CLOUD SEEDING EXPERIMENTS ON WARM CLOUDS IN PAKISTAN

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Abstract. Cloud seeding experiments were conducted on warm clouds in Pakistan during the year 2000. This was the first full-fledged experimental activity taken up in Pakistan to augment precipitation through the cloud modification programme. The activity emerged as a consequence of the history's worst drought in provinces in the southern half of the country in 1999-2000. Government of Pakistan immediately felt the need of combating this most crucial catastrophe and thought of taking up the project of artificial rainfall in the country particularly in the drought vulnerable areas. This paper will attempt to give a summary of the methodology adopted in the cloud modification experiments and the synoptic conditions under which the experiments were performed. What really was achieved out of these experiments, what were the limitations and problems and what should be the future strategies to improve the quality of such a work are the discussions contained in this study.

1. INTRODUCTION

Cloud seeding technology has developed over the last 45 years as a means for augmenting precipitation primarily in regions where additional precipitation is required as economic aspect (Elliot et al 1995). The adaptation of this technology gets justified when seen in the context that Pakistan, in each season, has at least some regions vulnerable to drought (Sheikh 2001). The technology is not without uncertainties but it still offers economic benefits (Reinking et all 1995). Although difficult to measure exactly, the perceived benefits far outweigh the cost of implementing programmes (Dennis 1980). Besides the above, cloud seeding is a highly potable and flexible technology. It does not require construction of large, permanent and costly structures such as dams or water conveyance systems. Comprehensive laboratory and field studies have indicated no significant environment impacts (Griffith et al 1999).

Hygroscopic seeding has revealed renewable interests in the past few years (Matheretal 1996, Cooper et al 1997). Matheretall (1997) & Bigg (1997) have studied the effects of seeding convective clouds in South Africa with hygroscopic flares and found strong indications of rainfall increases as much as 30 to 60 % increases from individual cloud complexes (Orville, et all, 1999).

Research on weather modification is going on in Australia, South Africa, Mexico, Canada, Israel and the United States. 38 weather modification activities were carried out in the United States in 1997. The technology was used in 1995 in the Northern Province of South Africa. The Government of South Africa approached the National Precipitation Research Program (NPRP) to employ cloud seeding as an emergency response to drought in the province (WMO Report No 35; 2002).

The history's worst drought in the country during 1999-2000 made the Government of Pakistan to go for the weather modification exercise to make a sound scientific judgment on the basis of short field experiments.

2. CLOUD SEEDING REQUIREMENTS

These required:

- In depth knowledge of the physical basis for cloud seeding.
- Tools for experimentation, their proper selection and use.

2.1. Physical Basis for Cloud Seeding

If cloud seeding is to trigger precipitation, certain atmospheric conditions must exist. Clouds must be present, for seeding cannot create clouds (Frederick et al 1998, Cloud Seeding page 129). Clouds are formed when atmospheric moisture condenses on small particles in the atmosphere called condensation nuclei. The number of cloud particles per cubic centimeter ranges from less than 100 to more that 1000 (Britannica Encyclopedia, vol. 3, 1996, "Cloud Seeding"). The cloud temperature is the important characteristic in the rain process. A warm cloud is a cloud above 0^oC and super cooled clouds are those below 0^oC. Rain in warm clouds (above 0^oC) is formed when large droplets collide and join together with smaller droplets. Opposite electrical charges may bind the cloud droplets together (Federick et al, 1998, page 421). The sizes, types and concentrations of nuclei play an important role in determining the efficiency with which a cloud system forms and ultimately produces rain or snow.

Man can assist nature by furnishing appropriate types and number of nuclei through seeding the clouds at the proper time and place (Atmospheric Incorporated, USA; www.atmos_inc.com/wedmod.html).

Seeding with very large condensation nuclei (hygroscopic particles such as salt crystals) can be done to accelerate the warm rain process (ibid). The consideration of cloud seedling to produce large and/or more vigorous clouds is, by its nature primarily limited to convective (cumulus) type clouds, although cloud modeling results in the 1980s have indicated the possibility of stimulating the formation of embedded connective clouds in stratiform clouds (Grant et al).

