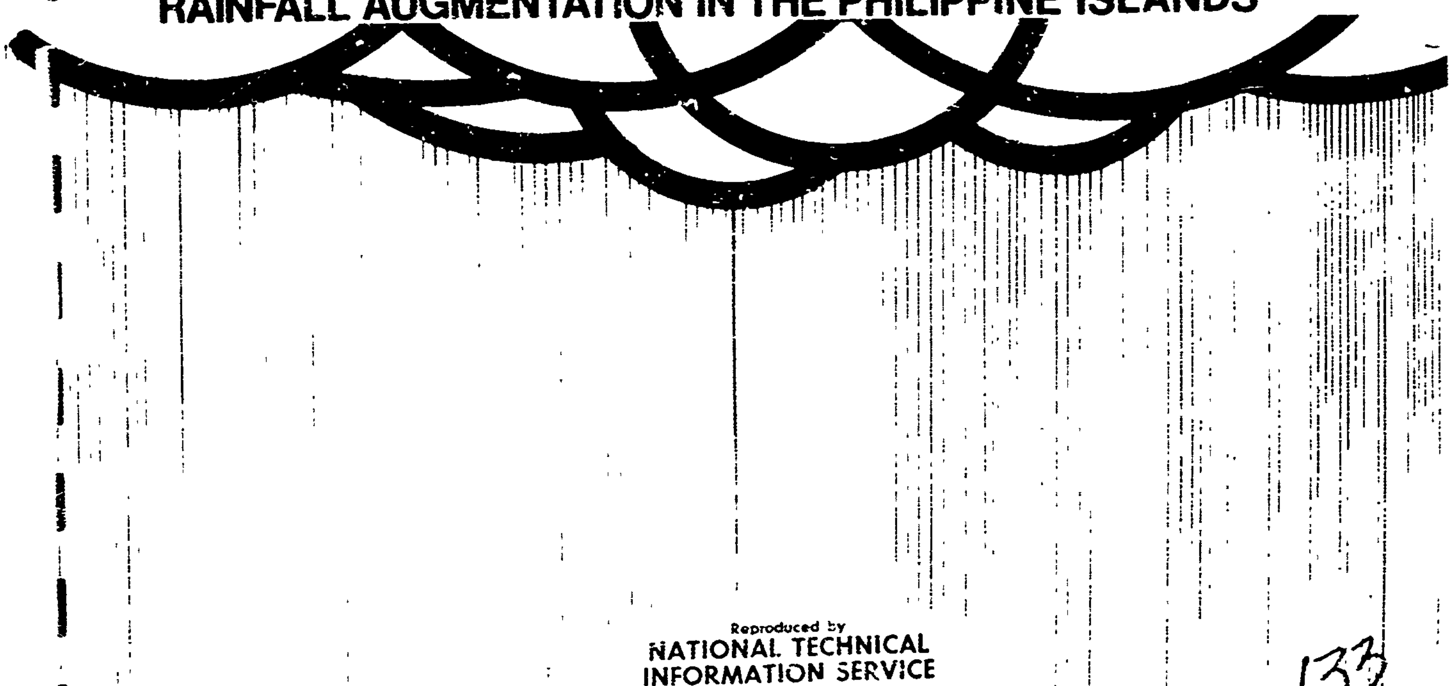
# GROMET II

## RAINFALL AUGMENTATION IN THE PHILIPPINE ISLANDS





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NAVAL WEAPONS CENTER • CHINA LAKE, CALIFORNIA • NWC TP 5097 • MAY 1971

UNCLASSIFIED
Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1 ORIGINATING ACTIVITY (Corporate author)<br>Naval Weapons Center<br>China Lake, CA 93555 | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b GROUP |

3 REPORT TITLE

GROMET II: RAINFALL AUGMENTATION IN THE PHILIPPINE ISLANDS

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

5 AUTHOR(S) (First name, middle initial, last name)

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| 6 REPORT DATE | 7a. TOTAL NO OF PAGES | 7b. NO OF REFS |
|---|---|---|
| May 1971 | 110 | 4 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO<br>b. PROJECT NO.<br>AIRTASK A5405401 216D OW37170000<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>NWC TP 5097<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |

10. DISTRIBUTION STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Naval Air Systems Command<br>Naval Material Command<br>Washington, DC 20360 |

13 ABSTRACT


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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Cloud Seeding Techniques | | | | | | |
| Cold Cumulus Seeding | | | | | | |
| Cloud Seeding | | | | | | |
| Silver Iodide Seeding | | | | | | |
| Rainfall Stimulation | | | | | | |
| Rainfall Enhancement | | | | | | |
| GROMET II | | | | | | |
| Philippine Rainfall Augmentation | | | | | | |
| Pyrotechnic Seeding of Clouds | | | | | | |
| Airborne Seeding of Clouds | | | | | | |
| Weather Modification | | | | | | |

NWC TP 5097

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## RAINFALL AUGMENTATION IN THE PHILIPPINE ISLANDS

by
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T. L. Wright
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*Research Department*





NAVAL WEAPONS CENTER ● CHINA LAKE, CALIFORNIA ● MAY 1971

## ABSTRACT

A severe drought in the Philippine Islands during 1968 and 1969 led the Philippine Government to try cloud seeding as a means of rainfall augmentation. With the help of the United States, a silver iodide seeding project, GROMET II, was conducted over the entire archipelago from the end of April through mid-June 1969. Pyrotechnically generated silver iodide was released in updrafts in growing clouds, and through judicial placement and timing of seeding events individual clouds were organized into larger cloud systems. Rainfall estimated as at least 3 X $10^{10}$ cubic meters of water fell from seeded clouds. The precise extent of rainfall augmentation resulting from seeding cannot be calculated; nonetheless, rainfall augmentation from tropical cumulus clouds was accomplished in a simple operational manner. Benefits derived, at least in part, from the project included marked improvement in the agriculture, increased sugar production amounting to 43 million U.S. dollars, and augmented crops of rice and corn sufficient to make anticipated importation unnecessary. In addition, local personnel were trained in seeding techniques. Because of the success of GROMET II the Government of the Philippines conducted a similar operation during 1970 and planned another for 1971.

**NWC Technical Publication 5097**

Published by .................................... Publishing Division
Technical Information Department

Collation .................. Cover, 58 leaves, DD Form 1473, abstract cards

First printing .................................... 500 copies

Security classification .................................... UNCLASSIFIED

NAVAL WEAPONS CENTER
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND
W. J. Moran, RADM, USN ........................................ Commander
H. G. Wilson ........................................ Technical Director

## FOREWORD

GROMET II was a rain enhancement project undertaken in the Philippine Islands at the request of the Philippine Government toward the end of a period of severe drought. The U.S. Air Force had operational responsibility for GROMET II, and the Naval Weapons Center provided technical direction under AIRTASK A5405401 216D 0W37170000, Airborne Pyrotechnic Seeding Devices, from AIR-540, Naval Air Systems Command.

Between 28 April and 18 June 1969, 58 seeding missions were conducted. Each had as its primary objective the production of useful rain. The testing and refinement of NWC-developed cold cumulus seeding procedures were secondary objectives. The extent to which each of these objectives was realized is the subject of this report.

Released by
PIERRE ST.-AMAND, *Head*
*Earth and Planetary Sciences Division*
12 April 1971

Under authority of
HUGH W. HUNTER, *Head*
*Research Department*

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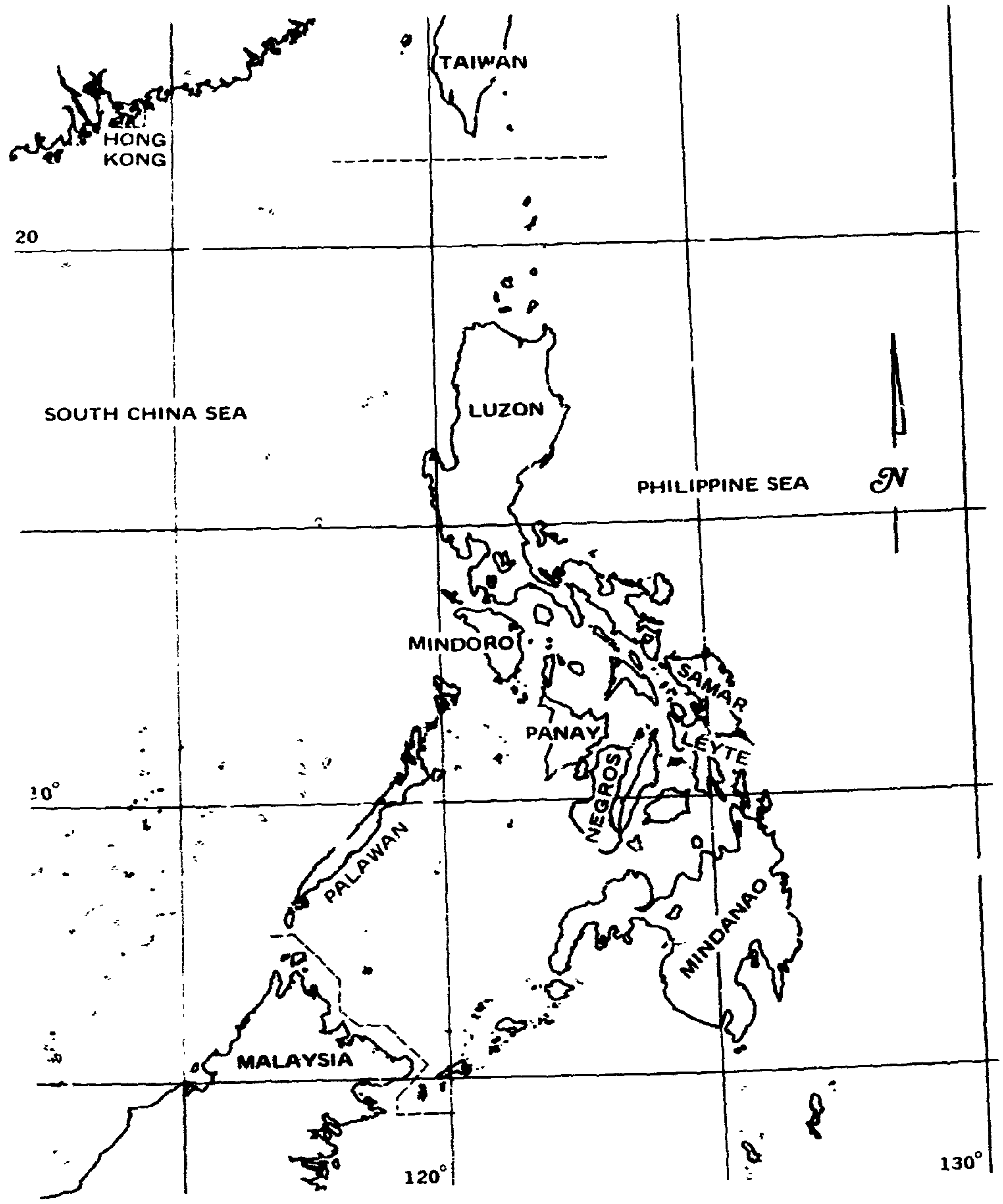


Philippine Islands.

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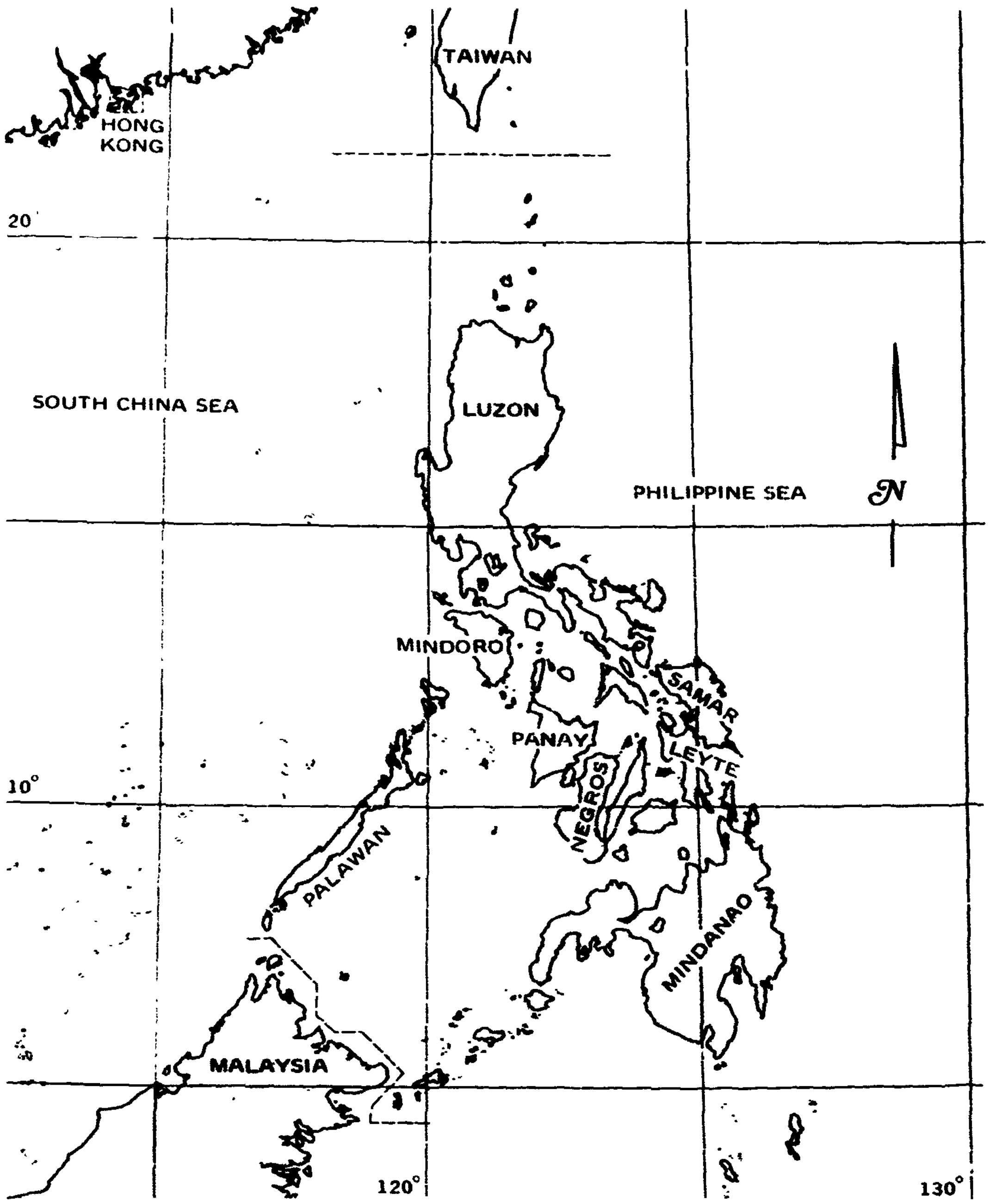


Philippine Islands.

## INTRODUCTION

This report describes GROMET II, the Philippine rainfall augmentation project conducted by units of the U.S. Air Force and the Naval Weapons Center with the cooperation of Philippine agencies from April to mid-June 1969. (The name of the project is derived from the words *agronomy* and *meteorology*.) Included in the report are discussions of data-gathering equipment, seeding materials and techniques, details of a typical seeding mission, and results from visual, rain-gauge, and radar interpretations of amounts of rainfall from treated clouds. The impact of GROMET II on Philippine agriculture is considered. GROMET II had the additional purpose of training local Philippine personnel in seeding techniques. Although GROMET II was not set up as a true experiment because of the urgency of the need for rain, guidelines are also given here for the conduct of a more rigorous cloud seeding experiment. A summary of all project operations appears in Appendix A. Appendix B gives some suggestions based upon experience from this project for the efficient conduct of future rainfall augmentation programs. Appendixes C and D are the observations of two meteorological consultants.

## BACKGROUND

The Philippine Islands, jewels of green in a calm blue sea, have been famous for the bounteous climate that furnished all the water needed for domestic and agricultural purposes and for the growing of some of the world's finest hardwood forests. With growing population and increased planting, however, water needs became critical, and water storage and distribution systems could not keep pace with the increased water demand.

Thus, in 1968 the country began to feel the effects of a gradually increasing drought. Still dependent upon natural rainfall, crops suffered, with great danger to the national economy (Ref. 1). The Philippine Bureau of Agricultural Economics estimated a drop of 8% in rice production. Reports from the Visayan Islands showed that Leyte faced a shortage of corn for the first time. The Philippine Sugar Institute concluded that the drop in sugar yield would prevent the Philippines from meeting the U.S. sugar quota and might lead to reduction of future sugar quotas. The availability of domestic and irrigation water was reduced. Operations at some mines were in danger of curtailment because of lack of water for milling and processing. As the season wore on and little or no rain fell between January and the end of April 1969, crops in the fields turned brown and died, and the soil became too hard to plow.

Public alarm became widespread, the Philippine Government moved to let a contract with a commercial firm to seed warm clouds over the sugar-producing areas, and a similar, larger effort was launched by the Philippine Air Force. From mid-March until the end of June, warm clouds were seeded at cloud tops at altitudes between 5,000 and 10,000 feet with brine solution, crystalline salt, or powdered urea.

Although this effort involving 196 flights was successful in producing rain, it was early recognized that locally available resources were inadequate to meet the widespread water requirements. Therefore, additional help was sought from the United States. Project GROMET II was the name given the U.S. project.

# PROJECT GROMET II

## ORGANIZATION

Project GROMET II was organized in response to a request for help from the United States from President Ferdinand Marcos of the Philippines. The request came through the U.S. Embassy in Manila and the U.S. State Department to the Department of Defense.

President Marcos appointed Mr. Edgardo Yap, his special consultant for water resources and an officer of the Philippine Sugar Institute, as his special representative to handle liaison with participating Philippine agencies. Control of the U.S. effort resided with the American Minister, Mr. James Wilson, U.S. Chargé d'Affaires. The Defense Attaché, COL Alfred Patterson, USAF, served as Project Director; COL Phillip Loring, USAF, 13th Air Force Director of Operations, was Project Coordinator; LTCOL Theodore Mace, USAF, Commander of Detachment 2, 9th Weather Reconnaissance Wing, was Operational Director; and Dr. Pierre St.-Amand of the Naval Weapons Center was Scientific Director.

Operational responsibility was assigned to units of the U.S. Air Force, and technical help was given by advisors from NWC. Clark Air Base (AB) on Luzon was the base of operations.

Participating Philippine agencies included the Philippine Air Force, the Philippine Weather Bureau, and the Philippine Civil Aviation Authority.

## AIR TRAFFIC CONTROL

Air traffic over the Philippines is not heavy, except around central Luzon where numerous commercial flights converge on Manila International Airport and military aircraft are operating out of Clark AB, Cubi Point Naval Air Station (NAS), Sangley Point Naval Station (NS), and Basa. Interisland traffic is modest.

It was decided, following discussion with civil and military authorities, to conduct the seeding operations under special visual flight rule clearances in a block airspace between flight levels 180 and 220 (18,000 and 22,000 feet).

To make effective use of airspace, the Philippine archipelago was divided into five areas. Clearance was granted by radio to utilize one or more of the GROMET II operating areas, occasionally dividing them into eastern and western portions.

Communications were available plane to plane and with Clark Approach Control, Clark Airways, Clark Weather Radar, Detachment 2 of the 9th Weather Reconnaissance Wing (Dodo Control), Manila Approach Control, Manila Center, and Cebu Center.

Navigational aids consisted of UHF tactical air navigation (TACAN) on Luzon, a few vortacs, and numerous nondirectional beacons. Navigation, especially pinpointing seeding locations, was frequently done by radar.

The U.S. and Philippine traffic control system functioned smoothly, and no difficulties were experienced in navigation or in air traffic control.

## EQUIPMENT AND INSTRUMENTATION

### Aircraft

Project aircraft were two WC-130 Lockheed Hercules aircraft sent to Clark AB by the 54th Weather Reconnaissance Squadron at Guam. The WC-130 (Fig. 1) is a four-engine turboprop transport capable of extended flight. Except for its cost (a less expensive aircraft could also be used), it is an excellent aircraft for cloud seeding and weather research.



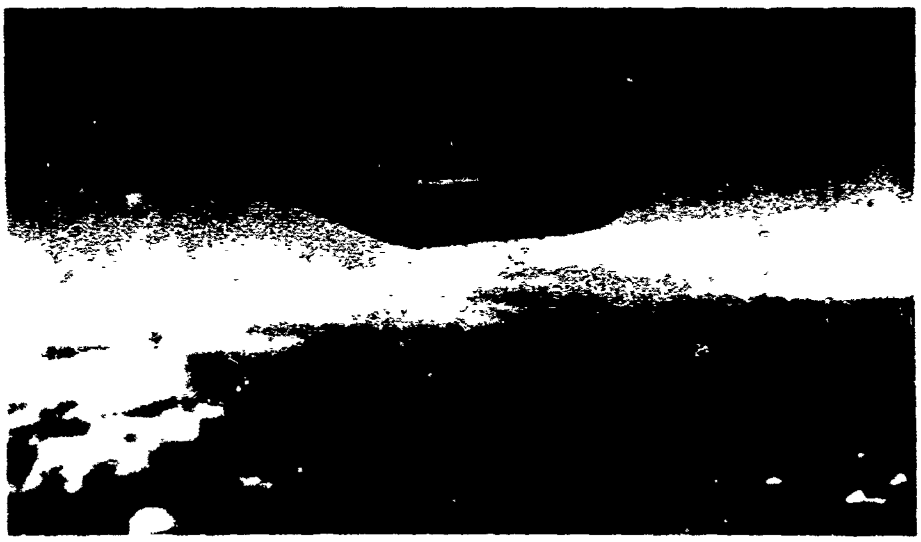

FIG. 1. WC-130 Aircraft Used on GROMET II Missions.

The two aircraft were equipped for cloud seeding by the addition of one or two 26-unit A-6 photoflash racks mounted on one or both sides of the plane below and aft the wings. The flight deck area of each plane had an opening for a standard Very pistol.

## Seeding Agents

Pyrotechnic seeding agents (Fig. 2) were used exclusively in GROMET II. These were fired from either a standard photoflash ejector rack or a standard Very signal pistol. (Fig. 3.)

Three different seeding agents were employed, LW83, EW20, and TB2. The compositions are given in Table 1, and the agents are described in detail in Ref. 2. The EW20 and TB2 agents differ only in type of polymeric binder. The charges are of pressed pyrotechnic. Silver iodate is reduced by a metal fuel and the binder to produce silver iodide, aluminum-magnesium oxide spinel, and, in the case of EW20 and TB2, some potassium oxide and a minor amount of potassium iodide.

The activity curves shown in Fig. 4 are considered the most reliable, although these values are a little lower at -20°C and higher at warmer temperatures than values sometimes given.

The smoke particles produced by the burning seeding agents are mainly between 0.05 and 0.1 micron in radius, with a relatively few particles approaching a 1-micron size. The LW83 produces a more monodispersed smoke than the other two

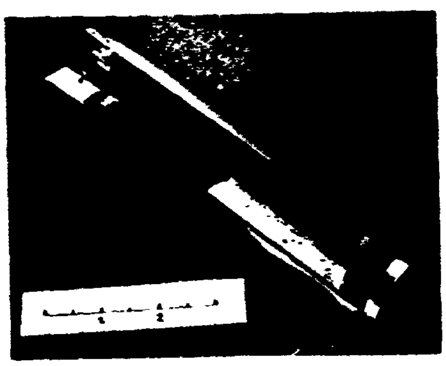

FIG. 2. Cutaway View of Dummy Pyrotechnic Round for the A-6 Photoflash Rack. Note simulated charge and balsa wood filler. Very pistol rounds are shorter and therefore require no balsa filler; they also have percussion rather than electrical primers.

FIG. 3. Weather Officer Firing Very Pistol in WC-130 Aircraft.

TABLE 1. Composition of Seeding Agents.

| Material | Composition, wt. % | |
|---|---|---|
| | LW83 | EW20 or TB2 |
| Precombustion: | | |
| Silver iodate | 78 | 28 |
| Aluminum | 12 | 11 |
| Magnesium | 4 | 11 |
| Potassium nitrate | 0 | 44 |
| Binder | 6 | 6 |
| Postcombustion: | | |
| Silver iodide | 79 (100 g) | 20 (20 g) |

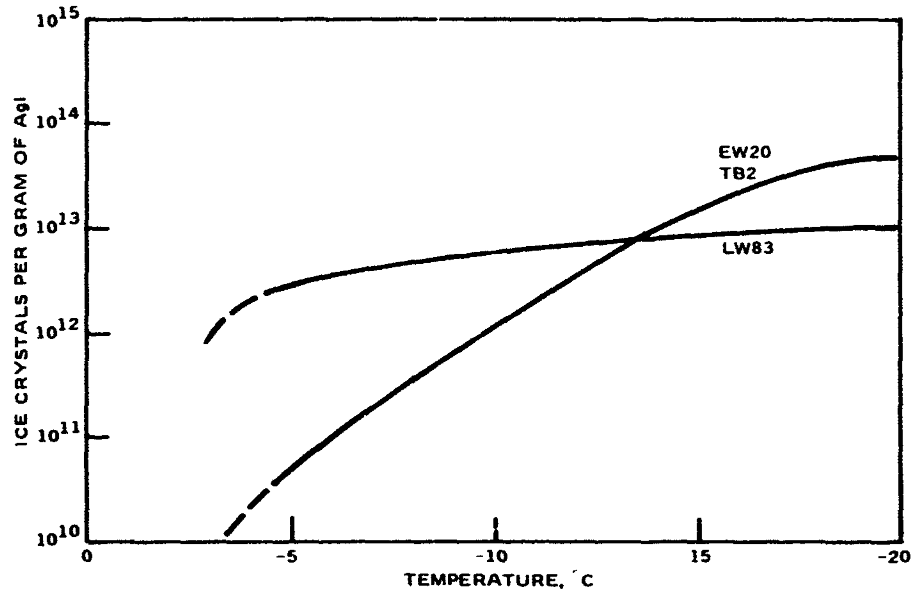


FIG. 4. Activity Curves for GROMET II Seeding Agents. Multiple cloud chamber determinations at South Dakota School of Mines made by John A. Donnan and Donald N. Blair (Ref. 3). Initial liquid water content is 3.0 g/m$^3$.

agents. The seeding devices are designed to fall for 6,000 to 8,000 feet while burning, so that when dropped at the -4°C level, most of the material is placed in warm clouds at altitudes below the freezing level. This permits the updraft to seed the subfreezing portion of the cloud for a period of 5 to 10 minutes after the original deposition.

With LW83 most of the nuclei work before the cloud reaches the -5°C level. This agent is very effective on marginally cold clouds with tops in the -2.5 to -4.8°C range, but is too active to be used on thin, isolated towers or on very cold clouds because the resultant growth is too fast. In general, LW83 devices were reserved for use on marginal targets or on well-established systems of moderate height.

The EW20 and TB2 agents produced slower effects and were commonly used on clouds that had already reached the -4°C level or were clearly going to do so in a short time. Also, because they were less expensive and less apt to cause overdosage, EW20 and TB2 were the materials of choice on most occasions.

The charges were, in general, too large in diameter and should be reduced for future operations. If they were carefully placed, one to four charges were more than adequate for a collection of several towers

## Data-Gathering Equipment

The aircraft were equipped with Rosemount Engineering Co. temperature gauges, with dropsondes, and with good, but uncalibrated, forward- and side-looking X-band radars (AN/APN 59). The radars were useful in estimating rainfall area and cloud turbulence as well as in navigation.

