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MIDWAY ISLANDS CLOUD SEEDING PROGRAM, JULY 1969

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ABSTRACT. The U.S. Naval Station, Midway Islands, depends upon rainfall for its fresh water supply. During the first 6 months of 1969, a decrease in rainfall reduced fresh water reserves to critical levels, and a cloud seeding program was undertaken in July by the Naval Weapons Center to increase precipitation. Lack of clouds suitable for available silver iodide seeding techniques precluded success; however, valuable observations were made of the meteorological regime in that area, and a number of naval personnel (civilian and military) were trained in weather modification techniques.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA * DECEMBER 1970

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

W. J. Moran, RADM, USN ..... Commander

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FOREWORD

Following the Gromet II operation in the Philippines during which considerable rain was produced by artificial stimulation, the Naval Weapons Center was asked to send a team to the Midway Islands to see whether it might be possible to augment rainfall there. The team was sent in July 1969. Because of a lack of suitable clouds, no rain was produced during the operation, but flight crews were trained, and materials were left at Midway so that seeding could be done if proper conditions arose. This report describes the operation and discusses the water collection problems of the Islands.

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INTRODUCTION

By the end of June 1969, the U.S. Naval Station, Midway Islands, was suffering the consequences of a prolonged drought. Rainfall, upon which the station is dependent for its water supply, had averaged only 35% of normal over the preceding 6 months, and fresh water reserves were becoming critically low. Commander Fleet Air Hawaii took under consideration three approaches to alleviate the problem: (1) barging fresh water from Hawaii, (2) developing brackish water wells on the islands, and (3) applying weather modification techniques to stimulate rainfall. The Naval Weapons Center, with its extensive background in weather modification, was directed to undertake the third approach.

BACKGROUND

The Midway Islands are a coral atoll formed atop a volcanic seamount near the northwestern end of the Hawaiian archipelago, some 1,150 miles from Honolulu and 140 miles east of the international date line (Fig. 1). The islands were annexed by the United States in 1908, and the first permanent constructions were undertaken at that time, in connection with the laying of the first trans-Pacific telegraph cable. In 1940 a Naval Station was established, and today Midway is a vital element in the Navy's Pacific facilities.

The atoll consists of two inhabited islands, Sand and Eastern, totaling 3 square miles in area, and several smaller islets, enclosed within a reef approximately 5 miles in diameter. A general view of the islands as seen from the southwest is shown in Fig. 2, with Sand Island in the foreground. This island, 2 miles long by 1 mile wide, with a maximum elevation of a few tens of feet, houses all but approximately 50 of the 2,300 personnel–military and civilian–residing in the islands, and is shown in more detail in Fig. 3.

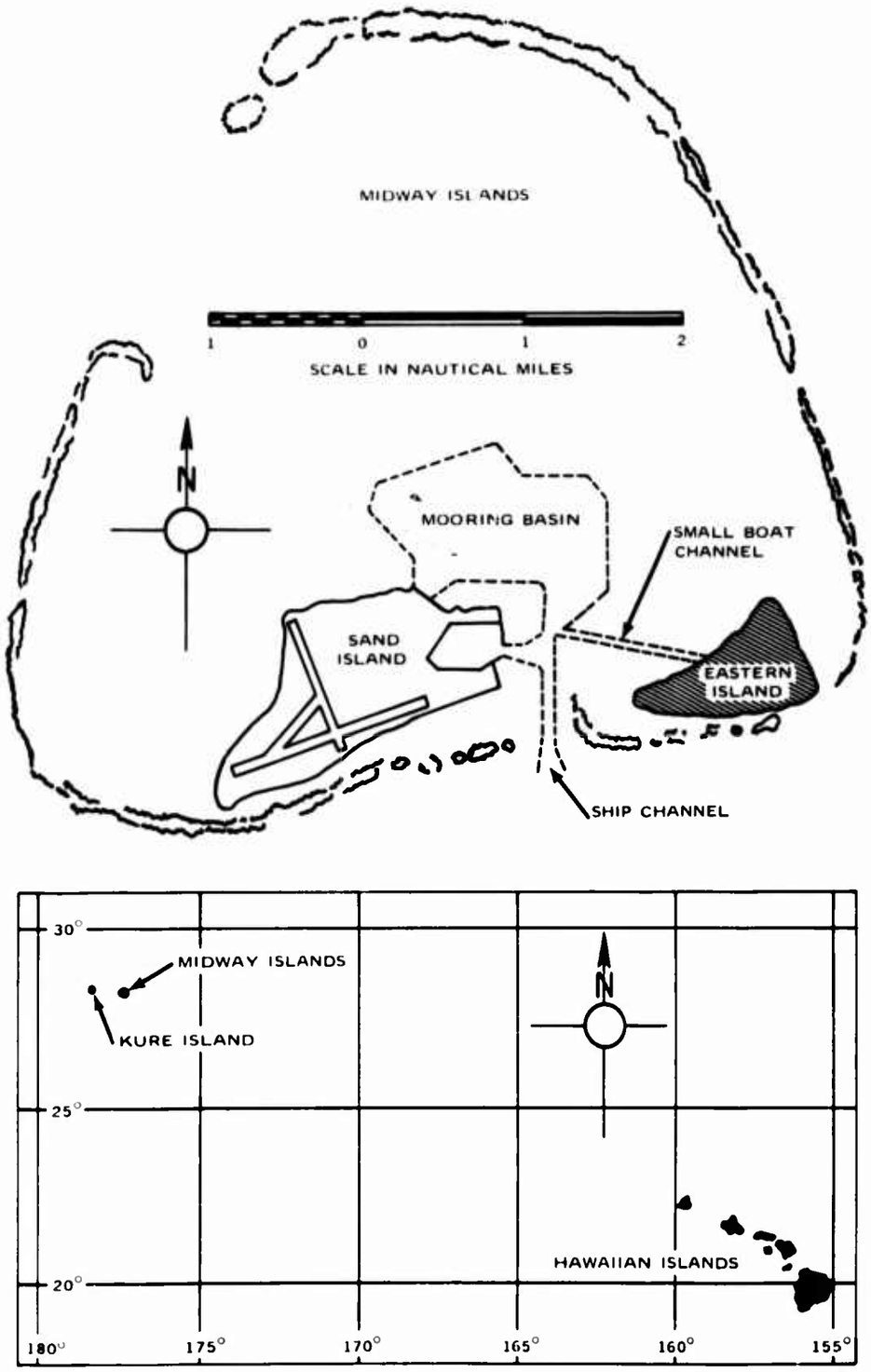


FIG. 1. Midway Islands.

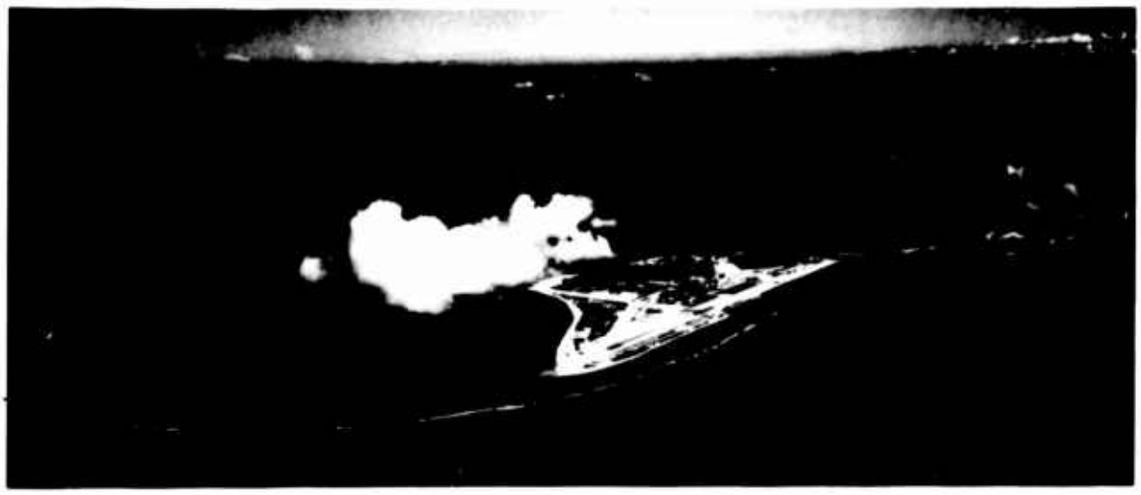


FIG. 2. Midway Islands, Oblique View From Southwest. Sand Island in center foreground, Eastern Island to right.

