CLOUD SEEDING TO REGULATE WATER SUPPLIES AND THEIR ECONOMIC EFFICIENCY IN KOREA

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Abstract: Cloud seeding has not been used now to regulate water supplies in Korea and this results in losses to economy. The lastest experiments on precipitation enhancement in the world show that there are real possibilities to increase precipitation by 10-20%. Investigations of economic losses due to the lack of routine cloud seeding experiments in Korea have shown that they exceed about 100 million US dollars in 1999. Recommendations on cloud seeding activities including works on precipitation augmentation and prevention of heavy rains are presented. Spatial and temporal necessity to carry out this or that work is discussed.

Key Words: cloud seeding, precipitation enhancement

1. INTRODUCTION

Drought, hail, fog, and hard rain continue to cause havoc in many parts of the world. The associated loss of life and property has been growing as the population concentration increases. Cloud seeding as routine work to improve weather conditions, to exclude losses in the economy due to dangerous atmospheric phenomena, is carried out in many countries such as Argentina, Bulgaria, China, Italy, Serbia, Uzbekistan, Russia etc.(Abshaev *et al.*, 1987; Birulev *et al.*, 1996; Xu *et al.*, 1999, Dovgaljuk *et al.*, 1998; Grickiv *et al.*, 1968; Kamalov, 1999; Polovina, 1980; Sedunov, 1971; Sinkevich; 1992, Vucinic, 1999). Cloud seeding experiments were conducted in Korea in 1995-1996 (METRI, 1997; Hong and Eom, 1997; Chung *et al.*, 1998). However, these experiments have not been continued, although they clearly show the possibility to obtain positive results. Possibly, the discontinuation of experiments was the result of an insufficient economic basis for their carrying out. Here we try to improve our knowledges in the economic value of cloud seeding experiments.

2. CLOUD SEEDING ACTIVITIES FOR PRECIPITATION ENHANCEMENT

A lot of experiments have been carried out on

Table 1. Projects on weather modification to enhance precipitation during 1990-20000.

Project Area	Project goal-precipitation for benefit:	Years	Seeding effect
Yakutia, Russia	Agriculture	1995-1997	12-117%
Syria	Agriculture	1991-1998	7-17%
Iraq	Agriculture	1992-1995	0-67%
Honduras	Hydroelectric power Production	1993-1997	6-15%, calculated benefit/cost-23.5/1
Italy	Agriculture	1988-1994	Could not be assessed using statistical methods
Turkey	Water reservoirs	1992	Could not be assessed using statistical methods
Baiyang River Basin, China	Increase in annual flow	1984-1995	11.6%
Shandong province, China	Agriculture	1989-1995	0.8-1.5% increase in wheat production
Xinjiang, China	Agriculture(to reduce an nual frost damage area of winter wheat)	1978-1994	80%
Hunan province, China	Water reservoirs	1998	252 mln RMB yuan, benefit/cost – 8/1
Uzbekistan	Agriculture	1985-1991	-3 – 43%
Taiwan	Agriculture	1992	No information
Guatemala	Hydro-electric power Production	1991,1992, 1994	No information
Utah, USA	Water reservoirs	1989-2000	14-20%
California, USA	Hydro-electric power Production	1990-1997	No information
Idaho, USA	Water reservoirs	1992-1996	No information
Colorado, USA	Water reservoirs	1992-1995	No information
Greece	Water reservoirs	1992-1993	No information
Thailand	Agriculture	1995-1993	Averaged rain volume of seeded clouds in 109% greater than that of the un-seeded
Mexico	Agriculture	1997-1998	No information

Source : WMO(1999); AMS(2001); Weather modification Corp. Web page

Table 2. Losses in electricity production due to lack of cloud seeding

Reservoir (Dam)	Irrigation water (m^3/year)	Increase in Irrigation water (m^3/year *10^5)	Electric power Losses (kWt/hour *10^5)	Economic Losses (won *10^7)
Soyang	1,213	2,426	654	654
Chungju	3,380	6,760	1,826	1,826
Andong	926	1,852	500	500
Imha	592	1,184	324	324
Hapcheon	599	1,198	322	322
Naktong-gang	750	1,500	404	404
Namgan	593	593	160	160
Naju	489	978	264	264
Jinyang	350	700	188	188
Puan	35	70	18	18
Taecheong	1,649	3,298	890	890
Total	10,576	21,152	5,716	5,716

poses in the history of cloud seeding. A list of some of the latest experiments which have been carried out around the world with the aim of precipitation enhancement is presented in Table 1. It has been known that one can obtain on average 10-20% precipitation changers due to cloud seeding (see Table 1)