Figure 5 shows a Minilab data-gathering device manufactured by Weather Science, Inc. (WSI), Norman, Okla.[1] The Minilab console was installed abaft the

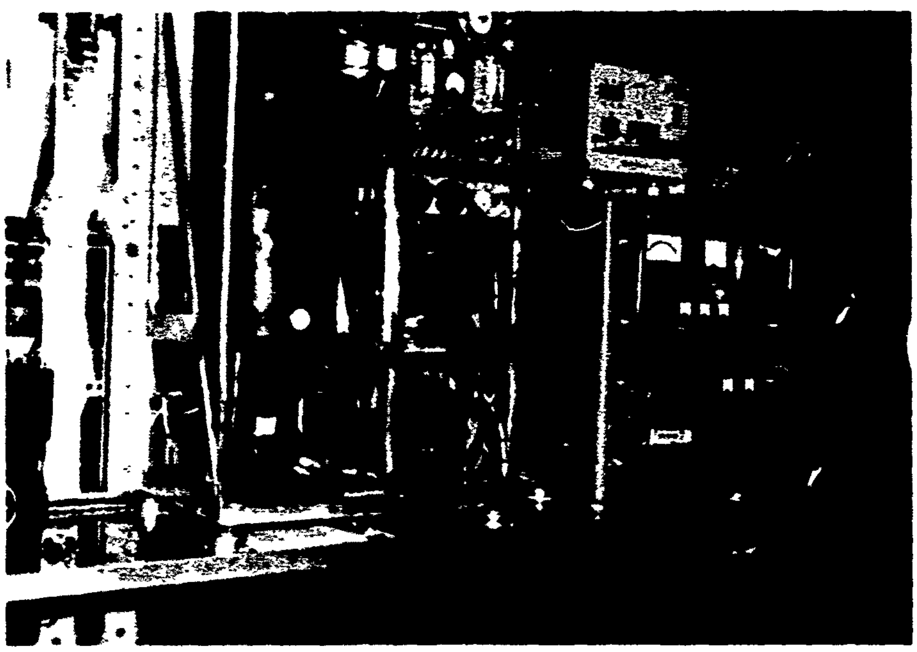

FIG. 5. Minilab and Ice Nucleus Counter in WC-130 Aircraft. Magnetic tape and strip chart recorder are on top of Minilab.

[1] Weather Science, Inc., Manual "A" Theory of Operation and Maintenance WSI Airborne Meteorological System Serial Number 11-15. Research Park, Norman, Okla., WSI. Naval Weapons Center Contract No. N0012367-C-3007.)

cockpit bulkhead on a table mounted on the cargo deck. This console was connected to sensors mounted on the outside of the aircraft (Fig. 6).

Cloud-physics and aircraft-flight data gathered for each sortie included liquid water content, temperature, rain rate, airspeed, altitude, and rate of climb. Supplementary visual and observational data were recorded as coded digital indices put into the system by the Minilab operator by means of a knee pad with numbered push buttons. All this information was displayed on a strip chart and recorded on digital magnetic tape for later reduction by computer. Figure 7 is a portion of a Minilab record.

A WSI continuous ice nucleus counter of the National Center for Atmospheric Research-Bollay type was also installed in the aircraft (Fig. 5). The counts were automatically recorded on the digital tape, and an aural output was available for use over the aircraft intercom system.

The only ground radar suitable for following storms was the C-band weather radar (AN/FPS 77V) belonging to base weather at Clark AB.

FIG. 6. Outside Installation of Minilab Sensors. Rain-rate sensor is on top. Johnson-Williams liquid water content gauge in center, and reverse-flow-thermometer housing below.

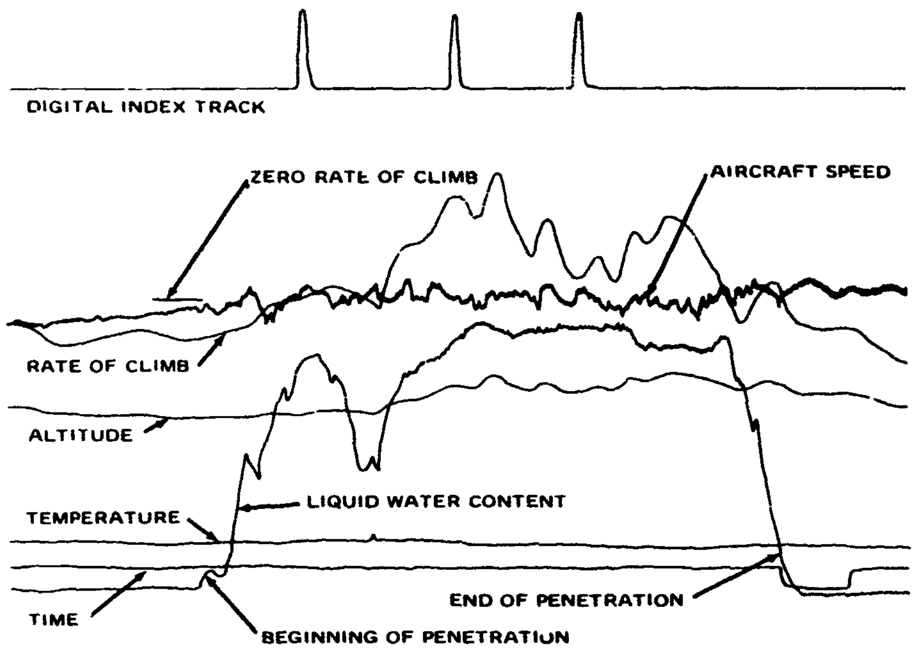


FIG. 7. Partial Reproduction of a Minilab Strip Chart Corresponding to Seeding Penetration Over Baguio (Mission 19, 11 May 1969). Note moderate downdrafts immediately outside the cloud and the strong, sustained, and erratic updraft within the cloud. The digital-index track indicates three shots were fired in the cloud, one in a region of high liquid water content and two in the strong updraft.

## PROJECT OPERATION

### Typical Day's Activity

A typical day's operation began with a morning briefing conducted at Clark AB at least 2 hours before takeoff. The synoptic situation over the whole of Southeast Asia and the southwestern Pacific, with emphasis on the Philippines, was given; wind-flow charts at various altitudes, temperature and humidity profiles, satellite photographs, and forecasts for the day were presented. In spite of the meager data available, these forecasts were remarkably good. At first they tended to underestimate the degree of cumulus development, but as the project progressed, the forecasts improved to the point that the predictions of degree of cloud growth and isolation and of times and places of occurrence were as good as needed, and even the extent of seedability was called out with a high degree of reliability. These forecasts were more than adequate for operational decision making.

On the basis of the forecast, pilot reports of cloud occurrence, and word as to the need for water in certain locations, the NWC crew selected the seeding areas for the day, assigned seeding advisors to the aircraft, and specified ordnance loads. Aircraft and crews were assigned to the selected areas; and communication procedures, operational restrictions, special instructions, and emergency procedures were agreed upon.

In keeping with the training function of GROMET II, an instructional session for new personnel and visitors was held after the briefing. The theory and practice of cloud seeding, ammunition handling, and flight procedures were covered.

At approximately 1000 local standard time (LST) the planes took off and proceeded to their assigned areas. Departures were timed so that aircraft arrived on target before cumulus growth had become well established. If takeoff was for any reason delayed, the operational area was changed to one near enough to be reached in time.

Just after takeoff the aircraft flew out over the ocean, and on climb-out fired one or more seeding rounds from each rack while in a tight turn. This permitted visual check-out of the ejection and ignition of the seeding cartridges. The aircraft then climbed to 18,000 feet and proceeded to the target area.

If possible, a dropsonde was released en route, and the data were reduced. The weather officer made periodic observations as well as special observations in each region seeded.

Once a target cloud or cloud system had been selected, seeding was done by the crew. The cloud-top height was estimated, and the seeding altitude and outside air temperature at drop were recorded. The navigator recorded the position of each shot, and, when possible, the laboratory gear was activated. Emphasis was placed on seeding of clouds over agricultural land and on developing isolated clouds by merging them into active mesoscale systems.

If time and terrain permitted, so-called rain runs, descents to observe and measure rain below seeded clouds, were made.

Occasionally the two aircraft operated as a team, one going in first to initiate growth in clouds and the other following 15 minutes later to build up the clouds more and to join them into systems.

Operations continued until new cloud growth seemed over for the day or darkness was beginning to fall. During the return flight targets of opportunity were seeded, and if possible, an additional dropsonde was released.

At the end of the flight a debriefing was held in which working areas were described, results estimated, and difficulties discussed. Plans were then outlined for the following day.

## Training

During GROMET II every opportunity was taken to teach the local people how to seed clouds for rain augmentation. Fifty Philippine officials, Air Force pilots, and Weather Bureau personnel were given instruction in cloud physics and cloud seeding theory and techniques and were taken aloft on operational missions.

On a typical mission the first target selected was usually an isolated cloud tower so that seeding effects could be observed and described in detail. The mission then proceeded with a discussion of each target cloud and the strategy to be employed. After an hour or more, the students were given a chance to select and seed targets.

The response to this approach was remarkable. After two hours of work the students not only were convinced that the techniques worked but became enthusiastic about it. Both Air Force and Weather Bureau personnel developed a keen interest in the processes, and the basis for further training in case of need was firmly laid. As it happened, a number of the trainees were participants in the 1970 follow-on program financed by the Philippines. Thus, the technology was transferred to the host country for them to use if needed and desired.

## PHILIPPINE METEOROLOGICAL SITUATION

### METEOROLOGICAL PERIODS

Two distinct meteorological periods occur each year in the Philippines: the southwest monsoon, from July through September, and the trade-wind epoch, from December through April. During the southwest monsoon period a gentle southwesterly flow sets in, giving widespread layer cloudiness associated with zones of maximum wind speed. Frequent, extensive, and protracted rain showers are common. Owing to pulses in the flow, however, rainy periods may alternate with dry periods of several days to 2 weeks. The southwest monsoon affects most of the islands, although the southernmost are thought to lie at times in a rain shadow from Borneo and the Celebes.

During part of the trade-wind epoch, in December and January, a small northeast monsoon moves over the northern islands. This period is characterized by low clouds, cumulus activity, and infrequent, but heavy rain. A strong subsidence inversion develops (Fig. 8) with cloud growth capped by the inversion, above which lies warmer, drier air. As the season wears on, the inversion lifts, and a more isothermal region is established.

The intertropical convergence zone moves northward about this time. Clouds develop along coastal hills and are markedly affected by the presence of mountains in the area (Fig. 9). The period of May and June, in which most of GROMET II was carried out, has a gradual transition to the southwest monsoon. Atmospheric soundings for typical dry and moist days during this transitional period are shown in Fig. 10 and 11.

Wide seasonal and geographic changes are reflected in the rainfall. Typical data are summarized in Table 2. Cited cities are shown in Fig. 12. It must be remembered that rainfall in the Philippines is usually measured at the larger cities, mostly on the seacoast. Hence, the statistics more accurately represent rainfall from monsoons and typhoons rather than that from cumulus activity.

The effects of the southwest monsoon are clearly seen in the records from Manila and Baguio for July through September. Baguio has a strong orographic enhancement of rainfall most of the year. Dumaguete, on the east coast of southern Negros, lies in local and regional rain shadows, has relatively little rainfall by

Philippine standards, and has almost no annual variation. On the other hand, Borongan, on the east coast of Samar, develops most of its rainfall during the trade-wind epoch. Casiguran, on the east coast of northern Luzon, has a clear addition to its rainfall during the short northeast monsoon.

## A NATURAL RAINFALL PROCESS

During the period of the year in which a strong subsidence inversion covers the archipelago, cloud growth is limited by the inversion, and clouds rarely reach altitudes great enough to permit a vigorous coalescence process to take place. Because the condensation nuclei on which water droplets form are numerous and updrafts are limited, the cloud droplets do not have a good chance to grow to sizes large enough to permit high fall rates and effective capture of other drops.

Occasionally, in one of the more important rain processes, one tower will rise above the others and, by slightly greater vigor, penetrate the inversion layer. The cloud, while growing, has a fine white appearance and after a while reaches the apex of its ascent, remaining well above the others. As the smaller droplets evaporate, the appearance of the mass changes to a wispy striated gray. Shortly after, cooled by evaporation of the smaller droplets, the tower falls rapidly into the mass beneath. The lower mass darkens as falling drops grow by incorporating smaller, more slowly falling drops, and a shower develops. No ice is necessary to this process. Indeed, the Bergeron-Findiesen process plays little or no role in the clouds over the Philippines because these clouds are usually ice-free even at altitudes to 30,000 feet.

## CLOUD SEEDING TECHNIQUES

In general, cloud seeding involves locating updrafts in clouds and releasing small amounts of seeding material into the updrafts. The seeding agent causes supercooled drops to freeze, releasing heat of fusion and setting in march a more rapid condensation of water vapor on the frozen drops than is possible on the liquid droplets, with, of course, concomitant release of heat of condensation at a greater rate. The heating makes the air more buoyant, and the updraft is increased, sucking in more air from below and causing increased condensation throughout the ascending column.

The techniques of seeding cumulus clouds, as used in GROMET II, represent a combination of the best features of a number of seeding methods developed by NWC and by commercial cloud seeders.

Such cloud seeding is not difficult; the proper procedures can be learned by an intelligent, instrument-rated pilot in about 4 hours and can be developed to a high degree of skill after a week's practice. Specific procedures for handling the aircraft are given in a later section, Flight Procedures in Cumulus Penetration. Seeding

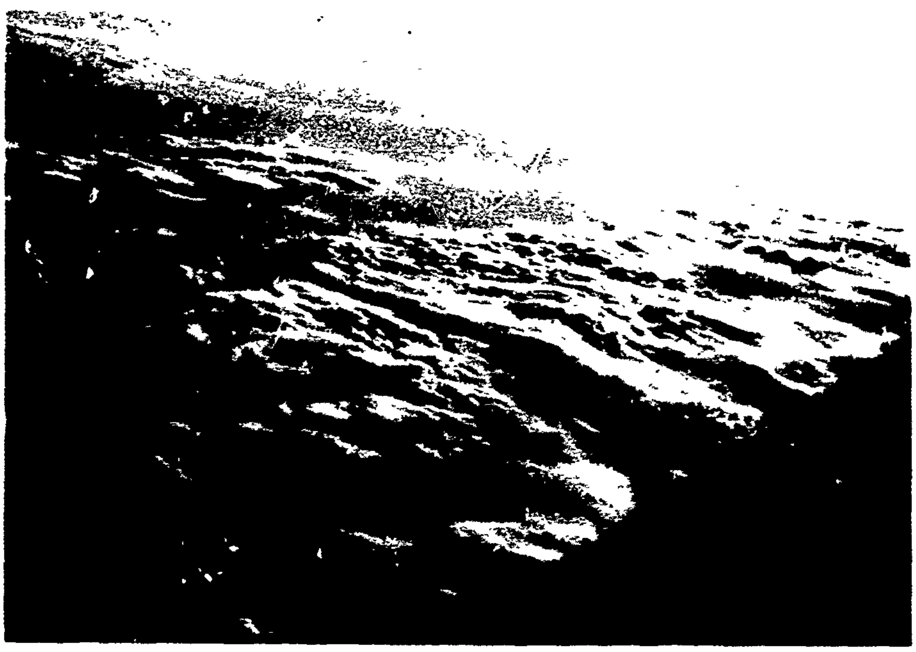

FIG. 8 Mission 2, 1745 LST. Inversion capping air polluted by smoke, with small stratocumulus developing on inversion top. Cumulus growth under these conditions is unlikely. Photographed from 19,500 feet over Negros Island, looking north toward Guimaras Island.

FIG. 9. Visayan Sea, Looking North From Negros. Note development of clouds over islands. Wind is light and variable; air is moist and unstable.

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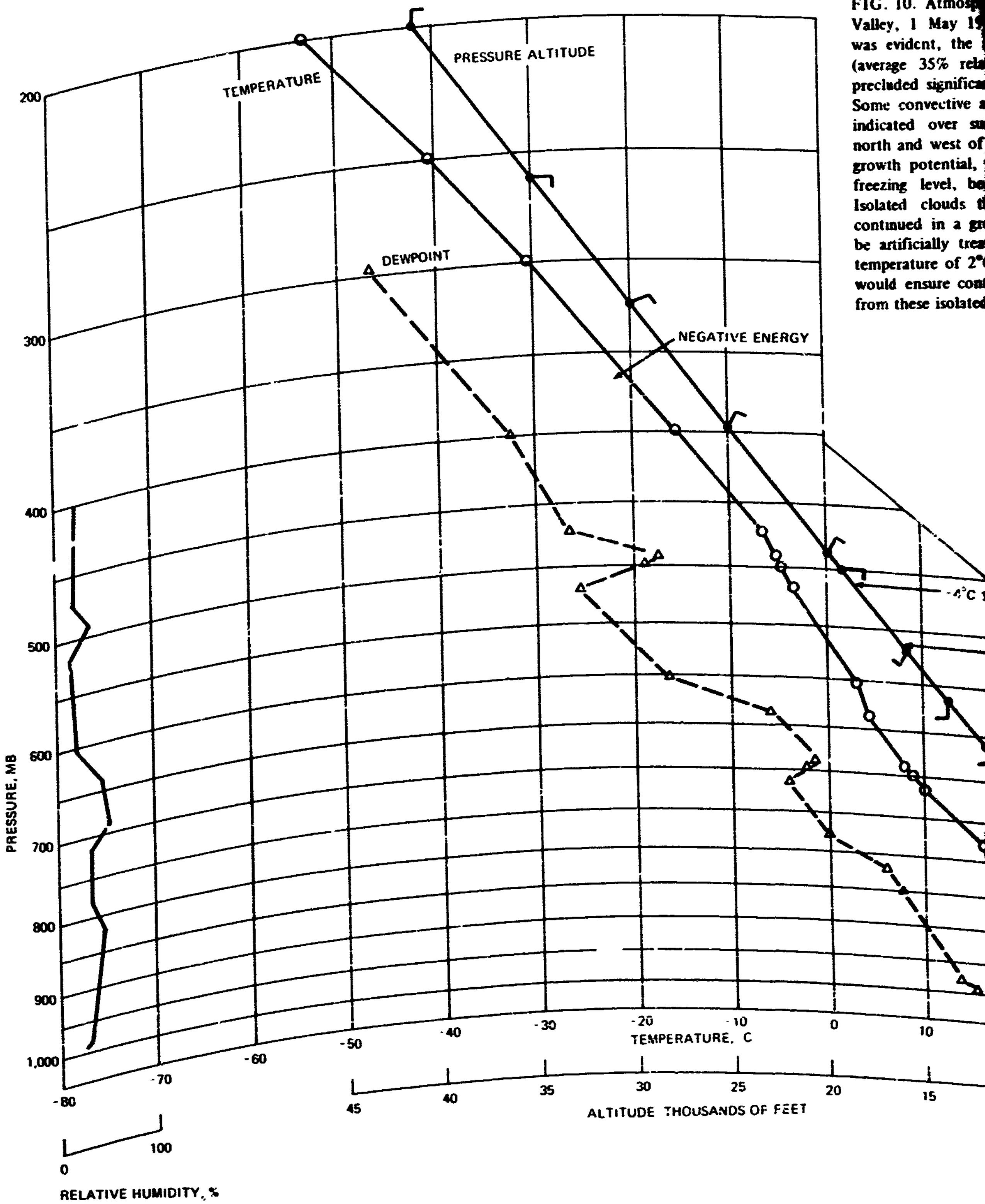


FIG. 10. Atmosp
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FIG 10. Atmospheric Conditions Over Central Luzon Valley, 1 May 1969 While sufficient low-level instability was evident, the absence of adequate low-level moisture (average 35% relative humidity in lower 100 millibars) precluded significant cumulus development over the valley. Some convective activity caused by orographic lifting was indicated over surrounding mountains, primarily to the north and west of Clark AB. This activity would have little growth potential, with few clouds expected to exceed the freezing level, because of the lack of instability aloft. Isolated clouds that did exceed the freezing level and continued in a growth state through the -3°C level could be artificially treated at that point. An increase in cloud temperature of 2°C, with the release of the heat of fusion, would ensure continued growth and localized rain showers from these isolated cells.

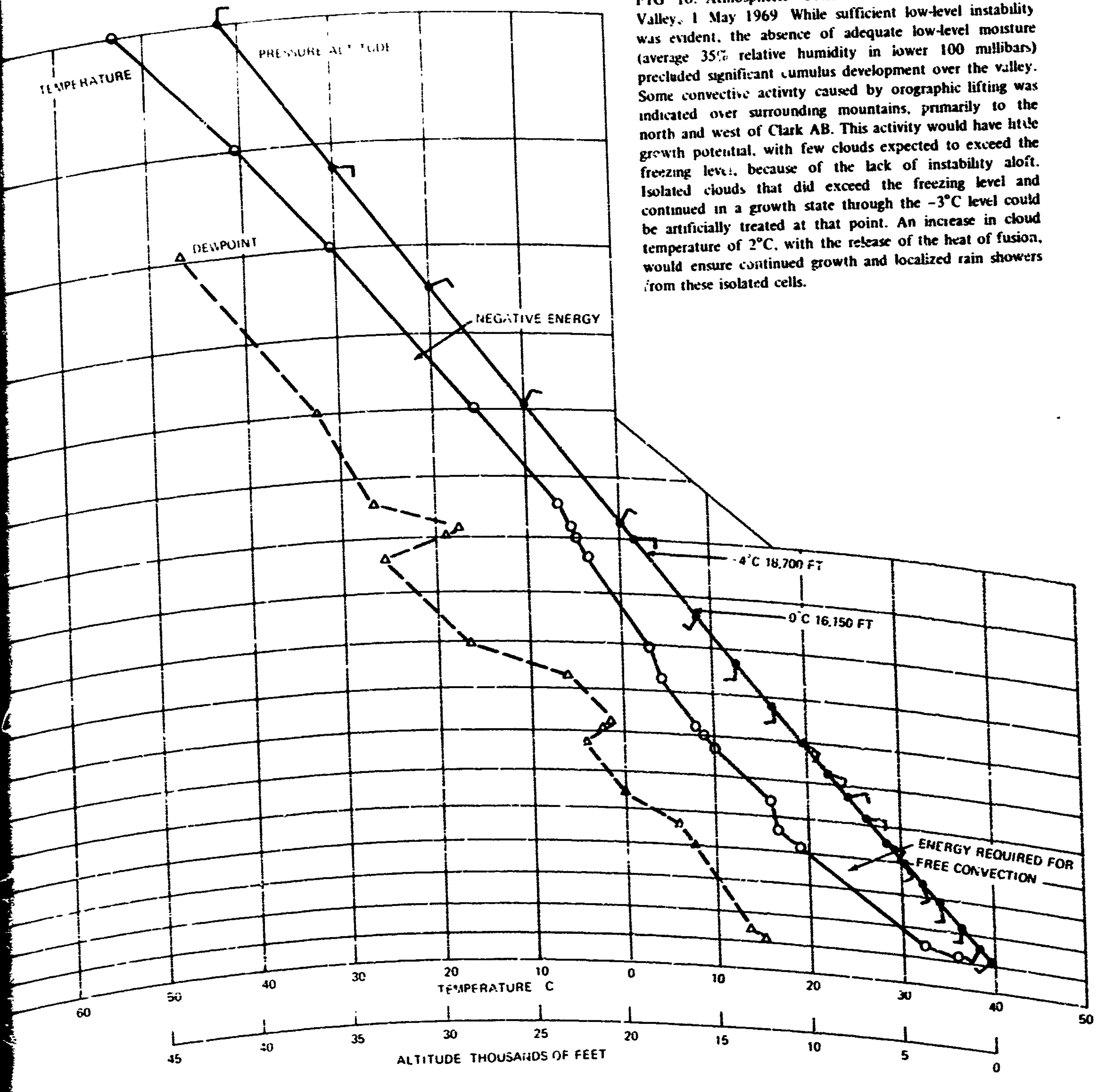
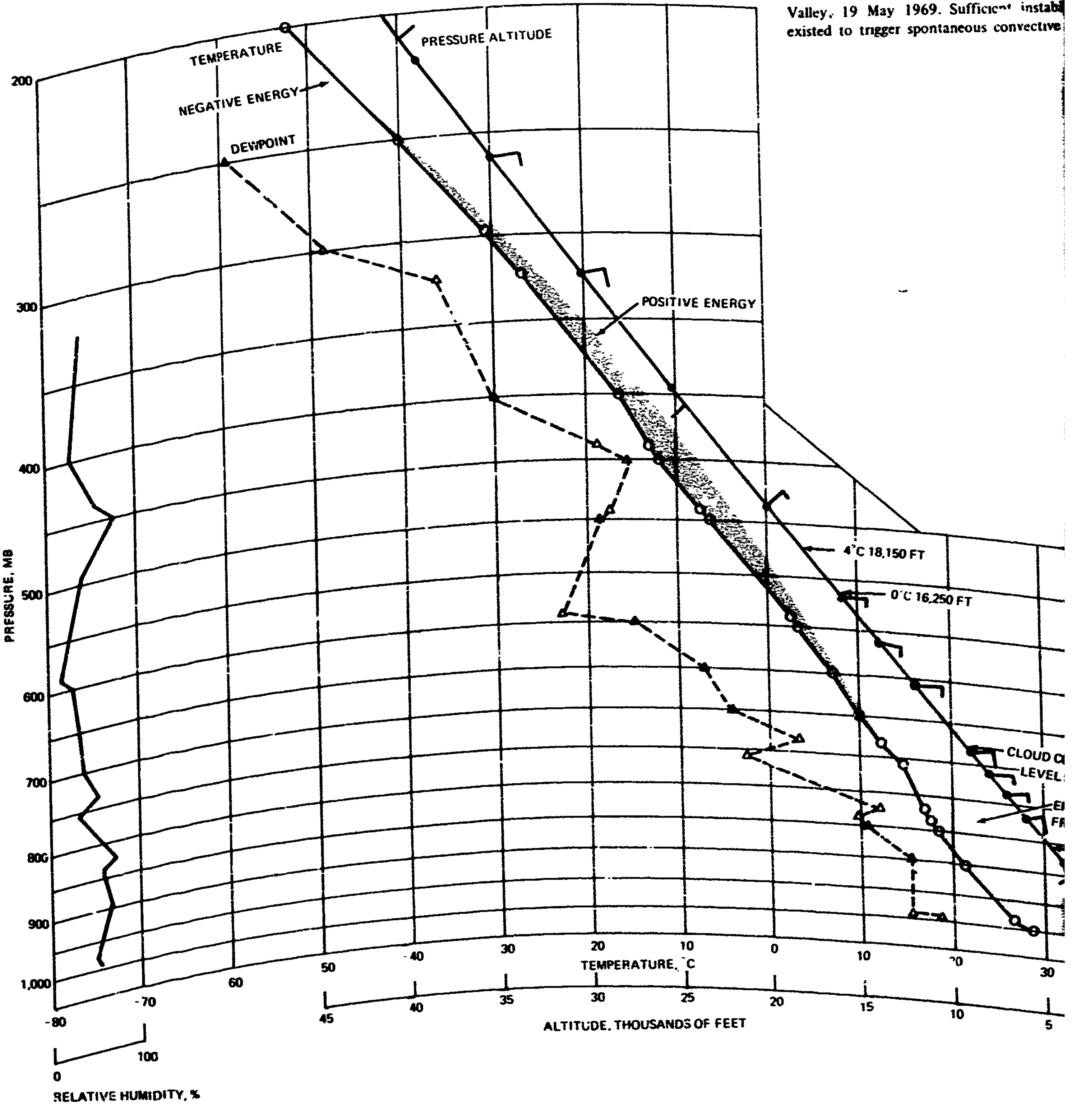


FIG. 11. Atmospheric Conditions Ov[er] Valley, 19 May 1969. Sufficient instabi[lity] existed to trigger spontaneous convective



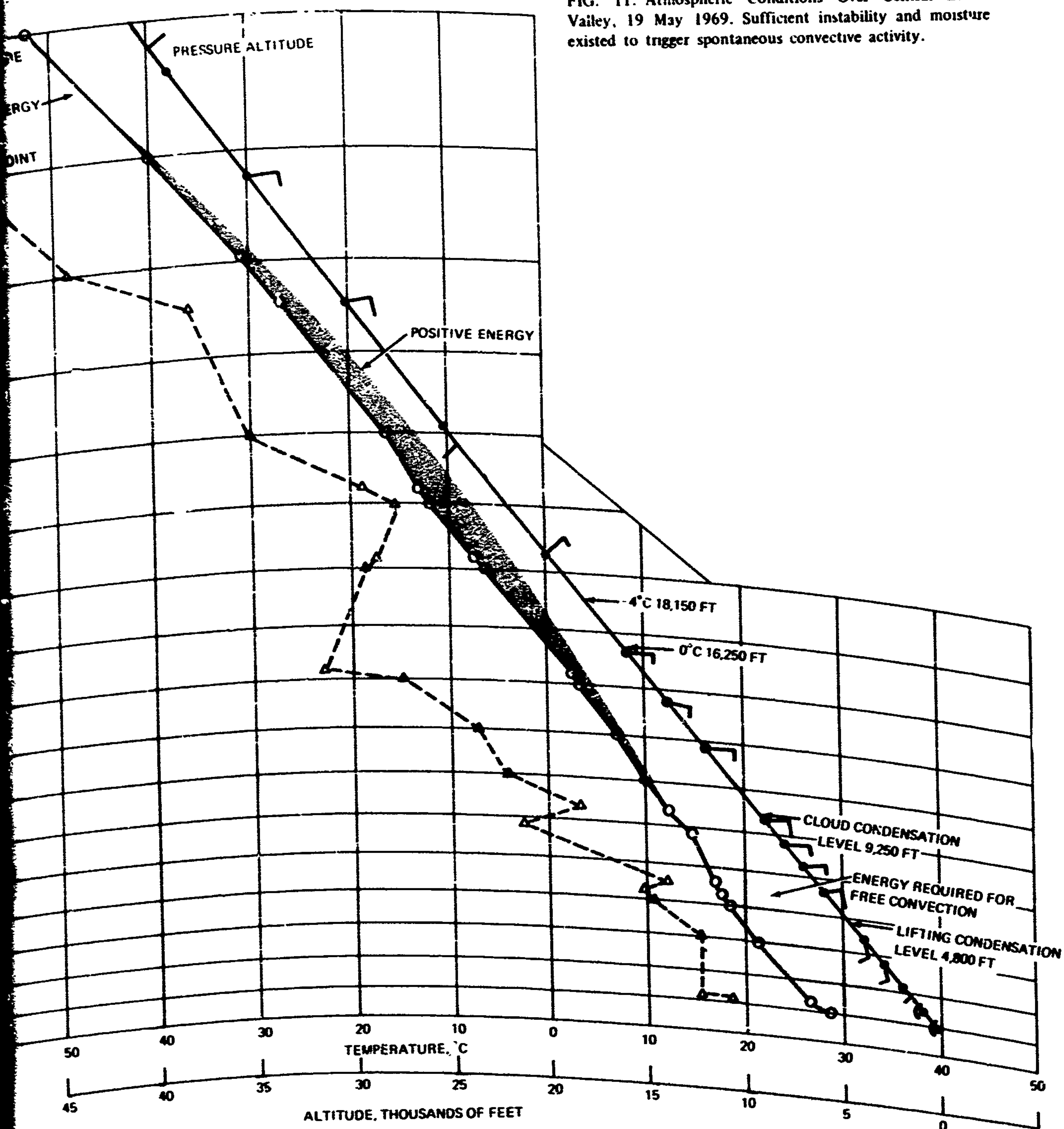



FIG. 11. Atmospheric Conditions Over Central Luzon Valley, 19 May 1969. Sufficient instability and moisture existed to trigger spontaneous convective activity.