The cloud seeding experiments in Pakistan were conducted during the period July to Sep, 2000 when there were monsoonal rains in the country. The experiments, however, were conducted in the regions which mostly lay outside the monsoonal belt. The season was ideal in the sense that convective warm cloud formation was common in the season. Mostly Sc and Cu but Ac and As isolated cloud patches also were picked up for seedling. On the day of seedling, it was specifically kept in view that the target area was outside the influence of any natural rainfall generating weather system

2.2. Tools for Weather Modification

2.2.1. Radar Requirements

Radar data should be collected and analyzed in the cloud seedling experiments (Clouds Seedling Experiments in South Africa, WMO Report No35, 2000). Different weather radars are available in a variety of wavelength (K, X, C, S) each of which serves a slightly different function in cloud seeding projects (Don A. Griffith et al). By far the most commonly used radars are C-band (5 cm) radars. They provide sufficient sensitivity to both rain and snow. S-Band (10 cm) Doppler radars are superior but lack sensitivity in measuring snow (Griffith et al). A network of five 3 cm, six 5 cm and one 10 cm Doppler radar covering almost 80% of the country made it possible to study seeding responses in a way k not previously possible.

2.2.2 Satellite Remote Sensing – an Integral tool for Cloud Seeding Experiments

Satellite remote sensing can provide temporally and spatially uniform observational data useful in evaluating the opportunities and effects of hygroscopic seeding (WMO Report No. 35, WMO/TD No. 1006, 2000). The geostationary satellites (even polar orbiting satellites) allow routine observations over a wide area that can be targeted by aircraft for seeding and measurement activity (WMO Report 35, 2000). APT & HRPT system facilities are available at Karachi, Quetta, Lahore and Islamabad, and the satellite imageries / observations effectively supported the management of operational programmes of cloud seeding in Pakistan.

2.2.3 Aircrafts

The type of cloud seeding agent and the delivery system dictates the type of aircraft used (Don A. Griffthetal, 1995). However the commonly available aircrafts can be modified to carry an assortment of cloud seeding devices (ibid). Beaver and Fletcher aircraft of Plant Protection Department with liquid dispensers and Mashhaq aircraft of Army Aviation, mounted with solid dispenser joined the mission. Mashhaq aircraft was modified to the extent that a solid dispensing machine, indigenously manufactured in accordance with the requirements of Pakistan Meteorological Department (PMD) was fitted to the aircraft. The aircrafts were very old and had the limitations to go beyond a certain height. Some cases where conditions were conducive for cloud seeding could not consequently be tampered.

3. EXPERIMENTS CONDUCTED

Forty eight experiments in all were conducted, 14 in Sindh, 18 in Balochistan, 3 in NWFP and 13 in Punjab out of which 10 were undertaken in Southern Punjab. More than eighty percent experiments were conducted south of 30°N where intensity of aridity was much higher as compared to the aridity in northern half of the country. Experiments were made during the period 20th June to 15th September, 2000 which practically is the monsoon period in Pakistan where convective type of clouds makes their sufficient availability.

4. EVALUATION OF THE SEEDING RESULTS

Convective cloud systems have a strong special variability and the rain gauge measurements are not very accurate (WMO Report No. 35, WMO/TD No. 1006, 2000). In addition, it is almost never possible to gather the correct rainfall information from individual storms with surface data.

The best tool is radar. Though temporary rain gauges were installed in some of the experiments but the evaluation of the success or otherwise of the experiment were made using the radar pictures collected at nearby radar stations or through the general public. Mostly experiments were made in areas covered by weather radar or by a Met. Station, where the recorded rainfall data helped evaluating the experiments

5. OVERVIEW OF SOME SUCCESSFUL EXPERIMENTS

5.1. Experiments Conducted In Sindh

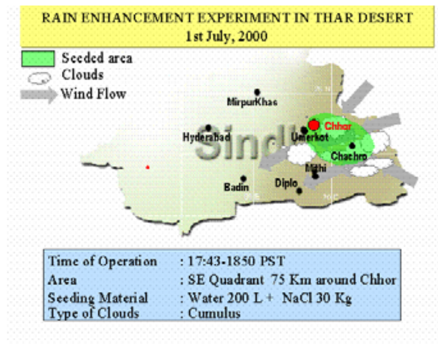
Thar desert is located in the Sindh Province. Eight experiments in this drought affected area were conducted from 1st July to 15th July, 2000; out of which six were successful. The experiments yielded that much rainfall, which at least eased out the drought conditions in the area. Chhor (25°31' N; 69°47'E; Height 19 feet) was the field station established for the purposes of carrying out cloud seeding activity in the desert area. Chhor is more a monsoon dominated station as compared to winter rains. The month of July on the average receives 79.0 mm of rainfall and the average number of rainy days is 3.8 days (Climatic Normals of Pakistan, 1961-90, PMD; 1993).

