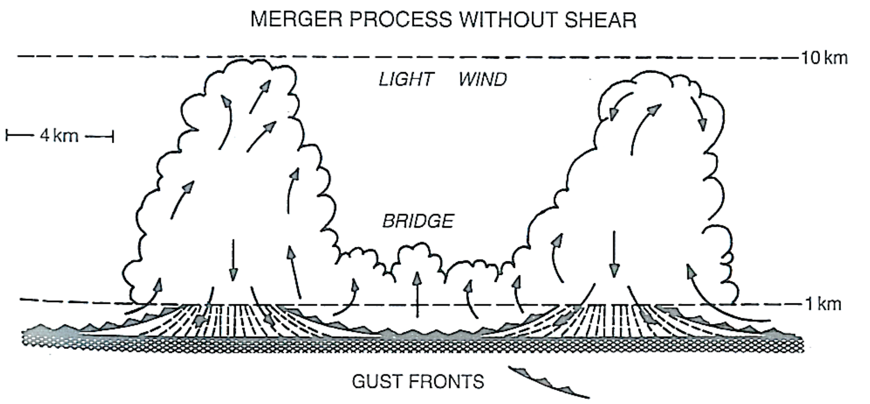

Figure 7: Bridging and Merger of Clouds (Simpson, et al., 1980)

In practice, the dynamic seeding concept was applied primarily in West Texas in the late 1980's and early 1990s. Results from seeding projects of 183 convective cloud cells suggest that seeding increased the maximum height of the cloud by 7 %, the overall area of the cell by 43 %, the duration by 36 % and the total rain volumes of the cloud by 130 % (Rosenfeld, et al., 1989, 1993).

3.2.3 Methods

Most of the weather modification operations are dedicated to increase the amount of CCN in the air. To achieve this target, the cloud seeding agent (mainly silver iodide or dry ice) is being introduced into the cloud in different ways. All methods, beside the releasing of dry ice from above the cloud, have in common that the seeding agent is either present as solid material (pellets) or in an acetone solution. By combustion, the agent is released into the circumambient air and works as a condensation nucleus.

It is differentiated between airborne and surface methods. Airborne operations use generators or torches attached to the wings, which can be ignited from the cockpit at any given time. This ignition initiates the process of releasing the cloud seeding agent. Due to the usage of airplanes these methods are relatively costly. Approaches, which are operated from the ground, are more economical. This includes ground based rockets (Figure 8) and artillery shells. The rockets and artillery shells contain the seeding agent and after being shot into the cloud, the explosion releases the cloud seeding agent.

Figure 8: Hail suppression by simple rockets in Rosenheim in the 1960s (Hagelabwehr Rosenheim, 2010)

3.3 Hail Suppression

Hail suppression is a form of cloud seeding, but in contrast to the aim of precipitation increase with cloud seeding, hail suppression techniques tend to weaken the process of hail formation in order to avoid big losses mainly in agricultural areas.

The suppression of hail by cloud seeding can be performed with several concepts (Table 1), where some of them are not very practical. The complete conversion of cloud water droplets individually into cloud ice particles (complete glaciation hypothesis) needs unrealistically large amounts of glaciogenic seeding agents, around 1kg AgI per minute (Rogers, 1979). The glaciation process is also not very popular due to scientists believe of reducing rainfall along with hail. Since most hail-liable regions are semi-arid as well, the loss in rainfall can have a greater negative impact on agriculture than economic gains from hail suppression. The promotion of coalescence concept and the trajectory lowering would require large quantities of hygroscopic seeding agents. (Dennis, 1980)

The competing embryos concept focuses on the introduction of modest concentrations of hailstone embryos (10 per m^3) in the areas of main hailstone growth. The concept plans to involve millimeter-sized ice particles, which will then compete beneficially for the available supercooled water and result in numerous small hailstones rather than a few large, possibly damaging hailstones (Rogers, 1979).

Table 1 Conceptual Models for Hail Suppression by Cloud Seeding (Dennis, 1980)

Introduction of competing embryos
Complete glaciation of cloud water
Trajectory lowering
Promotion of coalescence
Seeding for dynamic effects, premature weakening of updraft

The majority of hail suppression projects have been performed using glaciogenic seeding agents with the purpose of increasing competition among the hailstone embryos.

Artificial ice nuclei have been delivered to the cloud system by different technologies. First, it must be distinguished between the general approaches for releasing the agents into the cloud: The introduction from the cloud basis, which uses the updraft to transport the agents into the supercooled zones of the cloud, and the releasing of the agents into the cloud from above the cloud.

Generators at the aircraft wings is the most common form to deliver material, working from the base of the cloud, using the updraft for carrying the agents to the supercooled level. By burning an AgI Acetone mixture up to 400 billion nuclei are released at -5°C per gram of AgI. The time to ice nuclei formation is thereby ca. 5 minutes at -5°C. These generators can perform up to 2,5h permanent operation, but are not very effective as temperatures increase. Another downside is the efficiency of the machines and the amount of maintenance required (Langerud, 2015).

A second method for hail suppression from the base of the cloud is by using torches. Twelve torches on each wing of the aircraft provide ice nucleation of AgI. At -6°C the torches release 6 trillion nuclei, which take approximately 1,5 minutes to form ice nuclei. The fast formation of ice nuclei is definitely a plus, whereas the firing time of 48 minutes and the costs per torch are disadvantages not to ignore (Langerud, 2015).

Figure 9: Cessna 340A: Used for Hail suppression operations with torches (Langerud, 2015)

The key question, in the method using the updraft to carry the seeding agents in the active zones, is whether diffusion has sufficient time to spread the material throughout the updraft before it arrives at the -5°C level, where it is supposed to become active. Sample calculations show that the time available for dispersion ranges from as much as 10 minutes in clouds with moderate updrafts to as little as 1 or 2 minutes in seeding clouds with strong updrafts, up to 20 m / s. Additionally calculations show that the released plumes would indeed spread to fill all of the typical convective updraft (0.5 km across), in approximately 10 minutes, but not even the strong updrafts in cumulonimbus clouds would be adequate to spread the seeding agent plume throughout an updraft of 2 or 3 km of width in less than 2 minutes (Dennis, 1980). Calculations in the 70s have shown that a single aircraft working below the base of a large thunderstorm could affect only as much as 1-2 % of the updraft air by the time the air reached the -5°C level (Figure 10).

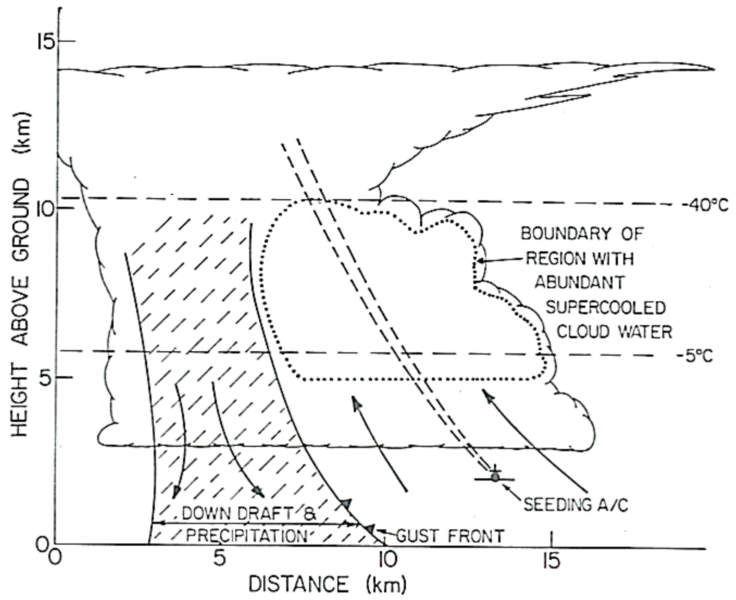

Figure 10: Schematic comparison of seeding from just below, affecting as little as 1 or 2 % of the air (Dennis, 1980)

Top seeding, injection of seeding agent from above the cloud, is performed primarily using dry ice pellets (6mm) at a release rate of approx. 1,3kg per minute (form 1 trillion ice nuclei per gram). The pellets almost instantly form ice nuclei due to the low temperatures at the top of the cloud. Disadvantage is the fast melting process during the flight and the substantially higher and longer flight duration, which corresponds to higher costs (Langerud, 2015).

3.3.1 Alberta Hail Project

Alberta Hail Project was the name of a research project to study hailstorm dynamics and physics. It was the longest scientific investigation of the potential physical and chemical processes in a hailstorm front. The results were supposed to help designing and testing means for hail suppression. Operated and sponsored by the Alberta Research Council and the governmental department Environment Canada, the project was performed from 1956 until 1985. The main laboratory was located at the Red Deer Industrial Airport in Alberta, Canada. (Brimelow, et al., 2002)

The project area included 33,700 km^2 and was centered on the Penhold radar site located near the Red Deer Airport. The project used different ways to evaluate the detection of the atmospheric conditions for hail. In springtime, approximately 20,000 farmers in the program area recorded any event of hail including the size of the hailstones. On average, one observer per 20-30 km^2 gave report (10-20%). In combination with telephone surveys, the observation density was as high as one report per 3km^2. It is believed that only a small percentage of hail went undetected (Brimelow, et al., 2002).

Within three hours of the hailstorm and a radius of 100 km, radiosondes were released from the Penhold radar site to gather information about the atmospheric conditions on hail days. The radar was then used to detect the intensity of the precipitation by its reflectivity, as well as the type of hydrometeors (bits of solid or liquid water). These data were then compared with the surface observations to gain information about the structure of the thunderstorms leading to hail formation. Additionally, at definite times there would be aircraft flights in and around convective areas to gather further information on the atmospheric conditions. (Brimelow, et al., 2002)

The Alberta Hail Project was the scientific basis for the commercial hail suppression projects sponsored by insurances starting in the 1990's and leading to up to 60 hailstorms seeded in 2014 in Central Alberta alone (Tighe, et al., 2014). Globally, the program paved the way for the implementation of numerous hail suppressing projects, which are down to this day element of a damage-reducing strategy against hailstorms (see 5.4).

3.4 Weather Warfare

Since Langmuir and Schaefer started Project Cirrus in cooperation with the United States Military, the utilization of weather modification for military purposes was only a matter of time. Sure enough, the idea of the tactical implementation of artificial rain to undermine the supply system of the enemy was performed in the Vietnam War from 1967 until 1972 by the US military and came to be called *Operation Popeye*. Up to this date, it has been the only reported weather modification program for military purposes.

Presently the usage of weather manipulation procedures for military purposes falls under the outcome of the Environmental Modification Convention (ENMOD), formally the Convention on the "Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques" of 1978, which prohibits the hostile use of environmental modification techniques (see 5.1.1).

3.4.1 Operation Popeye

Operation Popeye/Operation Intermediary/Operation Compatriot was a highly classified artificial weather alteration project, operated from March 1967 until July 1972 in Southeast Asia. The US Military, in the Vietnam War, ran the program trying to extend the monsoon season. The focus was on the areas of the Ho Chi Minh Trail, where the National Front for the Liberation of South Vietnam (Vietcong), People's Army of Vietnam and the North Vietnamese Army controlled their supply lines (United State Senate, Subcommittee on Oceans and International Environment of the Committee on Foreign Relations, 1974).

