OBSERVATION OF THE SOVIET HAIL PROJECTS

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I INTRODUCTION

For more than 20 years the USSR has been deeply involved in both research and operational aspects of weather modification. Hail suppression has occupied a large portion of these activities.

In the mid-1950's, the USSR began a number of systematic studies of thunderstorms and hail processes. The administrative and research guidance for these initial studies was delegated to the USSR Hydrometeorological Service (Moscow) and the Institute of Geophysics of the Academy of Sciences of the Georgian Soviet Socialist Republic (Tbilisi). Scientific institutes under these two heads were such groups as the Transcaucasian Hydrometeorological Institute (ZAKNIGMI - Tbilisi), the Central Asian Regional Hydrometeorological Institute (SARNIGMI - Tashkent), the High Mountain Geophysical Institute (VGI - Nalchik), and the Central Aerological Observatory (TSAO - Moscow), and the Institute of Geophysics of the Georgian Academy of Sciences (IGAN - Tbilisi).

In addition to the normal reasons for basic research, these early activities were developed primarily for hail damage protection of agricultural crops. The solutions to a number of basic problems were necessary. Some of these could be identified as (1) identify the hail mechanism, (2) discover at least one area of modification which could produce a decrease in hail intensity, and (3) develop a technology suitable for modifying the natural mechanisms of hail formation.

By 1967, a number of strong basic studies had been concluded in Armenian SSR, Georgian SSR and Moldavian SSR. Basic information included updraft profiles, motion of hail zones, hail paths, spectrum of hail, hailstone structure, accumulation zones and a number of the standard cloud physics parameters.

Full operational hail suppression activities have been conducted in the USSR since 1967.

II MECHANISMS OF HAIL FORMATION

In the early SSR investigations, attention was focused on the motion of hail zones, spectrum of hail and hail paths on the ground. Later, in the early 1960's, some elementary cloud models began to emerge from northern Caucasus studies which noted the updraft speed in clouds increased with

(Note: The information in this summary report is a result of a 9000 mile invitational trip around the weather modification operational sites provided to the author by the USSR in August 1974. The report does not completely cover all of the observations or information made available during this on-site inspection tour.)

altitude, finally attaining a maximum speed in the upper portion of the cloud then decreasing with further altitude. This lead to the speculation on accumulation of large drops in the upper part of the cloud and the formation of a cloud volume with high water content ("accumulation zone"). It was believed that hailstone embryos formed as a result of the freezing of these large drops in the accumulation zone. Later in the study period, scientists within the Georgian SSR proposed the development of multiple accumulation zones forming simultaneously within a cloud.

Several USSR researchers (Lebedev, Robitashvilli, Gutman) have addressed the subject of mathematical cloud models. Although very elementary, these initial models did suggest areal changes in updraft speed and noted the importance of water content and vertical temperature profiles. A complete detailed model of a hail producing system is not available from the USSR work at this time. However, it is important to note that these original laboratory and field studies produced information believed adequate for the initiation of applications programs in the field, even though serious limitations in understanding were recognized.

All of this work eventually lead to the development of a hail prediction scheme. Rawinsonde data were used extensively in this hail prediction method. Important points within this scheme included maximum updraft velocity, altitude of the accumulation zone, temperature profiles, advection of air masses and the potential for melting of hail in the warm part of the atmosphere. The hail prediction method was tested during actual hail suppression projects and verification is claimed to be better than 90%. The system has broad practical use on present hail suppression projects. Here again, it is important to note that the prediction model does not claim any rigorous description of isolated details within the hail formation zones and is quite acceptable for applications by users!

Once the working model of a cloud was established, and verified to a reasonable degree in the field, then it became possible to develop a technology for the artificial modification of the hailstorm mechanisms.

III TECHNOLOGY OF MODIFICATION

Following the development of a concept on hail mechanisms, and the field tests of forecast schemes, an artificial modification method was developed. It was believed in the USSR that an effective means for preventing hailstone growth would be a continuous supply of artificial ice nuclei to that volume of cloud where hailstones form. The USSR computations indicated that ice nuclei concentrations must be maintained at around 10^6 m^{-3}. As in operational hail suppression programs here in the U.S., it was noted that the quantities of ice nuclei necessary to maintain this concentration over the total protected area during any high potential hail period would be unreasonably large. Hence, the competing hailstone embryo concept was developed in the USSR. Further experiments in the 1960 period indicated that it was possible to decrease the diameter of hailstones by a factor of 4 with a freezing nuclei application of about 100 grams km^{-3} within that volume of cloud where hailstones develop. An interesting and provoking thought arises. What if the cloud system is extremely large and maintains its growth characteristics through extreme updrafts continuously replenishing liquid water? Conceivably the indicated concentration of ice nuclei would be insufficient to limit hailstone growth below a desirable size. In the USSR it is believed that such conditions seldom, if ever, exist and there is a limit to the sizes and lifetimes of convective clouds. Additionally, falling hailstones enhance downdrafts which lead to the decay of the hail producing cloud. Therefore, in the USSR it is believed possible to always maintain a concentration of ice crystals high enough to limit the excessive growth of hailstone embryos.