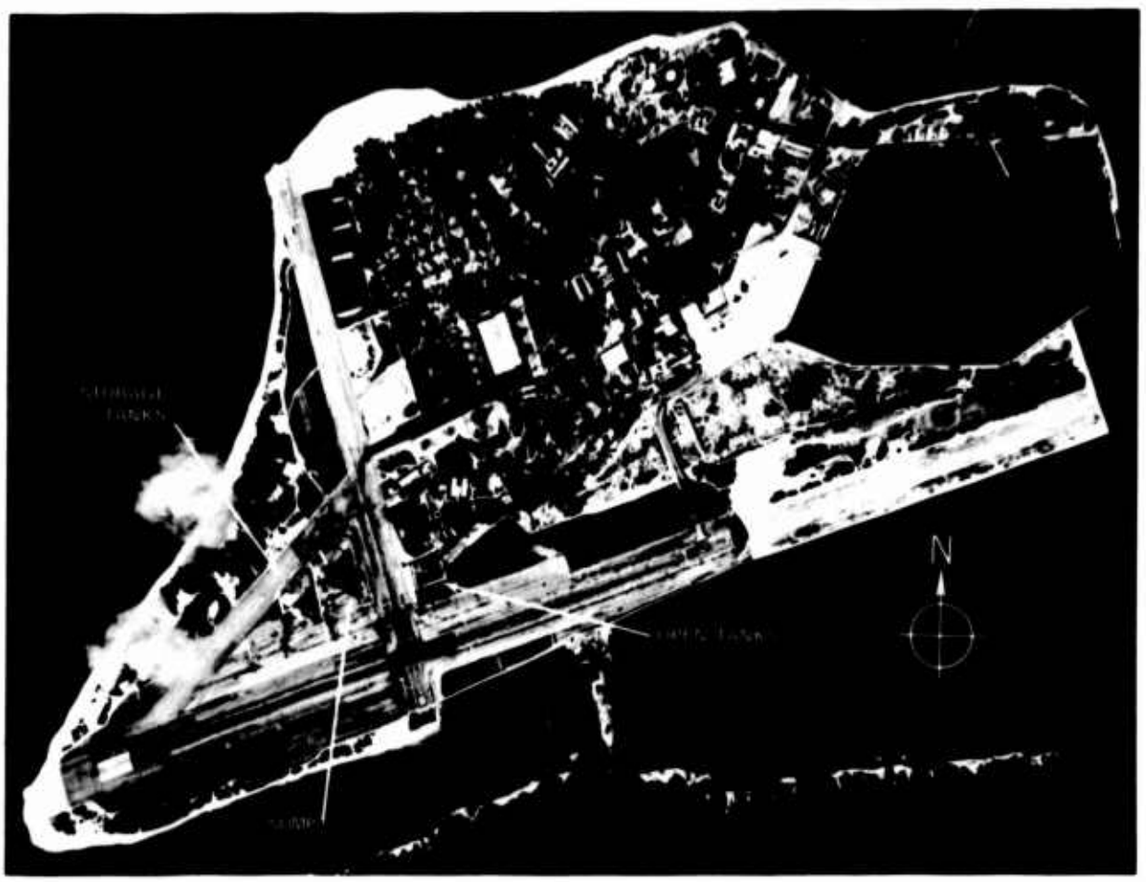


FIG. 3. Sand Island. Fresh and brackish water collection and storage areas lower left; Runway 06 overrun landfill right center.

WATER SUPPLY SYSTEMS, SAND ISLAND

Fresh Water

The runways, taxiways, and parking aprons are graded, surfaced, and embanked to provide a catchment area for rainwater. The fresh water thus collected is channeled into a sump visible as a small dark triangle between the two runways and the diagonal taxiway to the lower left in Fig. 3. From this sump the water may be pumped into the three 4-million-gallon storage tanks lying just to the west. The water from these tanks is then purified, chlorinated, and otherwise treated, batchwise, in one of the four 1.1-million-gallon square open tanks, lying to the east of the sump, just across Runway 33. The purified water is then stored in two half-million-gallon underground holding tanks in the community area and pumped as needed into a tower tank in the center of the island for delivery by gravity to the fresh water system. The ultimate capacity of this system is thus somewhat over 17 million gallons if all four treatment tanks are used for storage. This is generally impractical, however, and a figure of 13 to 15 million gallons is more representative.

The term fresh water is a relative one; because of the sea spray and other contaminants accumulating on the catchment surface, the fresh water has a normal content of dissolved chlorides (principally sodium chloride) of 85 to 110 parts per million (ppm). This fresh water is used for drinking and cooking (with one or two outlets per household), for more critical washing and sanitation applications, and for fire fighting, for which a minimum reserve of 540,000 gallons must be retained. It is reasonably estimated that one million gallons of water are collected for 1 inch of rainfall. A minimum rainfall of 0.20 to 0.30 inch is required to prime the collection system, but rainfall of much over 1 inch during a given day will exceed the pumping capacity of the system. Normal daily water consumption ranges upward from an average (under a mild, essentially voluntary, rationing regime) of 87,000 gallons per day to more than twice this figure in times of plentiful supply. The fresh water system is thus adequate, when fully charged, for over 100 days' supply.

Brackish Water

The highly permeable soil of the island collects the rainfall falling outside the paved catchment area. Because of the differing densities of fresh water and seawater, the former displaces the latter, providing a lens of fresh water beneath the surface of the island. In the absence of lateral percolation and mixing of the two types of water, the Ghyben-Herzberg principle[1] requires that for every foot of fresh-water-saturated soil above sea level, the seawater below will be displaced and replaced by some 39 feet of fresh water below sea level. This principle operates, with varying degrees of efficiency, in many Pacific islands; in the Midway Islands it provides a large, but as yet undetermined, ground water reserve of brackish water. This water has been tapped by a number of shallow wells in the south-central portion of the island. Again, the term brackish is a relative one, all but one of the wells currently in use yielding water with chloride contents ranging from 250 to 125 ppm; one well runs considerably higher, 400 ppm. This brackish water is normally stored in a half-million-gallon underground tank, treated, pumped as needed into a gravity supply tower, and then fed into a secondary supply system paralleling the fresh system, for utility, sanitary, and other noncritical purposes.

Since the water from the better wells is only slightly higher in chloride content than the fresh water from the catchment system, it is feasible to mix it, after proper treatment, into the latter. (A level of 250 ppm is considered acceptable for potability, except for infants, for persons on

[1] "Ground Water," in *Encyclopedia Britannica*. Chicago, William Benton, 1964. Vol. 10, pp. 494-51.

low-sodium diets, and for a few other situations.) The principal problem in relying on such a system (apart from its aesthetics) lies in the lack of knowledge of the rate of depletion or degradation of these wells under heavy pumping. The use of these wells and the careful monitoring of water quality in brackish/fresh mixes will help to provide answers to these problems for application to future planning. It does not appear likely, however, in view of the Ghyben-Herzberg principle, that excessive pumping will permanently affect the general water reserve; with cessation of pumping, rainfall accumulation should eventually restore the original balance.

It has been suggested that the fill area comprising the southeastern portion of the island, extending roughly 3,500 feet west-southwest/east-northeast by 2,000 feet and surrounded by sheet piling, might be developed as an artificial ground water reservoir. This seems worthy of consideration, provided tests indicate suitable soil conditions and exclusion of seawater. (Test drilling by Ladd, Tracey, and Gross[2] indicates the presence of at least 200 feet of unlithified marine deposits above a limestone/dolomite basement.)

Salt Water

The island was originally provided with a seawater piping system with pumps, a tower tank, and a distribution system to appropriate outlets. This system is in use to a very limited extent only; much of the piping has deteriorated because of corrosion, and the tower is considered unsafe and is scheduled for demolition. Although replacement with modern corrosion-resistant PVC (plastic) plumbing would be technically feasible, economics and the excessive complications involved in a triple water supply system suggest that this system will be abandoned in the near future.

WATER SUPPLY SYSTEM, EASTERN ISLAND

This island, approximately one square mile in area, houses some 50 personnel, although this number may increase in the future. Its runway system, now out of service, also provides a rainwater catchment area for an independent fresh water supply system. At least one brackish water well also exists on the island, but is not being pumped. The situation here is not regarded as critical, and with modest development of the fresh water system, already scheduled, there should be no problem in providing for the needs of an increased number of personnel.