The objectives for the program was to "increase rainfall sufficiently in carefully selected areas to deny the enemy the use of roads by:

1. Softening road surfaces
2. Causing landslides along roadways
3. Washing out river crossings
4. Maintain saturated soil conditions

beyond the normal time span." US Senate - Hearing on Weather Modification, 1974

The operation started March 20 1967, continuing through every rain season (March – November) until July 1972. Five airplanes (three WC-130A, Figure 11, and two RF-4C) with associated crew and maintenance personnel were the heart of the project. The used material was both silver iodide and lead iodide. The annual cost for the operation (Operation, maintenance, duty pay, seeding material) was approximately $ 3.6 million (United State Senate, Subcommittee on Oceans and International Environment of the Committee on Foreign Relations, 1974).

In the US Senate hearing on Weather Modification of 1974, Dennis J. Doolin (Deputy Assistant Secretary of Defense, East Asia and Pacific Affairs) along with Lt. Col. Ed Soyster (Organization of the Joint Chiefs of Staff) stated that "while this program had an effect on the primitive road conditions in these areas, the results were certainly limited and unverifiable. It was conducted because of its apparent contribution to the interdiction mission and the relatively low costs." (United State Senate, Subcommittee on Oceans and International Environment of the Committee on Foreign Relations, 1974)

Figure 11: WC-130A, aircraft used during Operation Popeye (Robison, 1970)

4 Critical Reflection and Key Uncertainties

Since the first experiments of Vincent Schaefer, Irving Langmuir and Bernard Vonnegut of the General Electric Laboratory the science of weather modification has dealt with constant doubts and disbelief. Even at the time of the Schaefer experiments, it was well known that the clouds used in those demonstrations were too small and contained too little water to reach a significant amount of precipitation. “Scientists were aware that useful amounts of precipitation required deep cloud layers with updrafts and continued inflow of moist air, and that natural precipitation results from a progression of and complex interactions between microphysical processes and cloud dynamical processes.” (National Research Council, 2004)

In the years after the experiments, the enthusiasm in the scientific sector was relentless. In 1951, in the US congressional hearings on the controversy of weather modification, Dr. Vannevar Bush, the president of the Carnegie Institute for Science, testified, “I have become convinced that it is possible under certain circumstances to make rain. As it stands today, we are on the threshold of an exceedingly important matter, for man has begun for the first time to affect the weather in which he lives, and no man can tell where such a move finally will end. “ (National Research Council, 2004) Even in the late 70’s the Department of Commerce’s Weather Modification Advisory Board reported that a practical technology for enhancing rain and snow, and weakening the possible adverse impacts of weather is scientifically possible and within sight.

This led to a overselling of the topic weather modification to the publicness with the main message: Weather modification is the solution to all climatological problems. As the time went by, the federal funding increased noticeable and by 1985, the federal funding in the United States for weather modification research became so small that no federal agency kept track of it. This was due to several aspects but mainly the poor experimental designs, the unsubstantiated claims of success and the widespread use of uncertain modification techniques. Another crucial point was that weather modification was oversold to the public and legislatures and in the change in public attitude toward the environment.

The scientific evidence of cloud seeding effects remains a concern to the day. Bernard Silvermann (2001), in his article on the critical assessment of cloud seeding, states in the conclusion that “Based upon a rigorous examination of the accumulated results of the numerous experimental tests of the static-mode and dynamic-mode seeding concepts conducted over the past four decades, it has been found that they have not yet provided either the statistical or physical evidence required to establish their scientific validity.” (Silverman, 2001)

The National Research Council (2004) goes even a step further and states that the statement of Silverman, even though it was specifically made in reference to glaciogenic seeding of convective clouds, “applies to virtually all efforts aimed at precipitation enhancement or hail suppression.” Key to the successful development of weather enhancement programs is the progress of atmospheric modeling and weather forecasting. The successful implementation of any weather modification program can best be tested by comparison with a prediction of what might have happened without the artificial intervention into the atmosphere. This is to the day the biggest challenge for weather modification, as the natural variability makes statements about the result of cloud seeding not easy.

In addition, the science underlying weather modification is full of knowledge gaps and uncertainties, including fundamental microphysics and the effectiveness of seeding technologies. Most questions remain about liquid and ice nuclei numbers and nucleation processes, as well as the presence and concentration of supercooled water in clouds, and most importantly the natural variability of all these aspects. Effectiveness of the seeding materials still remains an uncertainty and the distribution of the material in the clouds. The interactions between clouds and areas within the same cloud system and the effects of seeding on areas outside the seeded parts have not been fully described and understood. (National Research Council, 2004).

The World Meteorological Organization (WMO), a sub-organization of the United Nations, stated in its report on weather modification that “Purposeful augmentation of precipitation, reduction of hail damage, dispersion of fog and other types of cloud and storm modifications by cloud seeding are developing technologies which are still striving to achieve a sound scientific foundation.” (WMO, 2010, 1.3) Additionally, the organization points out that “Evidence for significant and beneficial changes in precipitation on the ground as a result of seeding is controversial and in many cases cannot be established with confidence.” (WMO, 2010, 3.1)

The hail suppression techniques are mentioned in the report of the WMO as well, stating that „Scientific evidence to date is inconclusive and evaluation of the results has proved difficult and the effectiveness remains controversial.” (WMO, 2010, 4.1)

The National Research Council, in the report on the critical issues in weather modification research has identified the key uncertainties, which need to be addressed before substantial progress in weather modification is likely to be made.

Cloud and precipitation microphysics issues

- Background concentration, sizes, and chemical composition of aerosols that participate in cloud processes
- Nucleation processes as they relate to chemical composition, sizes, and concentration of hygroscopic aerosol particles
- Ice nucleation

Cloud dynamics issues

- Cloud-to-cloud and mesoscale interactions as they relate to updraft and downdraft structures and cloud evolution and lifetimes
- Cloud and sub-cloud dynamical interactions as they relate to precipitation amounts and the size spectrum of hydrometeors
- Microphysical, thermodynamical and dynamical interactions within clouds

Cloud-modeling issues

- Combination of the best cloud models with advanced observing systems in carefully designed field tests and experiments
- Extension of existing and development of new cloud-resolving models explicitly applied to weather modification

Seeding issues

- Targeting of seeding agents, diffusion and transport of seeding material, and spread of seeding effects throughout the cloud volume
- Interactions between different liquid and ice nuclei in cloud

From National Research Council, 2004

5 Weather Modification in Different Countries

The following chapter deals with the implementation of weather modification projects in different countries. History has shown that the nations have dealt with weather alteration very differently. Since the discovery of dry ice as a cloud condensation nuclei source of Schaefer, weather modification in the United States experienced a massive hype in the 1950’s and 1960’s. In the late 70’s, however, the funding levels in weather modification research began to fall and is nowadays in the order of only 10% of its peak level in the middle 1970’s (Cotton, et al., 2007).

China, on the other hand, seems to get only started with national weather modification programs. In 2014, the National Development and Reform Committee and the China Meteorological Administration released a 6-year-development plan for weather modification in the country. This plan gives weather modification a key role in the development of China and aims to provide support for food production, ecological environment and electricity generation (National Development and Reform Commission; Chinese Meteorological Administration, 2014).

In Europe, the weather modification focuses on the suppression of hailstorms, so that precipitation enhancement is only reported by very few sources.

First, however, the international legal aspects for weather modification programs, outcomes of conventions of the United Nations, are introduced. These agreements form the international legal base for the implementation of weather modification projects.

5.1 United Nations

The United Nations have released two important agreements on weather manipulation introduced below: The UN Environmental Modification Convention and the Convention on Biological Diversity, yet, both of these treaties include only some few aspects and applications. Whereas the Environmental Modification Convention focuses on the hostile use of weather modification techniques, the Convention on Biological Diversity concentrates on the possible application in Geoengineering.

5.1.1 Agreements

UN Environmental Modification Convention

After Operation Popeye (see chapter 3.4.1) and the weather modification programs prior to the Vietnam War, the hostile use of weather manipulation was brought on the international agenda in the first half of the 1970’s. In 1972, the US Air Force stopped all the weather alteration in South East Asia and in 1973 the US Senate released a resolution calling for an international agreement on the prohibition of weather modification used for military purposes. This led to the bilateral talks of the US government with the UDSSR in July 1974, which resulted in a bilateral agreement between those two states a year later.

The treaty was accepted by the General Assembly of the United Nations on 10 December 1976 (UNOG, United Nations Office at Geneva, 2012).

The United Nations Environmental Modification Convention opened for signature on 18 May 1977 in Geneva and entered into force on October 5 1978. As of yet, the convention has been signed by 48 countries, 16 of the signatories have not yet been ratified (UNOG, United Nations Office at Geneva, 2012).

The scope of the convention is that “each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party.” (Article I, UNOG, 1977)

According to the convention the term environmental modification technique means “any technique for changing -- through the deliberate manipulation of natural processes -- the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space.” (Article II, UNOG, 1977)

Convention on Biological Diversity

The convention on biological diversity is a multilateral treaty, with three main goals: Conservation of biological diversity, sustainable usage of its components and fair and equitable sharing of benefits arising from genetic resources. It was first opened for signature in Rio de Janeiro on June 5 1992, and entered into force on December 29 1993. 168 states signed the treaty thereof 30 ratified it (among others Germany, China). The United States signed the treaty but have not yet ratified it. (CBD, 2015)

The tenth ordinary meeting of the parties of the convention was held in Nagoya, Japan in October 2010. In the decision statement X/33 (Biodiversity and climate change), §8(w), the conference of the parties confirms “that no climate related geoengineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting […], and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.” (CBD, Conference of the Parties to the Convention on Biological Diversity, 2010)

The Nagoya Protocol on Biodiversity and Climate Change has been ratified by 72 countries (among others European Union). Neither Germany nor China have signed the protocol until now.

The convention does not specifically mention weather modification programs; the focus is clearly on future geo-engineering techniques. That being said, weather modification projects, in altering the atmosphere and therefore shifting the natural atmospheric processes, actively interfere with naturally developed ecosystems. Furthermore, the main intention of weather manipulations is to enhance precipitation in areas of scarcity of water, often due to climate change.

5.2 China

The role of weather modification in China became clear after the country made a sensation worldwide with the assurance of rain free Opening Ceremony of the Olympics in 2008, where clouds were injected with silver iodide to prevent from raining. In China, weather modification plays an important role in the development of the country. Due to the big agricultural production regions and the potential water shortage, the government sees high potential in the industry of weather modification.

The implementation of the Weather Modification Development Plan (2014-2020) by the National Development and Reform Commission and the China Meteorological Administration in December 2014 shows the high priority and confidence the Chinese government puts into the performance of artificial weather.

> "Artificial weather, in ensuring food security, protecting the environment and major events, has become an important measure for governments at all levels to strengthen disaster prevention and improve public services, agriculture and water security nationwide."
> - *Chinese Weather Modification Development Plan (2014-2020)*

China is the world's most active implementer of weather modification projects. In 2012 the administrator of China Meteorological Administration CMA Zheng Guoguang, stated that since 2002, 560,000 manipulations have been performed (Xin, 2012). After the positive start of the pilot project in the North East part of China in 2012, China is executing the National Development Plan of Weather Modification (2014- 2020). According to the Planning, by 2020, China will establish a more comprehensive weather modification working system, achieve important results of basic research and application technology, improve support capacities and security control level and increase service benefits for eco-social development. In that time, artificial precipitation is supposed to be increased by over 60 billion cubic meters per year and artificial hail prevention areas are supposed to increase to 540,000 km^2 (Jing, 2014).