TABLE 2. Mean Monthly Rainfall for Selected Philippine Cities.

| Period | Mean rainfall, in. | | | | |
|---|---|---|---|---|---|
| | Manila | Baguio | Dumaguete | Borongan | Casiguran |
| Tradewind: | | | | | |
| Dec. ........... | 2.5 | 2.0 | 5.1 | 25.3 | 15.5 (Northeast monsoon) |
| Jan. ........... | 1.0 | 0.9 | 4.5 | 25.3 | 7.1 (Northeast monsoon) |
| Feb. ........... | 0.5 | 0.9 | 3.1 | 17.3 | 9.1 |
| Mar. ........... | 0.7 | 1.7 | 2.1 | 12.9 | 12.2 |
| Apr. ........... | 1.2 | 4.3 | 1.8 | 10.3 | 5.4 |
| Transitional: | | | | | |
| May ........... | 5.1 | 15.8 | 4.3 | 9.6 | 9.1 |
| Jun. ........... | 9.9 | 17.2 | 5.3 | 9.3 | 8.3 |
| Southwest monsoon: | | | | | |
| Jul. ........... | 17.0 | 42.3 | 5.6 | 7.4 | 9.1 |
| Aug. ........... | 16.0 | 45.7 | 4.3 | 5.7 | 10.9 |
| Sept. ........... | 14.4 | 28.1 | 5.5 | 7.2 | 12.1 |
| Transitional: | | | | | |
| Oct. ........... | 7.8 | 15.0 | 7.7 | 13.0 | 13.1 |
| Nov. ........... | 5.6 | 4.9 | 5.8 | 21.2 | 25.0 |
| Annual ........... | 81.7 | 178.8 | 55.1 | 164.5 | 136.9 |
| Number of years observed ....... | 73 | 36 | 27 | 36 | 10 |

success is based on visual observation of the clouds, interpretation of the airflow in and around the clouds, and placement of the seeding charges so that the processes causing cloud growth are augmented. Figure 13 shows this growth.

Timing and restraint are important. Growing towers, recognizable by their hard, cauliflower-like appearance, should be seeded just as they pass the -3°C level and before they have begun to stabilize or fall back. Restraint is necessary to preclude too rapid growth, which causes spindly towers (Fig. 14) to break off at midcloud level and separate, and also to prevent overseeding to such an extent that an outflow shield develops.

The most productive technique is to cause neighboring clouds to join, thereby increasing the areal extent without causing growth to more than about 28,000 or 30,000 feet of altitude. Fine examples of this are shown in Fig. 15 and 16.

The procedure of seeding the updrafts of clouds minimizes the energy dissipated in turbulence and in changing momentum so that only delicate treatment is necessary. It is unproductive of rain to seed the whole cloud top because such overseeding induces too rapid growth, which results in disturbing the internal organization of the cloud and the air currents sustaining it (Fig. 17).

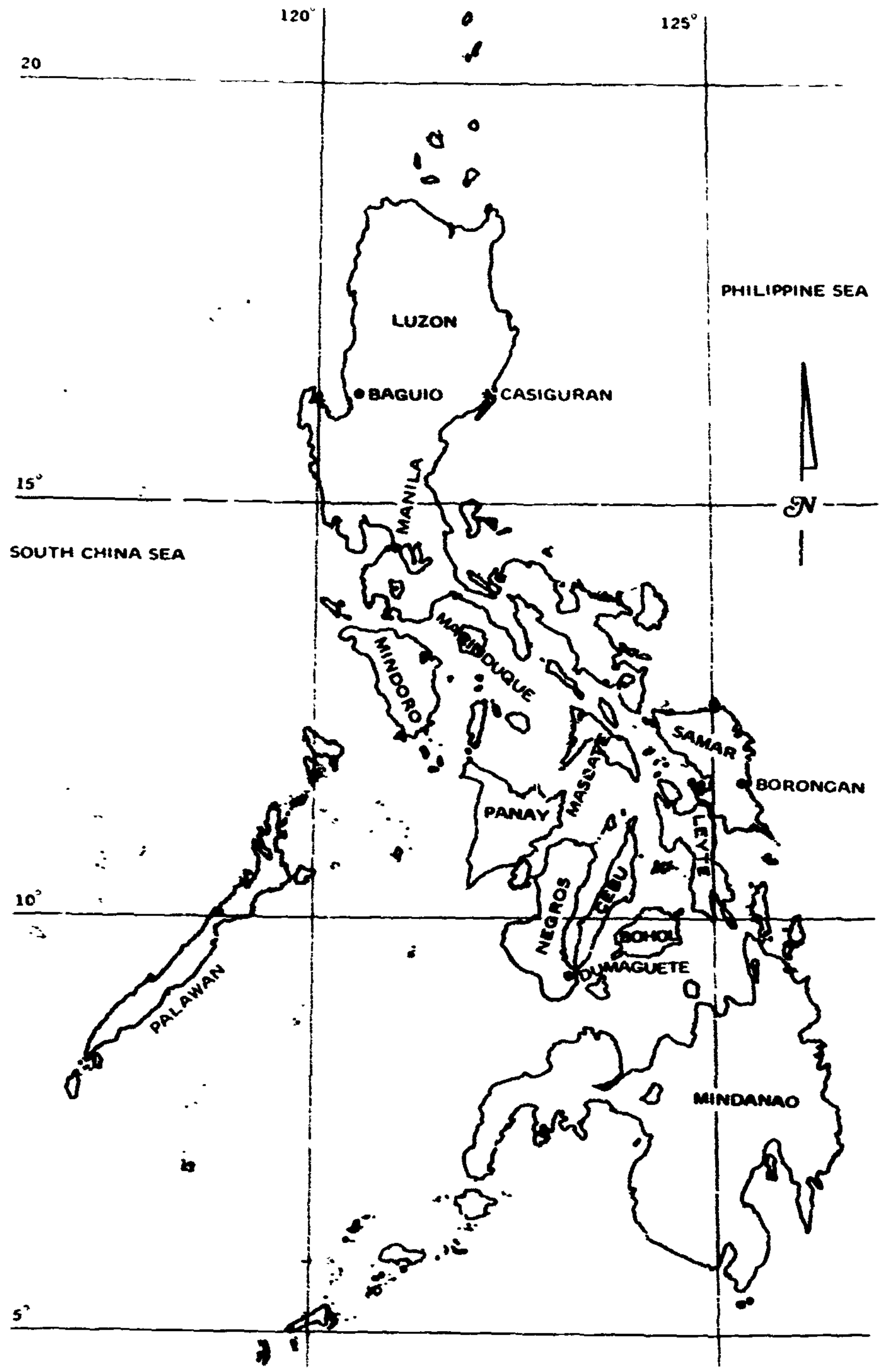



FIG. 12. Philippine Cities Cited in Table 2.

## WIND SHEAR CONDITIONS

While almost all seeding of GROMET II was done between the -2°C and the -7°C level, the method of emplacement of the charges depended on the type of cloud and the wind shear. Different wind shear situations required different techniques. Three of these conditions are illustrated in Fig. 18 under arbitrary categories Class A, Class B, and Class C clouds.

### Class A Clouds

For clouds of Class A, where the wind shear was insignificant, the usual approach was to select an altitude as near the -4°C level as possible and fly over the cloud top or penetrate the tower at that altitude.

Generally, when Class A clouds (Fig. 19) occurred as isolated towers, they were seeded if they were more than 1 1/2 nautical miles in diameter, although some smaller towers were seeded. The penetration technique was to approach the cloud (Fig. 20) at a safe-penetration airspeed, with power and trim adjusted for level flight at a distance of several nautical miles from the cloud. From that time on, the pilot carefully maintained the same attitude that had been set up after power adjustment. The aircraft was headed toward the cell, and the course was adjusted so that penetration would occur in the most vigorously growing portion.

Before entry into the cloud, as the aircraft came within a distance of one to one-half cloud radius, a downdraft was usually observed. Just before entry the data-recording apparatus was placed on high paper speed. When the cloud was entered, it could be seen that individual turbulent rolls in the cloud were moving up, but that the air around the outside was moving down with respect to the ascending roll. Some turbulence was noticeable, but the general up- and downdrafts were light. A few seconds after penetration a hard jar was felt, followed by a sustained updraft. Continuing to fly attitude rigorously, the pilot used only the gyro horizon and gyrocompass and ignored altitude and rate of climb. Once the updraft was well identified, one seeding cartridge was fired. After 3 to 5 seconds the aircraft penetrated the updraft core. The core was easily recognizable because abundant liquid water in the form of large drops appeared on the windshield and there was occasional icing. Liquid water content jumped from less than 1 $g/m^3$ to from 1.5 to 5 $g/m^3$. It was found that if the amount of liquid water was small, say less than 1.5 $g/m^3$, or if the updraft velocity was less than 200 ft/min, seeding did not result in appreciable cloud growth.

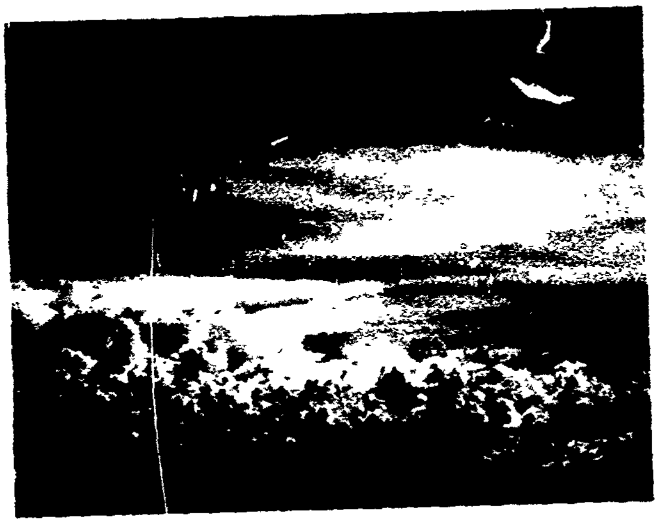
Normally, the forward speed of the aircraft, about 200 knots true airspeed (TAS), carried the projectile into the updraft core. If the updraft core was adequately wide so that the liquid water content reading remained high for 10 seconds after the first shot, a second shot was sometimes fired.

The liquid water content gradually diminished as the plane flew through and past the core; the updraft decreased slightly, until suddenly there was another hard jar, the aircraft began to drop to level flight, and the updraft changed to a more turbulent regime. A few seconds later the aircraft broke into the clear, and a sustained downdraft was encountered.

(a) 1212 LST. Area on north coast of Mindanao looking east before seeding. Average clouds reach 18,000 to 20,000 feet.

(b) 1311 LST. Photographed from same position as view (a), same area after seeding: large, well-developed cumulonimbus dominates area.

FIG. 13. Examples of Cloud Growth, Mission 61, 18 June 1969.



(c) 1311 LST. Similar area, over Calabugoa Plains, near area of (a) and (b) but not seeded. Clouds show only slight growth.

(d) 1345 LST. Slightly more distant view of (a) and (b). Cloud growth is continuing well.

FIG. 13. (Contd.)

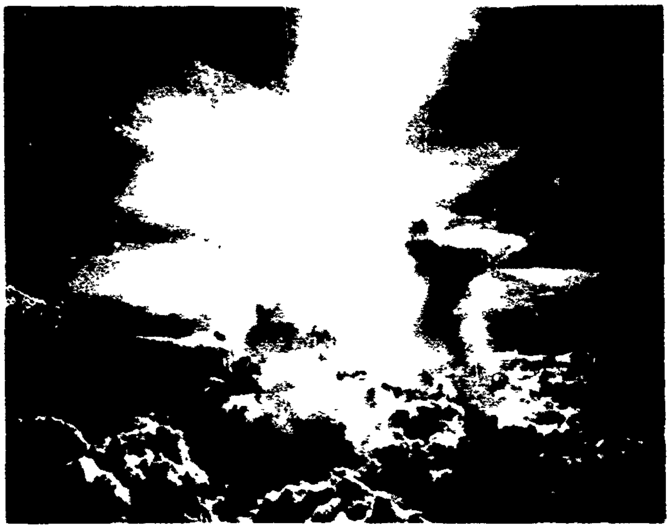


FIG. 14. Mission 26, 15 May, 1538 LST. The isolated high cloud with virga was originally the top of the diffuse tower in the near center of the picture. After the top was seeded, it rose rapidly and pulled away and was blown to the right by the wind, which increased sharply in velocity just above cloud top.

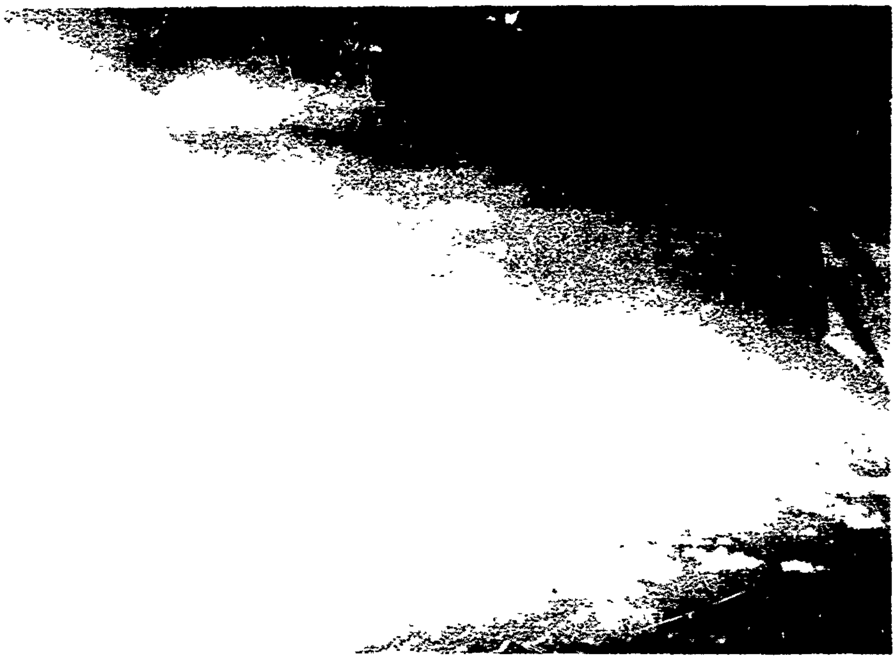


FIG. 15. Mission 5, 30 April 1969, 1550 LST. Mass of clouds grown together into a large flat-topped storm.

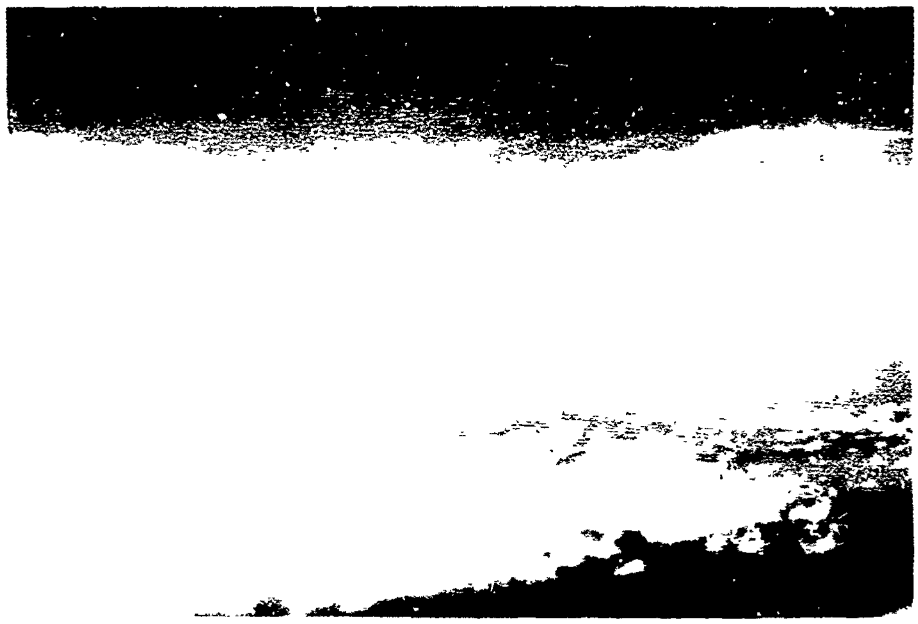


FIG. 16. Target 35c, 27 May 1969. Zamboanga Peninsula, western Mindanao. Line of clouds fused into single mass 10 by 150 nmi. Growth limited to about 25,000 feet. Moderate to heavy rain fell for more than 3 hours.

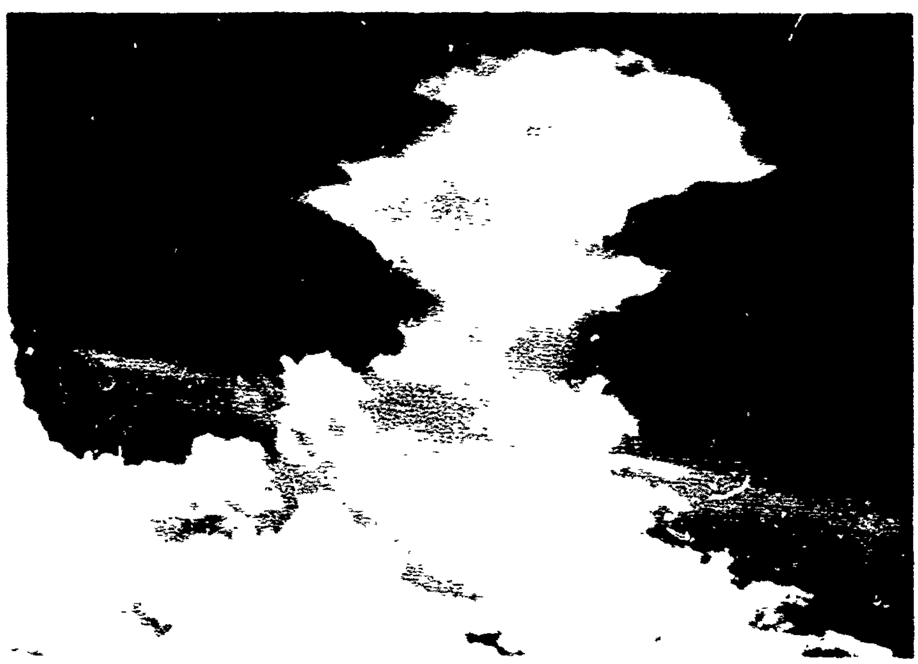
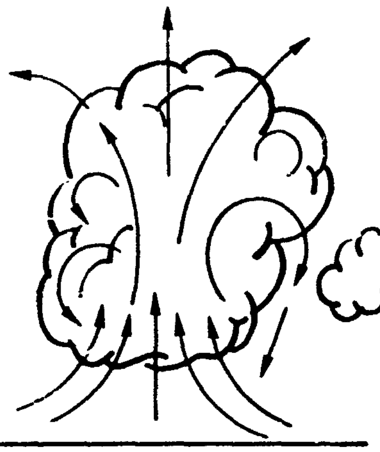
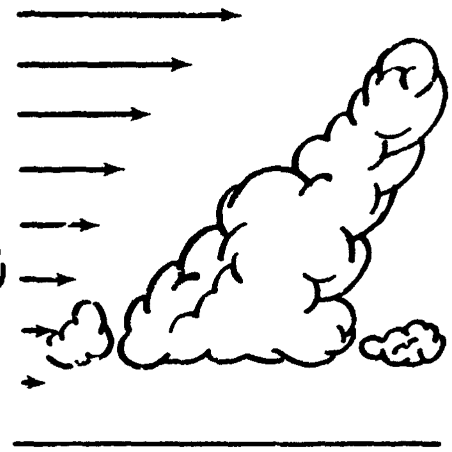


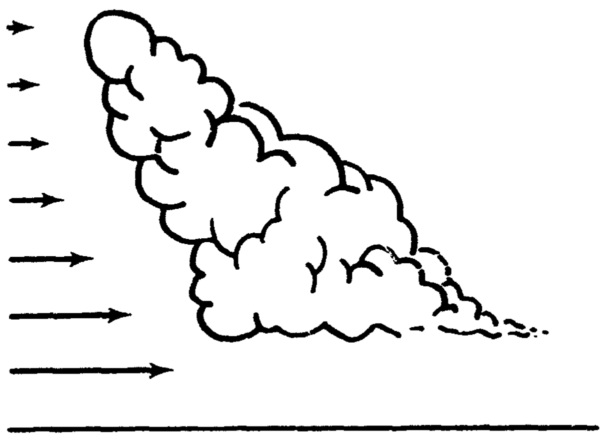
FIG. 17. Mission 14, 1329 LST, Southwest Panay; Top of Overseeded Cloud Blowing Off.



(a) Zero wind shear (Class A clouds).



(b) Wind increases with altitude (Class B clouds).



(c) Wind decreases with altitude (Class C clouds).

FIG. 18. Various Wind Shear Conditions.

Ordinarily, the pilot would fly the aircraft away from the cloud for about 1 minute and then make a 90- to 270-degree turn to look back at the point of penetration. In almost every case enhanced growth of the tower could be noted on completion of the turn. Such towers (Fig. 21) were not seeded again until considerably more growth had occurred and adventitious towers at the sides had begun to develop.

By the time of reentry and repenetration of the updraft there was usually a notable increase in turbulence, in liquid water content of the updraft, and in updraft velocity. In addition to the increase in liquid water, large particles of graupel formed against the windshield and stuck, the water running off the dark ice particles that slid slowly along

FIG. 19. Cloud Over Trough of Philippine Fault Zone, Bicol Peninsula. Central tower seeded with one shot. Tower on right in collapsing state. Typical cloud from which moderate growth and limited rainfall may be expected.

Repeated attempts to measure ice nuclei in such towers failed, primarily because of rapid uptake of the nuclei by droplets or growth of ice embryos thereon. Nuclei were always found in clear air tests and around the periphery of seeded rain showers at cloud base.

Seeded single small turrets of at least 1 to 2 miles in diameter grew rapidly–at rates of about 1,000 to 2,000 ft/min–and had some increase in diameter. The growth would proceed for a few minutes, the appearance of the upper part would change from a hard, cauliflower-like white mass (Fig. 22a) to a light gray wispy condition with the appearance of plucked cotton (Fig. 22b). This change was due to evaporation of the smaller droplets, which made it possible to see further into the cloud. Following a period of quiescence, the uplifted portion dropped back into the mass beneath, and the portion below rapidly developed a dark appearance (Fig. 23). At first a light rain would fall and then a rain shower, producing about 100 to 500 acre-ft of rain, would continue to fall for 15 to 20 minutes with an intensity of about 1 to 2 in/hr (Fig. 24). Frequently, the center of the cloud would punch out completely after the rain and leave a ring of disorganized cloud around the seeding site.

In general, single towers properly seeded would regenerate, usually upwind, and nearby towers would begin to grow. The mechanism for this is not clear, but it appeared that the enhanced downdraft and cold air around the tower was lifting the surrounding moist air like a micro cold front. Possibly, a counterrotating vertical cell (Fig. 25) was formed beside the cloud.

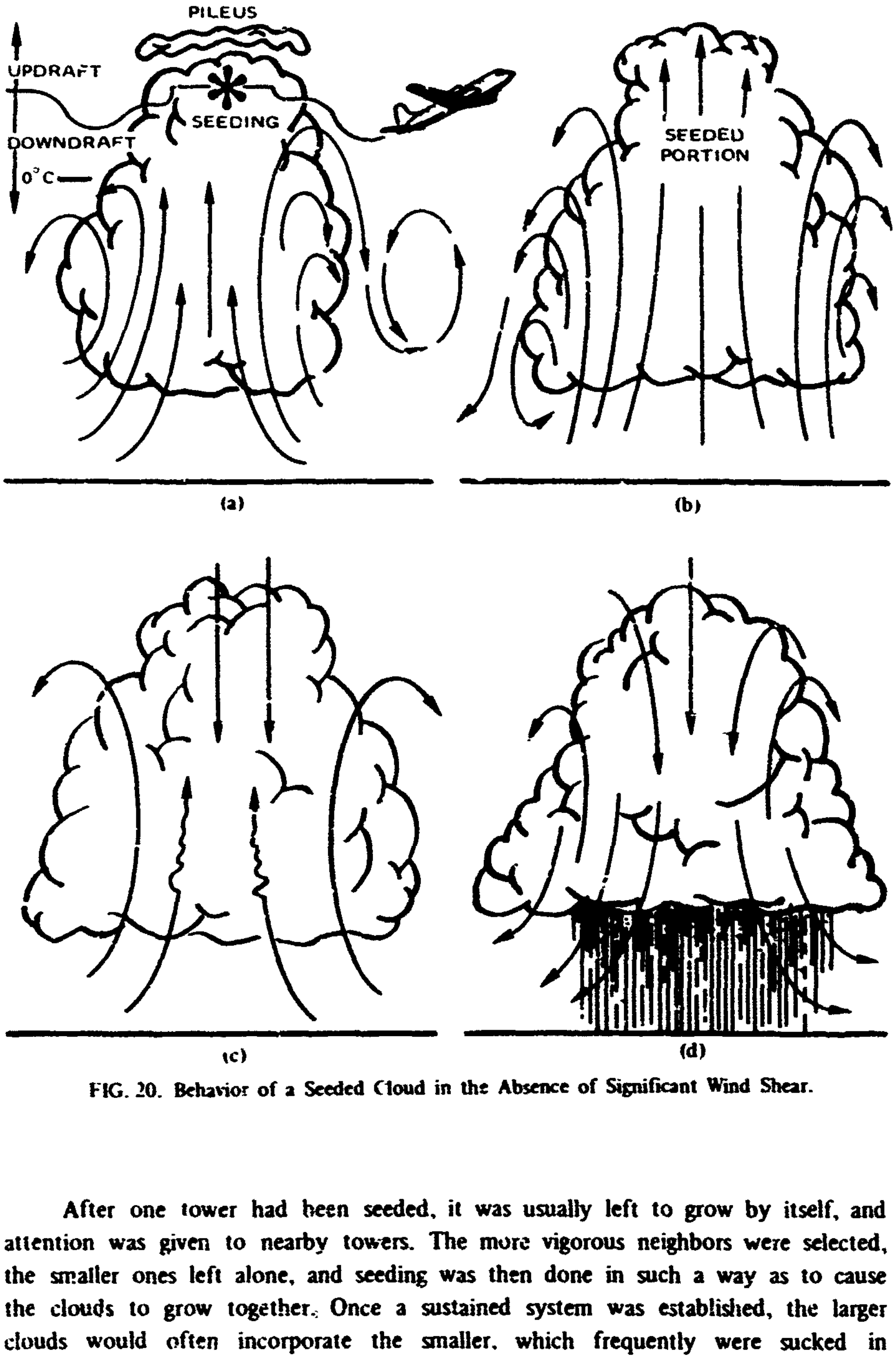



FIG. 20. Behavior of a Seeded Cloud in the Absence of Significant Wind Shear.