RAINFALL

There has apparently been no need in the past to investigate the climatology of the Midway Islands in depth from the standpoint of atmospheric water resources. The 11 days during which aerial and ground observations were conducted during this program represent a statistically negligible, and apparently atypical, sampling. During this period, a highly stable high-pressure system paralleled the north flank of the Hawaiian archipelago. Airflow aloft was from the northeast, east, or southeast at 10 to 25 knots, and the relative humidity was extremely low, averaging 10 to 15%, above a layer extending from the surface to between 6,000 and 10,000 feet. A typical rawinsonde chart is shown in Fig. 4. Under these conditions growth of clouds to and above the freezing level, which lay at 15,000 to 18,000 feet, was an exceptional event, only two or three such cloud groups being observed within 50 miles of Midway during the course of the program. The typical regime was one of small tradewind cumulus clouds, isolated or in small groups, and on a few occasions in roughly defined north/south lines, based at 1,500 to 2,000 feet,

[2]Ladd, Harry S., Joshua I. Tracey, Jr., and M. Grant Gross. "Drilling on Midway Atoll, Hawaii," Science, Vol. 156, No. 3778 (26 May 1967), pp. 1088-94.

ANATION

① isobars - p in mb

② Dry Adiabats
θ in °C

③ Saturation Adiabats
θ_{ew} in °C

④ Saturation Mixing Ratio
w_s in grams/kilogram

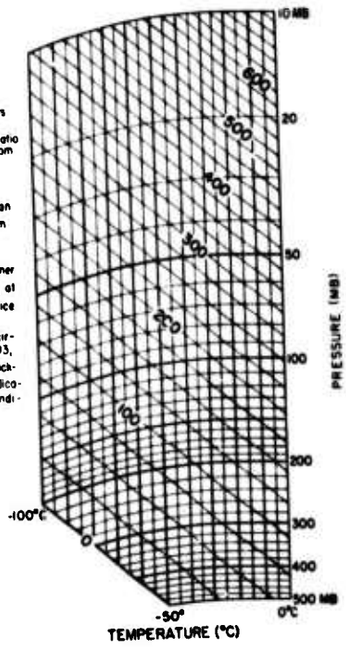
⑤ isotherms - t in °C

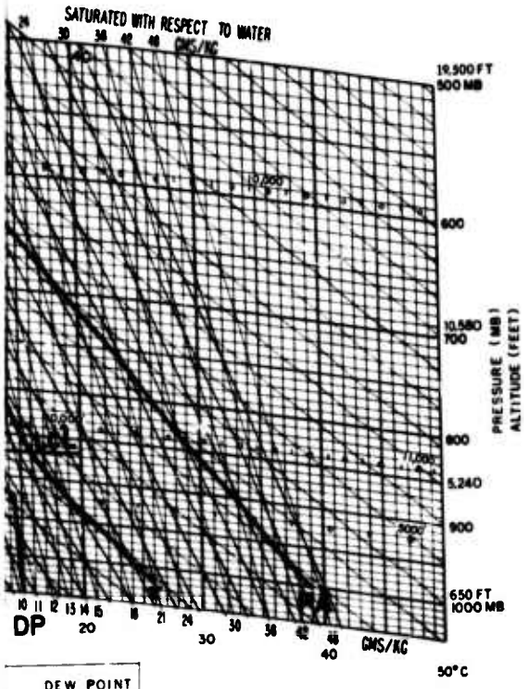
centimeter represents an
ift on the large diagram
pt

bs at temperatures warmer
d with respect to water, at
- 40° C with respect to ice

omputations arrays of cir-
along the 923, 838, 593,
s, these indicate the thick-
rd pressure surfaces indica-
te 100's of feet, pips indi-

ESS	USE THE ARRAY
)	FOUND AT
MB	923 MB
MB	838 MB
MB	593 MB
MB	368 MB
0 MB	245 MB





DEW POINT
TEMPERATURE
RESSURE ALTITUDE

with only the most vigorous growing above the tops of the moist layer. These latter almost invariably evaporated immediately upon entering the dry layer, the resultant cooling effect terminating upward convection while the residual larger drops fell back to form brief showers or spread into altostratus patches at the top of the moist layer. These showers were generally small, less than a mile in diameter, and lasted from 20 minutes to perhaps an hour. Such shower activity was encountered on virtually every day of observation, and over a dozen passed wholly or partially over the island. The maximum rainfall produced by one of these showers amounted to 0.22 inch and was insufficient to activate the water collection system; the majority of such showers yielded only trace precipitation. A typical example is illustrated in Fig. 5.

The observation was made by a number of Midway inhabitants that such showers tend generally to avoid the lagoon and island by day, apparently being deflected around the area. That this may not be entirely a subjective interpretation is suggested by the fact that the operators of the S-band ground control approach (GCA) radar have observed a similar behavior on the part of radar precipitation echoes. The reason for this behavior, if real, should be determined.

Convective activity in these low clouds was very weak; updrafts encountered on penetrations did not exceed 300 to 500 ft/min. In the few tall clouds extending above the freezing level, precipitation appeared to be initiated by homogenous nucleation, through the cooling produced by rapid evaporation. In the few seedable clouds (i.e., those showing relatively rapid growth, little or no evaporation, and high supercooled liquid water content), the rapid and dramatic response achieved by seeding suggests a relative scarcity of natural heterogenous freezing nuclei. These cloud groups, which on at least two occasions achieved the status of lines of cumulonimbus activity, formed along a direction paralleling the archipelago (east-southeast/west-northwest) but lying 50 to 200 miles to the south of Midway (Fig. 6).

Accumulated data suggest that the majority of the useful precipitation occurs at night. The program period unfortunately occurred around new moon, and effective nighttime observations were not possible. Flights at dawn and dusk, however, revealed no obvious diurnal effects as compared with flights during the middle of the day, although the majority of the showers recorded did occur at night.

FIG. 5. Typical Precipitating Tradewind Cumulus Group Southwest of Midway, 12 July. Apex of cloud (left of center) is at 11,500 feet; a small shower is visible directly below.

FIG 6. Cumulonimbus Line Lying East-Southeast/West-Northwest 175 Miles South of Midway, 11 July. Tops of main cells, approximately 35,000 feet. Developing clouds to left of mass in center were later seeded successfully.

Monthly rainfall records, covering most of the period 1918 through 1969, are presented in Table 1 together with monthly averages, maxima, and minima. From this table it is evident that (1) rainfall is relatively uniformly distributed throughout the year, although it is slightly heavier for the period August through January; (2) for those years for which full records are available, there is relatively little variation about the average annual rainfall of approximately 42 inches (about three times the storage capacity of the current fresh water system), nor are any obvious long-term trends present; (3) annual precipitation for 1967 and 1968 was well above average, despite rainfall for March 1968 being the lowest of record; and (4) there were several instances of drought comparable to that experienced preceding the investigation period, but in no case did the dry period exceed 90 days without adequate replenishment.

It thus does not appear that Midway has a serious water problem in the long-term sense; given the present system capacity and utilization rates per capita, a considerably larger population could be supported for long periods without shortages, and a moderate (perhaps 50%) increase in storage capacity should cover all foreseeable circumstances. On the other hand, the aberrant situations experienced on occasion in the past do pose very real problems, requiring emergency measures.

EMERGENCY WATER SUPPLY MEASURES

Three approaches were taken toward alleviating the 1969 water shortage at Midway: barging water, introducing low-salinity brackish water into the fresh water system, and cloud seeding.