5.2.1 History

The first artificial rainfall in China was implemented in 1958 after the Soviet Union captured the idea. After the Jilin Province in the summer of 1958 suffered the worst drought in 60 years, two pilots of the Chinese Air Force school Zhou Zheng Du drove a bomber in the clouds spreading nearly 200 kg of dry ice (CMA, Chinese Meteorological Administration, 2013).

Since then, the organizing and administration system under the guidance of governments at all levels and under the supervision of competent meteorological organs has been formed gradually. After the implementation of the Weather Modification Regulations in 2002, particularly since the 2nd National Weather Modification Conference held in 2004, China's artificial weather modification has been improved at a faster pace, and the operational competence and the service efficiency have been enhanced notably. (Liang, et al., 2012)

In 2008, the National Development and Reform Commission and the China Meteorological Administration released the first national development plan of Weather - Artificial weather modification Development Plan (2008-2012) -, which greatly promoted the country's scientific development of weather modification. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

In 2009, the government’s plans to strengthen a national weather modification system received another push. In February, Northern China suffered the worst drought in 38 years, which let the calls for artificial rain grow even louder. (CMA, Chinese Meteorological Administration, 2013)

5.2.2 Utilization

Since then, China has become the country with the most weather modification projects worldwide. The administer of the CMA Zheng Guoguang stated in 2012, that since 2002 560,000 manipulations using rockets and projectiles have been performed, that helped releasing 489.7 billion tons of rain, about 3 times the water storage of three gorges project and saved about $10.4 billion in economic losses. (Xin, 2012)

Artificial weather modification operations have been carried out 328,000 times since 2008, including 5481 aircraft operations. According to administrative authorities, weather modification operations are currently carried out in 30 provinces, 2,359 counties and 357 cities. The equipment of the weather modification operations nationwide consists of 7,632 rocket launchers, 44 planes and nearly 7,000 guns. Furthermore, the weather modification agencies employ 47,700 people nationwide. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

Since 2008, the average annual rainfall operation area amounts to 5,000,000 km^2, which is over half of the total area of China. The area of hail suppression projects amounts to about 470,000 km^2. In the assessment of the status of weather modification, the National Development and Reform Commission states that in total the artificial weather operations helped generating an increase of 310 billion cubic meters of precipitation. The total economic benefit of hail suppression and artificial rainfall is estimated to be 240 billion yuan (32 billion €) and the input-output ratio is 1:30 (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

Since 2008 the Chinese government funded weather modification projects with a total of 1.723 billion yuan (232.6 Mio €), which splits up into 920 million yuan (124.2 Mio €) for operation maintenance, 750 million yuan (101.3 Mio €) for infrastructure and 53 million yuan (7.1 Mio €) for research. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

In addition to precipitation enhancement and hail suppression, weather modification is being used to reduce the smog pollution in metropolises. Beijing, in 2014, has assigned 20 million yuan (2.78 million €) for weather modification to reduce air pollution. It was the first time the Chinese capital’s meteorological bureau has listed weather modification aimed at smog reduction in the annual budget. The investment was designated for smog-reduction experiments and the acquisition of required equipment. (Qian, 2014)

As a result, by 2015 local weather authorities will be able to use weather modification techniques to improve the air quality when heavy smog arises, a document released by the China Meteorological Administrations states (Qian, 2014).

2011 marked a milestone in the development of weather modification in China. With the implementation of a pilot project in North East part of China the government wanted to gradually promote the expansion of weather modification projects nationwide. The pilot project was funded with $ 150 million (134.5 Mio €), thereof $ 46 million (41 Mio €) was invested for three planes with advanced cloud-monitoring equipment. The North East part of China was chosen for the pilot project due to the major wheat-growing zone, which is at risk of forest fires in the event of a long drought. By end of 2015, the area is supposed to produce 100 million tons of wheat a year. In 2009, the production in the provinces Liaoning, Jilin and Heilongjiang amounted to 89.3 million tons, which is 16.8 percent of the total production nationwide (Qian, 2011).

Additionally, the pilot project area is equipped with advanced radars and automatic rainfall stations, testing the precipitation enhancement results. Alongside the establishment of a national command center for weather intervention, the investment in research and development for weather modification technology is being increased.

After the successful pilot phase in Norteast China, with the National Development Plan 2014-2020, the system is extended to the entire country.

5.2.3 Laws/Regulation

Regulations on Administration of Weather Modification

The regulations on administration of weather modification were the first set of rules in the country. They were adopted at the 56th Executive Meeting of the State Council on March 13, 2002, promulgated by Decree No. 348 of the State Council of the People's Republic of China on March 19, 2002 and effective as of May 1, 2002 (State Council, of the People's Republic of China, 2002).

These rules were formulated in order to strengthen the administration of weather modification and prepare against and mitigate meteorological disasters. (Article 1) The regulations denote in Article 3 the term weather modification as all activities "carried out for rain or snow enhancement, hail suppression, rain suppression, fog dispersal, or frost protection by exerting […], artificial influence on local atmospheric physical and chemical processes through scientific and technological means, so as to mitigate or avert meteorological disasters and properly exploit climatic resources." – Article 3 (State Council, of the People's Republic of China, 2002).

The "competent meteorological department" at the respective administrative level is responsible for the implementation of such weather modification projects under the leadership and coordination of local people's governments at or above the county levels in places where such activities are carried out (Article 4, State Council, 2002). Furthermore, the regulations state that after approval of the local government the projects are of public welfare, which means that all expenses required are to be included into the budgets of the local government.

The time and the place of weather modification operations have to be publicly announced in advance and a notice to both the flight control department and the local public security organ to ensure the safety and security has to be delivered. (Article 12, State Council, 2002)

The possible conflict of weather modfications implemented crossing the borders of different provinces is regulated in article 14. The relevant governments of the provinces "shall make a decision through consultation. If no agreement is reached through consultation, the decision shall be made by the competent meteorological department of the State Council in consultation with the relevant people's governments of the provinces." (Article 14, State Council, 2002)

Lastly, the regulations include the theoretical use of weather modification activities for military purposes in article 21. It states that "the specific measures for administration of weather modification activities carried out for military purposes shall be formulated by the Central Military Commission." However, the accession of the People's Republic of China to the UN Environmental Modification Convention for the prohibiting of weather warfare (see 5.1.1) occurred three years later on June 8, 2005. (UNOG, United Nations Office at Geneva, 2012)

State Council comments on further strengthening Weather Modification/ Document No. 44

The document No. 44 is the legal basis for the National Development plan of weather modification (2014-2020). The document formulates the basic principles of the enhancement of weather modification in China, yet does not give direct instructions on how to implement the targets. After shortly explaining the guiding ideology, the basic principles and the development goals, the document focuses on the key areas of weather modification operations such as the agricultural production and the disaster mitigation. In addition, it underlines the importance of further developing the national and local linkage between the military, the meteorological and other departments, and the governments at the respective level.

The last aspect of the document no. 44 of the Chinese State Council deals with the need to strengthen "scientific propaganda" (State Council, of the People's Republic of China, 2012). It further declares artificial weather as an important part of public safety and quality, and the necessity of vigorously promoting the positive effects of artificial precipitation in the society.

National Development Plan of Weather Modification (2014- 2020)

In 2008, the National Development and Reform Commission of China and the China Meteorological Administration released the first national development plan of weather modification (Artificial weather modification Development Plan (2008-2012), which promoted the country's scientific development of weather modification. In 2009, artificial rainfall and hail suppression projects were part of the "National grain production plan

(2009-2020)." 2011, the cloud water resources utilization was the first time part of a Five-Year Plan (National Economic and Social Development Twelfth Five-Year Plan), which furthermore underlines the high priority the Chinese government gives to the development of weather modification.

In 2012, China started the first regional-level demonstration project – the Northeast Regional Weather Modification project started implementation. After the successful pilot phase, the advanced weather modification system was transferred to the entire country.

In December 2014, the National Development and Reform Commission and the China Meteorological Administration jointly issued the National Development Plan of Weather Modification (2014- 2020). It describes a comprehensive analysis of the present status of the development status of weather modification in China as well as the problems facing the new situation and new requirements. Especially under the background of global climate change, where Chinas environmental and ecological problems are getting worse, the development plan is a crucial part of strengthening disaster prevention and mitigation. The sensitivity of the agricultural or transportation industry, as well as many other industries in the country, to drought, fog, hail or heat waves is another vital point for implementing and enhancing the weather modification industry countrywide, the plan states.

The development plan is divided into multiple parts. After analyzing the status of weather modification in the country and highlighting the main problems weather modification faces at the moment, the necessity and the feasibility of an improved and well-structured system is presented. The second part covers the objectives and principles of the development plan, such as the development goals, whereas the following segments focus on the overall layout of the weather modification system and the environmental impact assessment.

The main problems in the status quo of weather modification, the National Development Commission and the Meteorological Administration see in the poor condition of the equipment. At present, nationwide mainly small aircraft operations were conducted, with a small total number of airplanes, which do not meet the expectations. The land coverage is too low, they are not able to reach sufficient height for the scientific investigations and the operational capacity cannot meet the growing demand.

Another problem, according to the development plan, is the lack of scientific support at the moment. The low proportion of Research & Development and the lack of suitable laboratory tests and field trial bases show how inadequately represented the scientific research of atmospheric processes is. As a result, the efficiency of operations is quite low. An additional problem is the weak regional coordination of artificial rain operations. Cross-regional operations have caused many conflicts, due to the lack of national and regional unified command and coordination systems.

In the plan, the Chinese National Development Commission really is responsive to the necessity of the development of weather modification. The reasons are diverse: the most crucial necessity for artificial weather programs requires the disaster prevention and the agricultural production security.