There still remains some minor controversy as to the dispersal rates of ice forming nuclei. In some areas it is believed that nuclei concentrations of 10^5 m^{-3} are required. Assume an efficiency of about 10^{12} nuclei per gram of material, the critical concentration leads to dispersing rates ranging from 0.1 to 2.0 kg km^{-3}. Dispersal of the material, diffusion problems, measurement of cloud volumes, concentration of existing hailstone embryos, cloud droplet concentration, aggregation, and ice forming activity curves are all important considerations which can cause problems at the operational level. However, in the USSR it is felt that most requirements are satisfied, although not completely understood, through confirmation by field experiment results and calculations. Selecting the proper material and developing dispersal techniques were primary concerns in establishing an operational technology. Silver iodide and lead iodide were the primary materials chosen for field use. Once having chosen the type of artificial ice nuclei, it then became a matter of determining <u>where</u> to place the material in the cloud. Radar has been the primary tool in the USSR for determination of hail zone locations. A number of physical parameters are used in many of the operational programs but two of these weigh heavily in describing the hail bearing properties of any particular cloud. These two are the ratio of the reflectivity between 10.0 and 3.2 cm wave length radars and the temperature at the top of the accumulation zone.

In the early stages, field experiments conducted in the USSR, silver iodide and lead iodide were delivered to the clouds from the ground by means of pilot balloons. The method was considered ineffective. During the late 1950's, seeding agents were delivered to clouds by aircraft. This method was also considered dangerous and difficult for large areas.

In the end, artillery shells and rockets were developed as the best method for delivering the ice nuclei. Once these delivery systems were developed for safe and practical use in the field, full scale operational programs began in earnest.

IV OPERATIONS

Beginning in 1971, hail suppression field experiments were conducted in the Georgian and northern Caucasan regions of the USSR. Carrier systems for the freezing nuclei were especially developed rockets and artillery shells. Foremost among these initial experiments were those conducted by the Ministry of Agriculture in the Georgian area. By 1964, the USSR Hydrometeorological Service began a more formal organization of all hail suppression activities and in the following year, total area covered by these programs was about 700,000 hectares.

During this development period, and still continuing today, are the various research activities and experimental work focused on improvements in radar methods, nuclei delivery systems, and various hail predictor systems. By 1971, the protected area had increased to 3.5 million hectares, within which approximately 30 hail suppression units were active.

Most hail suppression units are organized in response to requests from agricultural areas within the USSR. Maximum priority is provided to those areas where hail damage is most persistent from year to year.

Areas of about 100,000 hectares are considered maximum size for a single hail suppression unit. As in the United States, there is difficulty in delineating all cloud characteristics within, and adjacent to, protected areas which are too large. Buffer zones are established around the protected areas and, when possible, clouds are treated inside this zone prior to the time they enter the actual protected area.

In the USSR, a hail suppression "unit" consists of a radar group, a communications group, a modification group, a delivery system group, a monitor group, and a technical and materials support group. As many as four or five units can work together, with one of the units acting as a lead group which directs and coordinates the operations of the overall group. In this case, the supervisory unit has a meteorological forecast group which provides data for all. It is common to find more than 100 scientific, technical and operational persons associated with an individual operational unit.

Each morning during the operational period, there is a personnel meeting where operational status is discussed. From this time onward, all personnel move through a very normal standby-alert-operation flow system as clouds appear and approach hail intensity. As hail clouds form inside the protected area or approach from adjacent areas, the hail zone coordinates are determined and appropriate information passed to the artillery shell or rocket installations, which then activate the delivery systems according to instructions.

As noted, the nuclei delivery systems include special artillery shells (Elbrus-2 and Elbrus-3) and special rockets (Oblako, Alazani, and P. G. I.). The artillery shells are constructed of a special alloy which disintegrates to very small particles on detonation. Ice nuclei material is embedded in the explosive charge. Two of the special rockets have the same general features in that nuclei material is embedded in the explosive charge which detonates at some point along the trajectory. The resultant fragments are small and present no danger when falling back to earth. The Oblako rocket is a much larger unit and, after the nuclei material is dispensed along some portion of its flight path, a parachute lowers the casing to ground level.