After one tower had been seeded, it was usually left to grow by itself, and attention was given to nearby towers. The more vigorous neighbors were selected, the smaller ones left alone, and seeding was then done in such a way as to cause the clouds to grow together. Once a sustained system was established, the larger clouds would often incorporate the smaller, which frequently were sucked in from the sides or from below along with whatever scud was present. Occasionally, a clear aureole would develop around a family of towers that had been consolidated into a vigorous mass.

About this time, the cloud base would begin to lower and widespread rain would develop. Care was taken not to seed too much but to try to encourage

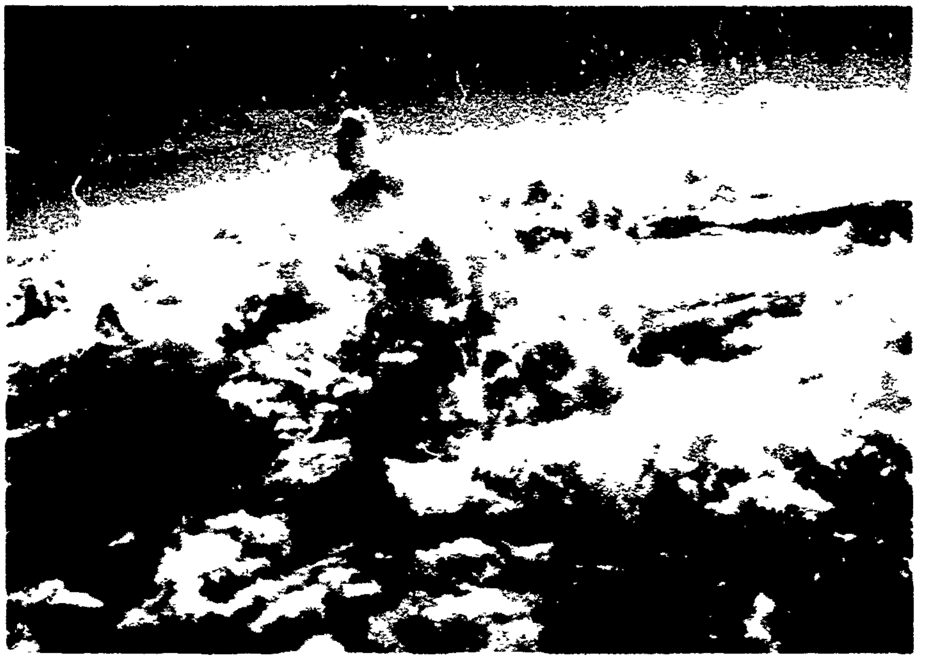


FIG. 21. Mission 4, 30 April 1969, Northern Mindanao. Photographed from about 9,000 feet. Seeded target is thin tower growing into dry air in a weak wind field. Typical unseeded lower clouds surround seeded tower.

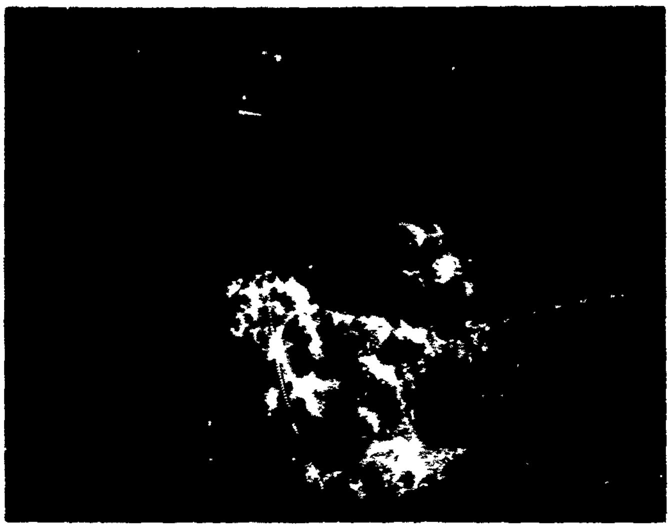
growth only to the 25,000- to 28,000-foot level. The use of caution would prevent forming a cumulonimbus cloud by ejecting material into the high wind shear that was usually present at 30,000 to 35,000 feet. Figure 26 shows the development of such a cumulonimbus.

On occasion, tower complexes grew to heights in excess of 60,000 feet, as measured by the weather radar at Clark. This growth (Fig. 27), while spectacular and thrilling, is not desirable, because shadowing of sunlight by the outflow shield can cause cloud growth to be discouraged in adjacent areas.

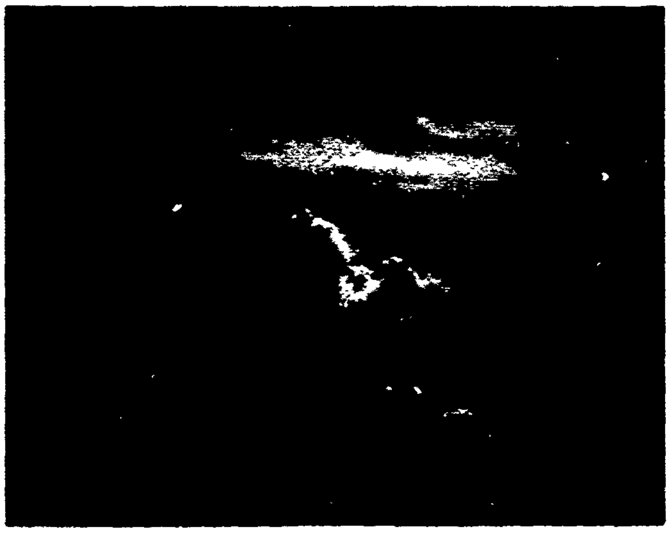
In a low-wind field, ammunition expenditures in excess of 10 rounds per hour did not result in more rain and usually deteriorated performance of the clouds. Timing is extremely important in that one must arrive at the seeding point while the cloud is still growing, or at least before the top has begun evaporation and is beginning to fall. Such clouds can occasionally be rejuvenated, but the prognosis is generally poor. Seeding of puffy masses projecting from larger clouds with no substantial amount of cloud below them is fruitless.

Seeding should be confined to updrafts because it is more effective in that slight supersaturations, larger drops, and higher liquid water concentrations exist. These ensure more rapid activation of the nuclei by diffusion and faster heat release because of more rapid conversion of water to ice by contact nucleation of drops.

Seeding in downdrafts should be assiduously avoided. The nuclei are not so active under the conditions of subsaturation, the liquid water content is less, and the material is soon carried down below the freezing level where ice cannot form at all. Moreover, it appears that meddling with the downdraft can interfere with cloud



(a) 1414 LST. Note hard, cauliflower-like appearance of seedable towers. Tower to left was seeded with two Very pistol rounds. Tower to right has reached climax.



(b) 1425 LST. Seeded tower, looking west. One more Very pistol shot has been put into seeded tower. Seeded tower has climaxed at considerable height above nonseeded tower and is falling back, dropping virga. Unseeded neighbor has begun to regrow. This is an example of good target clouds and overenthusiastic seeding.

FIG. 22. Mission 11. Southern Zambales Mountains Looking South.

FIG. 23. Mission 14, 1308 LST. Southwest Corner of Panay. Seeded tower collapsing, falling through scud, and producing rain.

There are also dynamic reasons for seeding an updraft. It already has some upward momentum and is embedded in a circulation pattern associated with its rise. Seeding a downdraft tends to inhibit an established circulation pattern that in itself may help the total cloud activity. For example, seeding of isolated towers with a fuzee by flying around the tower often results in rapid disappearance of the cloud.

Seeding for rainfall augmentation must always be done so as to aid cloud development by emphasizing the large-scale features of the circulation and minimizing activity that would lead to dissipation of energy in small-scale turbulence.

## Class B Clouds

Class B clouds are those subjected to a mild wind shear of about 5 to 10 knots over a vertical distance of a few thousand feet when the wind velocity increases with altitude. These clouds lean slightly with the wind because the upper parts are carried along faster than the lower parts. Seeding of this type (Fig. 28) is similar to that done for Class A single towers in a low or zero wind shear state.

In this case, however, seeding is not done in the exact center, but preferably on the forward or upwind front of the cloud (Fig. 29). If the cloud is small, penetration can be done in any direction, but prudence dictates entry of larger clouds at right angles to the wind shear or penetration of the front portion only.

After it has been seeded, the front edge of the tower rises more steeply, and a new cloud begins to grow upwind. The second seeding should not be done on the already stimulated mass seeded first, but on the newer cloud forming upwind of the previously seeded area. Frequently, whole new towers form, and these should be seeded.

Such clouds can easily be made to grow upwind but rarely downwind Lateral growth is frequently easy to bring about, and isolated leaning clouds of orographic origin can be joined together to make a linear array of clouds. After a few hours, however, such arrangements usually develop into one or more isolated cumulonimbus clouds that dominate the scene.

While successful seeding of leaning clouds requires a larger cloud mass to begin with than in the case of vertical towers, the leaning clouds can easily be made to produce abundant rain. Care must be taken to prevent development of cumulonimbus clouds, which results in a narrow zone of very heavy rain and increased wind.

(a) 1240 LST. The beginning of a rain shower, 1 mile east of the seeded turret. At 1250 the Weather Officer in the aircraft above reported, "3,500-foot growth in 10 minutes; mass much larger; towers beginning to build adjacent to main cell; considerable rain beneath."

FIG. 24. Missions 12 and 13, 6 May 1969. Sequence of shower development over town of San Pablo, southern Luzon. At 1230 LST a small cloud was seeded with one TB2 round at 17,800 feet, -2.5°C, by flying over the highest tower. At 1253 a second TB2 was placed 3 miles west at 20,700 feet, -8.5°C. The shot points were slightly north of San Pablo. At 1313 a third shot was placed just south of San Pablo at 19,600 feet, -6 C. During this operation one aircraft remained above, the other below the cloud. There was only a light wind of a few knots from the west at ground level. The size of the cloud can be estimated from the shadows.

(b) 1250 LST. The rain was now a light shower, in places moderate, as visually estimated.

(c) 1300 LST. Same shower was raining heavily and was somewhat increased in size. Note the larger shadow area in each successive picture. Radar runs gave rain rates between 0.5 and 4.0 in/hr. During the time of observation, the rain shaft drifted some 5 nautical miles to the east.

FIG. 24. (Contd.)

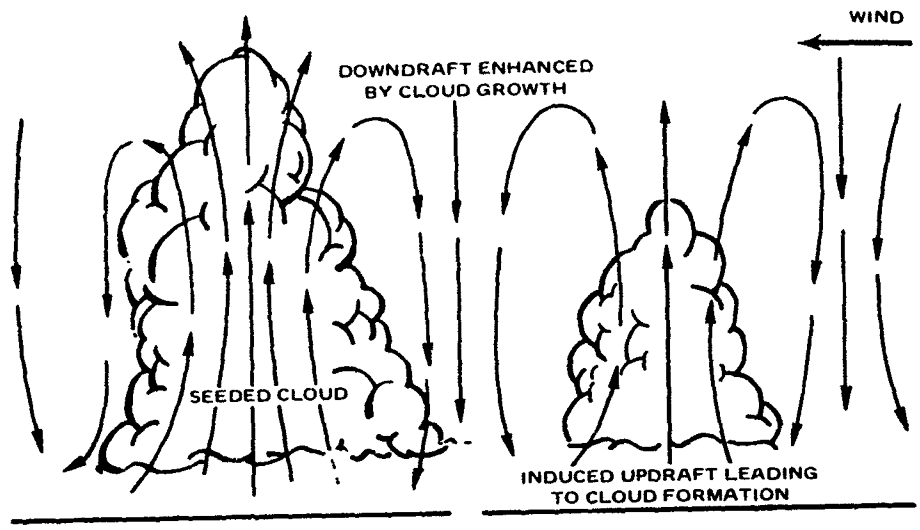



FIG. 25. Possible Mechanism for the Regeneration of a Seeded Cloud.

Well-developed cumulonimbus in a good wind shear regime can be sometimes cut off by very heavy seeding in the main trunk. Penetration is at right angles to the wind shear, and a seeding unit is dropped every 5 seconds. Excessively rapid growth results; the central column narrows and breaks off; and the anvil blows away. The underlying cloud collapses and does not immediately regenerate. Updrafts of 2,000 to 4,000 ft/min have been noted in these shafts following seeding. It is supposed that the increased vertical flow results in induction of excessive amounts of drier air from the sides, and that the subsequent evaporation and cooling cause destruction of the cloud.

Occasionally, one encounters lines of towers arranged along the wind (Fig. 30). These are best seeded by proceeding as far upwind as one wishes to develop rain and seeding the nearest tower. The seeded tower grows, and its growth is followed by development and growth of the towers downwind from it. By working back and forth along the system, several clouds may be joined into a continuous line.

Seeding rates on leaning clouds are about the same or slightly higher than on vertical towers: 10 units per hour is a reasonable expenditure rate.

## Class C Clouds

With the onset of the southwest monsoon, a situation was frequently observed in which the wind velocity decreased with altitude. The upper part of the cloud moves downwind slower than the bottom, and the cloud appears to lean into the wind rather than with it. Clouds shaped by this kind of reverse shear are labeled here Class C clouds.

This situation can be foreseen from pilot balloon forecasts or recognized by noting smoke near the ground or waves on water.

(a) 1445 LST. Rising tower was seeded at 1448 at the point indicated. The tallest tower was not seeded because it was too late in the growth cycle. Cloud is over shoreline in southwest corner of Lingayen Gulf, looking west.

(b) 1459 LST. Close-up of seeded area. Seeded portion has grown up to original high tower.

FIG. 26. Development of Cumulonimbus, Mission 8, 3 May 1969.

(c) 1501 LST. Seeded area has increased in height above its neighbors; old tower in (a) has begun to fall, and its base has pulled up. Cloud is now beginning to rain.

(d) 1507 LST. Seeded tower is now well above all neighbors; top is beginning to pull off and is being blown over neighbor to left.

FIG. 26. (Contd.)

(e) 1514 LST. Top of seeded tower is still rising rapidly. Pileus is visible at the top; virga is falling into unseeded neighbor to left. Cells in foreground have been seeded and are rising rapidly. Original unseeded high tower is regenerating.

(f) 1520 LST. Seeded area is now spreading laterally, and virga is causing rain from neighbors below. Original tower is still regenerating.

FIG. 26. (Contd.)

(g) 1548 LST. Seeded tower has now grown a prominent shield towering above nearby clouds. A new tower has begun to grow to the left.

FIG. 26. (Contd.)

As in the case of Class B clouds, seeding should be done on the upshear side of the cloud so that the coalescence path of old cloud and new growth is a maximum. For Class C clouds, however, the upshear side is the downwind side. Again, seeding may be by penetration as in Fig. 31, or from on top of a rising tower. A properly seeded cloud in a reverse shear situation is shown in Fig. 32. Figure 33 is an example of the complex cloud formation sometimes associated with this wind condition.

## FLIGHT PROCEDURES IN CUMULUS PENETRATION

The dangers of penetrating cumulus clouds are great for a pilot who does not know how to do this. On the other hand, penetration can be done quite safely and without serious difficulty if a few rules of good airmanship are applied.

The difficulty arises in part from attempting to fly a combination of visual and instrument flight. As a pilot approaches a cumulus, he has a tendency to raise the nose, either because the visual horizon now becomes apparently the cloud top or because the cloud is rising. This results in a reduced airspeed. The airspeed can be reduced to the point that a high-speed stall is possible in the presence of turbulence. The loss of airspeed is corrected by dropping the nose and adding power until the rate-of-climb indicator returns to near zero. By this time airspeed is often excessive and heading may be lost.

Subsequent to entry, primary reliance on the rate-of-climb indicator leads to problems, because this device has a built-in time lag and often tells what the plane

FIG. 27. Massive Cumulonimbus Developing Over Central Luzon.

FIG. 28. Mission 2, 29 April 1969. Over Negros Island. Typical leaning cloud in shear field with wind increasing slightly with altitude. Updrafts are found along right-hand (upwind) edges, downdrafts to left. Small anvil of liquid water has begun to form. Cloud has been seeded on upwind edge; as a result the windward profile is steepened. New low towers on right can be expected to grow.

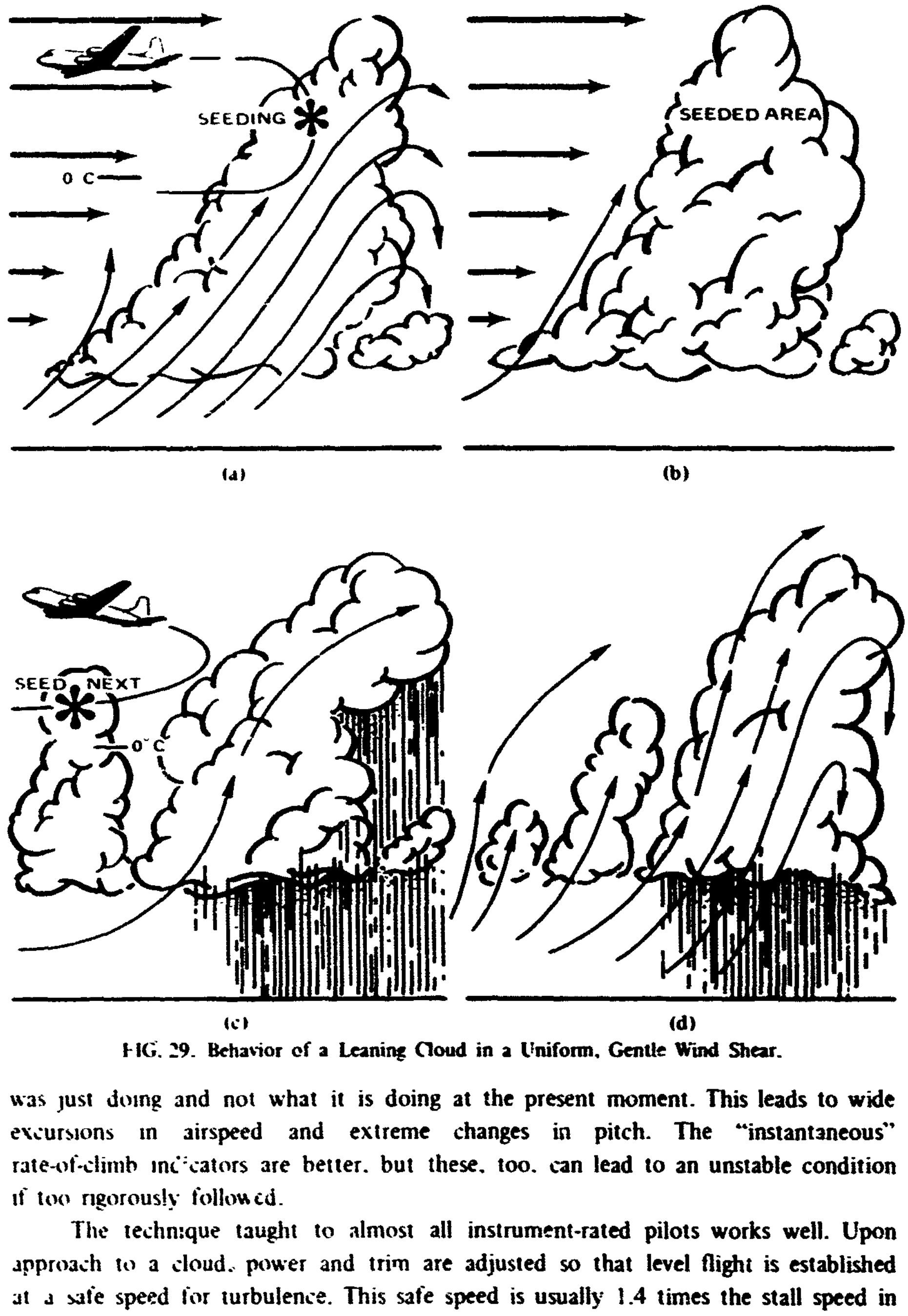



FIG. 29. Behavior of a Leaning Cloud in a Uniform, Gentle Wind Shear.

was just doing and not what it is doing at the present moment. This leads to wide excursions in airspeed and extreme changes in pitch. The "instantaneous" rate-of-climb indicators are better, but these, too, can lead to an unstable condition if too rigorously followed.

The technique taught to almost all instrument-rated pilots works well. Upon approach to a cloud, power and trim are adjusted so that level flight is established at a safe speed for turbulence. This safe speed is usually 1.4 times the stall speed in the condition in which the aircraft is being flown. For the WC-130s used in GROMET II safe speed is about 170 knots indicated airspeed (IAS), and for a Cessna 210 or 337 it is 110 knots IAS.

Upon establishing this speed and trim, the pilot then proceeds to fly entirely by use of the gyro horizon and gyrocompass. Airspeed is used as a backup, and the altimeter and rate-of-climb indicator are ignored. If the gyro horizon should fail or, in extreme circumstances, tumble, reliance should then be placed on the rate-of-turn

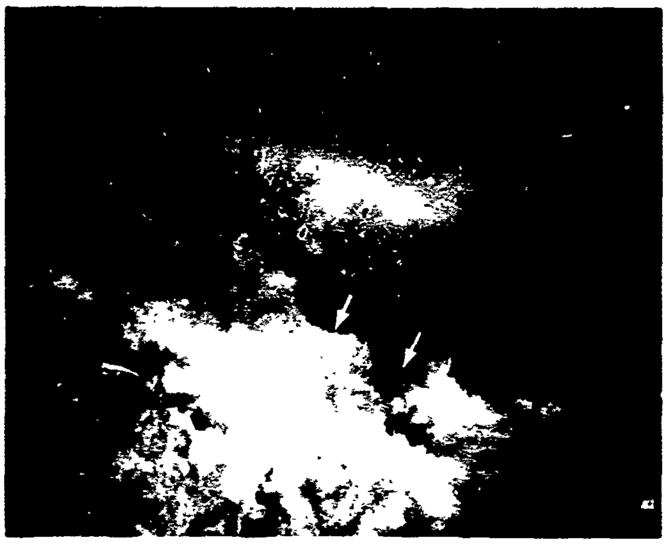


FIG. 30. Mission 38, 31 May 1969, 1458 LST, Over Mt. Arayat and Manila, Looking Southeast Along Southwest Flank of a Line of Clouds. Cloud in center is well seeded and growing. Next seeding points are indicated. The mass is being merged into a larger system. The cloud has begun to dominate the local circulation and is sucking in material from the south on the lower right. The wind at seeding altitude is light and into the picture to the southeast; at the altitude of the shield it is blowing to the south. The line of clouds is now over 30 miles long and 5 miles wide over the south Central Luzon Valley.

indicator, airspeed indicator, and gyrocompass; and operations should be terminated as soon as possible.

Ideally, an angle-of-attack indicator should be used and a constant angle of attack flown, but this instrument is generally not available.

Response to changes in pitch and bank should be rapid but not overcontrolled. If this procedure is followed, the rate-of-climb indicator will give a good indication of the velocity of the up- and downdrafts both inside and outside of clouds. This information is vitally needed for effective seeding.

Changes in altitude during a 2- or 3-minute penetration are not consequential unless the aircraft is flying over mountains or has a poorly functioning oxygen system. Icing occurs, but if pitot heat is us[ed] little harm results. The ice evaporates rapidly after the aircraft leaves the cloud. If the ice does not evaporate, a descent to the $-2^{\circ}C$ level will usually cause it to fall off, especially in a high-airspeed descent in which aerodynamic heating helps with the melting.

Turbulence in a well-grown cumulus congestus in the Philippines averaged 1.5 *g*, where stable conditions are taken as 1.0 *g*. The extreme noted was 2.1 *g* on one occasion when pilotage added to the problem.

The prudent pilot will so plan cloud penetrations that a properly chosen path will bring him clear of other clouds upon flying out. To this end, a curved

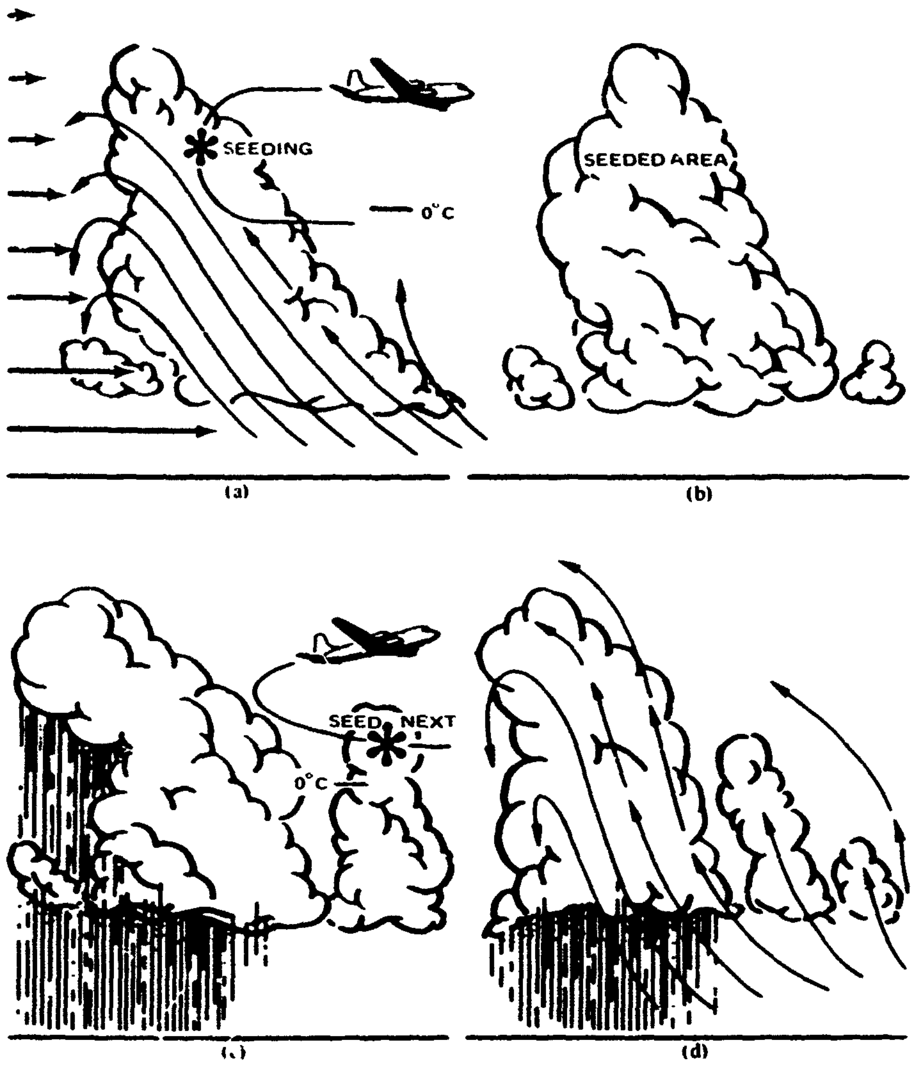



FIG. 31. Behavior of Seeded Cloud in Reverse-Shear Wind Field.

trajectory is sometimes advisable. Penetrations should be planned so that exit is possible within 1 to 2 minutes.