According to the National Development Commission, China is one of the world's most meteorological disaster endangered countries. More than 70 % of the total losses due to natural disasters are because of meteorological disasters. More than half of the meteorological disaster losses are due to drought catastrophes. Mainly responsible for that drawback is the uneven spatial and temporal distribution of precipitation in the country (Figure 12). The Northwest part experiences an average annual precipitation of under 100mm over the past 10 years and is covered to 80% by arid or semi-arid areas. The highest frequency of drought, however, is located in North China (Yellow River Basin) and in the province of Yunnan (Southwest China). Furthermore, the South-, and Northwest, regions of the Central Mountain area, suffer from hail disasters, seriously affecting crops and food production (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

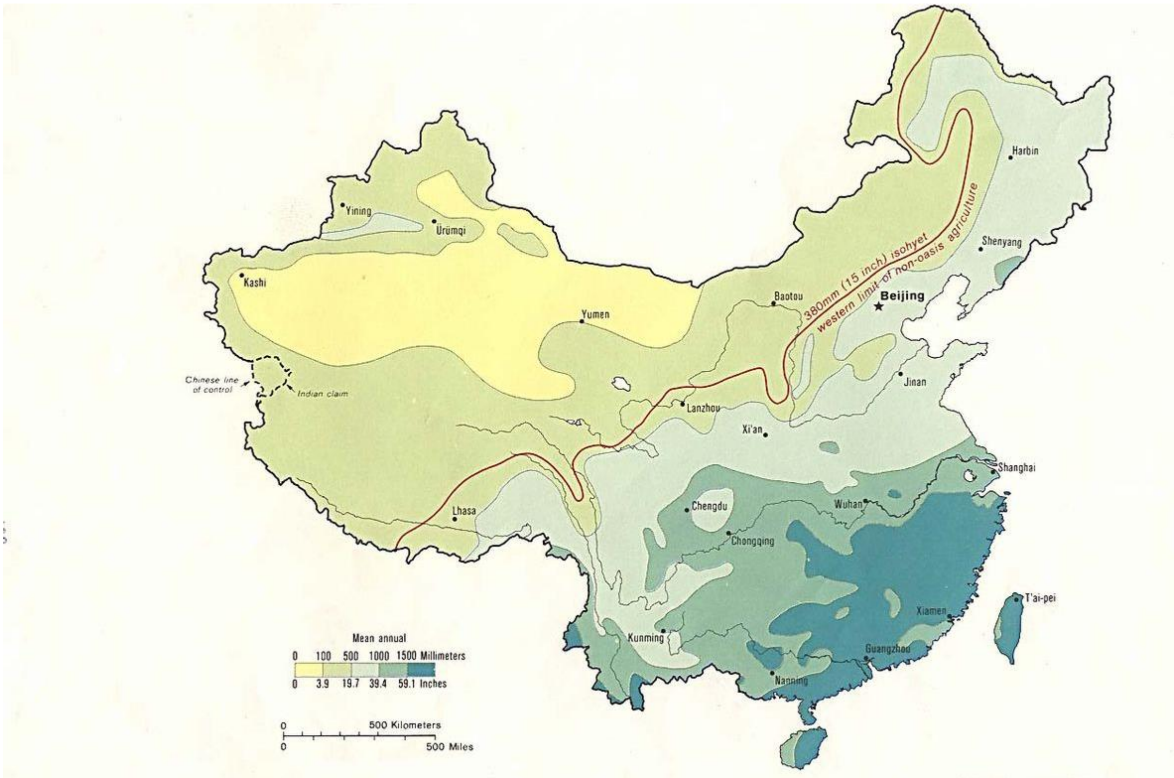

Figure 12: Mean annual precipitation in China (United States Government, 2005)

The protection of the food production areas is one major reason for enhancing weather modification in China, according to the development plan. The three core areas of food production Northeast (Provinces Heilongjiang, Jilin, Liaoning), Yellow-River and Huai-River Basin and the Yangtze River catchment face serious problems of water shortage. 63 % of the area in the Northeast and in the Yellow-River and Huai-River area are facing over-exploitation of groundwater, making the water situation worse and possibly suffer from frequent drought situations. The core area of the Yangtze River food production area has suffered frequent droughts in the last years as well. Weather modification is supposed to prevent and mitigate losses and the adverse effects of drought, hail, as well as strengthen the growth phase for crops in the affected areas. The goal of weather modification projects is to ease the threat of meteorological disasters and create conditions for achieving a high and stable food production yield.

Another necessity for weather modification, according to the Chinese government, is the need to protect water resources. Artificial rain programs should compensate the uneven distribution of precipitation. In increasing the precipitation in the upstream part of large river systems, the water reservoirs and the river runoff will increase, which will ease the contradiction between water supply and demand in the cities. This will help to ensure sustainable economic and social development; hence, the weather modification projects have an important long-term significance for the development of the entire country.

The last reason for the enhancement of weather modification programs is the need to guarantee the smooth conduct of major events, according to the Development Plan for Weather Modification (2014-2020). As China's economic and social development constantly proceeds, the successful hosting of major international events will become more frequent and urgent. The National Development Commission records in the development plan that the protection of rain for the Beijing Olympic Games, the celebration of the 60th anniversary of the People's Republic of China, the Guangzhou Asian Games, and the Nanjing Youth Olympic games was successfully organized and "has been universally praised from all sectors of society." (National Development and Reform Commission; Chinese Meteorological Administration, 2014).

Figure 13: Regional Distribution of weather modification areas (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

According to the development plan, the potential for the improvement of weather modification programs is constituted as well. Under the current technical capabilities, the potential of artificial rainfall is about 280 billion cubic meter per year, whereas the current real annual yield is only about 50 billion cubic meters of rainfall. This leaves a great gap for improvement, as per Development plan.

The National Development Plan for Weather Modification (2014-2020) gives clear instructions on how to improve the weather modification in the country. The country is reasonably divided into six regions (Figure 13). For the zoning, several principles were taken into account. The allocation of the different food protection areas, the needs of other industries (tobacco, forest fire prevention, forest development), the civil and military air traffic, the continuation of the last round of planning (Artificial weather modification plan 2008-2012) as well as the political regional development played a decisive role for the division into six regions. Northeast, northwest, north, central, southwest and southeast.

Northeast, Central and Southeast correspond to the three core areas for food production, whereas the priority of the Northwest area is the protection of key ecological areas. The main concern of the weather modification areas North and Southwest is the improvement of water resources as well as the protection of agricultural areas.

In the following, the realization of the development plan in the different regions is explained. The center of each region was established in the city, where the most research and facilities for weather modification has been established. The key protection areas of the weather modification regions were selected based on three principles:

- Principle of *food security*:
  Based on the "National Food Production Capacity Plan (2009-2020)", the core areas of food production have to be protected in order to establish a food supply guarantee for the country.
- Principle of *ecological security*:
  Based on the "National Ecological Protection and Construction Plan (2013-2020)", the layout of the weather modification areas should focus on the protection of water conservation areas, as well as key ecological areas such as natural reserves.
- Principle of *water security*:
  Due to the water shortage in bigger parts of the country and based on the "National Drought Plan", the layout has to pay attention on drought prone areas and on artificial water basins, which are key for the mitigation of drought and water shortage.

The six regions of weather modification are:

1) Northeast Region

The northeast region includes an area of 1.25 million km^2, consisting of the provinces Jilin, Liaoning and Heilongjiang. Furthermore, the eastern part of the autonomous region of Inner Mongolia is part of the northeast region of weather modification. The area includes the largest corn and soybean production, as well as areas of high-quality rice cultivation areas.

The province of Jilin was the first region to carry out weather modification in China. After 50 years of experience, the pilot project for weather modification was established in the Jilin province.

Head quarter of the Northeast Region for weather modification is Changchun, the capital city of the Jilin province. The city is located in the geographic center of the northeast region, so that the conditions for a short transport and for the establishment of the artificial weather center are favorable.

The protection areas for the northeast region, according to the Development Plan (2014-2020), are the following:

- Food production area: 227,000 km^2
- Forest and grassland fire protection area: 347,000 km^2
- Changbai mountain, water conservation area: 112,000 km^2
- Upstream areas of the Liao River: 51,000 km^2

2) Northwest Region

This area includes the provinces Gansu, Shaanxi, and Qinghai and the autonomous regions Ningxia, Xinjiang and parts of the Inner Mongolia. The total area amounts to 3.53 million km^2. The northwest region includes big parts of key ecological function areas, such as the Qilian Mountains and the Sanjiangyuan National Nature Reserve. Key ecological function areas describe regions of high ecological variability and biodiversity. These areas are mainly conservation areas or regions worthy of protection.

The Gansu province is the center of the northwest region for weather modification. The capital city of Gansu, Lanzhou, already has a strong scientific basis, so that the regional weather modification center will be located there. Considering the vast areas in the northwest of the country, a center will be established in Urumqi, Xinjiang as well. As the Xinjiang province takes up 1/6th of the land mass of China, the water shortage is a big concern.

For the northwest region, the protection areas for weather modification are the following:

- Qilian mountain ecological security area: 185,000 km^2
- Sanjiangyuan National Nature Reserve: 363,000 km^2

3) North China Region

The north China region of weather modification consists of the municipalities Beijing and Tianjin and the provinces Hebei and Shanxi, and the central part of Inner Mongolia, to a total number of 680,000 km^2. Since the capital Beijing is part of the north China region, this area is the core area of the political culture. A main factor is the water shortage.

In Beijing the center of the north region is located and as Beijing is already the seat of business for the China Meteorological Administration and due to the project in the past (sky clearing for the Olympics, Paralympics, 60^{th} anniversary celebration) the center of the north is established in Beijing. Moreover, the infrastructure in the capital is another reason to implement the center.

The designated protection areas in the north China Region are:

- Hebei Jin Meng water protection area: 169,000 km^2
- Jinan food production area: 32,000 km^2
- Tianjin sandstorm control security area: 275,000 km^2

4) Central Region

This region consists of 750,000 km^2, including the provinces Henan, Jiangsu, Anhui, Shandong, and Hubei. Croplands of wheat, rice and maize form the key protection areas for weather modification projects. In addition, the support of the South-West Water Transfer Project with artificial precipitation is scheduled.

Zhengzhou, Henan is the Centre of the central region of weather modification.

The protection areas for the central region, according to the Development Plan (2014-2020), are the following:

- Food production areas: 487,000 km^2
- Dabie mountain ecological security area: 88,000 km^2

5) Southwest Region

The provinces Sichuan, Guizhou and Yunnan, the autonomous regions Guangxi and Tibet and the municipality Chongqing make up the southwest region of weather modification (2.6 million km^2). In this area, the hydropower generation is of main concern, as well as the large tobacco plantations in the Yunnan and Guizhou Province.

For the southwest region, the province of Sichuan, more precisely the capital of Sichuan, Chengdu is the artificial weather center.

The designated protection areas in the southwest region are:

- Hydropower development: 250,000 km^2
- Yunnan, Guizhou desertification prevention: 250,000 km^2
- Northeast Tibet forest protection: 300,000 km^2

6) Southeast Region

This area includes the provinces Jiangxi, Zhejiang, Fujian, Hunan, Guangdong, Hainan and the municipality Shanghai, which amounts to an area of 820,000 km^2. The provinces Jiangxi and Hunan are the core area of grain production in the country. Furthermore, the Nan mountain forest and the central mountainous areas of tropical rainforest are key ecological areas and thus supposed to be protected by the artificial weather projects.

The capital of the Jiangxi province, Nanchang, is the center of the southeast region. It was chosen because of its history in implementing weather modification projects.

For the southeast region, the protection areas for weather modification are the following:

- Food production area: 175,000 km^2
- Poyang Lake & Dongting Lake wetland conservation area: 106,000 km^2
- Nan mountains water conservation area: 223,000 km^2
- West Guangdong & Hainan tropical fruit production: 67,000 km^2

Environmental Impact Assessment

Another aspect the National Development Plan (2014-2020) describes is the environmental impact of the artificial weather programs. Overall, the National Development Commission is convinced of the positive environmental impact of the projects. According to the commission, the beneficial effects of the implementation of an advanced weather modification program include mainly the increase of precipitation, which leads to an enhancement of ecological diversity, especially in the deserted areas. An additional positive effect is the prevention and mitigation of forest and grassland fires and hence the prevention of damage to the environment. The third effect listed in the Development plan is the improvement of air quality because of artificial rain. Unexpected environmental pollution, chemically or biologically, can be diluted with artificial rain and thus more severe impacts for the environment can possibly be averted.