Barging

Hauling water from Hawaii to Midway by barge offers a direct solution to the water shortage problem but also has certain drawbacks. At the beginning of July 1969, five barges were available, or potentially available, for this purpose. One self-propelled barge of roughly 250,000-gallon capacity was in commission and ready for use. Two towed barges of comparable capacity were available but in need of minor repairs and purging

TABLE 1. Monthly and Annual Precipitation From January 1918 to June 1969.[a]

Year	Monthly precipitation, in												Yearly total, in
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1918	8.19	3.63	3.28	0.46	0.97	0.35	2.84	5.64	7.43	10.01	0.70	1.54	45.04
1919	0.76	2.30	5.42	3.40	0.53	3.87	1.57	0.04	5.44	2.83	0.70	1.52	28.38
1920	1.50	4.22	6.85	6.16	3.87	6.53	0.91	2.84	4.80	2.38	2.57	4.77	47.40
1921	1.26	6.01	2.82	5.11	6.35	0.54	8.61	2.76	3.64	5.50	1.60	2.56	46.76
1922	2.30	4.41	3.60	0.36	2.46	2.33	4.48	4.70	5.26	3.67	5.14	6.04	44.75
1923	1.11	3.99	3.53	0.96	12.59	3.86	4.33	4.14	7.41	0.85	1.72	0.46	44.95
1924	8.58	1.31	2.58	1.52	0.87	5.06	1.17	5.10	3.42	3.47	0.43	6.25	39.76
1925	11.79	3.23	6.17	22.77	1.86	5.34	1.44	5.24	5.92	0.62	2.24	3.03	69.65
1926	2.48	2.30	2.81	0.83	3.75	0.46	2.37	4.14	1.17	1.12	6.92	3.25	31.60
1927	4.32	2.55	0.52	5.69	2.79	0.37	2.40	2.31	4.20	4.42	4.02	2.58	36.17
1928	2.16	0.14	8.14	1.48	0.14	2.40	10.57	6.73	8.14	0.71	2.50	0.98	44.09
1929	6.77	7.17	1.41	1.06	0.25	1.36	1.07	2.68	0.66	4.01	1.34	2.81	30.59
1930	3.43	1.82	0.09	0.95	0.65	1.60	4.81	0.35	10.98	1.64	1.23	0.62	28.17
1931	2.63	2.04	2.75	0.50	0.28	0.66	1.69	5.72	5.79	0.75	1.53	0.77	25.11
1932	7.40	3.56	1.51	0.57	0.57	0.90	3.58	3.87	4.67	5.03	6.25	8.09	46.00
1933	9.73	5.88	1.55	0.68	4.44	0.67	2.08	2.22	1.79	1.21	5.76	15.59	51.60
1934	8.33	2.67	2.88	0.26	1.69	4.25	2.26	3.98	2.87	2.84	3.35	3.63	39.01
1935	6.69	2.96	4.80	5.04	3.06	0.41	3.73	14.47	3.56	4.45	2.21	3.22	54.60
1936	3.75	5.23	2.14	0.61	0.62	1.68	7.68	8.47	2.09	1.67	0.47	1.69	36.10
1937	4.70	0.76	1.74	3.59	0.15	0.12	1.79	2.64	2.13	0.96	14.70	6.73	40.01
1938	3.31	3.48	2.15	0.10	0.45	2.39	3.24	7.36	1.59	...	...	...	...
1942	3.19	1.90	0.77	2.77	2.11	3.06	5.00	1.11	2.38	3.07	3.22	3.19	31.77
1943	5.89	4.18	6.12	1.95	0.91	8.68	3.67	8.73	2.48	0.92	0.30	2.94	46.77
1944	4.80	4.28	3.68	2.35	3.24	0.62	1.55	11.14	8.24	6.76	2.82	3.39	52.87
1945	3.46	3.14	2.75	0.70	1.01	2.02	3.16	0.79	1.69	5.81	4.27	7.05	35.85
1946	1.76	1.70	1.64	1.33	5.18	6.46	3.60	4.51	12.52	3.25	5.86	3.12	50.93
1947	7.03	2.49	2.19	0.37	0.18	1.51	3.99	4.36	2.44	2.93	2.72	3.74	33.95
1948	1.05	7.12	2.62	6.18	1.39	0.80	2.93	6.02	9.59	1.51	3.17	11.44	53.82
1950	...	...	...	...	...	...	...	3.50	0.68	1.37	3.47	3.07	...
1951	5.90	4.84	1.64	0.61	1.57	0.45	0.56	2.46	0.93	2.82	6.79	4.89	33.46
1952	3.71	3.12	1.04	2.35	0.55	13.42	3.06	4.35	4.11	2.88	1.96	1.10	41.65
1953	9.28	2.44	2.74	3.80	4.92	2.66	2.98	2.01	7.38	3.39	2.79	2.03	46.42
1954	2.76	0.89	1.76	5.78	0.27	1.56	3.09	1.19	5.73	0.70	1.66	1.80	27.19
1955	1.76	5.42	0.66	2.41	0.23	0.92	3.11	4.90	2.09	8.77	2.92	5.65	38.84
1956	5.03	4.61	0.87	0.34	1.34	6.68	6.83	9.37	5.17	8.76	0.67	4.43	54.10
1957	4.21	7.36	1.18	1.18	1.73	0.70	4.49	10.20	2.41	1.68	1.49	3.55	40.18
1958	8.49	3.28	3.70	0.22	0.91	2.15	1.49	1.01	2.44	2.87	2.02	...	...
1959	4.58	3.59	2.70	2.59	1.98	2.63	3.30	4.40	4.46	3.17	3.08	3.08	39.56
1960	6.90	3.79	1.22	4.70	13.28	1.56	0.96	10.69	2.69	3.60	...	...	...
1967	2.91	8.07	2.17	2.38	1.07	3.09	13.28	6.67	1.90	1.53	10.36	4.75	58.18
1968	7.68	4.52	0.04	0.95	2.48	2.44	1.05	7.18	5.43	1.37	3.85	17.85	54.84
1969	1.81	1.34	1.90	0.80	0.56	0.49	...	...	...	...	..	...	...
Max.	11.79	8.07	8.14	22.77	13.28	13.42	13.28	14.47	12.52	10.01	14.70	17.85	69.65
Min.	0.76	0.14	0.04	0.22	0.15	0.12	0.56	0.04	0.66	0.70	0.30	0.46	25.11
Av.	4.72	3.60	2.64	2.57	2.27	2.61	3.52	4.87	4.33	3.13	3.30	4.29	42.44

[a]Excluding the years 1939-1941, 1949, and 1961-1966.

of water tanks. Two additional barges required considerable work and expense to place in commission. Since funds were available, and ocean-going tugs were already scheduled to travel in the proper directions at the proper times, the first three barges were ordered to be prepared, loaded, and dispatched about 15 July if adequate natural or artificial rainfall was not forthcoming.

This approach, however, is at best a temporary one. Ocean-going tugs are scarce and heavily committed to other requirements; furthermore, the barges carry only approximately 10 days' supply of fresh water, and a round trip, including unloading and refilling, takes 12 to 15 days.

Brackish/Fresh Water Mixtures

Water from the wells of lowest salinity (125 to 250 ppm), to be augmented by new wells under construction, was introduced on 15 July into one of the treatment tanks for preparation of a trial batch of brackish/fresh water mixture. Although it is a direct and practical approach to the water shortage, this solution is dependent upon a continuous supply of low-salinity brackish water. As noted previously, the response of the ground water reserve to heavy pumping remains to be determined.

Cloud Seeding

The success of Project Gromet II in alleviating severe drought conditions in the Philippines led the Commanding Officers at Midway and Fleet Weather Central, Pearl Harbor, to ask NWC whether similar techniques could be applied at Midway. After discussing the availability of aircraft and seeding materials, and the probability of suitable seeding conditions at Midway, NWC decided to send two members of the Gromet II team with appropriate ordnance for Very pistol seeding to Midway, and to provide P-3A antisubmarine warfare patrol aircraft from the squadrons based at the Naval Air Station (NAS), Barbers Point, Hawaii, for approximately 10 days.

When the NWC group arrived at Midway they discovered that cloud seeding efforts using local resources and a different technique were already under way. During a previous dry period, in 1960, an officer associated with the meteorology detachment at Midway cited experiments conducted the preceding year involving the seeding of tradewind cumulus with powdered carbon in the form of lampblack and activated charcoal, dry and in solution, which appeared to have led to increased rainfall. He proposed that systematic seeding be undertaken to alleviate a water shortage then prevailing. This proposal was approved, and such seeding was carried out on numerous occasions over the next 4 years.

Although the efficacy of carbon black as a seeding agent and its mode of action have not as yet been clearly established experimentally or theoretically, favorable results were observed in numerous cases, and a substantial body of documentation was built up. This program was revived to combat the 1969 drought, and several such exercises were conducted using the HU-16D search and rescue amphibians assigned to Midway. When it is applied to the condensation regime in clouds lying below the freezing level, this technique, if effective, can complement the NWC techniques used at higher altitudes.

CLOUD SEEDING PROGRAM

Following the decision to undertake cloud seeding at Midway, the availability and capabilities of various aircraft were considered. It was decided to use P-3A/B ASW patrol aircraft based at NAS,

Barbers Point, Hawaii, which have the necessary performance characteristics and are equipped with a Very pistol port through which seeding ordnance can be fired. Arrangements were made for a P-3 from NAS, Moffett Field, Calif., to fly to NWC on 7 July, conduct a series of firing tests over the NWC range to establish the feasibility of firing the pyrotechnic cartridges under simulated seeding conditions, and then transport the NWC personnel and their equipment to Hawaii. Fleet Air Wing 2, Barbers Point, was then tasked to transport them on to Midway and to provide P-3A aircraft to support operations there for about 10 days.