Penetration at altitudes between 8,000 and 16,000 feet leads to the worst turbulence both inside and outside a cloud. This region should be avoided unless cloud physics data are needed.

Penetration along the wind shear in a cumulonimbus should be avoided, but penetration in small cumulonimbus at right angles to wind shear can be made safely, especially if the penetration is only a partial penetration.

Seeding beneath clouds can be done to good effect, but in the Philippines it was not practical owing to terrain and low cloud base. Cloud bases lower following successful seeding, and it is unwise to be caught in high terrain under these

FIG. 32. Wind Is Blowing to the Right. The growing tower to the right was seeded. Rain is falling from the main mass of the cloud. Seeding in the highest part would probably result in separation of the overhanging bulge.

FIG. 33. Complicated Structure at Cloud Top During Reverse-Shear Situation.

conditions, because the only alternatives are to exit by visual flight rules under marginal conditions of visibility or to attempt an instrument climb-out with no clear idea of which way to go.

With turbocharged aircraft at altitude, it is inadvisable to slow the aircraft below 90 knots, because ram air aids the turbocharger and too slow an airspeed may result in too rich a mixture, causing momentary engine failure.

## FACTORS AFFECTING SEEDING SUCCESS

### High Wind Shear

If the wind shear is too severe (Fig. 14), or if in the case of an orographic cloud, the wind is too strong, seeding may not result in much rain.

Figure 34 shows a situation in which a weak, mechanically sustained cloud in a low-wind field is subjected to a high shear, that is 20 knots or more within a few thousand feet just above cloud top.

### Layered Clouds

Frequently, a drier layer of air develops between the lower moist air and a higher layer of moist air. Under these conditions clouds may grow through the drier layer, thinning out in the middle (Fig. 35), and widening again at cloud top. This situation requires great care to make seeding work. Too much seeding can cause the towers to separate in the midsection. However, slow, careful seeding can make these towers grow. Such clouds were frequent on central Luzon, just north of Manila.

The strategy that seemed to work best was to go to the middle of a field of such clouds and select several of the larger, seeding them and causing enough growth up through and drizzle back down through the dry layer to humidify it. After about an hour of such activity, the middle air would be adequately moistened to permit cloud growth and normal seeding.

Occasionally moist layers below and aloft with reasonably moist air, say 50 to 60% relative humidity, between them would form a stratocumulus deck below and a higher stratus above. Seeding of rising towers in the lower mass would result in growth, with the towers penetrating the upper layer. Usually the towers rose above the upper layer and then settled back on the sides and spread out, although sometimes they reached considerable altitude following penetration. Figure 36 shows this effect on Luzon.

### Orography

In the Philippines clouds tend to form over hills or chains of hills. Such clouds develop earlier in the day than clouds over lowlands, and even on the

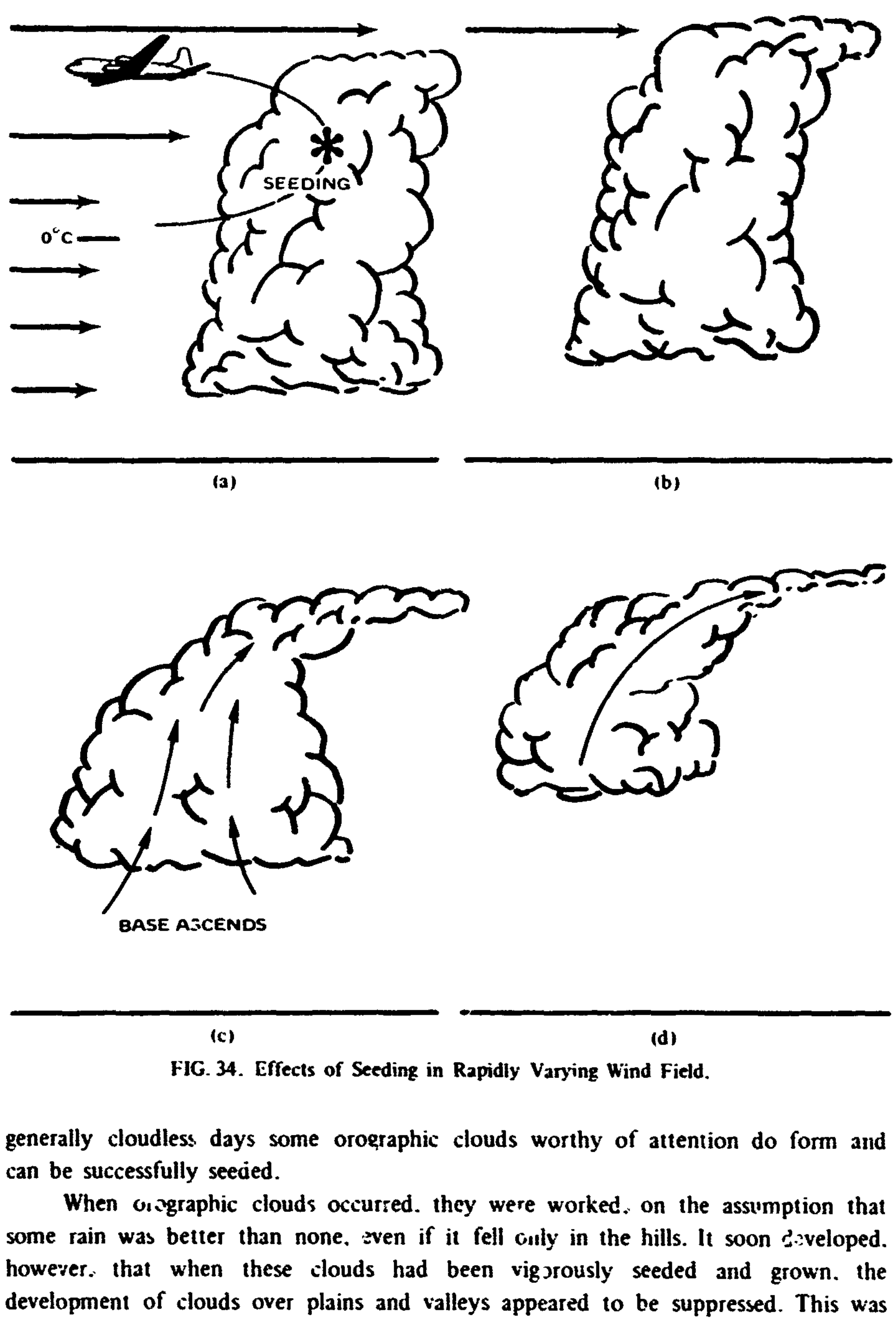


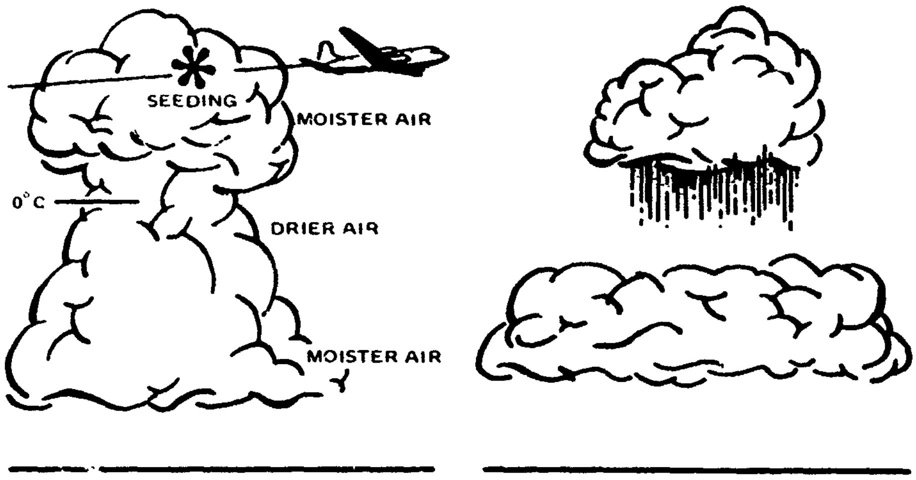

FIG. 34. Effects of Seeding in Rapidly Varying Wind Field.

generally cloudless days some orographic clouds worthy of attention do form and can be successfully seeded.

When orographic clouds occurred, they were worked, on the assumption that some rain was better than none, even if it fell only in the hills. It soon developed, however, that when these clouds had been vigorously seeded and grown, the development of clouds over plains and valleys appeared to be suppressed. This was especially notable in central Luzon and on Panay.

**Luzon.** The central valley of Luzon is an alluviated graben about 40 miles wide and 60 miles long bounded by the Zambales Mountains on the west and the Sierra Madre Mingan Mountains on the east. Figure 37 is a map of central Luzon.

A possible explanation for cloud suppression over the Central Luzon Valley is shown in Fig. 38. Air that has been uplifted over the hills descends over the valley.




(a) (b)

FIG 35. Cloud Growth Through Dry Layer.

with consequent adiabatic heating and destruction of the clouds in the valley. Under these conditions waves on Manila Bay and on Lingayen Gulf indicated a seaward drift of air.

If on the other hand one waited until some clouds had formed over the valley, usually to the south of Baguio, and then seeded those, an influx of air from Lingayen Gulf was noted and a sea-breeze front consisting of a line of clouds across the valley gradually formed some 10 to 20 miles inland. Once these were worked, the whole valley began to develop cloudiness, and a second sea-breeze front began to form north of Manila.

**Panay.** The island of Panay frequently has clouds over the north-south chain of hills on the western side of the island. If these were seeded first, development of clouds over the central and eastern portions of the island did not take place so rapidly as would have occurred naturally.

On days of very low wind the clouds over the valley were well developed before those over the hills dominated the circulation. On such days clouds usually appeared first on the southwestern and southeastern corners of the plains and then on the northwestern and northeastern corners, over some low hills.

By carefully avoiding the western mountain barrier and seeding the innermost members of the cloud systems, it was frequently possible to cover almost all the flat lands of Panay with rain. Once such an extensive system started, it was self-sustaining and rainfall continued for hours. At times rain rates between 3 and 5 in/hr were observed over large portions of the island, with lesser intensities between.

## Air Pollution

Almost every day in the vicinity of Manila and on many days elsewhere it was difficult to start cloud growth by seeding, and rain was scant. Near Manila the cloud bases were higher, generally around 5,000 to 8,000 feet; updrafts were less vigorous;

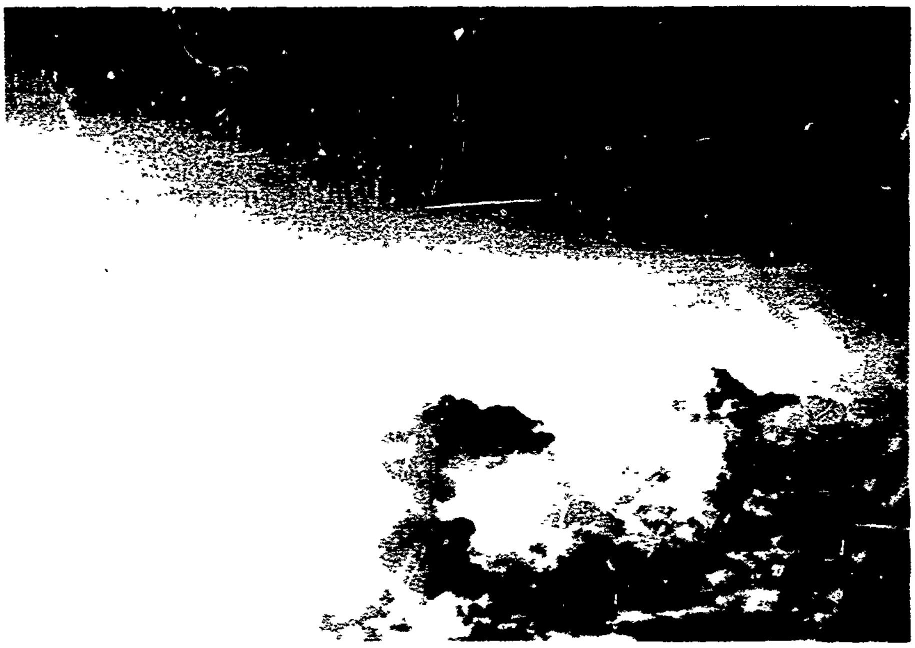


FIG. 36. Mission 6, 1 May 1969, 1337 LST, North of Iba on Luzon. Seeded clouds growing from lower scud through a drier layer and spreading out in all directions in a high-level inversion. Clouds lack buoyancy to penetrate further. Clouds originally seeded at 17,200 feet; photographed from 19,900 feet.

liquid water content was lower; and droplets were smaller, at least as indicated by the wetting of the aircraft windshield and by icing.

It is the opinion of the authors, an opinion corroborated by Ref. 4, that this effect was the result of air pollution, and that air pollution was indeed a major cause of the drought. The air was continually being polluted by the burning of enormous amounts of brush, grass, and slash from logging operations and by the burning of sugarcane waste.

An appeal was made to Philippine Government and Sugar Institute officials, with the result that the burning was stopped completely in some areas and confined to certain scheduled periods in others. In a short time the visibility improved, cloud bases lowered, droplet sizes increased, and seeding became more productive.

## Seeding Frequency

At the beginning of GROMET II clouds were not widespread and the search for suitable target clouds was difficult. After a few days of seeding the air became more humid, clouds formed more readily, and natural rainfall was more frequent. Wind velocity was low and wind direction was quite variable, so that the humidified air remained over the archipelago. Evaporation from the ground and transpiration from plants increased.

Had a statistical experiment of "controlled" or "one-day-on, one-day-off" seeding been tried, the apparent effects of seeding would have been a rapidly

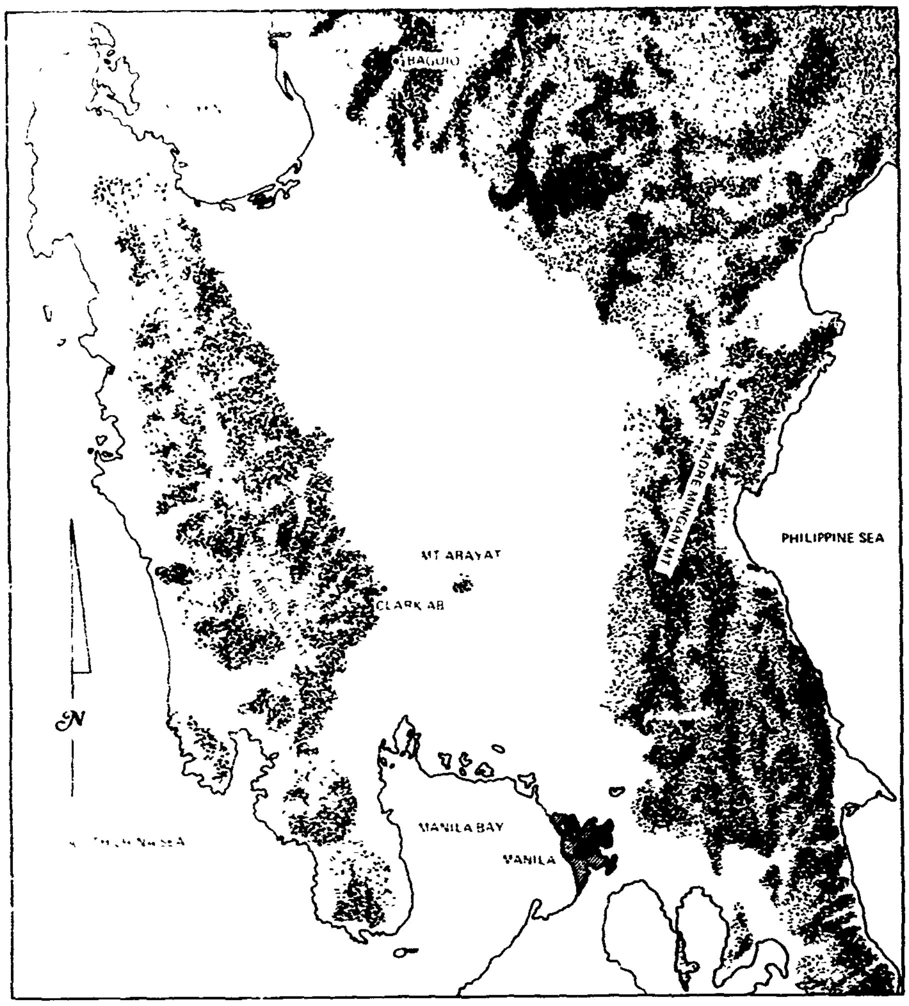



FIG. 37. Central Luzon.

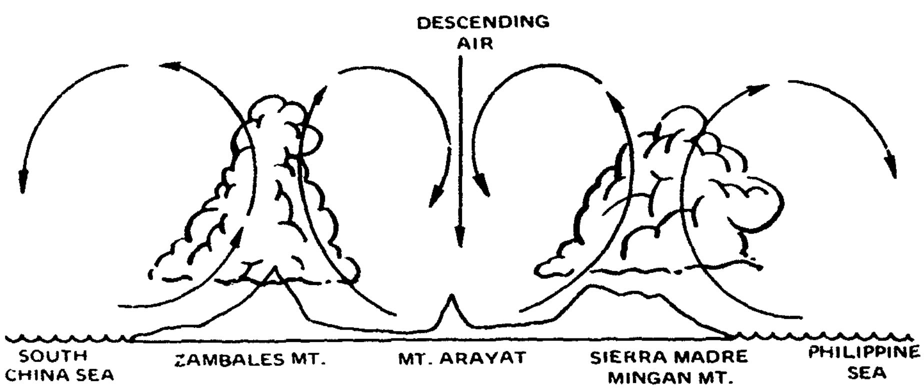



FIG. 38. Cross Section of Central Luzon, Showing Suppression of Clouds Over Central Valley

decreasing seeding effectiveness, while in reality the overall precipitation would have increased.

From experience we found that 1 day of heavy seeding over the Visayan Islands was more than enough for 3 or 4 days of rain, therefore, flights were scheduled less frequently, the same areas being revisited only every third or fourth day unless some operational requirements made it more convenient to return. Because of the permeable soil, most of the water would soak in quickly in 1 day, and the soil would soon again be dry.

## TACTICS OF A TYPICAL MISSION

Mission 47 on 7 June 1969 resulted in good cloud growth and extensive rain, and is a good example of the technique employed. Table 3, the day's seeding log, shows the details. After takeoff from Clark AB at 1110 local time (0310 GMT) the GROMET team proceeded to Palawan, where a high overcast with bases at 19,000 feet made cumulus development unlikely; the aircraft, therefore, was diverted to the Visayan Islands, previously agreed upon as a secondary target area and arrived at the southwest corner of Panay at 1300 local time.

The weather officer reported cloud coverage as 2/8 cumulus with bases at 2,000 and tops at 8,000 feet, 2/8 cumulus with bases at 2,000 and tops at 20,000 feet, and 5/8 cirrostratus between 22,000 and 25,000 feet. This cirrostratus was patchy and contained no ice. At 19,000 feet the outside air temperature was -5°C and the wind was estimated as 120 degrees at 20 knots, although it was probably less.

An isolated growing tower with some lower scud just east of the hills was seeded (point 2, Fig. 39) at 1302 at 20,300 feet at -8°C. Another much smaller isolated tower (point 3) was then seeded 7 minutes later. Five minutes later, at 1314, enough new growth had developed around point 2 to permit seeding at points 4, 5, and 6 in separate towers. Seven minutes later new growths had appeared around point 3 and had grown enough to permit shots 7, 8, and 9 in quick succession into separate towers that had grown to the 19,500-foot level. These two cloud families, designated A and B in Fig. 39, were left to grow by themselves, and Group C to the north, consisting of two towers (points 10 and 11), was seeded 13 minutes later. Group D, with tops only at the -2.5°C level, was just starting up and was seeded next at point 12. Group E was seeded next with one shot at point 13, followed by a return to D (point 14), where a rapidly growing cell was seeded at -4°C.

Six minutes later, Group F (points 15 and 16) was seeded, and the aircraft returned to G (point 17), by now growing in an area where only low clouds had been noted before.

Group D was filling in nicely, and point 18 was seeded next, some 25 minutes after the first attack, in an effort to pull the separate clouds of Group D together. They quickly merged, and F was struck again (points 19 and 20), followed by point 21 at the border of H. Next, two rapidly growing towers in Group E were merged

### TABLE 3. Copy of Seeding Log for Mission 47, 7 June 1969.

MISSION 47 — SEEDING LOG — ACFT NO: 12366 PILOT: HINKLE DATE: 7 JUNE 69

| | TIME | LAT | LONG | MH | IAS | ALT | OAT | RT | LFT | VERY | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 0317 | N 1439 | E 12037 | 181 | 205 | $11^1$ | +7.5 | | 1 | | TEST |
| 2. | 0502½ | 1047 | 12222 | 054 | 240 | $20^3$ | -8.0 | | 1 | | 2/8 CU 020/080, 2/8 CU 020/200, |
| 3. | 0509 | 1049 | 12228 | 064 | 240 | $19^1$ | -40 | | 1 | | 5/8 CS 220/250, |
| 4. | 0514½ | 1044 | 12218 | 270 | 220 | $19^8$ | -7.0 | | 1 | | 19,500/23°F/120/20 |
| 5. | 0515 | 1047 | 12216 | 255 | 220 | $20^2$ | -9.0 | | 1 | | |
| 6. | 0515½ | 1045 | 12217 | 254 | 220 | $20^2$ | -9.0 | | 1 | | |
| 7. | 0521 | 1051 | 12226 | 030 | 234 | $19^5$ | -6.0 | | 1 | | |
| 8. | 0521½ | 1052 | 12227 | 030 | 234 | $19^5$ | -6.0 | | 1 | | |
| 9. | 0522 | 1050 | 12229 | 061 | 235 | $19^5$ | -6.0 | | 1 | | |
| 10. | 0535 | 1119 | 12240 | 038 | 275 | $19^4$ | -4.0 | | 1 | | 2/8 CU 020/080, 2/8 CU 020/200, |
| 11. | 0536 | 1119 | 12240 | 050 | 300 | $19^1$ | -3.0 | | 1 | | 5/8 CU 220/250, 19500/23°F/120/20 |
| 12. | 0537 | 1118 | 12246 | 122 | 238 | $18^5$ | -2.5 | | 1 | | |
| 13. | 0541½ | 1122 | 12250 | 050 | 232 | $19^4$ | -4.0 | | 1 | | |
| 14. | 0545 | 1123 | 12246 | 286 | 240 | $19^6$ | -4.0 | | 1 | | |
| 15. | 0551 | 1119 | 12232 | 162 | 228 | $20^6$ | -6.0 | | 1 | | |
| 16. | 0551 | 1119 | 12232 | 162 | 228 | $20^6$ | -6.0 | | 1 | | |
| 17. | 0556 | 1058 | 12231 | 154 | 230 | $20^6$ | -6.0 | | 1 | | |
| 18. | 0603½ | 1120 | 12246 | 011 | 233 | $19^8$ | -5.0 | | 1 | | |
| 19. | 0608 | 1122 | 12232 | 212 | 226 | $19^5$ | -5.0 | | 1 | | |

MAC FORM JAN 66 360 PREVIOUS EDITIONS OF THIS FORM MAY BE USED GENERAL PURPOSE WORK SHEET

TABLE 3. (Contd.)

SEEDING LOG

ACFT NO: 12366 PILOT: HINKLE DATE: 7 JUNE 69

| | TIME | LAT | LONG | MH | IAS | ALT | OAT | RT | LFT | VERY | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20. | 0609 | 1121 | 12230 | 218 | 230 | $19^{6}$ | -6.0 | | 1 | | |
| 21. | 0617 | 1123 | 12254 | 088 | 228 | $18^{9}$ | -3.0 | | 1 | | |
| 22. | 0620½ | 1121 | 12261 | 272 | 172 | $19^{5}$ | -4.0 | | 1 | | |
| 23. | 0621 | 1120 | 12249 | 267 | 202 | $19^{7}$ | -5.0 | | 1 | | |
| 24. | 0622½ | 1125 | 12245 | 042 | 221 | $19^{6}$ | -5.0 | | 1 | | |
| 25. | 0625 | 1122 | 12265 | 101 | 290 | $18^{7}$ | -3.5 | | 1 | | |
| 26. | 0635 | 1103 | 2238 | 230 | 275 | $20^{7}$ | -7.0 | | 1 | | |
| 27. | 0701½ | 1032 | 12320 | 160 | 253 | $18^{6}$ | -4.0 | | 1 | | |
| 28. | 0724 | 1028 | 12314 | 059 | 270 | $20^{0}$ | -5.5 | | 1 | | 2/8 cu 015/200, 2/8 020/100, |
| 29. | 0726 | 1027 | 12321 | 072 | 280 | $18^{8}$ | -3.0 | | 1 | | 2/8 cu 220/250, 19500/23°F |
| 30. | 0735 | 0956 | 12336 | 136 | 270 | $20^{0}$ | -6.5 | | 1 | | 100/20 |
| 31. | 0735½ | 0959 | 12337 | 115 | 235 | $19^{8}$ | -6.0 | | 1 | | |
| 32. | 0737 | 0954 | 12336 | 220 | 221 | $19^{6}$ | -5.5 | | 1 | | same, 20,000/21°F/105/10 |
| 33. | 0738 | 0956 | 12337 | 251 | 226 | $20^{0}$ | -8.0 | | 1 | | |
| 34. | 0738½ | 0954 | 12338 | 247 | 225 | $20^{0}$ | -8.0 | | 1 | | |
| 35. | 0743 | 1003 | 12338 | 126 | 265 | 19.6 | -6.0 | | 1 | | |
| 36. | 0745 | 0956 | 12332 | 262 | 215 | $20^{6}$ | -7.0 | | 1 | | |
| 37. | 0745½ | 0955 | 12331 | 241 | 228 | $20^{6}$ | -7.5 | | 1 | | |
| 38. | 0748½ | 0944 | 12332 | 182 | 255 | $20^{2}$ | -7.0 | | 1 | | |

MAC FORM JAN 66 36a PREVIOUS EDITIONS OF THIS FORM MAY BE USED GENERAL PURPOSE WORK SHEET

TABLE 3. (Cont.)

SEEDING LOG

ACFT NO: 12366 PILOT: HINKLE DATE: 7 JUNE 69

| | TIME[a] | LAT | LONG | MH[b] | IAS[c] | ALT[d] | OAT[e] | RT[f] | LFT[g] | VERY[h] | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 39. | 0749 | 0943 | 12330 | 140 | 255 | $20^{8}$ | -7.0 | | 1 | | |
| 40. | 0752 | 0940 | 12331 | 205 | 250 | $19^{8}$ | -6.5 | | 1 | | |
| 41. | 0752 | 0940 | 12331 | 200 | 250 | $20^{8}$ | -7.0 | | 1 | | |
| 42. | 0752½ | 0939 | 12329 | 210 | 225 | $20^{3}$ | -7.0 | | 1 | | |
| 43. | 0758 | 0946 | 12327 | 037 | 275 | $20^{5}$ | -7.0 | | 1 | | |
| 44. | 0801 | 0957 | 12328 | 065 | 254 | $20^{9}$ | -7.5 | | 1 | | |
| 45. | 0801½ | 0958 | 12330 | 052 | 220 | $20^{2}$ | -7.0 | | 1 | | |
| 46. | 0809 | 1026 | 12346 | 028 | 265 | $20^{1}$ | -6.5 | | 1 | | same ; 20,000/21°F/135/15 |
| 47. | 0811½ | 1040 | 12349 | 358 | 258 | $20^{2}$ | -6.5 | | 1 | | |
| 48. | 0819 | 1034 | 12310 | 280 | 275 | $19^{8}$ | -6.0 | | 1 | | Same ; 20,000/19°F/135/15 |
| 49. | 0824½ | 1020 | 12321 | 210 | 245 | $10^{2}$ | -6.0 | | 1 | | |
| 50. | 0831 | 1031 | 12309 | 310 | 238 | $21^{0}$ | -9.0 | | 1 | | |
| 51 | 0831 | 1031 | 12309 | 310 | 238 | $21^{0}$ | -9.0 | | 1 | | |
| 52 | 0836 | 1027 | 12308 | 091 | 227 | $21^{0}$ | -9.0 | | 1 | | |

MAC FORM JAN 60 36a PREVIOUS EDITIONS OF THIS FORM MAY BE USED GENERAL PURPOSE WORK SHEET

[a] Greenwich mean time (add 8 hr for Philippine local time).
[b] Magnetic heading.
[c] Indicated airspeed.
[d] Altitude, ft.
[e] Outside air temperature, °C.
[f] Right seeding rack.
[g] Left seeding rack.
[h] Very pistol.