Another positive effect for artificial rain is the gain of stability in the agricultural sector. Weather modification makes the seeding, growing and harvesting phase more predictable and more stable, according to the Development Plan. This results in a more constant and, in the best case, an increase of income for farmers, who thus do not have to spade environmentally important areas for the security of basis of existence. Noteworthy is also the mentioning of protection against nuclear pollution. Increased precipitation can ultimately be used in case of protection against nuclear pollution, according to the Development Plan.

Possible adverse effects

The Development Plan lists some effects, which might have a negative impact on the environment. It states, that the planning, implementation and enhancement of artificial weather modification including infrastructure, integrated monitoring, operation command, impact assessment, technical support and personnel training does not involve toxic or harmful substances. The construction of plants is limited to a minimum; the implementation of the projects is supposed to proceed for the most part in existing facilities.

Possible adverse effects on the environment such as noise, waste gas and dust material resulting from transport, as well as pollution from machinery or earthmoving processes generated by the construction site are supposed to be minimized, to reduce the negative impact on the environment. The running of the laboratories as well as the testing operations do not have adverse impact on the environment, the Commission confirms in the Development Plan.

The next possible negative effect on the environment the Development Plan invalidates is the use of silver iodide and dry ice as a cloud seeding catalyst. Dry ice is easy to evaporate to form carbon dioxide, which itself is part of the natural composition of the air. Therefore, it is not of greater concern for the environment, as per Development Plan. National and international experiments have shown that the maximum concentration of silver iodide in the ground after artificial rainfall projects is far below the national health standards for drinking water threshold of ≤0.05 mg / l. The Beijing Weather Modification Office had carried out artificial precipitation for many years in the Miyun reservoir[2] region and by monitoring results the silver content was 0.0002 mg / l. Nevertheless, through scientifically proven design and implementation of operational programs, the environmental pollution should be held to a minimum, according to the Development Plan.

Furthermore, the Development Plan for Weather Modification (2014-2020) proposes several aspects to protect the environment. In the construction phase, preferably energy-efficient and environmentally friendly building materials and equipment are to be used. In addition, the strict implementation of environmental regulations, the reduction of waste, wastewater, emissions and noise is prescribed. Around newly constructed buildings, “a green, environmentally friendly and harmonious environment” (National Development and Reform Commission; Chinese Meteorological Administration, 2014) should be created, by planting trees and plants.

For the use of silver iodide or dry ice, it is necessary to consider the ice nucleation rate and costs, but also to consider the sustainability of the selected materials. At the same time, it should be kept an eye on new scientific research and development of environmentally friendly materials.

Benefit Analysis

The Development Plan undertakes a benefit analysis as well. It focuses on three aspects: the economic benefits, the social benefits and the ecological benefits.

For the *economic benefits*, the National Development Commission points out, that through weather modification projects, especially artificial rain and hail suppression, the jobs in the protected areas are stable and secure. The Commission reckons with an increase of

[2] Major source of water for Beijing

0.5 yuan / m^3 precipitation due to agricultural harvest improvement. Based on an increase of 10 billion m^3 per year, the economic benefits generate up to 5 billion yuan (approx. 703 million €) per year. Based on 70,000 km^2 of hail-protected area and the average of 20,000 yuan / (km^2 * a) hail benefit, the economic benefit is 1.4 billion yuan (ca. 197 million €). Thus, the National Development Commission expect around 6.4 billion yuan (ca. 900 million €) economic benefits per year.

The *social benefits* promoted with the implementation of weather modification are the improvement of national food security, water security, ecological security, public welfare. The enhancement of artificial weather improves the prevention and mitigation of meteorological disasters, strengthens the ability to cope with climate change as well as the meteorological security of major events. Altogether, it “strengthens the government’s public service and social management functions to promote sustained economic and social development”. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

The third aspect of the benefit analysis are the *ecological benefits*. Some of them are already mentioned in the Environmental Impact Assessment such as the ability of the environment to regenerate through artificial precipitation. The implementation of artificial weather projects is reason for the promotion of vegetation growth and recovery, the reduction of forest fire risk, the recharge of surface and ground water, and the improvement of local climate conditions such as air humidity and air quality. Improved water modification eliminates and reduces hail disasters and provide favorable conditions for ecological migration. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

Institutional mechanisms

The goal of the Development Plan for Weather Modification is not only to improve the equipment and infrastructure of the projects, but also to establish institutional structures for the implementation of the programs. The meaningful utilization of synergies between the different levels of management and the reinforcement of regional coordination are crucial aspects for the improvement of the overall efficiency, to “serve the national economic construction better”. (National Development and Reform Commission; Chinese Meteorological Administration, 2014)

The Development Plan suggests establishing four levels of management: the national, the provincial, municipal and county level. The regional level is integrated into the national level of management. These institutions a responsible for the business and equipment management for the respective level. Furthermore, the establishment of five levels of command is planned: the national, regional, provincial, municipal and county level. They coordinate and command the operations at the corresponding level. Lastly, the execution of the projects at each level. This is divided into national, regional, provincial, city, county and station level. The national, regional and provincial levels are mainly responsible for the implementation of weather modification projects involving aircraft operations, the city, county and station level on the other hand, are responsible for the execution of ground operations with rockets and cannons.

5.2.4 Authorities

In China, the *China Meteorological Administration (CMA)* is the highest department responsible for the implementation of weather modification operations. As it says in the Regulations on Administration of Weather Modification (see chapter 5.2.3), the "competent meteorological departments shall [...] arrange for the implementation of weather modification and administer such operations under the leadership and coordination of local people's government [...]." (Figure 14) The respective meteorological department in the regions are the local subsidiaries of the China Meteorological Administration.

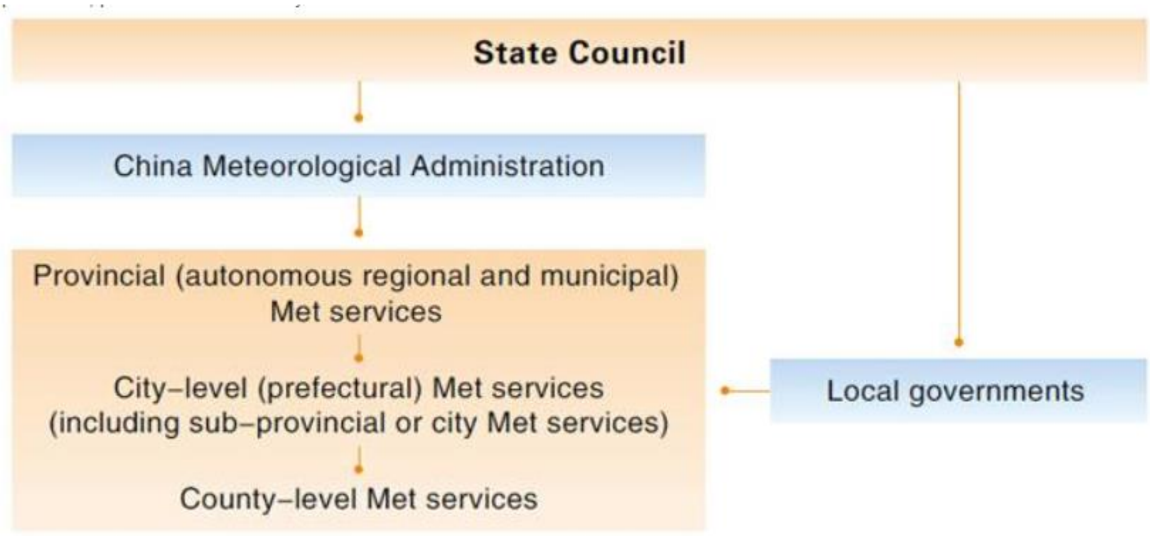

Figure 14: Command structure of weather modification (CMA, China Meteorological Administration, 2014)

The CMA is the national weather service of People's Republic of China, with the headquarter located in Beijing. Established in December 1949 as the Central Military Commission Meteorological Bureau, the organization replaced the Central Weather Bureau formed in 1941. In 1994, the CMA was converted from a subordinate governmental body into one of the public service agencies under the State Council.

Meteorological offices are established in 31 provinces, autonomous regions and municipalities, excluding meteorological services at Hong Kong, Macau and Taiwan. 318 meteorological bureaus are implemented at prefecture level and 2,300 bureaus at county level.

Inside the CMA, the Department of Emergency Response, Disaster Mitigation and Public Services is responsible for managing the local weather modification operations. The department is competent to perform meteorological support for unexpected public security incidents, as well as to provide meteorological support for nationwide major events. However, the main aspect of the department is the formulation and implementation of meteorological disaster prevention and the support of the central government's decision-making process in case of a meteorological disaster. As part of the disaster prevention and mitigation, the weather modification projects fall under the responsibility of the Department of Emergency Response, Disaster Mitigation and Public Services.

5.3 United States of America

The United States were the first country to investigate and conduct research in the field of weather modification. Furthermore, the US government was the first to permit and implement weather modification for military purposes in the Vietnam War (see chapter 3.4.1). In course of time, weather modification in the United States has undergone a drastic change. From the magic cure to all meteorological problems in the 1950s and 1960s, to the sharp fall of public funding of weather modification research in the 1980s, to the virtually not existing federal research funding nowadays. Nevertheless, the implementation of weather modification projects is still ongoing, especially in the arid and semi-arid areas of the United States.

5.3.1 History

After Project Cirrus, the exploratory cloud seeding experiments performed by Langmuir, Schaefer and Project Cirrus personnel (see chapter 2.2), the research in weather modification as well as basic research in the microphysics of precipitation processes, cloud dynamics and small-scale weather systems in general started to increase tremendously. At the same time commercial cloud seeding companies were established practicing the various forms of weather modification such as enhancing precipitation, dissipate fog and decrease hail damage. Unfortunately, the companies implemented the programs based on undeveloped knowledge of cloud physics and the meteorology of small-scale weather systems. The general opinion was “cloud seeding is good”. Scientists were now in the challenging position of proving that cloud seeding did indeed result in the enhancement of precipitation. (Cotton, et al., 2007)

For nearly two decades, research was carried out in the United States and elsewhere. Public funding in the US peaked in the mid 1970’s at nearly $19 million US per year Figure 15: Federal Funding levels in the US for weather modification research Figure 15), but still was only 6% of the total federal spending in atmospheric research. Overall, research on the basic microphysics of clouds benefited from the political and social support for weather modification. By the beginning of the 1980’s, the funding in weather modification research began to fall and by 1985, it had fallen to $12 million US per year. After 1985, the funding became so small that no federal agency kept records. (Cotton, et al., 2007)

The reasons for the appreciably decrease of federal funding were several:

- Poor experimental desings
- Widespread use of uncertain modification techniques
- Unsubstantiated claims of success
- Change in public opinion toward the environment
- Limited period of government and public interest in specific environmental problems

(Cotton, et al., 2007)

Also, the fragmentation of the support for weather modification research between the US Bureau of Reclamation (BR) of the Department of Interior, the Department of Defense (DD), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF) and the Department of Agriculture (DOA) led to a dilution of federal funding. The agencies were mission oriented, which resulted in substantial decrease of capital for basic research but rather to an increase of funding for the development of technology for the precipitation enhancement, agricultural uses and military implementations. It culminated in a great rivalry between the agencies where the most programs were of a black box nature. Clouds were seeded in a randomized statistical design and the only measurements regarded the amount of rain on the ground, rather than design studies in which the entire sequence of hypothesized responses to seeding were measured (Cotton, et al., 2007).