The experiments conducted on 1st July, 2000; 3rd July, 2000; 13th and 14th July, 2000 make part of this paper:

5.1.1 1st July, 2000

The synoptic weather situation on 1st July was that a weak low lay over the Indian states of Orissa and eastern Madhya Pradesh and a westerly wave had been affecting northern parts of Kashmir. The station going to be experimented upon was not under the influence of any of the above systems and no chances of any natural rainfall existed at the station.

Six octa low clouds of the type cumulus (4) & Stratocumulus (2) were available at 3000 feet over the experimental site which was located in the southern quadrant of Chhor (as shown in Fig.1). Real time humidity at the time of operation was 34%. Westerly wind of 4 knots had been penetrating the target area. The operation for cloud seeding using the aqueous solution of 30 kg of NaCl and 200 litters of water was completed during the period from 1743 to 1830 hours PST (Pakistan Standard Time). The seeding generated sufficient rainfall, light at seven stations and 30 mm each at two stations.



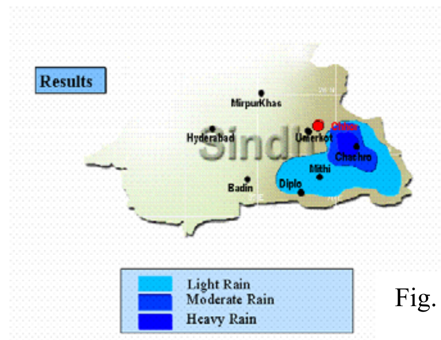


Fig. 1

5.1.2 3rd July, 2000

The synoptic situation on the day was that the monsoon low of 2nd July, 2000 over southwestern Uttar Pradesh had almost dissipated. The westerly wave, however, had still been affecting Kashmir and adjoining areas. Chhor had very little chances of getting any natural rainfall during that day. Over all six octa clouds, 5 Sc and 1 Cu were available at 3 to 5 thousand feet height. Relative humidity was 46% at the time of operation.

Beaver aircraft equipped with liquid dispenser used 60 kg of NaCl with 400 liters of water for seeding and completed its two operations during the period 1631 to 1730 and 1740 to 1840 PST. The area experimented upon encircled Chhor, Chachro & Mithi. Rain was reported from the following places:

Place	Rainfall / Type of Rainfall
Diplo	9 mm
Mithi	4 mm
Chachro	Light
Gudro	Light
Umar Kot	Light
Badin	Light