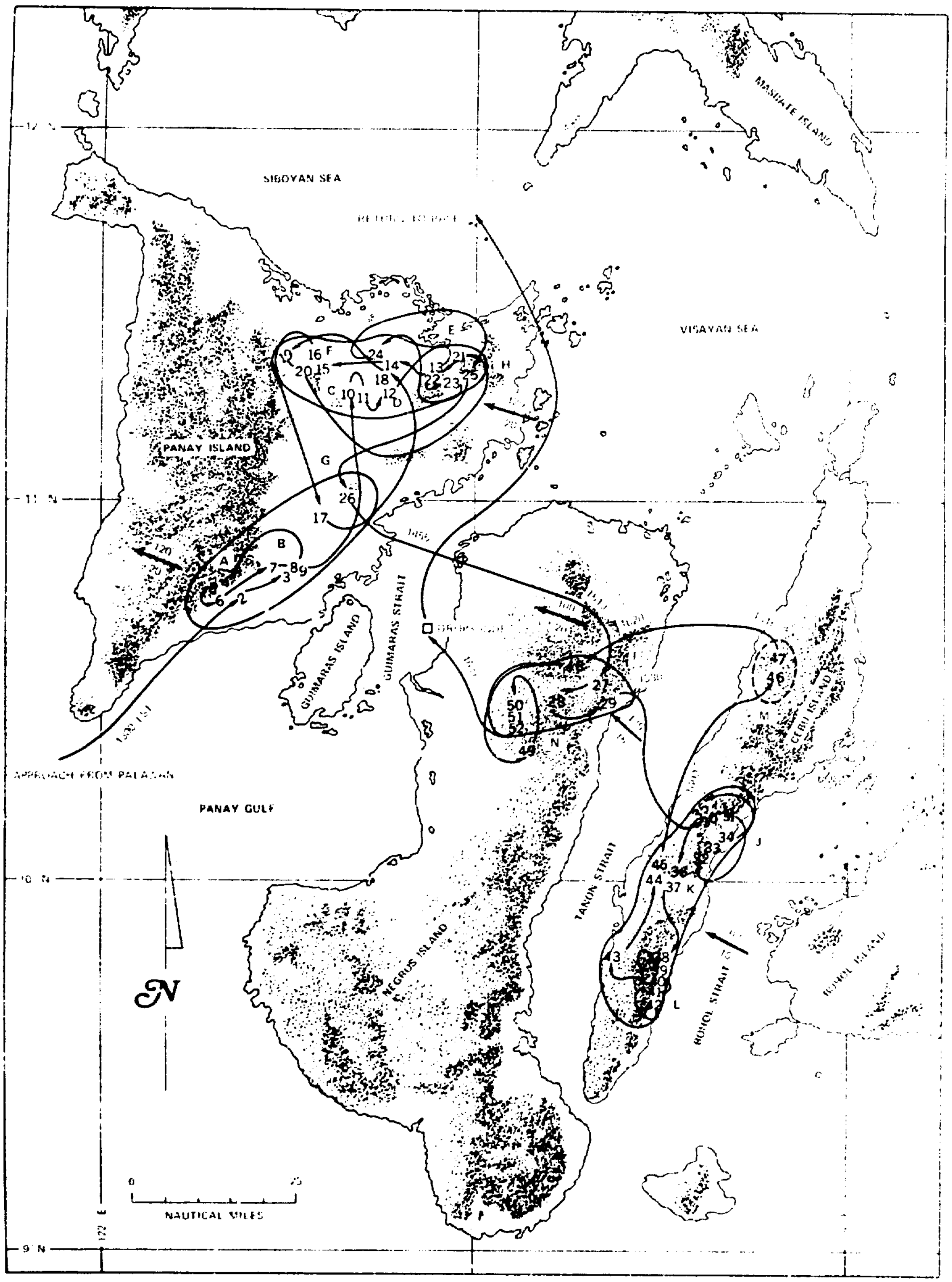



**FIG. 39. Target Locations, Mission 47, 7 June 1969. Symbols such as $\xleftarrow[10]{105^\circ}$ indicate wind direction (105 degrees) and wind speed (10 knots).**

following shots 22 and 23, and D was extended northward by shot 24. Shot 25 at H completed the seeding in the northern part of the island.

By now the whole of the northern mass had merged into a veritable wall of cloud, with tops to about 30,000 feet. A rain run was made under the group. Heavy precipitation was encountered all along the line. Liquid water content in the rain shaft reached 3 g/m$^3$ as measured on the Johnson-Williams meter. Rain rate was estimated at 1 to 3 in/hr. On climb-out Group G was reseeded at point 26, extending the southern sector to the east. The clouds there had by then also grown into one large mass.

Because both cloud groups were raining well, the aircraft departed Panay and arrived at northern Negros at 1510, where three points (27, 28, 29) in Group I were seeded. These were small clouds that grew well and merged into a large cumulus congestus. At 1530 the crew left Negros and worked central and southern Cebu, where a collection of towers was grown into a line of cumulonimbus by repeatedly working back and forth between various members of Groups J, K, and L, points 30 through 45. These merged within 25 minutes, and work began farther north on Cebu at points 46 and 47. Group M developed slightly, merged, and rained but did not appear promising. At 1619 one more shot, at point 48, was put into Group I and a new group, N, was seeded with four shots (49 through 52) over a 12-minute period.

At 1637 the team departed Negros and climbed and released a dropsonde (Fig. 40 and 41). By then the air was almost saturated to 20,000 feet, probably from all the cumulus activity.

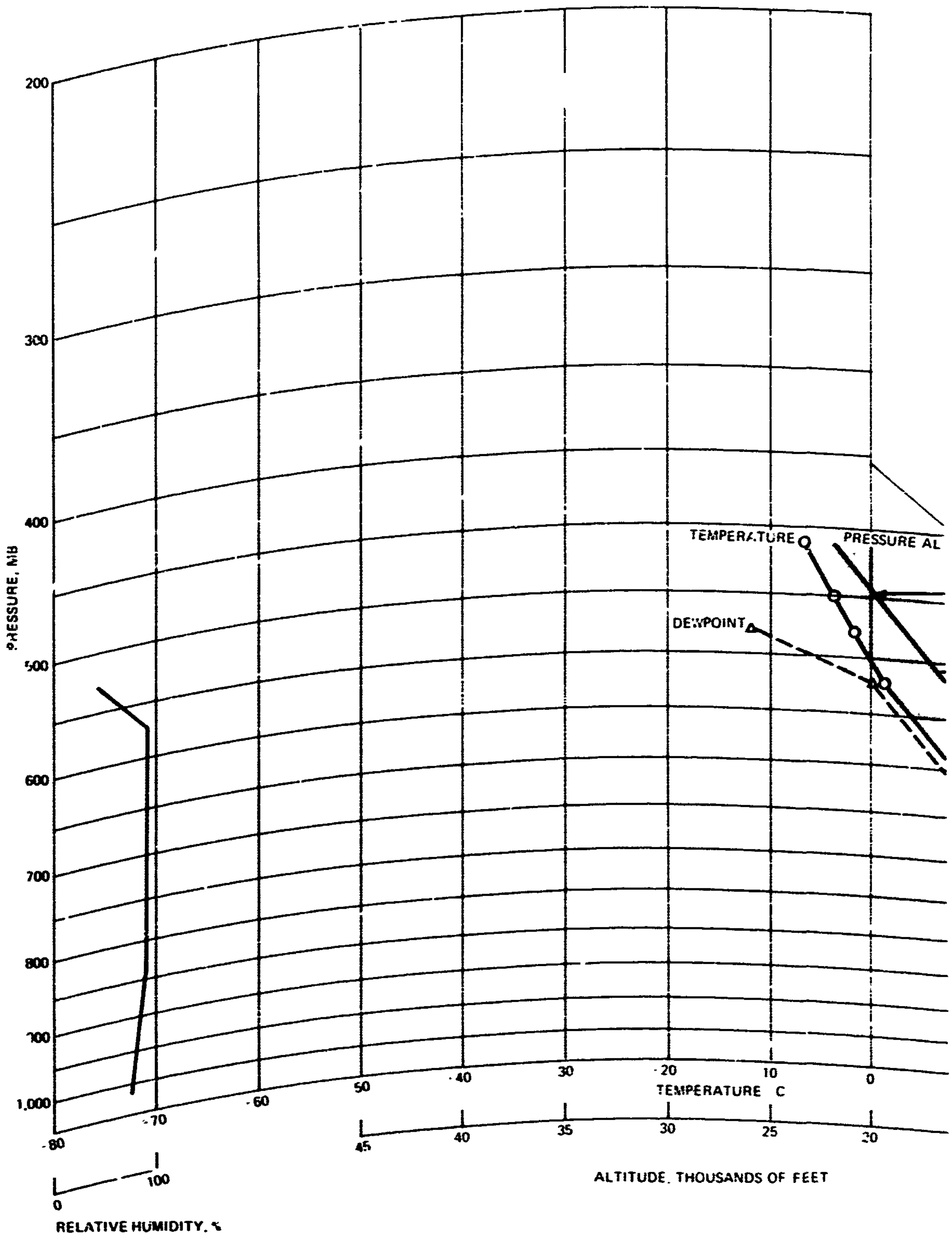
The clouds on Panay (Fig. 42) were still a formidable wall across most of the flatter parts of the island when the aircraft returned to base some 4 hours after start of seeding. Total rainfall on Panay on this day from seeded clouds was conservatively estimated as 160,000 acre-ft. Assuming 4,500 square statute miles as the area of Panay, this means an average rainfall of 0.7 inch over the whole of the island. That more may have fallen locally may be inferred from Fig. 43, taken during the rain run made early on this day.

## PROJECT FINDINGS

Detailed tabulation of the 62 missions conducted during the course of GROMET II is given in Appendix A. Tables in this section summarize some of the information in this Appendix.

Generally, rainfall intensity was estimated visually, but in a few cases the Weather Science, Inc., rain-rate meter was used to measure rain intensity.

If one could see through the rain shaft to objects beyond, the rainfall was called light (L). If one could recognize topographic features at least a mile into the shaft, it was called moderate (M). If one could see into the shaft less than a half mile, the rainfall was called heavy (H). These estimates vary, of course, with



200
300
400
500
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700
800
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1,000
PRESSURE, MB
TEMPERATURE
PRESSURE AL
DEWPOINT
-80
-70
-60
-50
-40
-30
-20
-10
0
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35
30
25
20
ALTITUDE, THOUSANDS OF FEET
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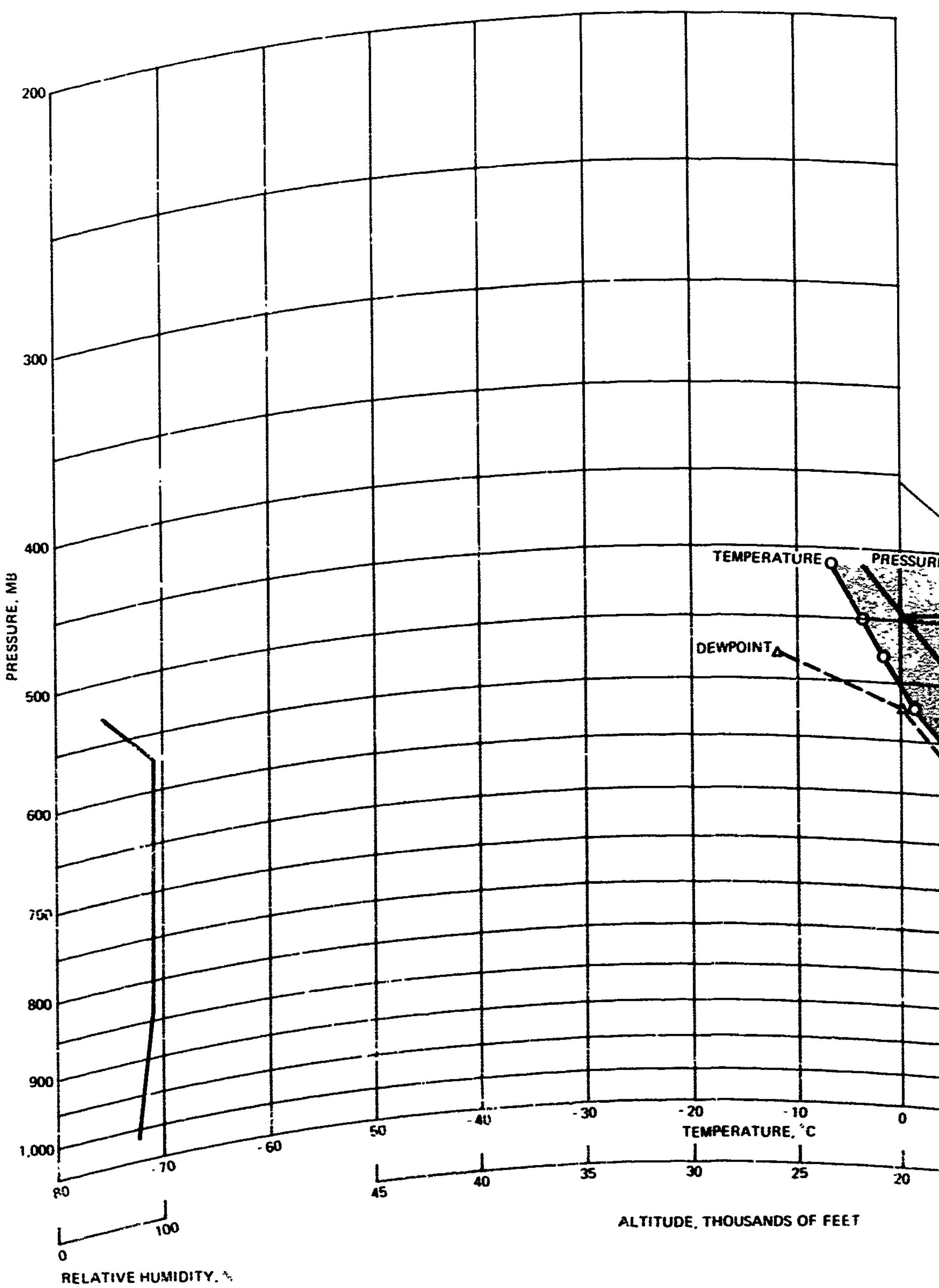
100
RELATIVE HUMIDITY, %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PRESSURE, MB
TEMPERATURE
PRESSURE
DEWPOINT
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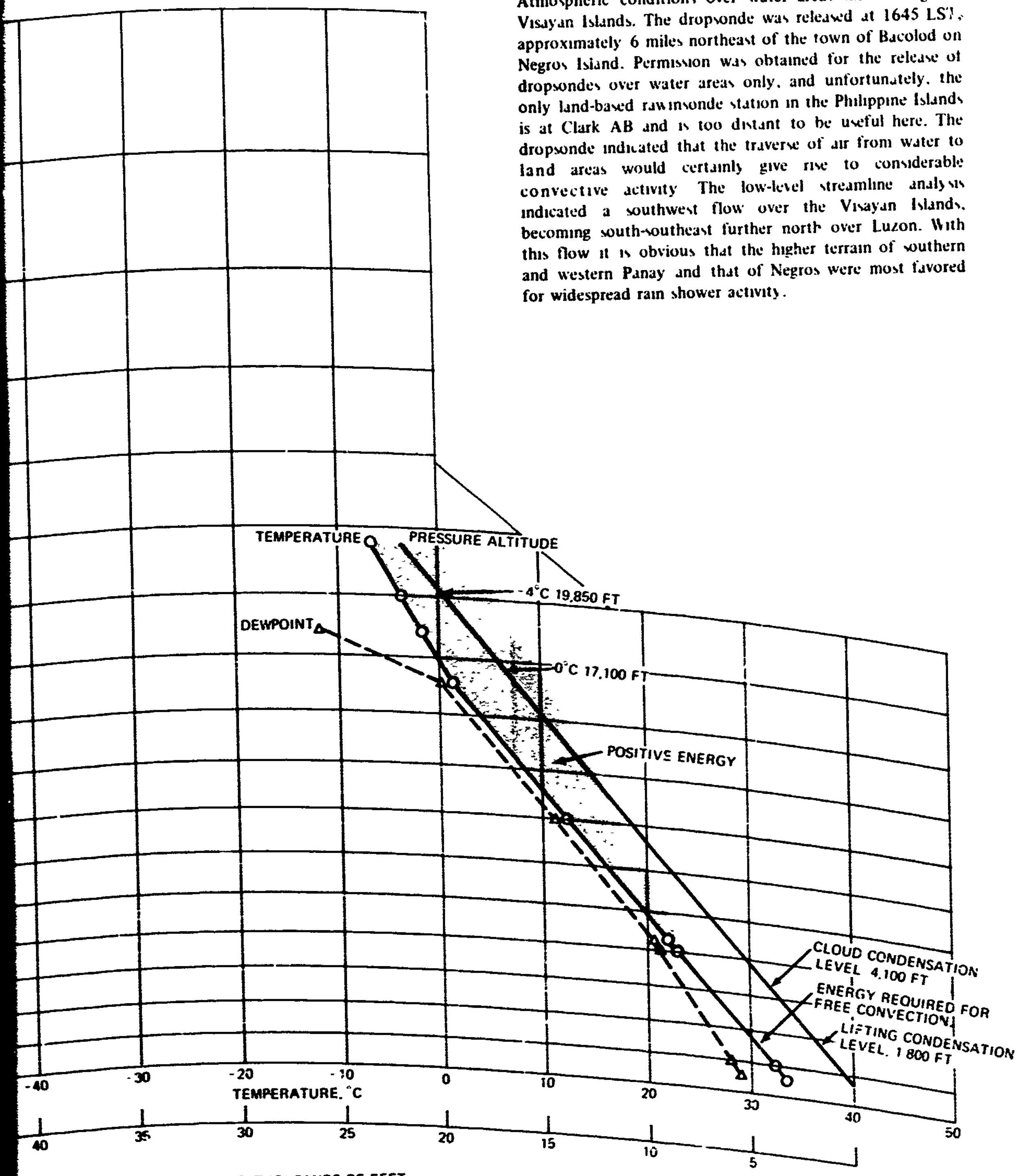
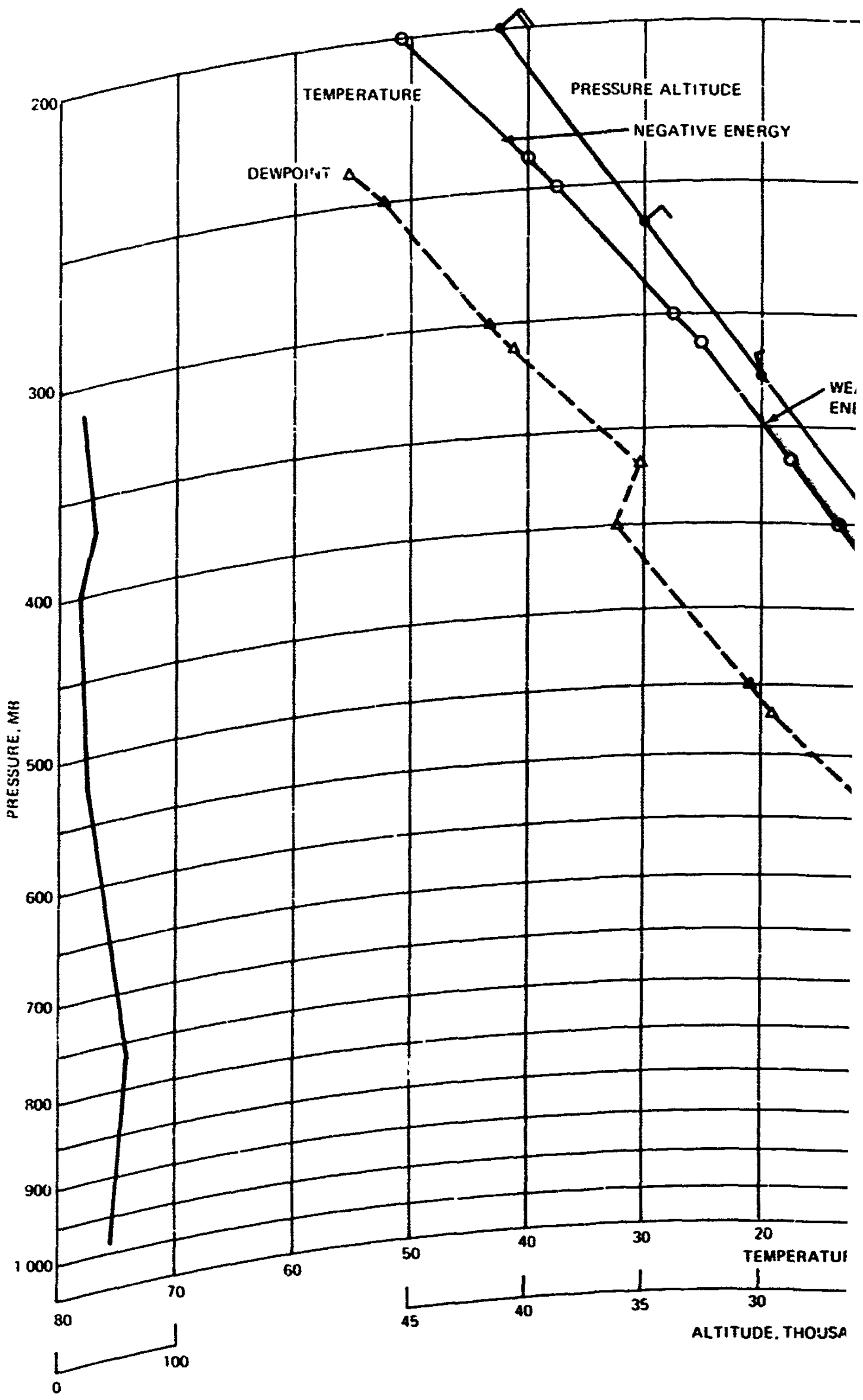
-70
-60
50
-40
-30
-20
-10
0
TEMPERATURE, °C
45
40
35
30
25
20
ALTITUDE, THOUSANDS OF FEET
0
100
RELATIVE HUMIDITY, %

FIG. 40. Mission 47, 7 June 1969, Dropsonde Data Atmospheric conditions over water areas surrounding the Visayan Islands. The dropsonde was released at 1645 LST, approximately 6 miles northeast of the town of Bacolod on Negros Island. Permission was obtained for the release of dropsondes over water areas only, and unfortunately, the only land-based rawinsonde station in the Philippine Islands is at Clark AB and is too distant to be useful here. The dropsonde indicated that the traverse of air from water to land areas would certainly give rise to considerable convective activity. The low-level streamline analysis indicated a southwest flow over the Visayan Islands, becoming south-southeast further north over Luzon. With this flow it is obvious that the higher terrain of southern and western Panay and that of Negros were most favored for widespread rain shower activity.




TEMPERATURE
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PRESSURE, MB
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TEMPERATU
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RELATIVE HUMIDITY, %
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35
30
ALTITUDE, THOUSA

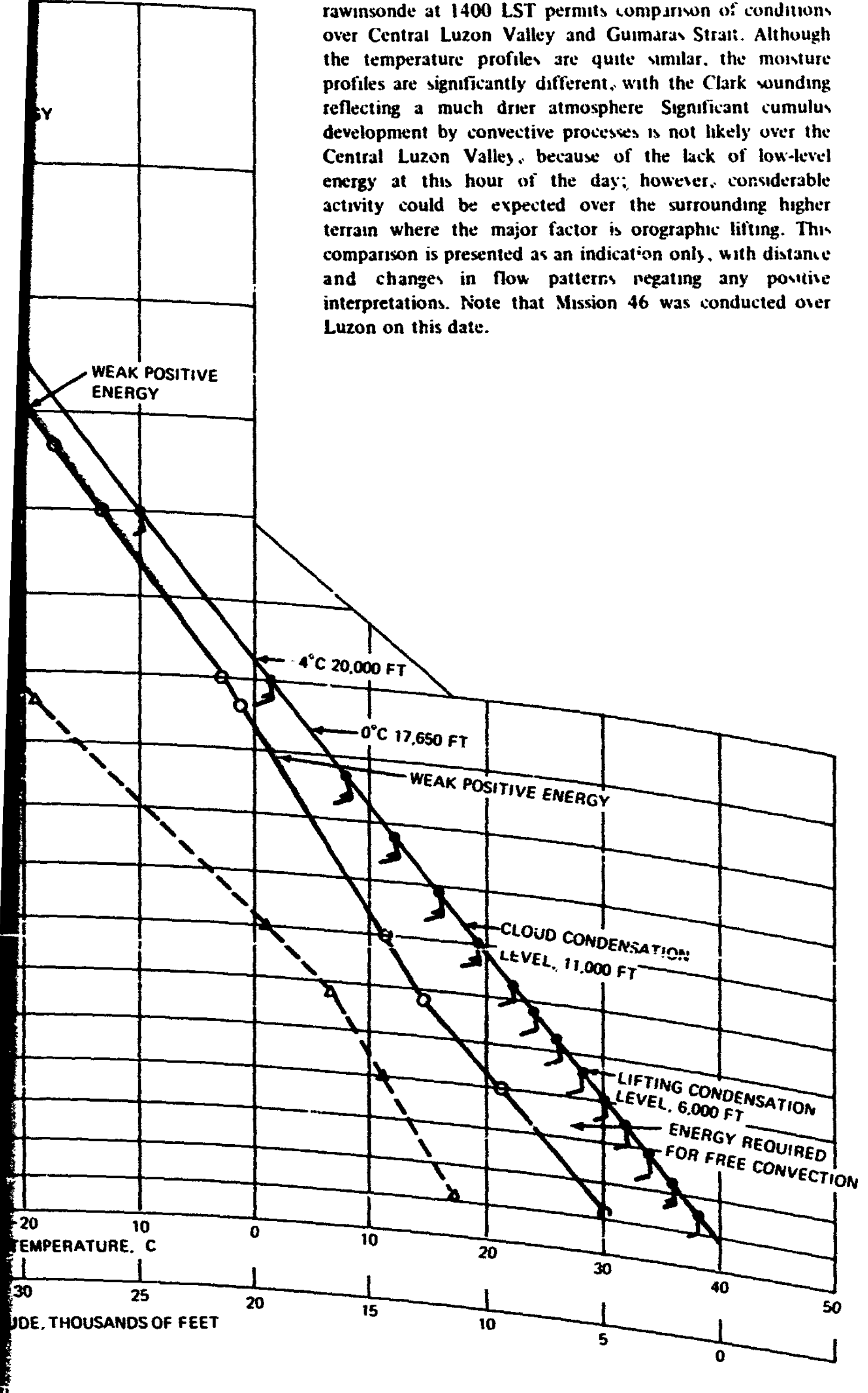



FIG. 41. Clark AB, 7 June 1969. The standard Clark AB rawinsonde at 1400 LST permits comparison of conditions over Central Luzon Valley and Guimaras Strait. Although the temperature profiles are quite similar, the moisture profiles are significantly different, with the Clark sounding reflecting a much drier atmosphere. Significant cumulus development by convective processes is not likely over the Central Luzon Valley, because of the lack of low-level energy at this hour of the day; however, considerable activity could be expected over the surrounding higher terrain where the major factor is orographic lifting. This comparison is presented as an indication only, with distance and changes in flow patterns negating any positive interpretations. Note that Mission 46 was conducted over Luzon on this date.