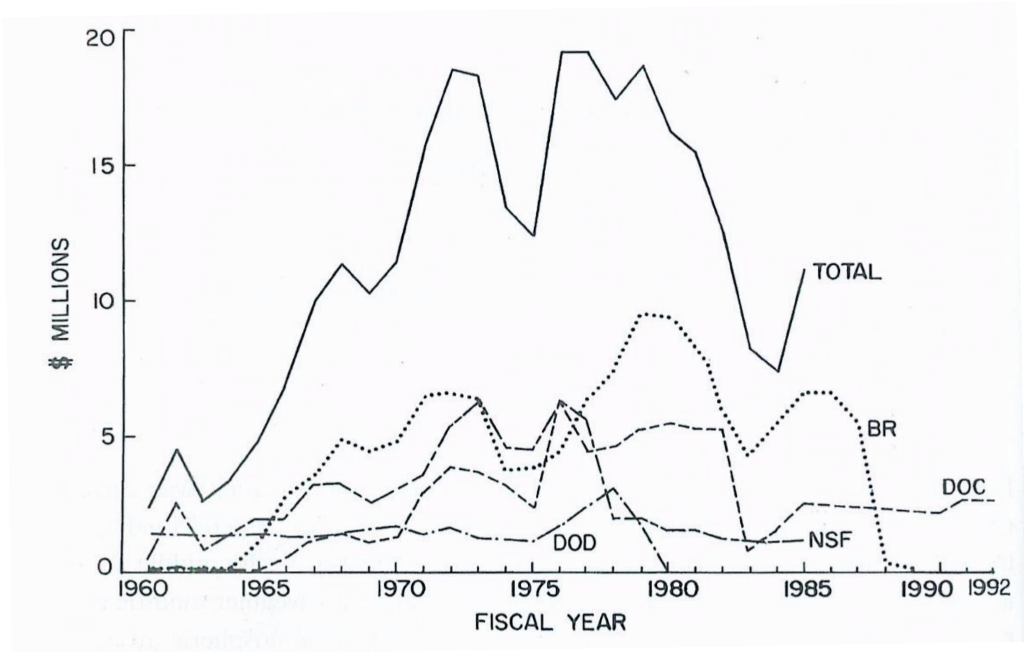

Figure 15: Federal Funding levels in the US for weather modification research (Cotton, et al., 2007)

Another aspect of the decline of weather modification research was that the public, since the early days of Project Cirrus, believed in miracle actions from weather modification due to the false proclamation of scientists and program managers. The opinion was that weather modification could enhance rainfall, suppress hail, weaken hurricanes, inhibit lightnings and quench a forest fire. After several unsubstantiated claims of success, the overselling has led to a lack of scientific credibility. In addition, in the middle 1970's to the 1980's precipitation was often above normal in the semi-arid western states of the United States, which were the key supporters of weather modification projects. Moreover, the philosophy toward the environment changed in this time. The aim of weather modification to change the weather no longer fitted the environmental ethic that predominated in many developed countries. (Cotton, et al., 2007)

The following years, in the late 1980's, 90's and beginning of the 2000s several weather modification projects were begun in response to droughts, such as the drought of 1988 and the extended drought in the early 2000's in the Southwest United States.

5.3.2 Utilization

Currently, there are 36 active weather modification programs in nine states located in the western United States. Often times, multiple cloud seeding projects are implemented in the respective states (WMO, World Meteorological Organization, 2013).

One of the most productive states in terms of weather modification is North Dakota. In 2015, artificial weather programs were conducted in eight counties and over an area of 30,000 km^2, concentrated in the western part of the state. The main task is the rain enhancement and the hail suppression, which is executed with eight airplanes in approximately 760 flight hours. The budget for the weather modification projects is $1,025,000 US, with $674,000 US coming from the involved counties and $351,000 US coming from the state North Dakota. (Langerud, 2015)

Other states with active weather modification programs are California (rain enhancement: 1,300 km^2; snowpack augmentation: 6500 km^2), Texas (rain e.: 110,000 km^2), Colorado (snowpack augmentation: 7800 km^2), Utah (snow: 33,000 km^2) and Idaho (snow: 28,500 km^2). In Nevada, Wyoming and Kansas weather modification projects are implemented as well (WMO, World Meteorological Organization, 2013).

5.3.3 Laws/Regulation

Several state governments license and regulate commercial weather modification operations. These regulations and the license procedures are all similar. The first aspect of the license process is to assure that the commercial weather modification company is competent (required to have at least a bachelor's degree in meteorology or related field, in addition they must have experience in weather modification). Secondly, state governments require companies to have the resources to compensate those harmed by their implementations (proof of financial responsibility). (Standler, 2006)

Generally, the governmental regulation of a weather modification company is performed in two steps. First, the government licenses individual cloud seeders, then, it grants permits to licensed cloud seeder for a specific place and range of time. Some states even conduct public hearings before granting a permit. (Standler, 2006)

In place of all the different state regulations, the Texas regulations on weather modification will be examined. Under the Texas Statutes, Agriculture Code – Title 9: Weather and climate in chapter 301 and 302, the Texas Department of License and Regulation discussed the legal requirements and possible consequences of weather modification projects. The code came into force on September 1, 2007 (Texas Department of Licensing and Regulation, 2007)

In section 301.101 the department formulates the prohibition of any activities of weather modification and control for persons who do not own a weather modification license and weather modification permit, which is issued by the department. The exceptions are "research, developments and experiments conducted by state and federal agencies, institutions of higher learning, and nonprofit research organizations", "laboratory research and experiments” and “activities of an emergent nature for protection against fire, frost, sleet, or fog” (Section 301.102, Texas Department of Licensing and Regulation, 2007).

The license for weather modification implementation is issued to an applicant who “pays the license fee and demonstrates, to the satisfaction of the department, competence in the field of meteorology that is reasonably necessary to engage in weather modification and control activities.” Each license is then valid until the end of the state fiscal year for which it was issued. The permit of weather modification projects is then issued to each applicant who first holds a valid weather modification license, then pays the permit fee, publishes a notice of intention and submits proof of publication and furnishes proof of financial responsibility. A separate permit is required for each operation. (Sections 301.103, 105, 107, 109 Texas Department of Licensing and Regulation, 2007)

Before conducting any operation, the license holder must publish a notice of intention, which includes the name of the operator, the specific type of the intended weather modification and the area in which and the time during which the operation is to be implemented. Furthermore, the public notification must include the area, which is possibly be affected and the materials and methods used in the operation. This notice “has to be published at least once a week for three consecutive weeks in a newspaper of general circulation in each county in which the operation is to be conducted”. 30 days after the first publication the permit is issued. (Section 301.111, 112, 153 Texas Department of Licensing and Regulation, 2007)

Due to the fact, that weather modification in the United States is mainly under the oversight of the federal states, there are not many regulations on national level. The public law 92 - 205, known as the Weather Modification Reporting Act, was established in 1971 and defines the obligation of any operator of weather modification to report directly to the National Oceanic and Atmospheric Administration (NOAA). In § 330a it states that “No person may engage, or attempt to engage, in any weather modification activity in the United States unless he submits to the Secretary such reports with respect thereto, in such form and containing such information, as the Secretary may by rule prescribe. The Secretary may require that such reports be submitted to him before, during, and after any such activity or attempt.” In addition, in § 330d the violation of the law is mentioned as “Any person who knowingly and willfully violates section 330a of this title, or any rule issued thereunder, shall upon conviction thereof be fined not more than $10,000.” (US Government Printing Office, 1971)

5.3.4 Authorities

In the US, on national level, the National Oceanic and Atmospheric Administration (NOAA) keeps records of weather modification projects on behalf of the Secretary of Commerce. As prescribed in public law 92 – 205, 15 USC §330, any weather modification program must be reported to the NOAA.

On federal state level, the regulation of weather modification differs from state to state. In Texas for example, the department of licensing and regulation (a state agency of Texas), is the main authority for commercial weather modification. In North Dakota however, the government agency responsible for weather modification is the North Dakota Atmospheric resource board, a division of the state water commission. The board is composed of the director of the state aeronautics commission, a representative of the environmental section of the state department of health, the state engineer, and one additional board member from each of the seven districts. (North Dakota Atmospheric Resource Board, 1988)

5.4 European Union

Compared to the immense effort and hope other countries put in to weather modification techniques, in the countries of the European Union a very small number of weather modification projects is being implemented. By contrast to China and the United States, the projects are not funded by any state authority. The existing programs of weather modification, especially in Germany and Austria, focus on hail prevention and are implemented by non-profit organizations.

5.4.1 History

In the aftermath of the first experiments of Langmuir and Schaefer in the General Electric's Research Laboratory, many countries all over the world put their own efforts in the research of weather modification. In Europe, the United Kingdoms implemented Project Cumulus to investigate the potential of weather modification, especially rain enhancement. This project was operational between 1949 and 1952 (Vidal, et al., 2001).

In Central Europe, the idea of artificially steering the weather came later. In Lower Austria, starting 1956 until 1976, the hail suppression operations were performed with ground rockets. After several severe hailstorms happened despite the hail prevention operations with rockets, the techniques were changed to airplanes in 1978. (Zentralanstalt für Meteorologie und Geodynamik, 2005)

In Germany, the first experiments with ground generators for hail suppression started in 1958 in Rosenheim, Bavaria. The first tests were declared successful and over the years, 140 rocket operators and 30 handlers of the generators were in action (Hagelabwehr Rosenheim, 2010). In the region of Stuttgart, hail suppression operations started in 1980 with two airplanes. Today, hail suppression is implemented by seven non-profit organizations in Southern Germany and Austria.

5.4.2 Utilization

Regarding utilization of weather modification in Great Britain, the United Kingdom Department of Energy & Climate Change released a statement in 2014, answering a formal request. It states that "Following a search of our paper and electronic records, I have established that this Department does not hold any record of any weather modification techniques being deployed in or above the UK currently or over the last 10 years." (UK Department of Energy & Climate Change, 2014)

In Germany, the weather modification projects are limited to hail suppression and restrict oneself to Bavaria and Baden-Wuerttemberg. The operations are conducted by non-profit organization who are financed by public and private investors. The association in the county Rems-Murr for instance, receives each year 75,000 € from the municipalities and the cities Stuttgart and Esslingen, 89,000 € from the union of viniculture, 17,000 € from private vineyards, 10,000 € from the union of fruit production, 30,000 € from local businesses and 50,000 € from the county Rems-Murr. (Friedrich, 2015) Some non-profit organizations finance themselves over the membership fees, as well.

The annual amount of operations differ from region to region. In the region of Stuttgart, the operators conduct 25 to 30 operations with two airplanes from May to October, in the region of Southern Palatinate only 7 operations were implemented in 2015. In the Southwest region of Bavaria, the protected area of the organization "Verein zur Erforschung der Wirksamkeit der Hagelbekämpfung im Raum Rosenheim e.V" amounts to 4,400 km^2, including the counties Miesbach, Rosenheim, Traunstein and some areas of Kufstein (Figure 16).