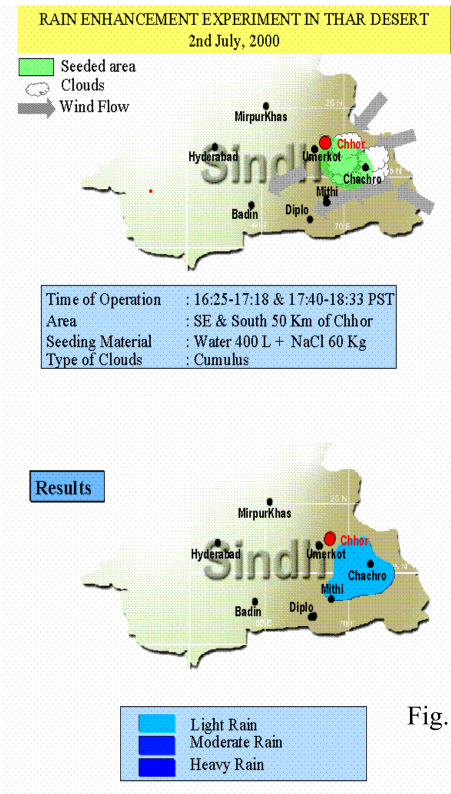


Fig. 2

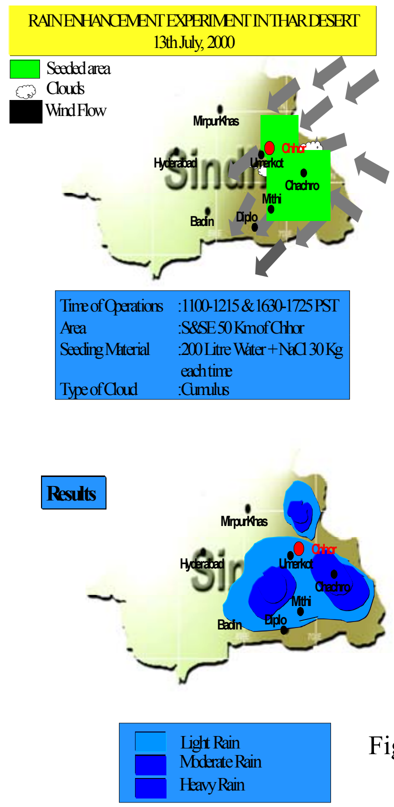


Fig. 3

The rain fell during 2330 to 2400 PST about 4 hours after the seeding. The nocturnal cooling along with abundantly available nucleating agents from seeding seems to have played a major role in causing this precipitation (Fig. 2).

5.1.3 13th July, 2000

The synoptic situation on the day was that a monsoon low which after having developed in Bay of Bengal, lay over northeastern Madhya Pradesh in India and was likely to move in the west northwesterly direction. It had been inducing monsoon currents in Kashmir, Punjab and Sindh. However there were no bright chances of rainfall at the station during the day time.

5 octa clouds, 3 Sc and 2 As clouds were available during the time 1100 to 1215 PST when the first operation was made and 3 Sc and 2 Ac were there during the second operation within 1630 to 1725 PST.

Beaver aircraft carrying 60 kg of NaCl and 400 liters of water was used for the seeding purposes. Area picked up was located southeast of Chhor within a triangle enclosed by Chachiro, Bavri and Jhakia as its vertices (Fig. 3).

Rainfall started three hours after the last seeding and continued till midnight. The nocturnal desert cooling and abundantly available nucleating agents from cloud seeding seemingly played their role. Rainfall ranging from 4 to 45 mm fell over six different stations. The dominant component of the rainfall seems to have occurred due to the incursion from the monsoon low over India yet the component from the seeding also seemed to have contributed as the rainfall over the seeded area was noticeably higher than the surrounding.

The most fascinating aspect associated to this experiment was that the reaction of the people living in the experimental areas was interesting and wonderful. Both Muslim and Hindu communities live in these areas. Muslims offered prayers whereas the Hindus put in their temples the idols of the Meteorological officer and worshiped him for being their "rain god".

5.1.4 14th July, 2000

The synoptic situation was that the monsoonal low over northeastern Madhya Pradesh in India on 13th July, 2000, after having moved in a west northwesterly direction, lay on the day over central Rajisthan. It had slightly weakened but still it had been a source of moisture incursion in the Sindh Province. However there were no immediate chances of rainfall during the time of experiment. 4 octa Sc, As clouds were available. Relative humidity was 55%.

Beaver aircraft carrying 60 kg of NaCl with 400 liters of water was used for seeding. Rain recorded was as under:

Place	**Rainfall**
Diplo	62 mm
Nagarparkar	22 mm
Mithi	20 mm
Badin	23 mm

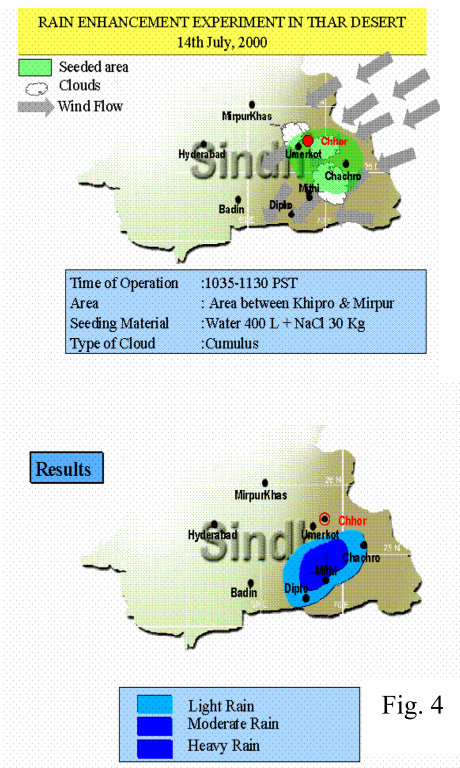


Fig. 4

The dominant contribution seemed to be due to the monsoon low over India, yet the pattern of rainfall over the seeded area supported the contribution of seeding activity too (Fig. 4).

5.2 Experiments at Zhob (31°21'N; 69°28'H; Height 4609 feet), Balochistan

Six experiments were conducted during the period 18th Aug, 2002 to 7th Sep, 2002 out of which four met the success. The station is dominated more by summer rains as compared to the winter rains (Climatic Normal of Pakistan, 1961-90; PMD, 1993). The mean normal rainfall and number of rainy days at the station during August are respectively 58.9 mm and 3.2 days (ibid).

Experiments conducted on 25th, 26th Aug, and 7th Sep, 2000 are made part of this study:

5.2.1 25th August, 2000 (Zhob)

The synoptic situation on the day was that a deep monsoon low lay over northwest Andhara Paradesh and adjoining Maharashtra state in India but the experimental station was not under the influence of this deep monsoon low. No westerly wave had been affecting Pakistan. The status around Zhob was either clear or partly cloudy. Over Zhob, in all, six octa clouds 5Sc and 1Ac at heights 5000 & 10000 feet were available. Relative humidity was 30%. Mashhaq aircraft carrying 22 kg of seeding material (Salt + Aerosil) was used. The operation was completed during the period 1712 to 1816 PST. Both low and medium clouds were seeded from a height of 11000 feet. The whole of the seeding material was consumed over an area of 20 square kilometers. The experiment yielded encouraging results and moderate to heavy rainfall fell over seven stations in the west, northwest & southwest directions (Fig. 5).

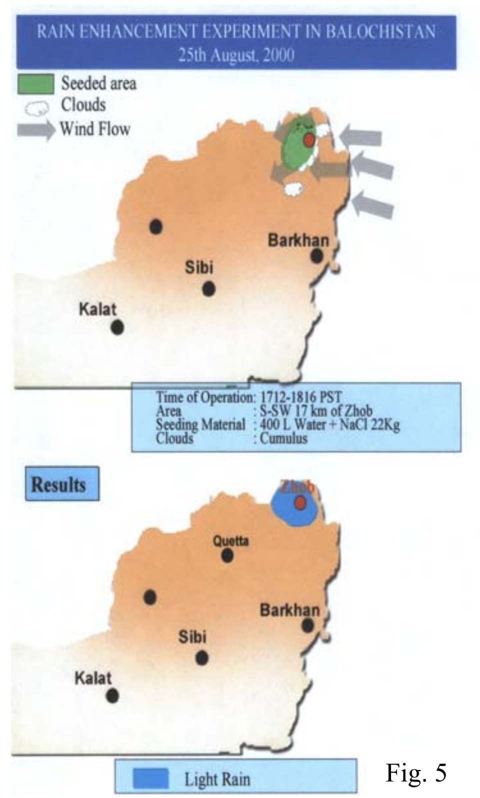


Fig. 5

5.2.2 26th August, 2000 (Zhob)

The synoptic situation on 26th August was that the monsoon low over India today existed over Gujarat and adjoining areas but it practically had no significant effect on the area of the experiment. 7 octa clouds, 5 SC & 2 AC were respectively available at heights 5000 & 12000 feet. Relative humidity was 25% and the conditions were conductive for the operation.