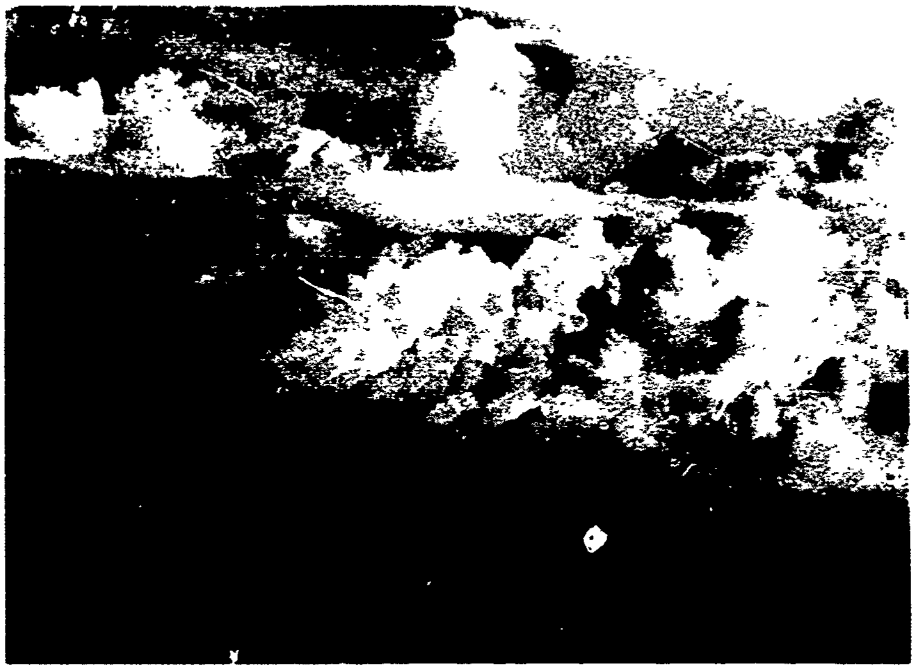


FIG. 42. Wall of Clouds Over Northern Panay at Termination of Mission 47.

illumination and the difficulties of seeing beneath the cloud and so are not entirely reliable.

Correlation of these visual estimates with the few actual measurements taken indicated that light rainfall corresponded to intensities between 0 and 1.0 in/hr, moderate to rainfall between 1.0 and 2.0 in/hr, and heavy to rainfall in excess of 2.0 in/hr (Table 4). Tables 5 through 11 summarize the more complete tabulation of all GROMET II missions given in Appendix A. For Tables 5 through 11 and Appendix A the following key applies to column headings:

| | |
|---|---|
| L | Light rainfall |
| M | Moderate rainfall |
| H | Heavy rainfall |
| No | No rain |
| No(V) | No rain from target cloud, but rain in vicinity within 10 nautical miles |
| U | Unobserved |

For the quantitative estimate of rainfall in Appendix A and in Tables 9 through 11, the following values are used:

| | |
|---|---|
| L | 0.5 in/hr |
| M | 1.5 in/hr |
| H | 2.5 in/hr |

These estimates are used to describe cloud systems or targets, which may be a single cloud, cloud complex, or several such that occurred in the same general area and responded similarly to treatment.

FIG. 43. Mission 47, 7 June 1969, Postseed. Well-wetted paddies and fields on Panay. Rain in distance, dark cloud base above.

## PRESEED AND POSTSEED RAIN INTENSITIES

Table 5 shows that of the 326 cloud targets worked, 258 were not raining before seeding, and only 74 of these were within about 10 nautical miles of raining clouds. After seeding, rain was observed to fall from 266 cloud systems.

In four cases rainfall intensity decreased after seeding, and in 36 no significant intensity change occurred. Twenty-three cases did not result in rainfall. In 37 cases clouds were seeded in passing, and rainfall that may have fallen was not observed. An increase in rain intensity occurred in 249 cases.

Table 6 expresses the data of Table 5 as percentages. Of all the cases seeded, rain did not fall or was reduced in intensity in 7.4%. An additional 4.9% were unchanged in intensity class, and 76.4% rained harder after than before seeding.

Table 7 expresses all cases in percentage of the preseed class. The low value of percentages for M in the initially nonraining class is probably an artifact of the assessment process wherein observations reported as LM were reduced to L and those observed as MH were augmented to H.

Of 23 cases with no postseed rain (Table 5), 5 cases could not have been expected to work because the clouds were too low or too warm. Table 8 combines classes No and No(V), eliminates U of Table 5, and is corrected for seven questionable cases in which rain was not reported following seeding. These dubious cases are explained in a footnote to Table 8. In this table 6.4% of the cases (No) in which the cloud was not raining beforehand were unexplained failures. Mismanagement in terms of seeding too late or overseeding, ordnance misfire or

TABLE 4. Measured Rain Rates Used To Quantify Observer's Rain Intensity Estimates.[a]

| Target no. | Average rain rate, in/hr[b] | | Length of rain run, nmi[b] | |
|---|---|---|---|---|
| Observer's Qualitative Characterization: Light | | | | |
| 12a ... | 0.05 | | 1.8 | |
| | 0.2 | | 4.2 | |
| | | (0.3) | | (2.1) |
| | 0.9 | | 1.1 | |
| | | (2.4) | | (0.2) |
| | 1.1 | | 1.3 | |
| | | (1.8) | | (0.2) |
| 19a ... | 0.2 | | 2.0 | |
| 24c ... | 0.9 | | 1.5 | |
| Light to Medium | | | | |
| 23b ... | 0.5 | | 7.1 | |
| | | (1.5) | | (0.8) |
| 25b ... | 0.7 | | 2.6 | |
| | | (0.9) | | (1.6) |
| 29a ... | 1.7 | | 2.6 | |
| | | (2.5) | | (1.5) |
| 25d ... | 1.6 | | 3.4 | |
| Medium to Heavy | | | | |
| 18b ... | 1.4 | | 3.0 | |
| | 2.1 | | 3.8 | |
| | | (3.8) | | (1.9) |
| 10a ... | 1.8 | | 2.7 | |
| | | (3.9) | | (1.0) |
| | | (0.8) | | (0.5) |

| Target no. | Average rain rate, in/hr[b] | | Length of rain run, nmi[b] | |
|---|---|---|---|---|
| Heavy | | | | |
| 25e ... | 3.4 | | 0.9 | |
| 10d ... | 3.9 | | 1.7 | |
| | 4.9 | | 1.9 | |
| Observations Not Characterized | | | | |
| 12a ... | 0.4 | | 1.3 | |
| | 0.6 | | 1.9 | |
| | 0.6 | | 1.4 | |
| | | (1.4) | | (0.3) |
| | 1.0 | | 0.8 | |
| | 1.6 | | 0.6 | |
| | 2.4 | | 0.7 | |
| | 3.2 | | 2.3 | |
| | | (6.4) | | [illegible] |
| | | (5.3) | | [illegible] |
| | 3.8 | | 3.4 | |
| | | (2.1) | | (0.3) |
| | 4.0 | | 2.3 | |
| | | (12.2) | | (0.2) |
| | | (8.1) | | (0.2) |
| | | (8.9) | | (0.2) |
| | 4.0 | | 2.2 | |
| | | (9.2) | | (0.2) |
| | | (8.7) | | (0.2) |

[a] These estimates apply only to the rain run and may differ from those for the whole target.

[b] Entries offset to the right refer to a portion of the preceding non-offset entry. For example, an average rain rate of 0.3 in/hr was sustained over a continuous 2.1-nmi section of the 4.2-nmi rain run over whose entire course the average was 0.2 in/hr.

TABLE 5. Correlation of Preseed and Postseed Rain Intensities for All Targets.

| Preseed class | Number of seeded targets by postseed class | | | | | |
|---|---|---|---|---|---|---|
| | No | L | M | H | U | Total |
| No .... | 16 | 65 | 32 | 47 | 24 | 184 |
| No(V) .. | 4 | 15 | 18 | 28 | 9 | 74 |
| L ..... | 3 | 11 | 18 | 22 | 3 | 57 |
| M ..... | 0 | 0 | 1 | 4 | 0 | 5 |
| H ..... | 0 | 0 | 1 | 4 | 1 | 6 |
| Total .. | 23 | 91 | 70 | 105 | 37 | 326 |

TABLE 6. Data of Table 5 Expressed as Percentages of Total Cases.

| Preseed class | Percent of total number of seeded targets by postseed class | | | | | |
|---|---|---|---|---|---|---|
| | No | L | M | H | U | Total |
| No .... | 4.9 | 20.0 | 9.8 | 14.4 | 7.4 | 56.5 |
| No(V) .. | 1.2 | 4.6 | 5.5 | 8.6 | 2.8 | 22.7 |
| L ..... | 0.9 | 3.4 | 5.5 | 6.8 | 0.9 | 17.5 |
| M ..... | 0.0 | 0.0 | 0.3 | 1.2 | 0.0 | 1.5 |
| H ..... | 0.0 | 0.0 | 0.3 | 1.2 | 0.3 | 1.8 |
| Total .. | 7.1 | 27.9 | 21.5 | 32.2 | 11.3 | 100 |

TABLE 7. Data of Table 5 Expressed as Percentages of Preseed Class, All Cases.

| Preseed class | Postseed, percent of preseed class | | | | | |
|---|---|---|---|---|---|---|
| | No | L | M | H | U | Total |
| No ..... | 8.7 | 35.3 | 17.4 | 25.6 | 13.0 | 100 |
| No(V) .. | 5.4 | 20.3 | 24.3 | 37.8 | 12.2 | 100 |
| L ..... | 5.3 | 19.3 | 31.6 | 38.6 | 5.3 | 100 |
| M ..... | 0 | 0 | 20.0 | 80.0 | 0 | 100 |
| H ..... | 0 | 0 | 16.7 | 66.7 | 16.7 | 100 |

TABLE 8. Data of Table 5 Modified.[a]

| Preseed class | Postseed class | | | | | | | | Total number of cases |
|---|---|---|---|---|---|---|---|---|---|
| | No | | L | | M | | H | | |
| | Number | % | Number | % | Number | % | Number | % | |
| No .... | 14 | 6.4 | 80 | 36.5 | 50 | 22.8 | 75 | 34.2 | 219 |
| L .... | 2 | 3.8 | 11 | 20.8 | 18 | 34.0 | 22 | 41.5 | 53 |
| M ..... | 0 | ... | 0 | ... | 1 | 20.0 | 4 | 80.0 | 5 |
| H ..... | 0 | ... | 0 | ... | 1 | 20.0 | 4 | 80.0 | 5 |

[a] No and No(V) combined; U of Table 5 eliminated.

Table 15 cases eliminated: 6c, 6f, 9c, 9f, 21e, as too warm; 26f, as having rained on first seeding; 44f, as probably not observed.

TABLE 9. Water Yield, All Storms With Sufficient Information for Estimate.

| Preseed Class | Postseed rainfall | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | L | | M | | H | | Total | |
| | Total yield, acre-ft | Number of storms | Total yield, acre-ft | Number of storms | Total yield, acre-ft | Number of storms | Yield, acre-ft | Number of storms |
| No .... | $3.6 \times 10^5$ | 43 | $1.2 \times 10^6$ | 30 | $1.2 \times 10^7$ | 44 | $1.4 \times 10^7$ | 117 |
| No(V) .. | $1.4 \times 10^5$ | 15 | $1.7 \times 10^5$ | 15 | $3.1 \times 10^6$ | 25 | $3.4 \times 10^6$ | 55 |
| L ..... | $8.2 \times 10^4$ | 9 | $1.5 \times 10^6$ | 18 | $3.4 \times 10^6$ | 20 | $5.0 \times 10^6$ | 47 |
| M ..... | ... | ... | $4.2 \times 10^3$ | 1 | $1.7 \times 10^6$ | 3 | $1.7 \times 10^6$ | 4 |
| H ..... | ... | ... | $1.2 \times 10^4$ | 1 | $8.5 \times 10^5$ | 3 | $8.6 \times 10^5$ | 4 |
| Total .. | $5.8 \times 10^5$ | 67 | $2.9 \times 10^6$ | 65 | $2.2 \times 10^7$ | 95 | $2.5 \times 10^7$ | 227 |

TABLE 10. Data of Table 9 as Percentages.

| Preseed class | Percentage of total estimated rainfall by postseed class | | | |
|---|---|---|---|---|
| | L | M | H | Total |
| No ... | 1.4 | 4.8 | 49.7 | 56.0 |
| No(V) | 0.6 | 0.7 | 12.5 | 13.8 |
| L .... | 0.3 | 6.0 | 13.7 | 20.0 |
| M ..... | . | Negligible | 6.8 | 6.8 |
| H .. | . | Negligible | 3.4 | 3.4 |
| Total . | 2.3 | 11.5 | 86.[illegible] | 100 |

TABLE 11. Water Yield per Storm (Data of Table 9).

| Preseed class | Average postseed water yield, acre-ft | | | Average water yield by preseed intensity class, acre-ft |
|---|---|---|---|---|
| | L | M | H | |
| No | $8.3 \times 10^3$ | $4.0 \times 10^4$ | $2.8 \times 10^5$ | $1.2 \times 10^5$ |
| No(V) | $9.5 \times 10^3$ | $1.1 \times 10^4$ | $1.3 \times 10^5$ | $6.3 \times 10^4$ |
| L | $9.1 \times 10^3$ | $8.4 \times 10^4$ | $1.7 \times 10^5$ | $1.1 \times 10^5$ |
| M | ... | $4.2 \times 10^3$ | $5.7 \times 10^5$ | $4.3 \times 10^5$ |
| H | ... | $1.2 \times 10^4$ | $2.8 \times 10^5$ | $2.2 \times 10^5$ |
| Average water yield by postseed intensity class | $8.7 \times 10^3$ | $1.4 \times 10^4$ | $2.3 \times 10^5$ | $1.1 \times 10^5$ |

malfunction, or poor choice of cloud was probably responsible in most of these cases. Some of this, with the exception of ordnance malfunction, was deliberate in order to emphasize the importance of target selection and management. Of the lightly raining clouds (L), only 3.8% stopped raining. Again, this was probably caused by seeding too late or by overseeding. Sometimes total rain was actually increased whereas the intensity may have been reported as unchanged, or perhaps decreased.

## ESTIMATES OF AMOUNT OF RAINFALL

Enough is known about 227 of the 266 raining cloud systems to estimate the amount of rainfall, and these form the basis for Tables 9 through 11 and Fig. 23 through 46. The aggregate from the 227 cases is 25 million acre-ft or 31 billion metric tons of water. The rainfall estimates are, of course, crude, and at present it cannot be told if they are systematically high or low. It is not claimed that all the rain that fell was the result of seeding; we have no way of assessing this. We do feel that more than 50% was artificially induced.

Table 9 shows the estimated water yield from all storms for which estimates are available. The number of such storms is also indicated. Clearly, the largest part of the rain came from the originally nonraining clouds. This is probably due to our policy of seeding nonraining clouds as well as to the fact that few already raining clouds were available, particularly at the beginning of the project. Those that were already raining were usually caused to grow to one side or the other or merged to nearby clouds, some raining, others not. In a few cases cumulonimbus clouds were deliberately cut off to show that this could be done.

Table 10 gives the data of Table 9 as percentages of the total estimated rainfall. About 70% of this total estimated rainfall fell from originally nonraining clouds and of this, 62% came from clouds induced to rain heavily. Figure 44 shows these data, except that No and No(V) are combined.

The estimated water yield per storm is presented in Table 11. Within each class of postseed rainfall intensity the yield per storm is almost constant. This may

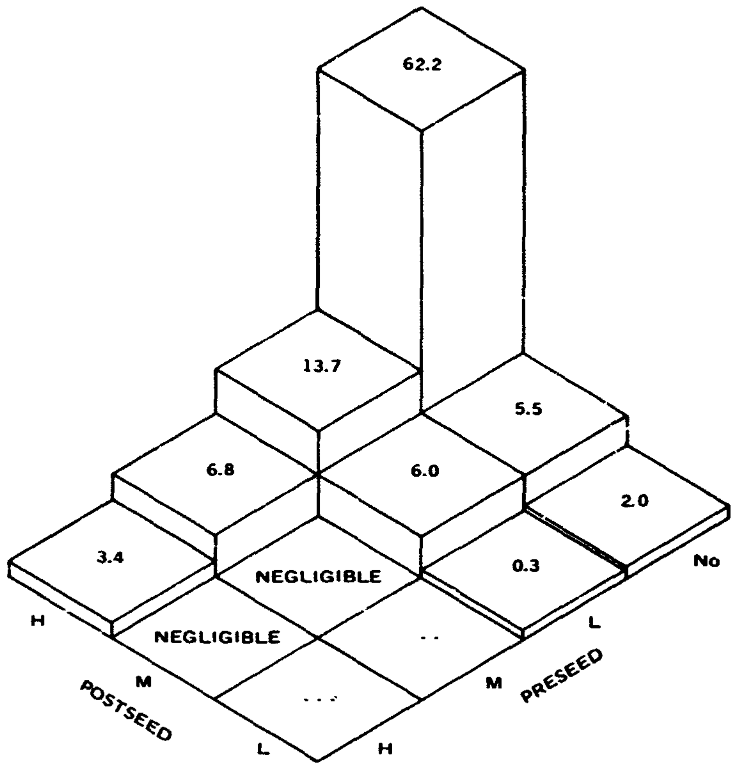



FIG. 44. Graphical Representation of Data of Table 10.

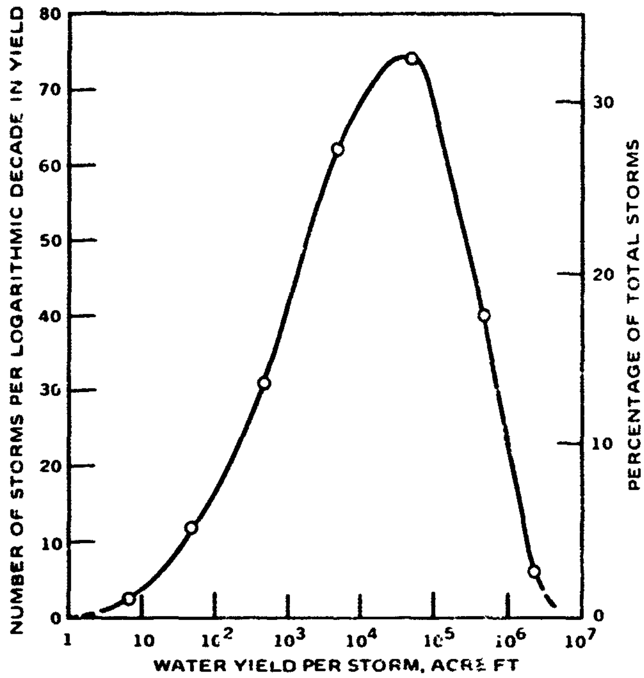
be an artifact of estimation, but more likely it is due to a relationship between the area of the storm, its duration, and the intensity of rainfall. It probably indicates that the same conditions that permit the development of a certain rainfall intensity determine the height of growth and the area of the storm as well, and that these are related to the duration.

Figure 45a shows the number of storms as a function of water yield. This is, of course, only applicable to the GROMET II experience. In Fig. 45b these data are normalized to 100 storms and adjusted to a constant class interval of 100 acre-ft.

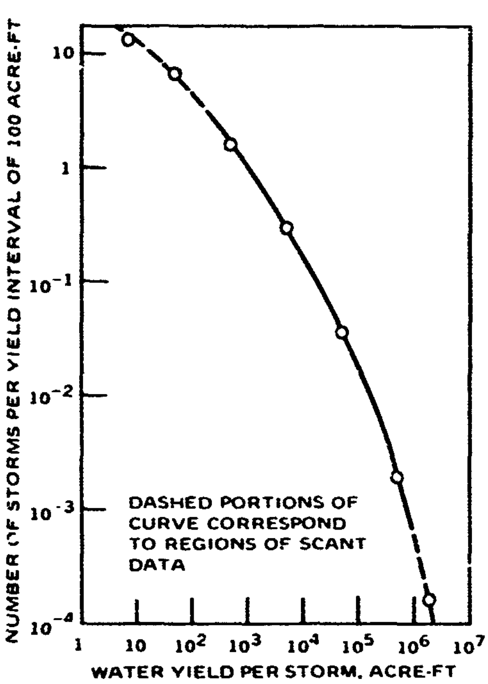
The rain produced by all the storms in each logarithmic class interval both as a linear curve and as a logarithmic curve is given in Fig. 46. Clearly, most of the water came from the larger storms. This suggests the importance of joining individual clouds into major systems.

## SEEDING-AGENT REQUIREMENT

Usage rate of seeding rounds is shown in Fig. 47. Average agent expenditure increased from a few shots for small clouds to 20 shots for the largest systems. Some of the high usage rate was due to overenthusiasm, some to poor management, and some to refractory clouds. The lower curve shows a more prudent possible usage rate and would, in our opinion, correspond to usage by a skilled seeder.




(a) All storms for which yield was estimated.




(b) Data of (a) normalized to 100 storms and a class interval of 100 acre-ft.

FIG. 45. Storm Frequency as Function of Storm Size.

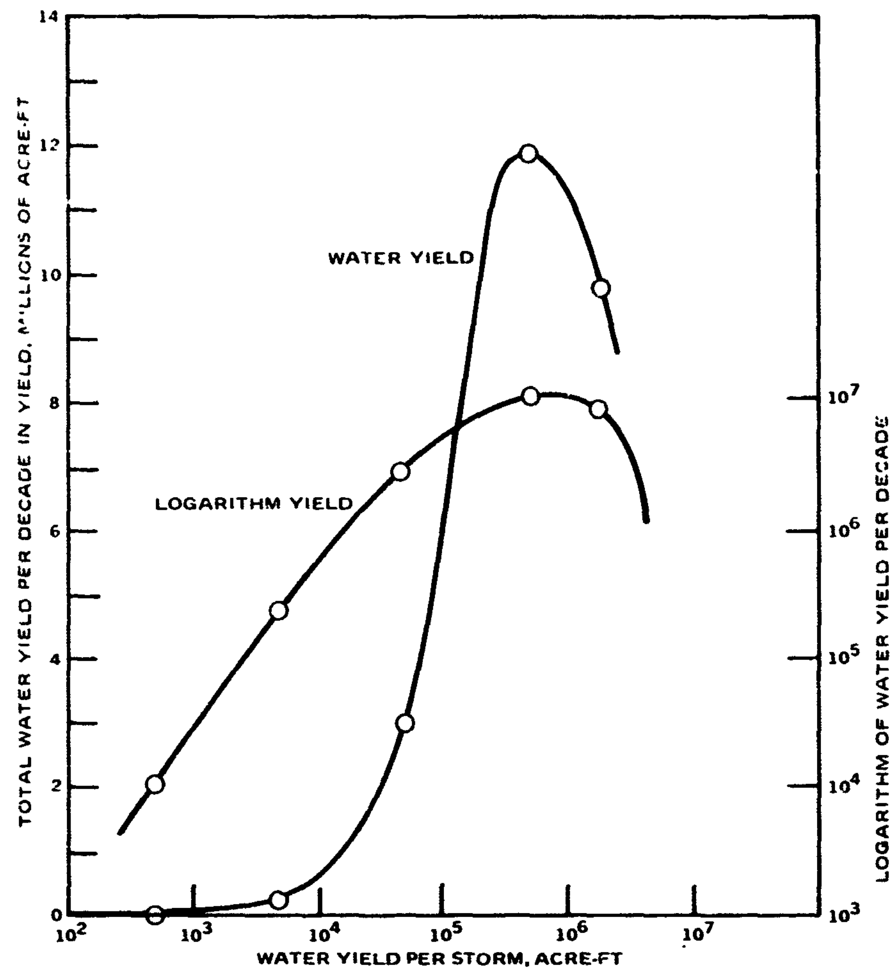



FIG. 46. Total Rain Yield as Function of Storm Size.

Average water yield per round rose from about 40 acre-ft for small clouds to nearly 100,000 acre-ft for the largest systems. This clearly indicates the economy gained by uniting separate clouds into large storms.

## GROUND MEASUREMENTS OF RAIN AT CLARK AB

Records of the total annual rainfall in the Philippines are incomplete because most of the rainfall from cumulus clouds occurs inland and most of the rain gauges are located at seaports, where cumulus showers are less frequent. Rain from monsoons and typhoons is well reported, but the important contributions from other sources are not often measured.

Thus, quantitative estimation of the effects of seeding was difficult, and reliance had to be placed on the visual observations of the seeding teams and on

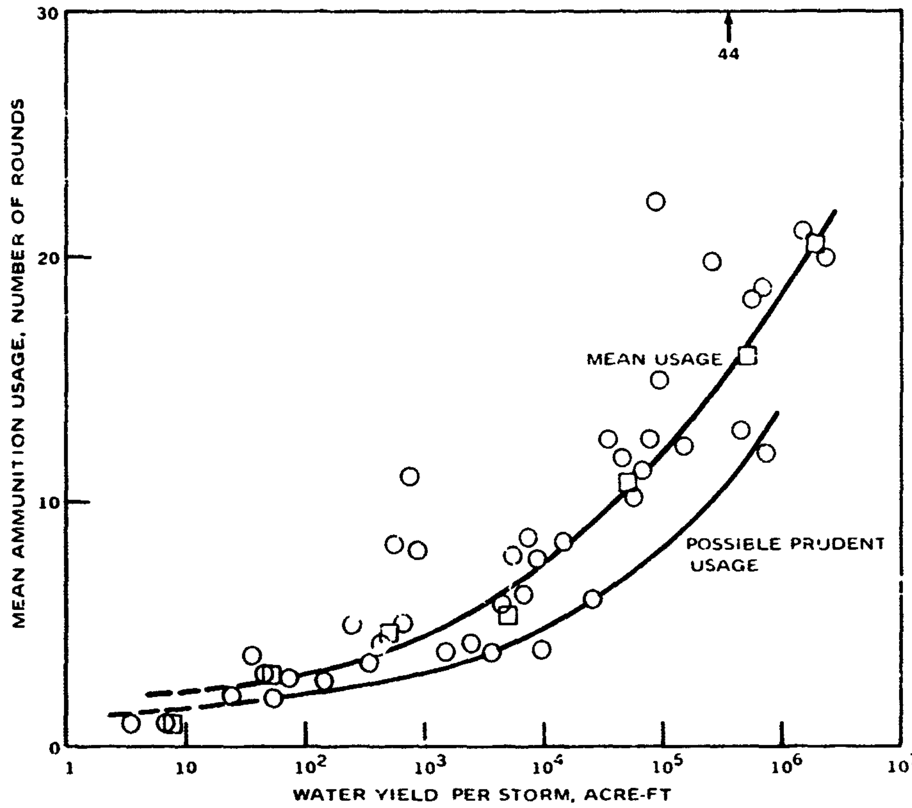



FIG. 47. Seeding-Agent Usage as Function of Water Produced by Seeded Storms. = number of rounds averaged over all storms with estimated water yield in same tenth of a logarithmic decade. □ = number of rounds averaged over all storms with estimated water yield in the same logarithmic decade

occasional rain runs made with the rain-rate meter. In most cases rain shafts could not be penetrated safely because of poor visibility. This factor and the loss of seeding time during rain runs precluded making such efforts frequently.

There was a good rain gauge at Clark AB, and both aircraft had instructions during the month of May to hold back a few seeding rounds and to return to central Luzon a little early, say by 1700, to seed all the suitable clouds near Clark.

The average rainfall over a recent 18-year period at Clark for the month of May was some 4.5 inches, with a standard deviation of 2.6 inches. In spite of the drought, reported to be the worst in 100 years, 8.85 inches fell in May 1969. If it is assumed that the various May rainfalls are normally distributed with a mean of 4.5 inches and a standard deviation of 2.6 inches, the chance that the 8.85 inches of May 1969 were the result of natural rainfall is less than 1 in 20. In other words, the hypothesis that the May 1969 rainfall was not all due to natural causes stands with a significance level of 0.05.