A lot of 190 Very pistol cartridges loaded with 2.6-inch, 125-gram charges of EW-20 pyrotechnic seeding compound was selected, inspected, and prepared for use; two M-8 pyrotechnic pistols were also procured. Just before departure from NWC on 7 July, when it was determined that the P-3 aircraft were equipped to dispense up to 52 photoflash cartridges of the M112 type, 156 rounds of EX 1 Mod 0 pyrotechnic cartridges, each containing a charge of 103 grams of TB-2 seeding mixture, to be fired from the P-3 photoflash racks were added to the equipment.

Program operations during the period 7 through 18 July are summarized in Table 2. Ordnance utilization is also summarized in Table 2, and target behavior is listed in Table 3.

A brief planning session and a ground demonstration firing of a Very pistol cartridge preceded the firings at NWC on 7 July. Six passes were made over B range, during which 14 rounds were fired at an altitude of 20,000 feet and at indicated airspeeds ranging from 180 to a near-maximum 240 knots. The P-3 pistol port, unlike that of the C-130, was found not to have a double pressure seal, and was somewhat more awkward to operate, but all rounds were fired successfully, and visual and photographic observations from chase aircraft indicated that all flares cleared the aircraft empennage by a safe distance. Because of the limited time and the unfamiliarity of the aircrew with the operation of the photoflash racks, testing of the EX 1 Mod 0 rounds was postponed until after arrival at Midway.

Upon arrival at NAS, Barbers Point, the NWC group was given a detailed briefing on the background of the Midway water situation, and there was a discussion of the water barging operation. COMFAIRHAWAII requested that a situation summary message of seeding operations be sent each day of operation, or every second day in the absence of seeding operations. Necessary equipment was obtained for the operation of the aircraft photoflash racks, and the AN/APS-80 radar aboard the P-3A aircraft was examined for operability. Departure for Midway was scheduled for 8 July.

8 July

The photoflash racks were loaded but not installed in their firing stations for the trip to Midway. The Very pistol and pistol cartridges were held in readiness in the event seedable clouds were encountered near Midway. The aircrew was briefed on the nature of the operation and given an introduction to the techniques of cloud seeding, and the NWC group was briefed on the operation and capabilities of the aircraft radar and navigation equipment.

In the vicinity of Midway, one possible target cloud area was observed some 45 miles north of the island. A call to the Station weather office yielded the following data: freezing level, 14,600 feet; -10°C level, 20,100 feet; winds, 340 to 360 degrees true, 11 to 19 knots between the surface and 20,000 feet; cloud bases, 1,500 to 2,000 feet. Permission was requested and received to work this cloud group. Two Very pistol rounds were fired into the highest part of the group, at about 16,000 feet; the top initially collapsed into a layer of raining stratus. Thirty minutes later new growth was observed in the group, with an active tower rising to 18,000 feet and a cluster of echoes 3 to 4 miles across appearing on the radar. Two more pistol rounds were fired into the tower, which continued to grow, the radar echoes moving along a 190-degree magnetic heading directed 5 to

TABLE 2. Operations Summary, Midway Cloud Seeding Program.

Date, July 1969	Mission no.	Location	Duration, hr	Aircraft	Squadron	Pilot	Observers	Rounds expended		Target no.
								Pistol	EX 1 Mod 0	
7	00	NWC	1.0	P-3B	VP-47	LCDR Devins	LT Beam LT Fant	14	0	...
8	01	Hawaii-Midway	1.0[a]	P-3A	VP-17	LT McGuiness	...	4	0	1
9	02	Midway	3.0	P-3A	VP-17	LT McGuiness	AGCS Clapper	0	5	2
10	03	Midway	3.6	P-3A	VP-4	LT Goddard	PH1 Hobbs	1	3	...
10	04	Midway	1.9	P-3A	VP-4	LT Goddard	...	0	3	3
11	05	Midway	3.7	P-3A	VP-4	LT Goddard	CDR Rollins PH1 Hobbs AG1 Allen	0	6	4, 5
12	06	Midway	2.8	P-3A	VP-4	LT Bartolini	AG3 Coloe AG3 Kay	0	3	...
13	07	Midway	1.7	P-3A	VP-22	LCDR Stevick	AGAN English	2	0	...
13	08	Midway	1.4	P-3A	VP-22	LCDR Stevick	CDR Rollins AGCS Clapper AG3 Hamilton	2	0	6
14	09	Midway	2.6	P-3A	VP-22	LCDR Stevick	...	3	0	7, 8
14	10	Midway	0.6	P-3A	VP-22	LCDR Stevick	CDR Rollins	0	0	...
15	11	Midway	1.5	P-3A	VP-22	LCDR Stevick	Mr. F. Mau AG3 Coloe AGAN English	6	0	9, 10
15	12	Midway	1.4	P-3A	VP-22	LT Krilla	CDR McCoy Mr. L. Rossiter	1	2	...
16	13	Midway	2.3	P-3A	VP-22	LT Krilla	AG3 Hamilton	0	4	11, 12
17	14	Midway	3.5	HU-16D	(NS, Mdwy)	CDR Rollins	Dr. Elliott	6	0	...
18	15	Midway	1.0[a]	P-3A	VP-22	LT Krilla	...	5	0	13, 14

[a]Includes only portion of flight devoted to reconnaissance/seeding activities.

TABLE 3. Target Behavior.

Date, July 1969	Mission no.	Target no.	Target initial condition	Altitude of cloud, ft	Altitude of 0°C level, ft	Seeding material	Target response
8	01	1	Active isolated Cu group	16,000	14,600	4 Pistol	Collapse, followed by growth to 18,000 ft; radar echo[a]
9	02	2	Low isolated Cu	11,300	14,800	3 EX 1 Mod 0	None[a]
10	04	3	Quiescent Cu mass	24,000	14,700	3 EX 1 Mod 0	Growth to active CB with extensive radar echo
11	05	4	Small active Cu between active CBs	>19,000	15,200	1 EX 1 Mod 0	Growth, merging with adjacent CB; good radar echo
11	05	5	Weak, small isolated cloud	18,000	15,200	2 EX 1 Mod 0	Dissipated with brief shower (overseeding)
13	08	6	Low isolated Cu	13,000	17,700	2 Pistol	None[a]
14	09	7	Low active Cu	14,500	17,300	2 Pistol	None[a]
14	09	8	Low active Cu	14,500	17,300	1 Pistol	None[a]
15	11	9	Large moderately active Cu group	18,000	16,600	5 Pistol	Moderate growth, followed by Str formation and precipitation
15	11	10	Large moderately active Cu	18,000	16,600	1 Pistol	Initial growth; mission aborted
16	13	11	Low isolated Cu	<15,000	15,600	2 EX 1 Mod 0	None[a]
16	13	12	Large quiescent Cu	18,000	15,600	2 EX 1 Mod 0	Slight growth, followed by dissipation
17	15	13	Active Cu adjacent to active CB line	17-18,000	15,000	4 Pistol	Rapid growth, good radar echo
18	15	14	Active Cu adjacent to active CB line	17-18,000	15,000	1 Pistol	Dissipated with brief shower

NOTE: Cu, cumulus; CB, cumulonimbus; Str, stratus.

[a]Targeting demonstration.

10 miles west of Midway. Unfortunately, limited fuel necessitated discontinuance of this operation, designated Mission 01, and the aircraft headed in to Midway.

Immediately after landing, arrangements were made for the stowage of the seeding material in the Station armory, adjacent to the aircraft parking apron, where it would be accessible, under guard, 24 hours a day. The NWC group was given meteorological background material and provided with working space in the Weather Office. The Air Operations Officer reported on the local carbon-black seeding operations, and arrangements were made for a reconnaissance/seeding mission at 0700 the next day.