Most of the field units are well trained and fine tuned. Personnel follow the operational rules very carefully, particularly in areas where aviation may be a hazard. Passenger aircraft are always notified of potential operations and they have the right to cancel any possible rocket or artillery shell launches even when hail is imminent.

The success of each hail suppression unit depends largely on the competence and responsibility exhibited by personnel in the field. As with any field operational system, breakdowns do occur but they appear to be rare. The operational areas are large, coordination is difficult, but the activities are certainly conducted by extremely dedicated people.

Some of the basic numbers relevant to the total weather modification involvement within the USSR are shown in the following Table 1.

TABLE 1

AVERAGE ANNUAL WEATHER MODIFICATION INVOLVEMENT WITHIN THE USSR

Number of weather modification expeditions:	8
Total area under protection (millions of hectares):	6
Total research and operational people:	2,500
Numbers of artillery shells expended (100 grams AgI):	35,000
Number of PGI-M rockets expended (1 kg AgI):	4,000
Number of Oblaka rockets expended (2.5 Kg PbI):	3,000
Average annual amount of nucleant dispensed:	15,000 Kg

The areas over which the author travelled to view the operational sites is shown in Figure 1.

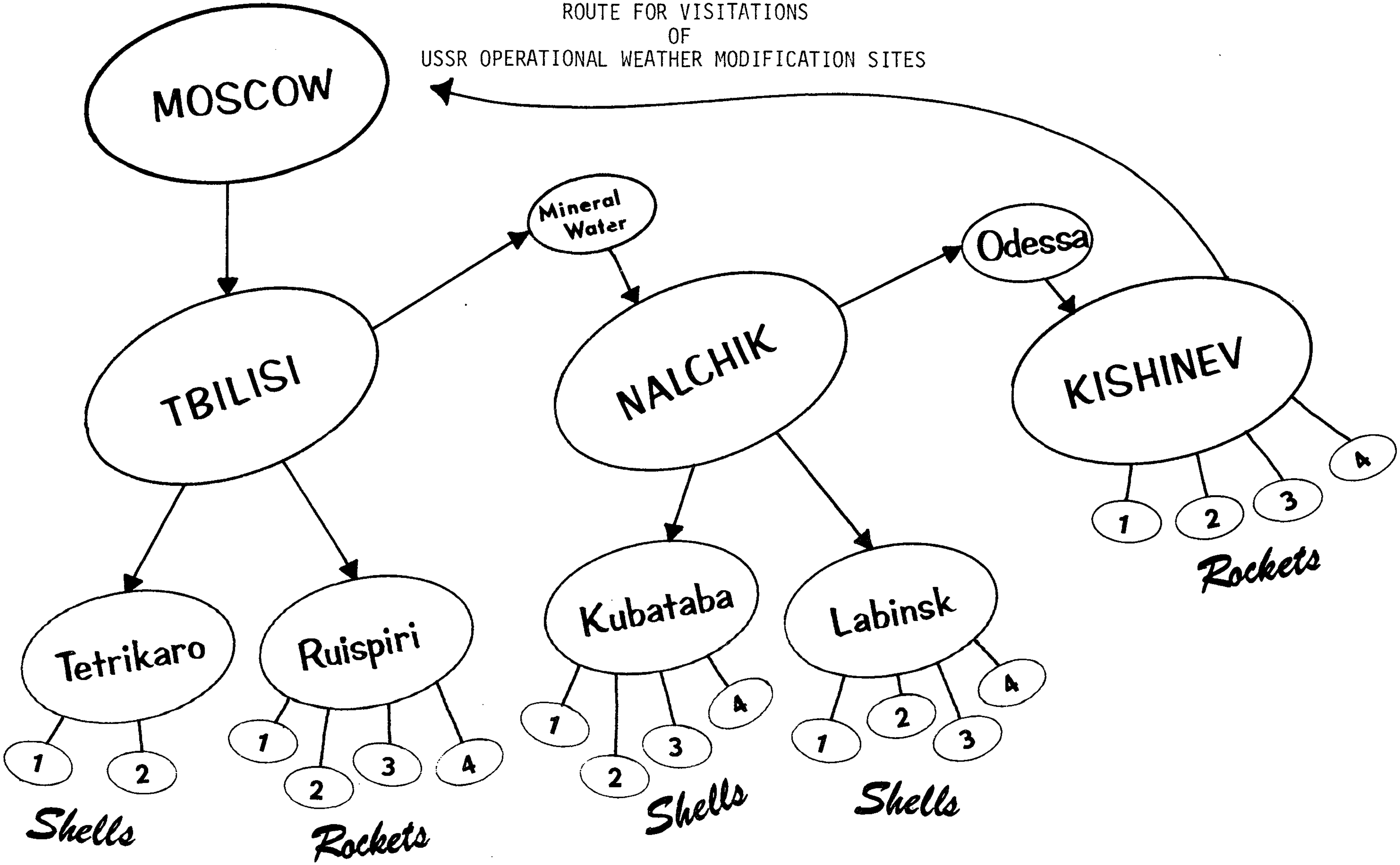
V EVALUATIONS

Evaluations of weather modification projects throughout the world have provided the most troublesome spot in the entire arena. The natural variability of weather phenomena does not easily lend itself to a precise discription of modification results. Although their results appear spectacular, establishing a precise scientific credibility at the international level has been just as difficult in the USSR as it has anywhere in the world.