In Austria, the region of Langenlois, Lower Austria and the Southeast part of Styria are protected by hail suppression organizations. The organization "Steirische Hagelabwehr Genossenschaft" counts 60 operations per year in not less than 97 municipalities. (Steirische Hagelabwehr Genossenschaft, 2014)

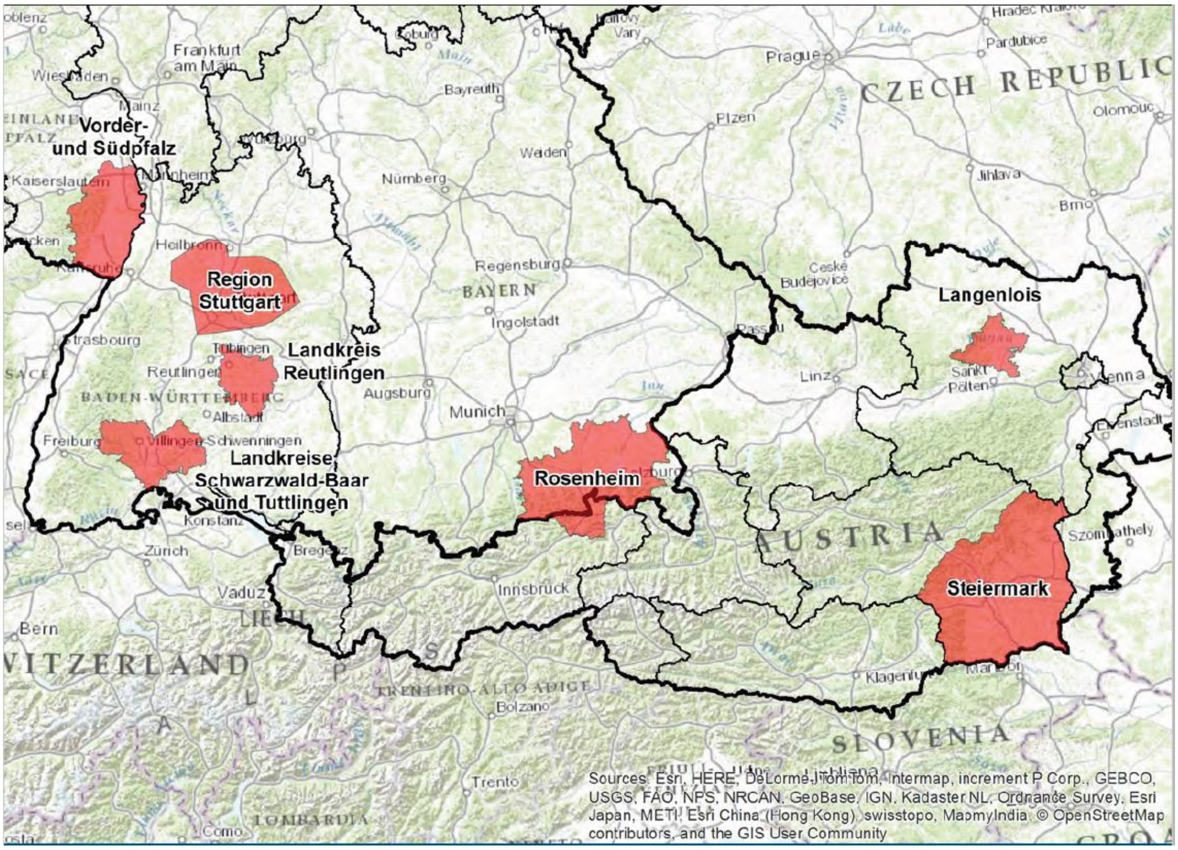

Figure 16: Areas of active hail suppression in Germany and Austria (Friedrich, 2015)

5.4.3 Laws/Regulation

Since all the hail suppression operations are carried out with airplanes, the projects fall under the regulations for air traffic. In Austria, hail suppression flights are specifically mentioned in the adaptions of the implementing regulation (EU) No. 923/2012 (Standardized European Rules of Air) and further in the rules of the air and air traffic control 2014 (LVR 2014). In § 9, "flights for hail suppression" of the Austrian adaptations, hail flights are given a special status, defining these flights as a special case of "flights with dropping or spraying of substances." With this exemption clause of minimum visibility conditions and minimum distance to clouds, the targeted purpose of releasing of substances at the clouds base to minimize the formation of big hailstones shall be ensured. Before a flight for hail suppression is conducted, the responsible air traffic control unit has to be informed. (Bundesministerium für Verkehr, Innovation und Technologie, 2014)

The German Air Traffic Act (LuftVG) does not mention flights for hail suppression.

5.4.4 Authorities

Since the legal regulation of weather modification is unclear in many countries such as Germany, the definition of competent authorities is vague as well. In case of doubt, the restrictive government of each level is responsible for any kind of weather modification. Furthermore, the activity of weather modification falls under the field of authority of both environmental authorities and air traffic control units.

6 Comparison and personal assessment

The different strategies of weather modification that countries have developed and executed in the last 70 years could not be more diverse. Whereas the science of weather alteration started in the 1940s in the United States and evolved to a promising industry, in the rest of the world it lasted several years until governments picked up the idea to artificially alter the weather. In the United States soon after the first experiments in the General Electric Research Laboratory, the federal authorities took over the management and started Project Cirrus. Many scientists believed in the inexhaustible potential of weather modification and the general view was that weather modification was the solution to all the meteorological problems. However, this view changed over the following decades and in the mid-1980s, the federal funding for weather modification research collapsed and reached only 10 % of the peak amounts in the 1970s.

China, on the other hand, executed the first weather modification operations in the late 1950s, but the real beginning of weather modification in China is marked by the implementation of the Weather Modification Regulations in 2002, particularly the 2nd National Weather Modification Conference held in 2004. Since then, the artificial weather projects in China have become a crucial part in the development plan of the People’s Republic of China. In contrary to the United States, where weather modification operations are carried out only in a few states, the program in China is expanded to the entire area of the country. With the implementation of the weather modification development plan, until 2020, the country is divided into six weather modification regions and every region has its own weather modification basis. Additionally, every region has key areas in which the artificial weather projects are being operated, such as agricultural areas and hail or drought prone areas.

In China, weather modification plays an important role in the national development. The National Development Plan for Weather Modification shows the high priority the State Council puts into the program. To guarantee food security, disaster mitigation and prevention, and freshwater security artificial weather is supposed to play the key role, according to the State Council. Nothing of the sort is happening in the United States. Despite several federal state funded projects, the covered area in the US is in no comparison to the covered areas in China.

Beside the covered area, the investment of China and the US in weather modification differs highly as well. The pilot project of the weather modification development plan in the Northeast of China cost 134.5 Mio € alone, whereas North Dakota spent less than one million € (1 Mio $) for the operation of artificial weather in 2015.

The weather modification projects in Europe are not able to match the dimensions of neither China nor the United States. In Europe, the projects focus on anti-hail programs, which started in Austria and Germany in the late 1950s. Contrary to China and the United States, the science of weather modification was never really funded by federal authorities. The operations have been carried out by non-profit organizations and have been funded mainly by donations of the fruit production sector.

Moreover, the political support makes the Chinese weather modification program unique in the world. Nowhere else, weather modification is given so much importance in the political, economic and social development of a country.

This however, has to be seen critically. The investment in an industry, which has not yet produced sufficient results to justify the hopes, is extremely risky. Especially in light of the fact, that there is still no sufficient knowledge of the mechanisms happening during cloud seeding. China wants to involve cloud seeding to mitigate meteorological disasters, but the possibility of rain enhancement in the seeded areas and the associated risk of floods has not been examined enough.

China’s development plan for weather modification exhibits some aspects, which are not entirely agreeable. First, the statement that the administer of the Chinese Meteorological Administration Zheng Guoguang released in 2012, claiming that since 2002, 560,000 manipulations have helped releasing 489.7 billion tons of rain. This statement shows the general difficulty to evaluate the success of artificial rain programs. How much of the 487.7 billion m^3 would have come to the surface without the rain enhancement program? What factor plays the natural variability in such events? How accurate are radar reflectivity measurements in measuring the differences between accumulated rainfall in seeded and unseeded clouds? By studying the Development plan for weather modification, it appears that the Chinese weather modification and governmental authorities do not bring the concept of weather manipulation into question. The numbers, which are supposed to show the success of the program, appear to be the total amount of rain measured in a certain area. Whether or not the artificial program helped the precipitation process, is not distinguished.

A positive issue is the inclusion of an environmental impact analysis in the development plan. Unfortunately, the aspects are not thought through. The plan states for example, that due to more precipitation, the ecosystems, especially in deserted areas, only benefit. Ecosystems however adapt to the environmental conditions, which makes a definition ‘ecosystem improves’ difficult. Deserted regions grant habitat to a countless number of species. Even the pretended threatening forest and grassland fires are to some extent an important guarantee for young plants to evolve. The possibility of a dilution of environmental pollution through enhanced precipitation is also an idea not practical. A chemical or biological pollution spreads even more if diluted with rain and possibly infiltrates into the groundwater, which makes the pollution even more uncontrollable. The mentioned solution for nuclear pollution is not explained into detail, but the idea does not make sense. Through rain, radioactive particles spread even more instead of being rendered harmless.

Another critical aspect in the development plan of weather modification in China is the possible lack of precipitation and water shortage in an area due to rain enhancement in the adjacent region. The development plan encourages a better institutional cross-linkage between the regional governments and the meteorological departments, but if a cloud seeding project is indeed successful in an area, the neighboring region does not see any precipitation. In case of uncertainty, the government and the meteorological department decide where the weather modification programs are implemented.

Another positive and welcome aspect of the development plan in China is the planned consolidation of the research and development department for weather modification. The implementation of the projects can only benefit from further research.

Overall, the study of scientific literature on weather modification shows, that still after 70 years of history the initiation of large-scale operational weather modification programs is premature. Many fundamental problems have not been solved to the day. Despite significant advancement in observational and computational capabilities, the emphasis of the industry is still on the operation of projects rather than the understanding of the involved processes. Once the processes behind the weather modification techniques are understood, the focus can turn to application of this understanding. This will not only be helpful for potential weather modification operations but for cloud modeling or weather forecasting as well.

Because weather modification could potentially contribute to alleviating water resource stress and severe weather hazards, it is attempted regardless of scientific proof supporting or refuting its efficacy. Every raindrop after cloud seeding is seen as proof for the successful implementation of the technique. Especially in China the hype of weather modification looks like a potential magic cure to all the social and economic problems in the country. At the same time, the weather modification operations worldwide are focused on the implementation of the projects, based on knowledge, which consists to a greater part on understandings from the last century. Questions that remain to the day include the variability of the aerosol concentration over the times of the year and different locations. What are the corresponding meteorological conditions and to what extent would weather modification operations be dependent on these background concentrations of aerosols? What are the effects of localized seeding on the larger systems in which the seeded clouds are embedded? What is the variability of cloud properties, such as structure, intensity and lifetime, within larger clusters?