9 July

Study of the 0200 Midway rawinsonde chart indicated east-southeasterly winds aloft at 14 to 21 knots, the freezing level at 14,800 feet, and the −10°C level at 19,500 feet. No significant inversions were present, but low humidity (less than 25%) prevailed between 12,000 and 19,000 feet. Mission 02 was begun at 0717 with the starboard photoflash rack of the P-3A loaded with 26 EX 1 Mod 0 rounds and with a number of Very pistol cartridges as backup. Aloft, cloud conditions were as anticipated from the sounding, with scattered stratocumulus based at 2,000 feet and rising to 8,000 to 9,000 feet and with a few individual clouds reaching 12,000 feet. The upwind (east-southeast) sector from Midway was patrolled out to a distance of 60 to 80 nmi. Several groups of low clouds showing visible rain and radar echoes were tracked; their motion correlated well with the winds obtained from the sounding and the aircraft Doppler navigation gear. Two EX 1 Mod 0 rounds were fired in clear air to verify functioning and establish the firing procedure. These rounds performed properly, and ejection of the inner canister could be readily observed from the aft observation window. For crew indoctrination and target practice, three more EX 1 Mod 0 rounds were fired into a low raining cloud group just south of Midway whose top was at 11,300 feet (+7°C). Targeting was found to be considerably more difficult with the side-ejecting racks on the P-3 than with the downward-firing racks generally used on other aircraft. In this and subsequent tests it was determined that following initial target selection by an observer on the flight deck, the actual firing command was best given by the aft observer; the blister window provides sufficient forward visibility to allow the latter to identify the target selected.

No seedable clouds had appeared in the vicinity of Midway by this time, and, no significant change in weather conditions being apparent, the mission was terminated.

The 1400 sounding showed even drier conditions aloft, the relative humidity having fallen to 10 to 15% above 6,000 feet. Forecasts indicated no prospect for immediate improvement, although breakdown of the highs to the north might allow frontal movement into the vicinity of Midway in a day or two.

Mission 03 was scheduled for 0630 the next day, with a tentative second mission in the late afternoon. Since a different P-3 aircraft and crew were to fly the mission, the pilot and crew were briefed on the operation.

Two showers in the evening and during the night yielded 0.03 inch of water. A carbon-black seeding experiment during a search and rescue mission in the early evening was conducted, with inconclusive results.

10 July

The 0200 sounding showed extremely dry conditions aloft above 7,000 feet, with the freezing level at 14,700 feet and east-southeasterly winds at 14 to 25 knots. No change in weather conditions was indicated. Mission 03 was begun at 0635 with the aircraft loaded with both types of seeding ordnance. Cloud cover was scattered to broken stratocumulus with bases at 1,200 feet and tops at only 3,500 feet. There was a layer of patchy stratus at about 9,000 feet and occasional cumulus reaching 10,000 feet. Most of this activity

extended along a line 40 miles long northeast to southwest, approaching Midway from 15 to 20 miles to the east. A line of what appeared to be developing cumulonimbus activity lay east-southeast/west-northwest 80 to 100 miles south of Midway. A series of EX 1 Mod 0 rounds and one pistol round was fired in clear air for crew indoctrination and photography. Since there was no indication of possible development of seedable clouds upwind of Midway, the mission was terminated. A second flight was scheduled for late afternoon.

The band of raining cumulus passed over the island about 1030, yielding only trace precipitation. A special sounding at 1000 showed no change in conditions aloft.

Mission 04 was begun at 1744 with the aircraft loaded with both types of seeding ordnance. Scattered low stratocumulus with bases at 2,000 feet and reaching to a maximum of 8,500 feet were observed around Midway. The line of cumulonimbus activity to the south had largely dissipated, leaving a mass of cirrostratus aloft, but one substantial mass was observed about 90 miles to the southwest. In the absence of any seedable clouds near Midway, it was decided to work this group for indoctrination and training purposes. Initially, the target consisted of a substantial, but relatively inactive, cumulus mass reaching to 24,000 feet with a 5-mile radar echo. Subsidiary cells on the windward flank were seeded with three EX 1 Mod 0 rounds over a period of 30 minutes. Immediate growth was observed, the group rapidly developing into a full-fledged cumulonimbus and the echo expanding to 10 by 15 miles, elongated toward and including the seeded area. Since there were no change in conditions and no seedable clouds at Midway, the mission was then terminated. Mission 05 was scheduled for 0600 the next morning, about the earliest time for which adequate visibility could be expected aloft.

A trace of precipitation was recorded in the late evening.

11 July

The 0200 sounding showed no significant changes, with easterly to east-southeasterly winds at 12 to 18 knots, freezing level at 15,200 feet, and air very dry from 5,000 to 20,000 feet. Mission 05 was begun at 0607. In the vicinity of Midway cloud cover consisted of scattered stratocumulus with bases at 2,000 feet and tops at 7,000 to 10,000 feet maximum; one tower 50 miles to the east was observed that reached 13,000 feet. To the south a line of cumulonimbus activity was observed, similarly oriented to that seen the previous day, but more intense, and 75 to 100 miles further south. We decided to conduct a training exercise in this area. A small growing cell between the two principal masses seen at center and to the left in Fig. 6 was selected and seeded with one EX 1 Mod 0 round. It grew very rapidly, merging with the main mass to the west and rising into the cirrus overcast within 15 minutes. Low clouds prevented visual rainfall observations, but substantial radar echoes were noted. An isolated small cell 10 miles to the north of the line was seeded with two EX 1 Mod 0s; it dissipated immediately with a brief shower, and clearly illustrated the consequences of overseeding. During the return to Midway, three EX 1 Mod 0 rounds were fired and their smoke trails were photographed. Conditions were found to be unchanged in the vicinity of Midway, with precipitation from several low stratocumulus groups but no clouds approaching the freezing level. The next mission was set for 0700 in the morning with a new aircraft and crew, and a briefing session was held.

An attempt was made to seed with carbon black during a HU-16D mission in the afternoon, but no conclusive results were observed.

12 July

The 0200 sounding showed easterly to northeasterly winds at 8 to 16 knots, a slightly

higher freezing level of 15,750 feet, and relative humidity of 10 to 20% between 8,000 and 25,000 feet, except for a somewhat moister layer (40%) at 15,000 feet. Mission 06 was begun at 0700 with both types of seeding ordnance aboard. Scattered stratocumulus clouds with bases at 1,500 feet and tops at 3,000 to 5,000 feet generally, occasionally reaching 8,000 feet, were observed in the vicinity of Midway. One group of cumulus rising to 12,500 feet was found 80 miles to the east-southeast with similar groups to the south and west of the island; no cumulonimbus activity was observed to the south, and no freezing-level clouds were seen within 200 miles. Several of the clouds to the east, south, and southwest showed shower activity. Attempts were made to fire seven or eight EX 1 Mod 0 rounds for demonstration and targeting purposes, but only three rounds were fired successfully; the problem was traced to a malfunction of the rack sequencing system, and the mission was terminated.

A visit was made to the island's GCA radar site. The radar is an AN/CPN-4 S-band (10-centimeter) instrument, with a 40-nmi range and no height-finding capability. Within its limitations, this radar is of excellent quality; several echoes were located and correlated with visually observed showers. Arrangements were made for direct radio contact between the GCA radar operators and the aircraft during future missions.

Several showers fell on the island during the day, producing a total of 0.22 inch of rainfall; this quantity, however, was insufficient to activate the rainfall collection system.

The 1400 sounding showed no improvement in conditions aloft; it was decided to schedule a morning and afternoon flight for the next day, and the crew of the aircraft to be used was briefed on the operation.

13 July

The 0200 sounding indicated a slight wind shift, to east-northeasterly at 12 to 18 knots; a higher freezing level, at 17,000 feet; and relative humidity less than 10% above 12,000 feet. Mission 07 was begun at 0753 armed with both types of seeding ordnance. Clouds were very sparse with bases at 1,600 feet and tops at 4,000 to 5,000 feet near the island; a few groups reaching as high as 11,500 to 12,000 feet were found 20 to 30 miles north and east of Midway, but no taller clouds could be seen within 200 miles. Two pistol rounds were fired in clear air south of Midway for indoctrination; several attempts were made to fire the EX 1 Mod 0 rounds, without success.

Investigation of the rack circuitry after the mission ended indicated problems requiring the use of a test set. Since one was not available at Midway, it was decided to continue with the Very pistol until the necessary equipment could be obtained.

The 1400 sounding showed little change, with easterly to northeasterly winds at 2 to 13 knots, freezing level at 17,700 feet, and extremely dry air above 12,000 feet. Several minor showers passed over Midway during the day, depositing only 0.04 inch of rainfall.

Mission 08 was begun at 1955. Several layers of patchy stratus were encountered at approximately 1,900, 5,000, and 7,000 feet over Midway and extending to the southwest through west to north with a few cumulus tops penetrating the stratus to 9,000 feet. A few individual cumulus clouds were observed in a north-south line eastward, reaching 13,000 feet. Two Very pistol rounds were fired into one of these, for training and target practice, with the expected lack of response. What little growth was encountered in this area ceased immediately at sunset (2055), and the mission was terminated. Morning and evening missions were scheduled for the next day.