However, establishing scientific credibility is quite different from establishing an economic benefit at some reasonable level acceptable to both those persons at the operational level and those persons who are the alleged beneficiaries. It is important to completely understand the difference between a scientific evaluation and an apparent positive economic

FIGURE 1

ROUTE FOR VISITATIONS
OF
USSR OPERATIONAL WEATHER MODIFICATION SITES



result. In the first instance, a scientific evaluation is usually associated with an experiment which has strong built-in statistical features. This approach stands the best chance of indicating a result, either positive or negative, at a reasonably high level of significance. In the second instance, the program may be a fine tuned operational effort without benefit of a tight statistical design. In this case, proper treatment of the basic data can indicate a result, either positive or negative, but at some level of significance below the one indicated in the scientific experiment.

The scientists, technicians, field engineers and operations personnel in the USSR completely understand these two concepts. There is a strong desire by most all of those persons directly involved in the weather modification effort to move ahead with operational programs which may well produce an economic benefit, still recognizing that there may be difficulty in delineating, and having accepted, a precise result. Additionally, there is a strong belief that the "science" will come along quite rapidly as the operational aspects are developed, applied and improved in the years ahead. It is clearly a case of "let's do something now in the absence of complete understanding" as opposed to the thinking, "let's put a stronger foundation under this science before we do anything at all!" If one does not understand the fundamental difference between these two concepts, as well as the differences between the evaluations which are applied to each, further "heavy" discussions between the proponents of each are useless.

Almost all weather modification efforts in the USSR have been strongly focused on operational aspects. For this reason, almost all evaluations of programs have a strong economic approach. There is strong science in the laboratories but very few scientific experiments in the field. Recognizing the extent of hail damage over large areas in the USSR, it is not surprising that the initial focus was placed on applications programs of hail suppression and not scientific experiments. Positive results are strongly suggested, and I'm sure have been obtained, but one should not look for a high level of significance as defined by the statistician. This philosophy is different from the man who spent a lifetime developing an ultimate gooseberry plant. By the age of 85, he had grown a magnificent high production gooseberry plant of the highest quality, but in the interim he had produced damn few boxes of gooseberries!

Target/control area relationships, current data/historic data comparisons, crop yield comparisons, insurance statistics, hailstone size distributions, and radar data have all been used for assessing results in the USSR, just as they have in this country. In the USSR, direct data comparisons expressed as "coefficients of effect" receive primary attention while the applications of sophisticated statistical methodology is minimal. I see the approach of stronger statistical methods but economic evaluations still occupy the strongest position.

An example of results from an economic approach are presented in Table 2. These results come from an operational area near Tbilisi which has developed and utilized the ZakNIGMI method (AgI and NaCl - Lominadze).

TABLE 2.

RESULTS OF EXPERIMENTAL (1966-1968) AND PRACTICAL (1969-1973) PROTECTION OF AGRICULTURAL CROPS BY THE ZAKNIGMI METHOD

Year	Protected Area, Hectares	No. of working days	No. of modification operations	No. of shells used			Areas damaged by hail according to State Insurance and Farm Committee. Reports covering 100% damage (hectares).			
				NaCl	AgI	In all	Within protected territory			Within Control Area
								Out of them		
							In all	Due to technical reasons	Due to un-knowns	
1966	50,000	2	7	26	10	36	0	0	0	-
1967	80,000	23	80	422	210	632	178	178	0	2000
1968	110,000	29	73	950	475	1425	351	351	0	3700
1969	150,000	24	95	1400	700	2100	289	91	198	5020
1970	170,000	36	95	1372	628	2000	78	17	61	6211
1971	200,000	25	124	1605	789	2394	0	0	0	4177
1972	250,000	57	192	2984	1474	4458	91	91	0	7999
1973	250,000	32	108	1556	675	2231	105	105	0	3715

It would appear that the application of sophisticated statistical methods to the results in Table 2, or similar data from other areas, would add power to the apparent results. In any event, there is strong evidence that hail suppression efforts in the USSR have produced a reduction in hail damage and this reduction could range from a low of about 20% to as high as 90% in some of the more spectacular instances.

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