3. ECONOMIC LOSSES DUE TO THE LACK OF CLOUD SEEDING ACTIVITIES IN KOREA

3.1 Harvest

Role of precipitation is highly complicated and depends on regional climatic regime and regional agricultural zones. We do not discuss in details requirements for the precipitation amounts to achieve the greatest yield. It is important to emphasize the fact that for the Republic of Korea it is usually desirable to have greater water supplies during the vegetation period (April-June). Here we discuss only the problem of rain which falls down on farmers' fields (problems of reservoirs' water supplies enhancement is discussed below, as we clearly understand that this water is also used for agriculture). It is a rather complicated task to assess the influence of rain deficiency on the whole agricultural production of the Republic of Korea, so we are obliged to simplify the task. There are assessments of artificial rain enhancement on rice production carried out by Chinese scientists (Yulin, 1999). We will use their data to assess possible losses in agriculture production due to lack of regular cloud seeding experiments. They have shown that the enhancement of precipitation yield on average to be 2 kg/mm·ha of rice. We are making the proposal that all agricultural production of Republic of Korea is rice. Territory in the Republic of Korea with agricultural fields is equal to 1,898,925 ha. There is need for additional precipitation from April to May (2 months). The averaged precipitation amount during this period is equal to 60 mm in Korea (METRI, 1977). Regular cloud seeding experiments can enhance the precipitation amount on average by 20%. So potential damage (due to the absence of cloud seeding experiments) to the economy of the Republic of Korea is equal to losses of 91×10^6 in agriculture production . Most occurrences of droughts are observed in the eastern parts of the country. So experiments on cloud seeding have to be carried out here. However due to the fact that there are no expressed agricultural regions, it is clear that to reduce drought consequences one has to plan cloud seeding in accordance with the real meteorological situation throughout the country. Losses in agriculture production due to the lack of possibility to carry out cloud seeding experiments in all parts of the country simultaneously may be assessed as 50%. In this case, losses in agriculture production will be equal to 45×10^6.

3.2 Hydro-electric power stations (water reservoirs)

Hydro-electric power stations mainly depend on the runoff formed by rainfall to generate electricity. Assuming that cloud seeding can increase the precipitation amount by 20%, it is possible to assess the benefit due to the use of additional water to produce electricity. It was shown (Xu *et al.*, 1999) that 3.7 cubic meters of water can generate one kilowatt electricity per hour. So losses to the Korean economy can be calculated simply from data on irrigation water. Calculations have shown that total losses are equal to 44×10^6. The distribution of losses between hydro-electric power stations is presented in Table 2. It is clear that not all irrigation water is used for electricity production. There are losses during the summer period when some water is released from reservoirs to prevent floods. So if we accept that these losses constitute 10%, then maximum profit will be equal to 40×10^6.

Most of the multi-purpose reservoirs are located in the northern and central parts of the

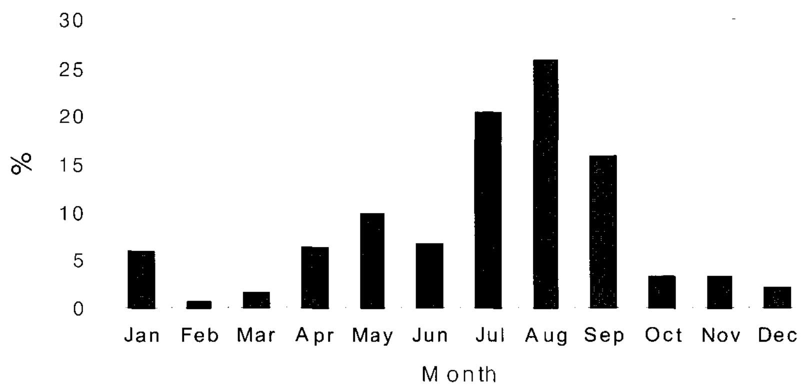

Fig. 1. Relative rate of monthly precipitation in North Korea (data from Climate data management system operated by Korea Meteorological Administration).

country (Soyang, Chungju, Andong, Imha, Taecheong). They provide 73% of benefits in the case of cloud seeding. So it is worthwhile to carry out cloud seeding in the northern part of the country. In these cases, possible reduction in profit will constitute 27%, and profit will be equal to $\$29\times10^6$.

Most experiments have to be carried out during periods when there is lack of water in reservoirs, namely October- June. Detailed experiments planning has to be carried on the base of monthly averaged precipitation data. The relative rate of monthly precipitation for the northern territory of the Republic of Korea is presented in Fig. 1.

It is clear that the best months to carry out experiments are January and April-June . If cloud seeding will be carried only in these months, benefits due to additional water within the reservoirs will be equal to $\$6\times10^6$ (precipitation water during these months constitutes 21.7% of all precipitation water).