14 July

The 0200 sounding showed a return of east to east-southeasterly winds at 9 to 19 knots with a slight lowering of the freezing level to 17,300 feet and relative humidity 10% or less above 8,000

feet. Shortly before the flight, GCA radar reported a pattern of echoes indicating a squall line extending from northeast through east-southeast 25 to 35 miles from Midway. Mission 09 was begun at 0754. Clouds in the vicinity of Midway consisted of small stratocumulus with bases at 1,400 feet and tops generally at 3,000 to 5,000 feet, occasionally reaching 8,000 feet. The squall line was found to consist of a belt of raining cumulus to the east with tops reaching a maximum altitude of 14,500 feet. Communications were established with the GCA radar operators, who vectored the aircraft to several of the more prominent echoes. One cloud was observed to grow to 16,000 feet, but evaporated almost immediately and fell back to the general cloud top level. Two Very pistol shots were fired into another cloud north of Midway, and a third into a cloud to the south, both of which showed signs of a similar growth cycle; as was to be expected, no effects of seeding were observed. With no further prospects for useful seeding, and no suitable clouds for demonstration or training purposes in the vicinity, the mission was terminated. The squall line passed Midway without depositing significant precipitation on the island.

The 1100 satellite photograph showed a band of extensive cloudiness some 750 miles west of Midway, and forecasts indicated a possibility for frontal development in this area moving toward Midway within the next day or so. The 1400 sounding indicated a continuation of previous conditions, with winds tending back to the east-northeast at 8 to 17 knots, the freezing level at 17,000 feet, and extremely dry air above 10,000 feet.

Mission 10 was begun at 1854. Clouds were very sparse with bases at 1,900 feet and tops reaching a maximum of 8,500 feet in the vicinity of Midway. The mission was terminated at 1925, with no ordnance expended.

15 July

The 0200 sounding indicated winds from east through northeast, becoming northerly above 20,000 feet at 8 to 25 knots; the freezing level was at 16,600 feet, and relative humidity was 10 to 15% above 8,600 feet.

Mission 11 was begun at 0756. Clouds in the vicinity of Midway consisted of a few sparse stratocumulus with bases at 1,300 feet and tops reaching to 6,500 feet at most. A group of taller clouds was visible to the east-southeast in the vicinity of Pearl and Hermes reefs. Upon investigation, this group was found to consist of three separate masses, each reaching approximately 18,000 feet. The central cloud was seeded with five Very pistol rounds over a period of 30 minutes, and grew 1,500 feet in about 11 minutes, then fell back and spread out into a broad, thick, raining altostratus deck at 16,500 feet. A second cloud in the group dissipated naturally. A third cloud was seeded with one pistol round and showed immediate growth; an engine malfunction, however, forced discontinuation of the mission.

Later in the morning, we made a detailed tour of the island's water works. During the afternoon a new aircraft and crew arrived, and the next mission was scheduled for 1830-1900.

The 1400 sounding showed generally easterly winds at 8 to 16 knots, a further lowering of the freezing level to 15,800 feet, and extremely dry air above 8,000 feet. The band of cloudiness to the west was no longer evident in the satellite photographs, and no change in conditions for the next few days was forecast.

Mission 12 was begun at 1849 with both types of ordnance aboard. Scattered stratocumulus with bases at 1,600 feet and tops at 6,000 to 7,000 feet were present in the Midway area; a few clouds to the east and north reached 10,000 feet, but no higher clouds were visible within 200 miles. Two EX 1 Mod 0 rounds and one Very pistol round were fired for indoctrination purposes.

16 July

The 0200 sounding did not provide data on the winds above 5,000 feet; at this level winds were easterly at 18 knots. The freezing level was

at 15,600 feet, while the relative humidity aloft had increased somewhat, ranging from 15 to 40%. Mission 13 was begun at 0708 with both types of ordnance aboard. No clouds at all were found within 20 miles of Midway; to the north, east, and south clouds were observed with bases at 1,600 feet and tops occasionally reaching 10,500 feet and evaporating. A group of taller clouds was observed about 70 to 100 miles to the southwest, and it was decided to work on these for practice. These clouds showed slow growth, their tops reaching as high as 19,000 to 20,000 feet, but with considerable evaporation and natural precipitation. Two EX 1 Mod 0 rounds were expended en route on a low cloud to test the targeting procedures that had been evolved, without effect, and two more were fired into the principal cloud top in the group, which was quiescent at 18,000 feet and was raining heavily. Slight growth followed the first shot, but no significant overall response was observed, and the whole group decayed rapidly. No improvement in conditions was found on returning to Midway, and the mission was terminated.

At this time we were requested not to undertake further flights unless ideal seeding conditions should develop. The 1400 sounding, the satellite photographs, and forecasts yielded no immediate prospect for change, and the afternoon mission was canceled. Arrangements were made for a flight the next morning to test the capabilities of the HU-16D as a seeding platform and to witness the carbon-black seeding technique. In the evening several clouds were seeded with carbon black during a practice HU-16D flight, again without significant results. Several showers during the late evening yielded only trace precipitation on the island.

17 July

The 0200 sounding showed east-northeasterly winds at 19 to 22 knots, the freezing level at 15,500 feet, and the relative humidity fluctuating between 10 and 40% above 4,000 feet.

Mission 14 was begun at 0922 using the HU-16D as the test aircraft. Ten rounds of Very pistol ammunition and several 1-pound sacks of commercial lampblack were carried for seeding tests. Scattered cumulus were encountered around Midway with bases at 1,650 feet and tops just reaching 10,000 feet; several showers were visible, and corresponding echoes were reported by the GCA radar. With the upper panel of the aft port hatch open, six Very pistol shots were fired into 9,500- to 10,000-foot cloud tops to establish targeting procedures and observe trajectories. Five lampblack packages as well were dispensed into the top of a 10,000-foot cloud. No effects were detected in either case, visually or on the GCA radar.

The HU-16D was then trimmed for climb to determine its altitude capability. Twenty-five minutes were required to climb from 10,000 to 21,000 feet, at the -10°C level. At this altitude the aircraft was found to be fully controllable at 115 knots IAS, and was still capable of climbing at 350 ft/min. The port hatch was again opened, without producing any drag or turbulence problems, and it was concluded that seeding would be entirely feasible under these conditions. No clouds reaching seeding altitude could be found, however, and the aircraft descended again. En route to Midway, the HU-16D was flown through several raining cells; although the maximum updrafts encountered did not exceed 500 ft/min, the performance of the aircraft tended to indicate that the type of turbulence encountered on normal penetration seeding runs should pose no problems with this type of aircraft.

Plans were made to terminate the program unless a major change in the weather pattern was evident during the next 24 hours. The 1400 sounding showed no significant changes, and no flight was scheduled for the afternoon. It was learned, however, that the P-3A would require a check flight the next morning, and it was decided that ordnance would be carried in case suitable clouds were encountered. The flight was scheduled for 0900.

During the evening and night, several showers

fell, yielding a total of 0.15 inch of rain, again insufficient to activate the collection system.

18 July

The 0200 sounding showed northeasterly winds at 6 to 18 knots; the freezing level was at 15,000 feet and the relative humidity was 10 to 20% above 7,500 feet, with three moister layers (to 45%) between 10,000 and 15,000 feet. At dawn there was a group of well-developed clouds 30 miles to the south of Midway whose northern fringes had probably been responsible for the rainfall during the night. (It is conceivable that had this cloud group been detected sufficiently far in advance, and given moonlit conditions adequate for target selection and aiming, useful precipitation might have been obtained by seeding.)

Mission 15 was begun at 0903. Only 10 rounds of Very pistol ammunition were carried. A few small fragments of stratocumulus with bases at 1,900 feet and extending up to perhaps 4,000 feet were found near Midway; to the north lay an extensive deck of stratus at 6,000 feet with some taller cumulus clouds beyond. The clouds to the south had developed into a line of cumulonimbus 40 to 50 miles long, oriented west-northwest/east-southeast 40 miles to the south and southwest of Midway. A fairly dense mass of lower cumulus and stratus extended from this line to within 20 miles of the islands. Two clouds flanking the main line, growing slowly, with tops reaching 17,000 to 18,000 feet, were seeded with four and one pistol rounds, respectively. The first cloud grew at least 3,000 feet in 30 minutes, expanding rapidly and producing a good radar echo; low clouds prevented visual rainfall observations. The later seeding passes penetrated the cloud, encountering moderate amounts of liquid water, most of which froze on impacting the windscreen, and slight turbulence. The second cloud dissipated rapidly into a brief shower. The aircraft returned to Midway, but no seedable clouds were found, and the seeding mission was terminated. The next 2 hours were devoted to aircraft check-out procedures. Shortly before landing, at 1202, observations of the seeded area from over Midway showed the original cumulonimbus activity almost dissipated, but the seeded area still moderately active.