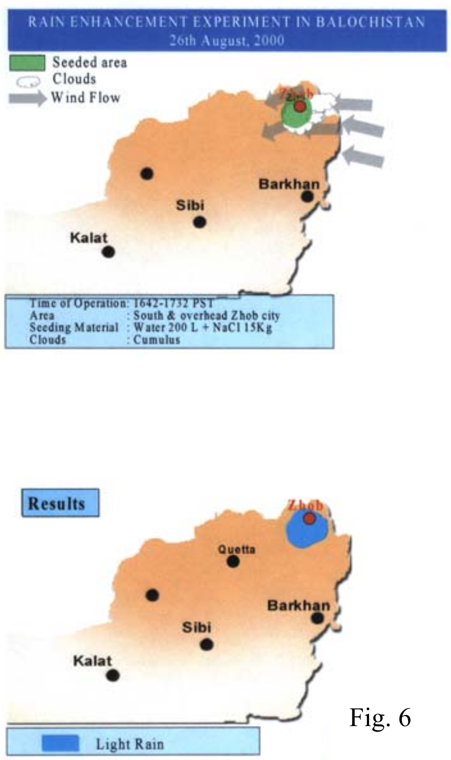


Fig. 6

Mashhaq aircraft carrying 15 kg of seeding material (NaCl + Aerosil) completed its operation during 1642 to 1732 PST. Seeding was done from a height of 11000 feet. This covered both the low & medium clouds over 4 square kilometer area south and over the station. After seeding, the clouds showed a rapid movement to the NNE direction.

Light to moderate rainfall fell in the North & Northeastern sides over the stations as given below (Fig. 6):-

Place	Location	
Moti Zai	16 km	N
Khajkzai	18 km	N
Narazai	21 km	N
Sohai	05 km	NE
Hassan Zai	06 km	NE
Manda Zai	06 km	NE

5.2.3 7th September, 2000 (Zhob)

According to the prevailing synoptic situation, a monsoon low was located stationary over Uttar Pradesh in India and a westerly wave persisted over Kashmir. A heat low also existed laying over northeastern Balochistan. The meteorological conditions, in aggregate, were favourable for convective cloud development, but there were still bleak chances of any natural rain to occur in a significant amount.

Two seeding operations were carried out during 1520 to 1614 and 1648 to 1741 PST, with Mashhaq aircraft mounted with solid dispenser. The seeding material contained 22 kg of NaCl mixed with an equivalent volume of aerosil. The clouds were seeded in an area of about 30 km radius in the west and northwest direction of Zhob. At the time of operation, half of the sky was covered with cumulus, stratocumulus and altocumulus clouds. The relative humidity was recorded as 44% while wind was blowing from east with an average speed of 10 knots.

About half an hour after seeding, rain started at Zhob and Meteorological observatory recorded 1.0mm rainfall. Moderate to heavy rainfall was reported from west and northwest up to 50 km of Zhob. It is note worthy here that the rain received as a result of cloud seeding was the first after a long dry spell of six months (Fig. 7).

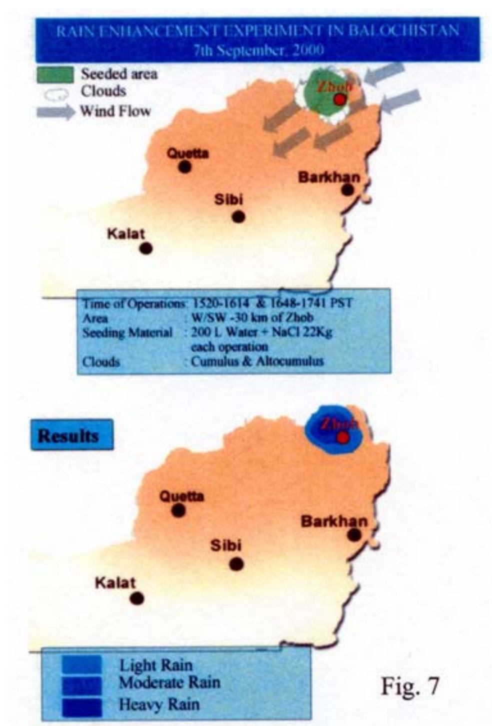


Fig. 7

5.2 Experiments on 25th And 27th August, 2000 at Quetta, Balochistan

Quetta (30°15'N, 66°33'E; Height 5253 feet) is the capital city of Balochistan. The city is dominated by winter rains (Dec to Mar) and lies mostly outside the influence of monsoon rains (June to September). The rainfall pattern (Climatic Normal of Pakistan, 1961-1990, PMD, 1993) reflects the position as given in Table:1.