Studies of Chinese scientists have shown (Xu *et al.*, 1999) that there are two kinds of benefits. One is direct financial benefit brought to the hydro-electric power station itself by generating electricity by means of artificial enhancement of precipitation. Usually there are some hydro-electric power stations along the lower parts of the river. So they also obtain benefit from additional water. This additional water may be used for civil or other necessities, so it also appears to bring additional indirect economic benefits. These indirect benefits were assessed 70 times greater than direct ones (Xu *et al.*, 1999). If we assume that these indirect effects will be equal 1000% in the Republic of Korea (one must clearly understand that this additional water can be used in agricultural purposes), we will obtain a final benefit as great as $\$6\times10^6$.

So, due to the absence of cloud seeding experiments to enhance water supplies in reservoirs of electric power stations in the northern regions of Korea, annual losses to the economy are equal to $\$60\times106$.

3.3 Heavy Rain Damage

Floods often take place in Korea. They are usually caused by heavy rains in the summer period, and bring enormous disasters to the population, losses in economy and even deaths Using data of the National Disaster Prevention and Countermeasures Headquarters, we have calculated averaged annual losses from storms and floods for the period 1995-1999 to be equal to $330,000\times10^6$ won. The average 40.6 heavy rains annually are one of the main reasons of floods formation in Korea. So it is clear that one of the most serious problems for cloud seeding experiments is the prevention of heavy precipitation. Experiments on heavy precipitation prevention have not yet been carried out, though there are some methods which make it possible to destroy clouds to prevent the formation of hail (Abshaev *et al.*, 1987; Abshaev, 1999) and methods to prevent precipitation (Birulev *et al.*,1996; Dovgaljuk *et al.*,1998; Grickiv *et al.*, 1968; Litvinov, 1967; Sinkevich, 1992; Stepanenko *et al.*, 1997). Experiments to prevent precipitation had shown rather good results, though cloud characteristics differ from those observed in Korea. Greater cloud heights are observed in Korea in comparison with Russia, and methods to prevent heavy precipitation have to be developed. Hail suppression methods have an efficiency which amounts to 60-85%. If we accept that in case of heavy rain this efficiency will be 25% (that is we can prevent 1 heavy rain in 4), the possible economic benefit will be equal to the prevention of 10 heavy rains annually. In this case the possible economic effect will amount to 70 billion won. It is hard to prognose heavy rains as they occur rather unexpectedly, leading to a reduction of the possible effects of cloud seeding. If cloud seeding will be carried out on only 50% of heavy rains processes then possible economic effects will be reduced to 35×10^9 Korean wons×(28 million US dollars).

Detailed analyze of spatial distribution of heavy rains carried out in METRI (METRI, 1997) had shown that heavy rains occur frequently on the South coast, near Jiri-mountain, in Kyonggi-province and on Jeju-island. So most experiments should be planned there.

To plan cloud seeding experiments, it is important to know the temporal distribution of heavy rains. Our investigations have shown that, in the last ten years, practically all heavy rains were registered in June-September. This data slightly differs from data on heavy rains which were observed between 1971-1990 (METRI, 1997). In accordance with their investigations, while heavy rains also were registered during October-November and March-May, most cases took place in June-September (greater than 85%). So it is clear that cloud seeding experiments have to be planned for June-September. In this case, nearly 15% of clouds which give heavy rains would not be seeded, and one could prognose a consequent increase in economy losses.

Results of the analyze show us that losses in the Korean economy due to lack of routine cloud seeding to prevent heavy rains and, hence floods, amounts to up to $\$24\times10^6$ annually.

Of course, this problem must be carefully studied. Moreover, better results usually are achieved when cloud seeding is carried out on weaker processes in comparison with heavy convective processes, and the economic effect may be significantly less. Still there is a need to study the problem more thoroughly, because prevention of only one flood will result in great economic and social benefit.

4. RECOMMENDATIONS ON CLOUD SEEDING ACTIVITIES IN KOREA

A lot of experiments have been carried out on precipitation augmentation in the history of cloud seeding. An analyse of the last experiments(1990~2000) have shown that there are real possibilities to change precipitation on 10~20%. Based on this data we have carried out some mutual meteorological and economic investigation of economic losses in Korea due to the lack of routine cloud seeding experiments to regulate water supplies. They show that total losses to the Korean economy due to lack of cloud seeding experiments now exceed 100×10^6 US dollars.

January and April-June is a period when it is worthwhile to carry out experiments on precipitation enhancement to increase water supplies in reservoirs and to increase precipitation for farmers. June-September is a period when experiments on heavy rain prevention have to be carried out. Precipitation enhancement is a routine work which can be fulfilled using world experience in the field. Prevention of heavy rain needs additional studies.

International experience shows that these works will significantly reduce losses to the Korean economy from severe atmospheric phenomena.

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