Weather modification, especially for the mitigation of severe weather hazards, which pose a significant threat to life and property, could be a future possibility to encounter such dangers. Instead of blindly injecting cloud seeding material into the clouds, the research effort in the areas of cloud and precipitation microphysics, cloud dynamics, cloud modeling and cloud seeding has to be strengthened, though. Furthermore, the legal basis of altering the atmosphere worldwide has to be strict, so that no country has to suffer from adverse side effects of weather alteration in an adjacent country.

For the moment, weather modification programs operate in a scientific twilight zone. Although there is physical evidence that seeding affects cloud processes, effective techniques for significantly modifying the weather generally have not been demonstrated (see chapter 4).

References

Brimelow, Julian C. and Reuter, Gerhard W. 2002. Modeling Maximum Hail Size in Alberta Thunderstorms. *Weather and Forecasting.* 2002, Vol. 17, 5.

Bruyn, Valentin de. 2012. [Online] January 3, 2012. [Cited: February 17, 2016.] https://upload.wikimedia.org/wikipedia/commons/5/57/Cloud_types_en.svg.

Bundesministerium für Verkehr, Innovation und Technologie. 2014. Regelung des Luftverkehrs 2014 . [Online] December 11, 2014. [Cited: March 9, 2016.] https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20008992.

Caviezel, Claudio and Revermann, Cristoph. 2014. *Climate Engineering - Kann und soll man die Erderwärmung technisch eindämmen?* [ed.] Büro für Technikfolgen-Abschätzung. Berlin : edition sigma, 2014. 978-3-8360-8141-2.

CBD. 2015. Convention on Biological Diversity. [Online] 2015. [Cited: February 24, 2016.] https://www.cbd.int/.

CBD, Conference of the Parties to the Convention on Biological Diversity. 2010. Convention on Biological Diversity. [Online] October 29, 2010. [Cited: February 24, 2016.] https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-33-en.pdf.

CMA, China Meteorological Administration. 2014. Leadership and Governance. *China Meteorological Administration.* [Online] 2014. [Cited: March 03, 2016.] http://www.cma.gov.cn/en2014/aboutcma/leadership/.

CMA, Chinese Meteorological Administration. 2013. Chinese Meteorological Administration. [Online] January 23, 2013. [Cited: February 25, 2016.] http://www.cma.gov.cn/kppd/kppdqxsj/kppdrgyxtq/201301/t20130123_203899.html.

Cotton, William R. and Pielke Sr, Roger A. 2007. *Human Impacts on Weather and Climate.* Cambridge, UK : Cambridge University Press, 2007. 978-0-521-60056-9.

Cotton, William R. 1990. *Storms.* s.l. : Fort Collins, Co.: ASTeR Press, 1990. Vol. 1. 978-0-962-59860-9.

Dennis, Arnett S. 1980. *Weather Modification by Cloud Seeding.* New York : Academic Press, Inc., 1980. 0-12-210650-4.

DWD, Deutscher Wetter Dienst. 2015. Deutscher Wetter Dienst: Wetterlexikon. [Online] 2015. [Cited: February 18, 2016.] http://www.dwd.de/DE/service/lexikon/Functions/glossar.html?nn=103346&lv2=100510&lv3=100572.

Friedrich, Bernd. 2015. *Unterstützung der Hagelabwehr durch die kommunale Seite, Tagungsband - Internationale Fachtagung Hagelabwehr.* Reutlingen : Landratsamt Rems-Murr-Kreis, 2015.

Gagin, A. and Neumann, J. 1981. The second Isreali randomized cloud seeding experiment: Evaluation of the results. *Journal of Applied Meteorology and Climatology.* 1981, 20, pp. 1301-1311.

Gathmaistn, Louis. 1891. *Method of producing rain-fall. US462795 A* USA, Juli 16, 1891.

Hagelabwehr Rosenheim. 2010. Hagelabwehr Rosenheim - Geschichte der Hagelabwehr. [Online] 2010. [Cited: March 8, 2016.] http://www.hagelabwehr-rosenheim.de/hagelwolke/geschichte.html.

Jing, Hao. 2014. China Meterological Administration. [Online] December 25, 2014. [Cited: February 13, 2016.] http://www.cma.gov.cn/en2014/news/News/201412/t20141225_270550.html.

Langerud, Darin. 2015. *Wetterbeeinflussung in North Dakota, Tagungsband - Internationale Fachtagung Hagelabwehr.* Reutlingen : Landratsamt Rems-Murr-Kreis, 2015.

Lewis, W. 1951. On a seven-day periodicity. *Bulletin of the American Meteorological Society.* 32, 1951.

Liang, Zhang, Shuzhong, Gu and Yufei, Wang. 2012. Policy Options on Scientifically and Reasonably Developing Cloud Water Resources. *Development Research Center of the State Council of the People's Republic of China.* [Online] 2012. [Cited: March 2, 2016.] http://www.chinadaily.com.cn/m/drc/2015-08/07/content_21528391.htm.

MOUK. 2014. Meterological Office United Kingdom. [Online] August 6, 2014. [Cited: February 17, 2016.] http://www.metoffice.gov.uk/learning/clouds/low-level-clouds/cumulonimbus.

—. 2014. Meterological Office United Kingdom. [Online] August 6, 2014. [Cited: February 17, 2016.] http://www.metoffice.gov.uk/learning/clouds/mid-level-clouds/nimbostratus.

National Development and Reform Commission; Chinese Meteorological Administration. 2014. National Weather Modification Development Plan (2014-2020). Beijing : s.n., December 25, 2014.

National Research Council. 2004. *Critical Issues in Weather Modification Research.* Washington, D.C. : National Academies Press, 2004.

NOAA, National Oceanic and Athmospheric Administration. 2013. National Weather Service. [Online] March 14, 2013. [Cited: February 17, 2016.] http://www.srh.noaa.gov/srh/jetstream/clouds/cloudwise/learn.html#how.

North Dakota Atmospheric Resource Board. 1988. North Dakota Century Code section 61-04.1-14. [Online] November 1, 1988. [Cited: March 7, 2016.] http://www.legis.nd.gov/cencode/t61c04-1.pdf?20160308090023.

Qian, Wang. 2014. china daily. [Online] March 18, 2014. [Cited: January 6, 2016.] http://www.chinadaily.com.cn/china/fightairpollution/2014-03/18/content_17356836.htm.

—. 2011. china daily. [Online] March 24, 2011. [Cited: December 1, 2015.] chinadaily.com.cn/china/2011-03/24/content_12218277.htm.

Robison, Tom. 1970. Air Weather Reconnaissance Association. [Online] 1970. [Cited: February 23, 2016.] http://1.1.1.5/bmi/www.awra.us/gallery-jan05_files/56-0522.jpg.

Rogers, R. R. 1979. *A Short Course in Cloud Physics.* Oxford : Pergamon Press, 1979. 0-08-023040-7.

Rosenfeld, D. and Woodley, W. L. 1989. Effects of cloud seeding in West Texas. *J. Appl. Meteor.* 1989, 28, pp. 1050-1080.

—. 1993. Effects of cloud seeding in West Texas: Additional results and new insights. *J. Appl. Meteor.* 1993, 32, pp. 1848-1866.

Silverman, Bernard. 2001. A critical assessment of glaciogenic seeding of convective clouds for rainfall enhancement. *Bulletin of the American Meteorological Society.* 2001, Vol. 5, 82.

Simpson, Joanne, et al. 1980. On Cumulus Mergers. *Arch. Meteor. Geophys. Bioklim.* A, 1980, 29.

Standler, Ronald B. 2006. Weather Modification Law in the USA. [Online] October 22, 2006. [Cited: March 07, 2016.] http://rbs2.com/weather.pdf.

State Council, of the People's Republic of China. 2012. Comments on further Strengthening Weather Modification/ Document No. 44. *Central People's Government of the People's Republic of China.* [Online] August 30, 2012. [Cited: February 25, 2016.] http://www.gov.cn/zwgk/2012-08/30/content_2213785.htm.

—. 2002. Regulations on Administration of Weather Modification. *National People's Congress of the People's Republic of China.* [Online] March 19, 2002. [Cited: March 2, 2016.] http://www.npc.gov.cn/englishnpc/Law/2007-12/14/content_1384183.htm.

Steirische Hagelabwehr Genossenschaft. 2014. Steirische Hagelabwehr Genossenschaft. [Online] 2014. [Cited: March 9, 2016.] http://www.hagelabwehr.at/.

Texas Department of Licensing and Regulation. 2007. Weather Modification and Control, Agriculture Code Title 9: Weather and Climate, Chapters 301, 302. *Texas Department of Licensing and Regulation.* [Online] September 1, 2007. [Cited: March 5, 2016.] https://www.tdlr.texas.gov/weather/weatherlaw.htm.

Tighe, Tony and Elliott, Tamara. 2014. Hail suppression team protects Alberta communities from major damage. *Global News Canada.* [Online] August 3, 2014. [Cited: February 19, 2016.] http://globalnews.ca/news/1487932/hail-suppression-team-protects-alberta-communities-from-major-damage/.

UK Department of Energy & Climate Change. 2014. Weather modification in the UK. [Online] June 23, 2014. [Cited: March 9, 2016.] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/322437/14_11578.pdf.

United State Senate, Subcommittee on Oceans and International Environment of the Committee on Foreign Relations. 1974. *US Senate Hearing on Weather Modification.* Washington, D.C. : s.n., 1974.

United States Government. 2005. Mean annual precipitation in China. [Online] January 15, 2005. [Cited: March 13, 2016.] https://upload.wikimedia.org/wikipedia/commons/8/8d/China_precipitation.jpg.

UNOG, United Nations Office at Geneva. 2012. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD). *United Nations Office at Geneva.* [Online] 2012. [Cited: February 24, 2016.] http://www.unog.ch/enmod.

—. 1977. US Department of State. [Online] 1977. [Cited: February 24, 2016.] http://www.state.gov/t/isn/4783.htm.

US Government Printing Office. 1971. Public Law 92 - 205, Title 15 US Code §330. *Office of the Law Revision Counsel.* [Online] December 18, 1971. [Cited: March 5, 2016.] http://uscode.house.gov/view.xhtml?path=/prelim@title15/chapter9A&edition=prelim.

Vidal, John and Weinstein, Helen. 2001. the guardian. [Online] August 30, 2001. [Cited: March 7, 2016.] http://www.theguardian.com/uk/2001/aug/30/sillyseason.physicalsciences.

Wahl, E. 1951. On a seven-day periodicity in weather in the United States during April, 1950. *Bulletin of the American Meteorological Society.* 32, 1951.

WMO, World Meteorological Organization. 2010. *WMO Documents on Weather Modification.* Abu Dhabi : s.n., 2010.

—. 2013. *WMO Expert Committee on Weather Modification Research.* 2013.

—. 2015. World Meterological Organization: The International Cloud Atlas. [Online] June 11, 2015. [Cited: February 17, 2016.] https://www.wmo.int/media/content/international-cloud-atlas.

Xin, Zheng. 2012. chinadaily. [Online] May 23, 2012. [Cited: December 15, 2015.] chinadaily.com.cn/china/2012-05/23/content_15360828.htm.

Zentralanstalt für Meteorologie und Geodynamik. 2005. *Hagelabwehr in Niederösterreich (1981-2000).* Wien : s.n., 2005.

List of Tables

List of Figures