Table: 1

Jan	Feb	Mar	Apr	May	Jun
56.7	49.0	55.0	28.3	6.0	1.1
July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
12.7	12.1	0.3	3.9	5.3	30.5

The normal numbers of rainy days during the month are 0.9 days (Climatic Normal, PMD, 1993). This brief preamble would help assess the experiments conducted in the Quetta Valley.

5.2.1 25th August, 2000

The synoptic situation on the day of the experiment was that Quetta was not under the influence of any significant weather system. One to two Octa Cu clouds were available over the city.

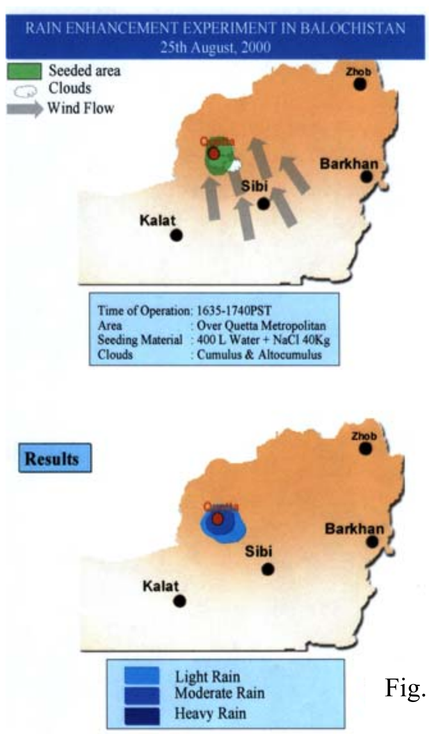


Fig. 8

Beaver aircraft carrying 40 kg of NaCl with 400 liters of water was used for seeding. The operation was completed within 1635 to 1740 PST. Light to moderate rainfall was reported to have fallen during the period 1815 to 1845 PST. It was something very interesting and amazing to note that this successful experiment terminated the long dry spell gripping the city for the last six months. Press media and masses expressed their feelings of happiness and lauded the efforts of Government and the cloud seeding team. The experiment is shown in Fig. 8.

5.2.2 27th August, 2000

The synoptic situation on 27th Aug, 2000 was that a monsoon low which had developed in the Bay of Bengal on 21st Aug, 2000 today lay over Northeastern Arabian Sea and adjoining coastal areas of Gujarat (India). Quetta was far out of the influence of this system. One to two octa Cu clouds were available over Mastung, a city some 40 km south of Quetta. Beaver aircraft carrying 30 kg of NaCl with 300 liters of water was used for seeding. The operation was completed during the period 1745 to 1838 which yielded light rainfall (Fig. 9).

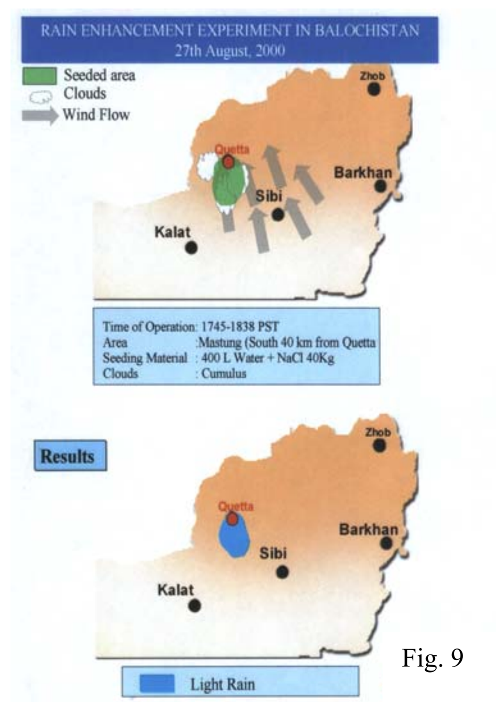


Fig. 9

6. CONCLUSION

Seeding the warm clouds was the first experimental exercise in Pakistan which apparently brought a reasonably high success. This, however, lacked many technical aspects to be followed. Even the technical evaluation of the experiments had no scientific and statistical assessment, yet the results reflected a promising potential in the technology to be applied in the country.

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