The afternoon soundings and forecasts indicated no prospects for change, and it was decided to terminate the program. The remaining seeding ordnance, 139 Very pistol rounds and 128 EX 1 Mod 0 rounds, was inventoried, packed, and stowed in the Midway armory.

SUMMARY

The results of the Midway cloud seeding program may be summarized as follows:

1. Despite 15 missions, encompassing 31 hours of flight in the vicinity of Midway, no clouds exceeding freezing level altitudes were encountered that, if seeded, would have produced rain on the islands. With the dubious exception of the group observed on the morning of 18 July, no seedable clouds were observed that might have been in a suitable position during periods when the aircraft were not being flown.

2. Fourteen targets were seeded in test and demonstration exercises; 9 of these were above the freezing level altitude. All clouds seeded responded in the manner anticipated from Gromet II and previous experiences: substantial clouds with good convection grew and spread actively, substantial clouds showing considerable evaporation and without active convection grew slightly, tenuous clouds dissipated immediately into brief showers, and clouds below the freezing level showed no response.

3. A number of people involved with the water supply problem at Midway participated in one or more missions, as indicated in Table 2. Most were able to witness successful seeding of

demonstration targets. A general understanding of the problems and procedures involved was evident. In spite of the relatively limited opportunities for effective training, and given the demonstrated capability of the HU-16D aircraft, it is felt that members of the Naval Weather Service Environmental Detachment (NWSED) staff are prepared to conduct successful seeding using the Very pistol ammunition if suitable working conditions arise.

4. Five P-3A crews participated in the program. Of these, four had opportunities to witness seeding of demonstration targets; the fifth crew received only verbal indoctrination. All crews demonstrated a ready grasp of the principles and procedures involved and, given modest further training under good conditions, should develop into effective seeding teams capable of independent work.

5. Effective seeding using the present techniques is dependent upon either the passage of frontal weather or major storm systems or the virtually random appearance of isolated clouds or cloud groups reaching above the freezing level. While the former may sometimes be forecast sufficiently in advance to permit deployment of a P-3A seeder and crew from NAS, Barbers Point, the latter can best be recognized and worked using the resources already available at Midway: local meteorological observations, cloud top reports by local and transient aircraft in the vicinity, GCA radar, the HU-16D aircraft, and the seeding materials provided by NWC. These resources can be mustered on extremely short notice and at relatively low expense.

6. The P-3 and HU-16D aircraft utilized in the program provide excellent vehicles for seeding. The P-3 is large, relatively fast, quiet (at least by comparison with the C-130 aircraft, which uses similar engines), and in the ASW configuration, well-instrumented with respect to navigation and radar equipment. The P-3 meets any reasonable requirements that might be imposed by the most sophisticated research program. The AN/APS-80 radar, though inferior to the AN/APS-20 of the WC-121 from the standpoint of quantitative rainfall analysis, is a much more compact system, ideally suited for searching out precipitation echoes and following their evolution in a qualitative sense. Working space and comfort levels are more than adequate for long missions. Although the Very pistol port is not really suited for heavy use under high-aititude conditions, it provides a satisfactory backup to the side-ejecting photoflash racks. These latter are somewhat more difficult to aim than the downward-firing racks that have been used on other aircraft, but can be employed effectively with a little practice. Two outboard suspension systems on the port wing could accommodate external racks. The limited downward visibility from the flight deck (as compared with the C-130) is more than compensated for by the four bubble windows in the main compartment and the small down-looking window in the galley. Although the P-3 has a reputation for "rough riding" in turbulence, no real disadvantage in this respect relative to the C-130 was noted. The P-3s, as used at Midway, did represent somewhat of an overkill, their speed, range, and high rate-of-climb capability not being really required.

The HU-16D proved to be a most surprising aircraft. Although its speed and rate of climb (and descent) are far below those of the P-3A, its performance and controllability at the -10°C level, 21,000 feet, were found to be entirely satisfactory. Turbulent weather performance is also reported to be good. The hull provides adequate equipment and crew space, the blister windows (and high wing) give visibility superior to that from the P-3A, and the rear doorway is large enough (and free from aerodynamic turbulence when opened in flight) to permit dispensing even the most bulky types of seeding materials. Navigation and radar equipment of modest capability are provided, although no opportunity offered itself to evaluate them. External stores capability is provided by JATO attachment points on the hull. The advantages of an amphibious aircraft in a ditching situation scarcely require comment. These features, combined with a relatively low cost of operation, comparable with

that of a modern light twin-engine private aircraft, make the HU-16D excellently suited to short-range seeding activities appropriate to a location such as Midway.

RECOMMENDATIONS

In 1967-68 the Pacific Division of the Naval Facilities Engineering Command made a detailed survey of the water supply at Midway and prepared a report in which the development of an all-fresh-water system of increased capacity is recommended. These recommendations, incorporated in the current water plan for Midway[3] include (1) retention of the present rainwater catchment system with minor improvements, (2) installation of a reverse-osmosis desalination plant of 200,000-gallon-per-day capacity drawing on the brackish-water well system, (3) construction of an additional 3-million-gallon water storage tank, and (4) abandonment of the present separate brackish- and salt-water distribution systems. This scheme will provide an all-fresh-water system adequate for all foreseeable requirements (including a 2-million-gallon fire-fighting reserve).

Implementation of this plan, however, will require time and the allocation of funds. Until the system can be completed, it is likely that occasional water shortages will continue to occur on Midway, as in the past. In such situations cloud seeding for rainfall enhancement or redistribution can provide relief at relatively nominal cost.

Looking beyond the immediate program described in this report, the following recommendations are offered.

1. The personnel at Midway should be encouraged and supported by providing them with reports and data relevant to their seeding problems. Improved techniques and materials should be passed on as they become available. NWC personnel traveling in the Pacific should, if time and routing permit, visit the islands and participate in any ongoing seeding activities. The Midway staff should be asked to accumulate as much information as possible, on a year-round basis, regarding the proportion of rain-producing cloud systems extending substantially above the freezing level, using sounding data, pilot reports, and any other information that may become available.

2. The records accumulated during the last 10 years in connection with the Midway carbon-seeding exercises should be analyzed with a view toward determining the effectiveness of these methods and identifying the most successful techniques.

3. Further exploration of existing "warm cloud" seeding methods, pyrotechnic and nonpyrotechnic, and development of new materials and techniques should be pursued with an eye to the production or redistribution of rain from the types of clouds chiefly encountered during the Midway program. Although they are not overly large or rich in moisture, such clouds are plentiful and do produce good showers, and may in the long run provide the principal contribution to rainfall at Midway. The possibility of stimulating the growth of such clouds to altitudes above the freezing level, if achievable, would permit the use of a "double-barreled" seeding mode.

4. In view of the foregoing, it is suggested that a small party of NWC personnel (two to four persons) travel to Midway for a period of 2 to 3 weeks to test such methods, prospective or practical, as may be available. Midway offers the opportunity to operate in a virtually pure oceanic temperate-latitude environment from a fixed base with good accommodations and resources. Most of

[3]Naval Station, Midway. Master Plan NAVSTAMID, 30 July 1968.

the techniques hitherto explored at NWC, up to and including small spray systems and large pyrotechnic ordnance of the Salty Dog type, could easily be accommodated by the HU-16D aircraft. Aircraft and ground instrumentation, including radar, are available on at least a modest scale, and might be supplemented by research-equipped aircraft from other sources, if needed.

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13. ABSTRACT

The U.S. Naval Station, Midway Islands, depends upon rainfall for its fresh water supply. During the first 6 months of 1969, a decrease in rainfall reduced fresh water reserves to critical levels, and a cloud seeding program was undertaken in July by the Naval Weapons Center to increase precipitation. Lack of clouds suitable for available silver iodide seeding techniques precluded success; however, valuable observations were made of the meteorological regime in that area, and a number of naval personnel (civilian and military) were trained in weather modification techniques.

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