Of the 8.85 inches, 6.53 fell from 11 seeded storms, and 2.32 inches fell from 9 unseeded ones. If it is assumed that in the absence of seeding, the 11 seeded storms would, in the aggregate, have behaved as 11 unseeded storms, each with the

TABLE 12. May Weather Statistics for Clark AB.

| Item | 18-yr av for May | May 1969 |
|---|---|---|
| Total rainfall, in . . | 4.5 (0.3 low, 11.7 high yr) | 8.85 |
| Seeded rain (11 rains), in | . . | 6.53 |
| No. of days with ≥0.004 in . . | 11 | 20 (11 seeded) |
| No. of days with >0.99 in . | 1 | 2 (2 seeded) |
| No. of days with thunderstorms . . . | 20 | 16 |
| Mean relative humidity at 0500, % . . | 84 | 77.5 |
| Mean relative humidity at 1400, % . . . | 54 | 49.5 |
| Mean cloudiness | | |
| At 0200, % . . . . . . . . | 58 | 58 |
| At 0800, % . . . . . . . . . . . . | 69 | 60 |
| At 1400, % . . . . . . . . . . . | 71 | 65 |
| At 2000, % . . . . . . . . . . . | 74 | 71 |
| No. of days with ≥ 6/8 cloudiness. | | |
| At 0200 . . . . . . . . . . . . . . | 14 | 14 |
| At 0800 . . . . . . . . . . . . . . . . | 19 | 15 |
| At 1400 . . . . . . . . . . . . . . . . . | 20 | 16 |
| At 2000 . . . . . . . . . . . . . | 21 | 20 |
| No. of days with ≤ 2/8 cloudiness | | |
| At 0200 . . . . . . . . . . . . . . . . . | 10 | 8 |
| At 0800 . . . . . . . . . . . . . . . . . . | 6 | 5 |
| At 1400 . . . . . . . . . . . . . . . . . . | 3 | 2 |
| At 2000 . . . . . . . . . . . . . . . . . . | 5 | 6 |
| Mean daily maximum temperature, °F . . | 93 | 94.4 |
| Mean daily minimum temperature, °F . . | 76 | 77.2 |
| Absolute maximum temperature, °F . . . | 99 (18-yr high) | 98.6 |
| Absolute minimum temperature, °F . . | 70 (18-yr low) | 75.2 |

rainfall of the average unseeded storm, then this partition of the May rain implies an increase of 3.70 inches, which is 72% of the remaining 5.15 inches of rain and 131% of that fraction that came from the seeded storms.

Table 12 compares the Clark statistics for May 1969 with an 18-year average for May.

Rainfall totals for Cubi Point NAS and Sangley Point NS, neither of which areas was extensively seeded, are

| | *Rainfall, in.* | |
|---|---|---|
| | *May av.* | *May 1969* |
| Cubi (Olongapo) . . . . . . | 12.9 (22 years) | 7.34 |
| Sangley (Cavite) . . . . . . | 6.4 (21 years) | 0.65 |

The rain received at Sangley, just southwest of Manila, is typical of the 1969 spring rainfall in the heavily polluted Manila area.

## RADAR INTERPRETATIONS OF RAINFALL FOR TWO OPERATIONS

Of the two operations discussed in this section Mission 29 is considered first as a typical seeding mission, and Missions 22 and 23 represent especially successful seeding operations.

### Mission 29

On the afternoon of 19 May 1969, seeding operations (Mission 29) were conducted in the Central Luzon Valley. Atmospheric conditions favored cloud formation and growth as shown by the Clark AB rawinsondes (Fig. 11 and 48).

The proximity of Clark AB permitted extended radar surveillance of subsequent storms. The approximate position of each storm as inferred from routine hourly observations with the C-band weather radar (AN/FPS 77V) at Clark AB is shown in Fig. 49. While these locations are accurate within about 5 nautical miles, they represent only some of the more intense portions of the storms. The less intense sections were either undetected or unreported. In addition, some of the more intense areas undoubtedly lay in the radar shadow of those shown. From the seeding team's log it is clear that these intense portions constitute only a matrix within a larger raining area. Nonetheless, these radar observations are valuable in that they provide a useful indication of the movement of portions of the storm and permit the calculation of a lower limit for rainfall.

Seeding was accomplished by means of 28 EW20 Very pistol rounds. The position and time of firing of about half of these, as indicated in Fig. 49, make their association with a particular storm obvious. Most of the remainder correspond to untracked portions of the storm, although a few may be associated with cumuli that failed to mature into rain.

The storms shown were not raining at the beginning of seeding. No preseed rain was observed visually or on ground or airborne radar. Seeded clouds grew and merged with a concomitant disappearance of small "feeder" clouds nearby. Rainfall was detected 20 minutes to an hour after seeding.

At about 0830 GMT a rain run was made in Storm E. Although heavy rain and cloud-to-cloud and cloud-to-ground lightning precluded a traverse through the heart of the storm, a flight along a 2.6-mile, relatively exterior chord yielded an average rain rate of 1.7 in/hr. The central 1.5 miles of this chord averaged 2.5 in/hr. From this traverse, it is conservatively estimated that the rainfall intensity averaged 1.7 in/hr over a 5-nautical-mile-diameter circle at the time of measurement.

With this intensity and this geometry and with the individual storm durations as indicated by the weather radar, it is possible to estimate the amount of rainfall for Storm E and each of the other seeded storms. The results are given in Table 13. From the calculated amount of rainfall, the 5-nautical-mile width, and the distance traveled by each storm as inferred from the radar tracks, an average depth of rain on the ground can be calculated. These values are also given in Table 13.

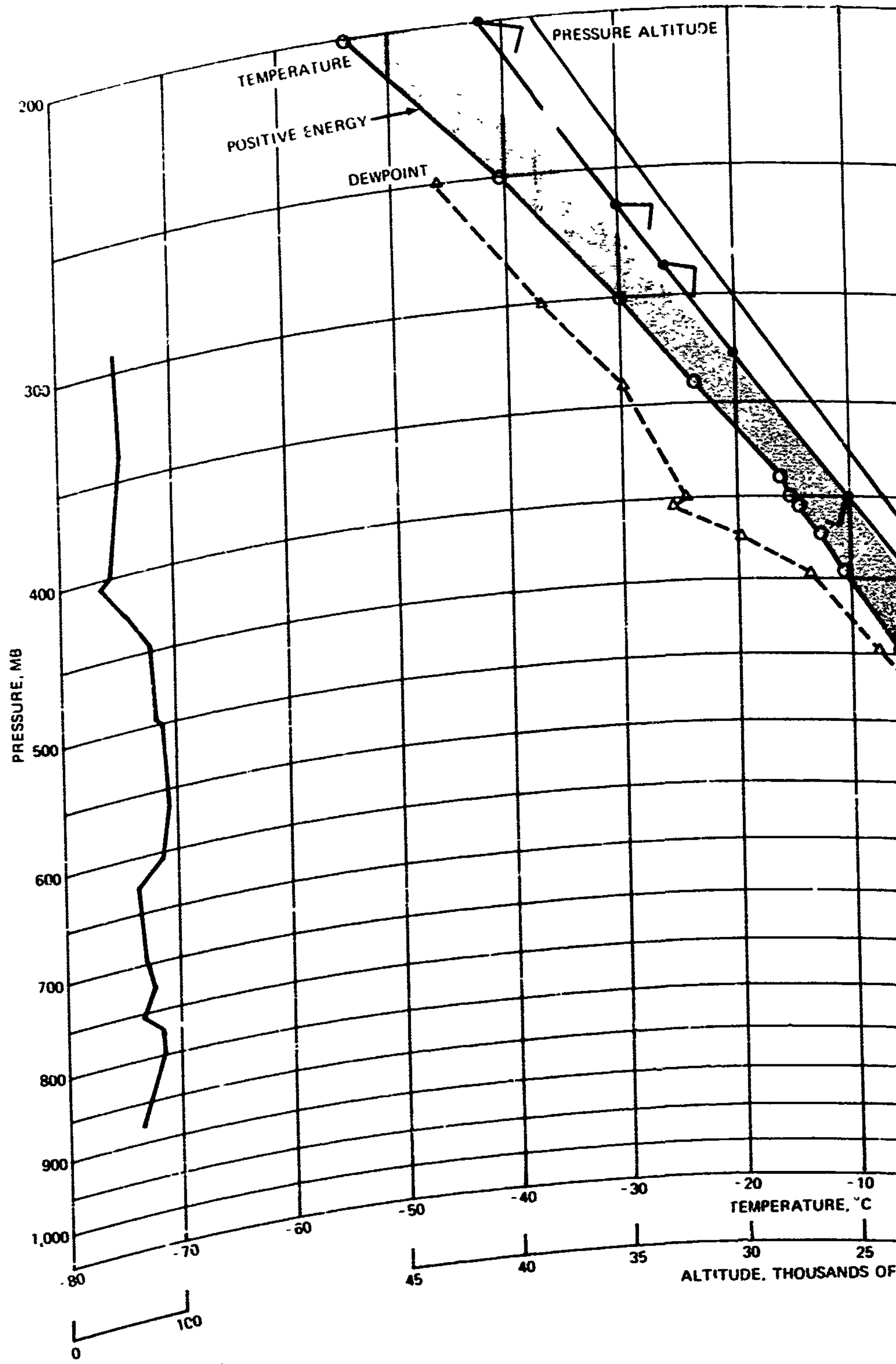
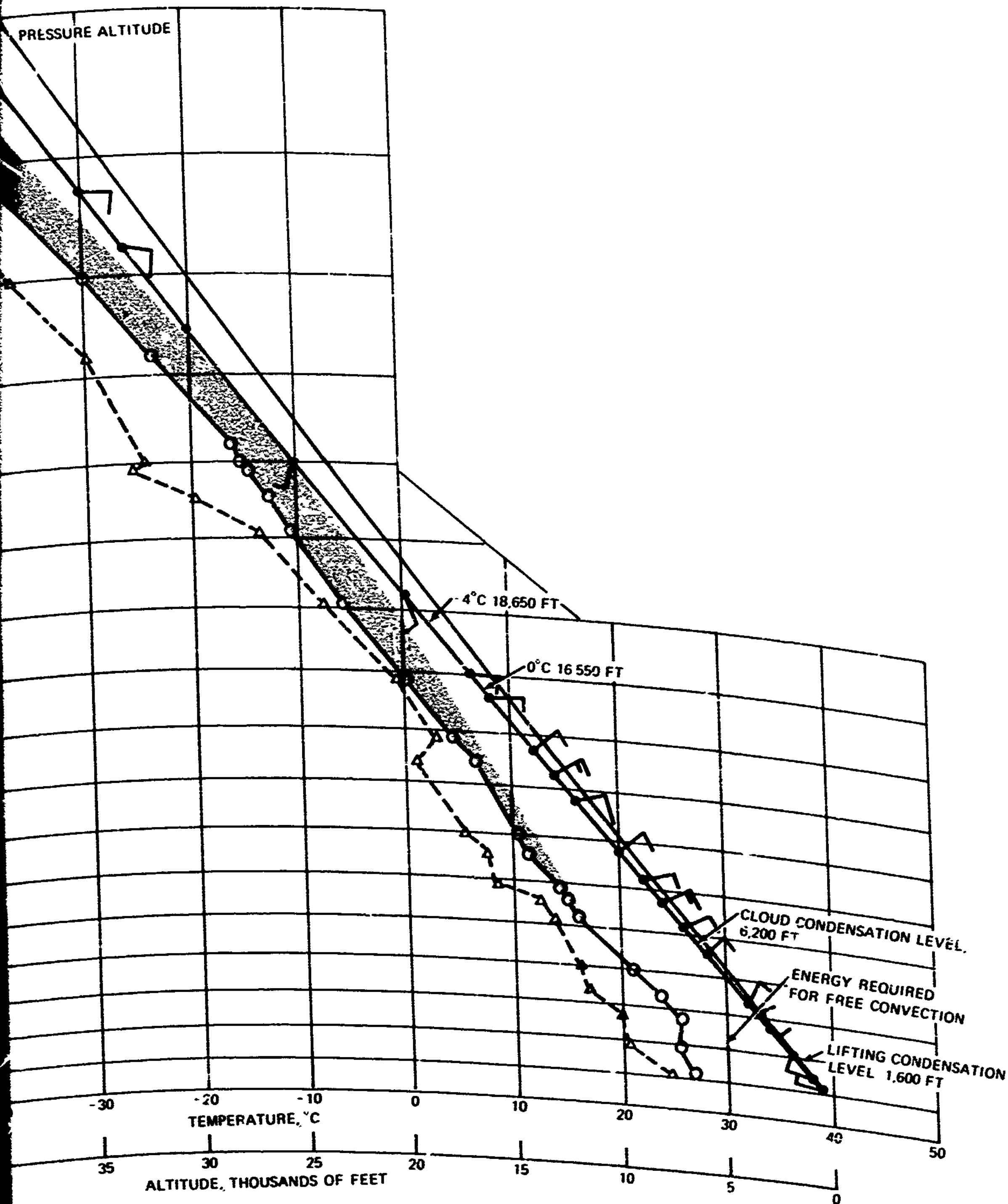

PRESSURE ALTITUDE
TEMPERATURE
POSITIVE ENERGY
DEWPOINT
PRESSURE, MB
200
300
400
500
600
700
800
900
1,000
-80
-70
-60
-50
-40
-30
-20
-10
TEMPERATURE, °C
45
40
35
30
25
ALTITUDE, THOUSANDS OF F
0
100
RELATIVE HUMIDITY, %

FIG. 48. Rawinsonde Data, Clark AB, 19 May 1969, 2000 LST.



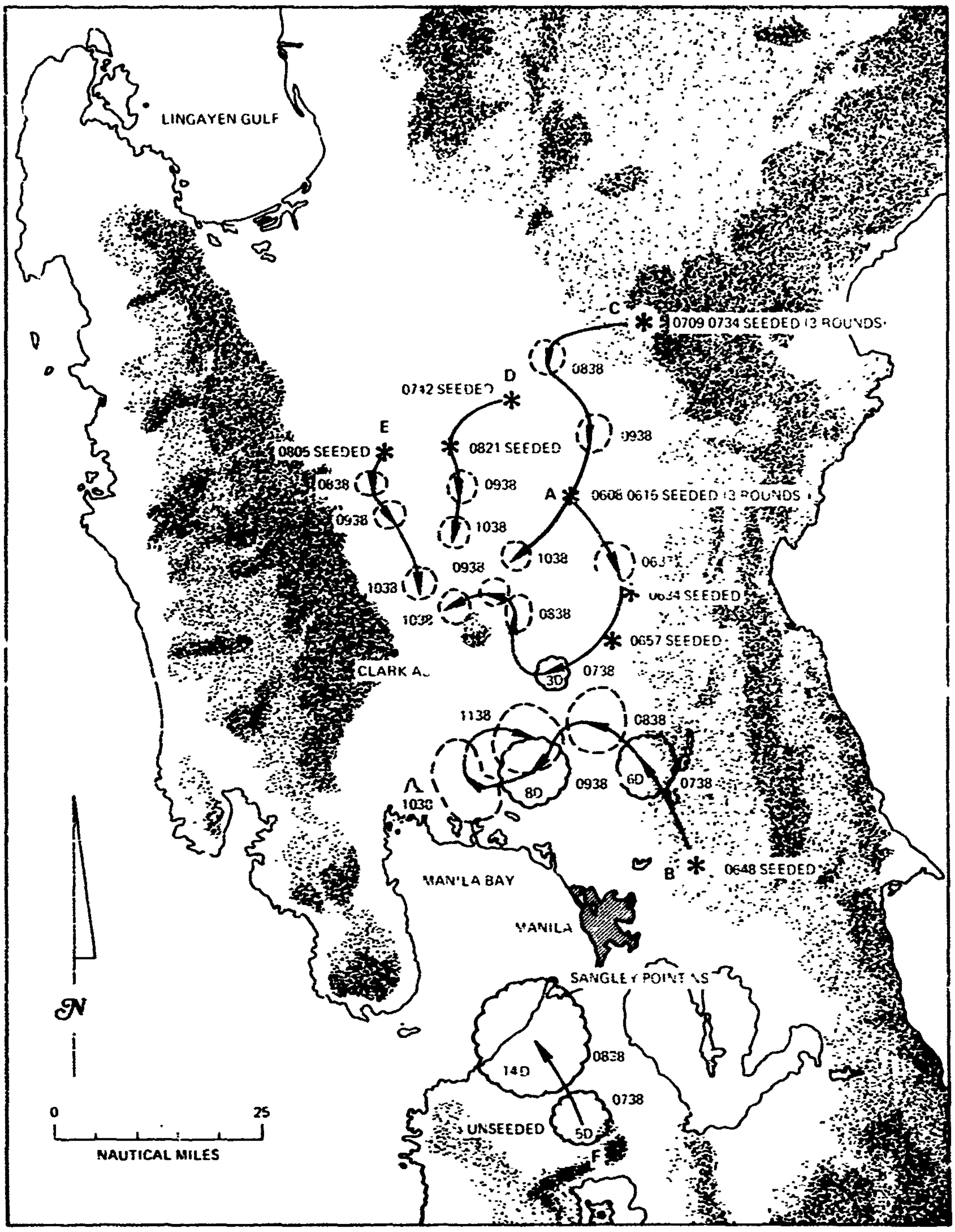



FIG 49. Storm Paths Over Central Luzon Valley, Afternoon of 19 May 1969 (Mission 29). Times are Greenwich mean time; for local standard time add 8 hours. Numbers followed by D as in "5D" are storm diameters in nautical miles. Dashed contours indicate storms for which the radar log gave no diameters.

TABLE 13. Parameters for Seeded Storms Over Central Luzon, 19 May 1969.

| Storm | Duration, hr | Rainfall, acre-ft | Length of storm path, nmi | Implied average depth of rainfall, in |
|---|---|---|---|---|
| A | 5 | 11,600 | 50 | 0.82 |
| B[a] | 5 | 23,200 | 57 | 0.66 |
| C | 3 | 7,000 | 45 | 0.44 |
| D | 2 | 4,600 | 15 | 0.87 |
| E | 3 | 7,000 | 25 | 0.79 |

[a] Radar records indicate this storm was approximately 7 nmi in diameter.

During the standard 1150 to 1600 GMT reporting period, Clark AB received 0.77 inch of rain. Storms A and E appeared headed for Clark, but could not be tracked closer than 5 nautical miles to the radar antenna. It seems reasonable to assume one or both of these storms contributed to the observed 0.77 inch.

Seeded storms persisted from 2 to 5 hours, while the only unseeded storm observed that afternoon, Storm F south of Manila Bay, lasted about 2 hours. Sangley Point NS, on the periphery of the storm, reported 0.29 inch of rain between 0600 and 1200 GMT.

Thunderstorm activity was still so intense in the evening that air traffic from Clark to Manila was suspended.

## Missions 22 and 23

Part of Mission 22 and the entire Mission 23 took place late on the afternoon of 13 May 1969, over central Luzon. Atmospheric conditions (see Fig. 50 and 51) were particularly suitable for convective growth and rain.

Of the 47 TB2 seeding units used this day, 35 may be assigned to 6 of the 10 storms whose tracks, deduced from radar, are shown in Fig. 52. None of these storms was identifiable on radar before initial seeding except Storm $F_1$. In several cases, light rain was observed visually from the target clouds or adjacent clouds at the time of initial seeding.

Careful seeding of the upwind edges of Storms $F_1$ and $F_2$ joined them into a massive storm, F. Penetration of the rain shaft was not possible because of low visibility in the rain and because of widespread lightning. A rain run through the edge of F yielded an average rain rate of 0.5 in/hr over 7.1 nautical miles, with a 0.8 nautical-mile segment averaging 1.5 in/hr.

The observer on the seeding aircraft reported "heavy" rain. His "heavy" was determined by calibration on other rain runs to correspond to rainfall rates of 2 to 5 in/hr. The conservative value of 2 in/hr is used in Table 14 for all the storms that afternoon because they were all repeatedly described as "heavy," except for Storm E, which was unobserved.

The rain run under the edge of F gave a storm width of at least 15 nautical miles. The other seeding aircraft some time later estimated a width of 20 nautical miles; this value is used to calculate the rainfall for Storm F in Table 14. Weather

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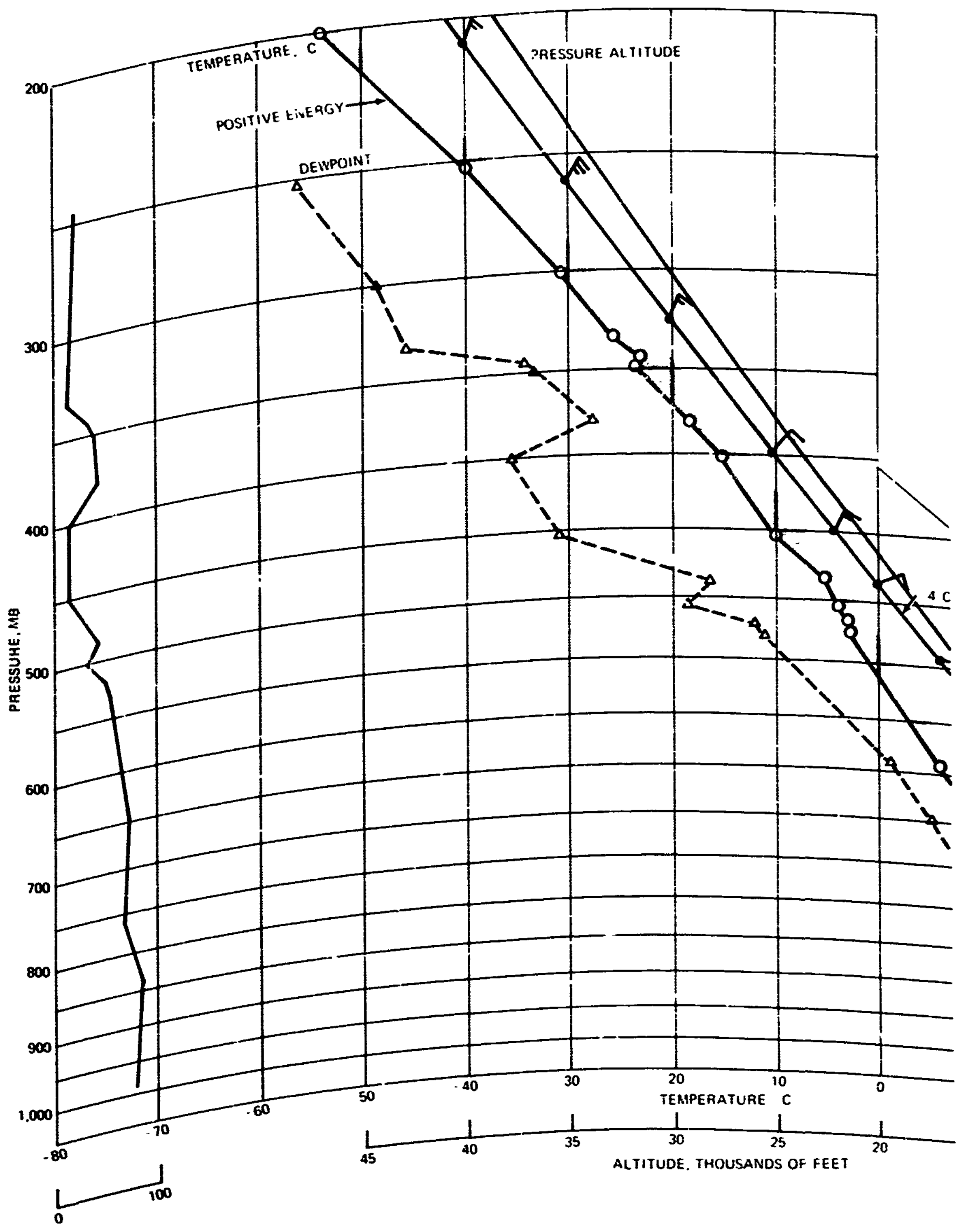
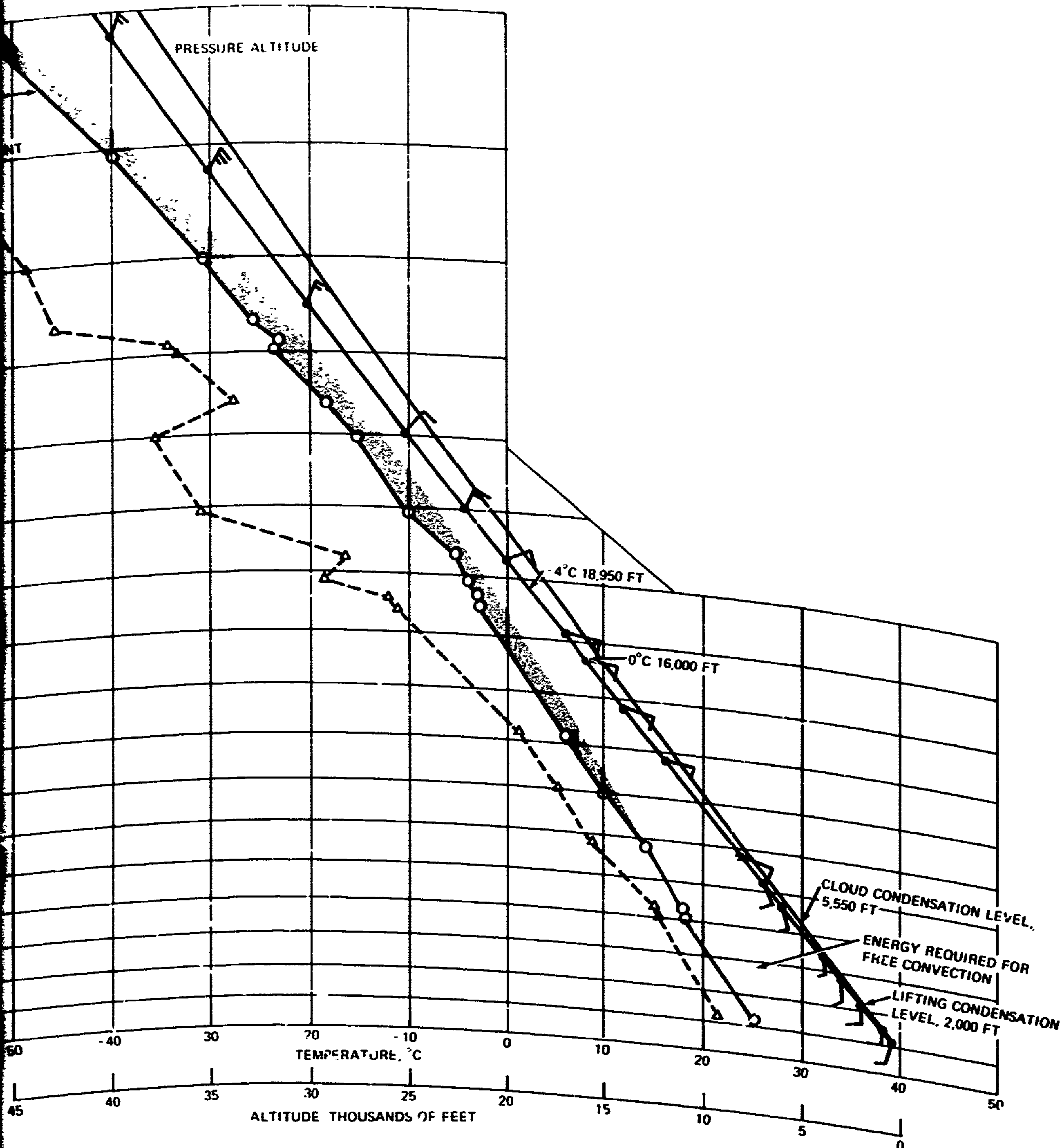

TEMPERATURE, C
PRESSURE ALTITUDE
POSITIVE ENERGY
DEWPOINT
4 C
PRESSURE, MB
200
300
400
500
600
700
800
900
1,000
-80
-70
-60
50
40
30
20
10
0
TEMPERATURE C
45
40
35
30
25
20
ALTITUDE, THOUSANDS OF FEET
0
100
RELATIVE HUMIDITY, %

FIG. 50. Rawinsonde Data, Clark AB, 13 May 1969, 0800 LST.



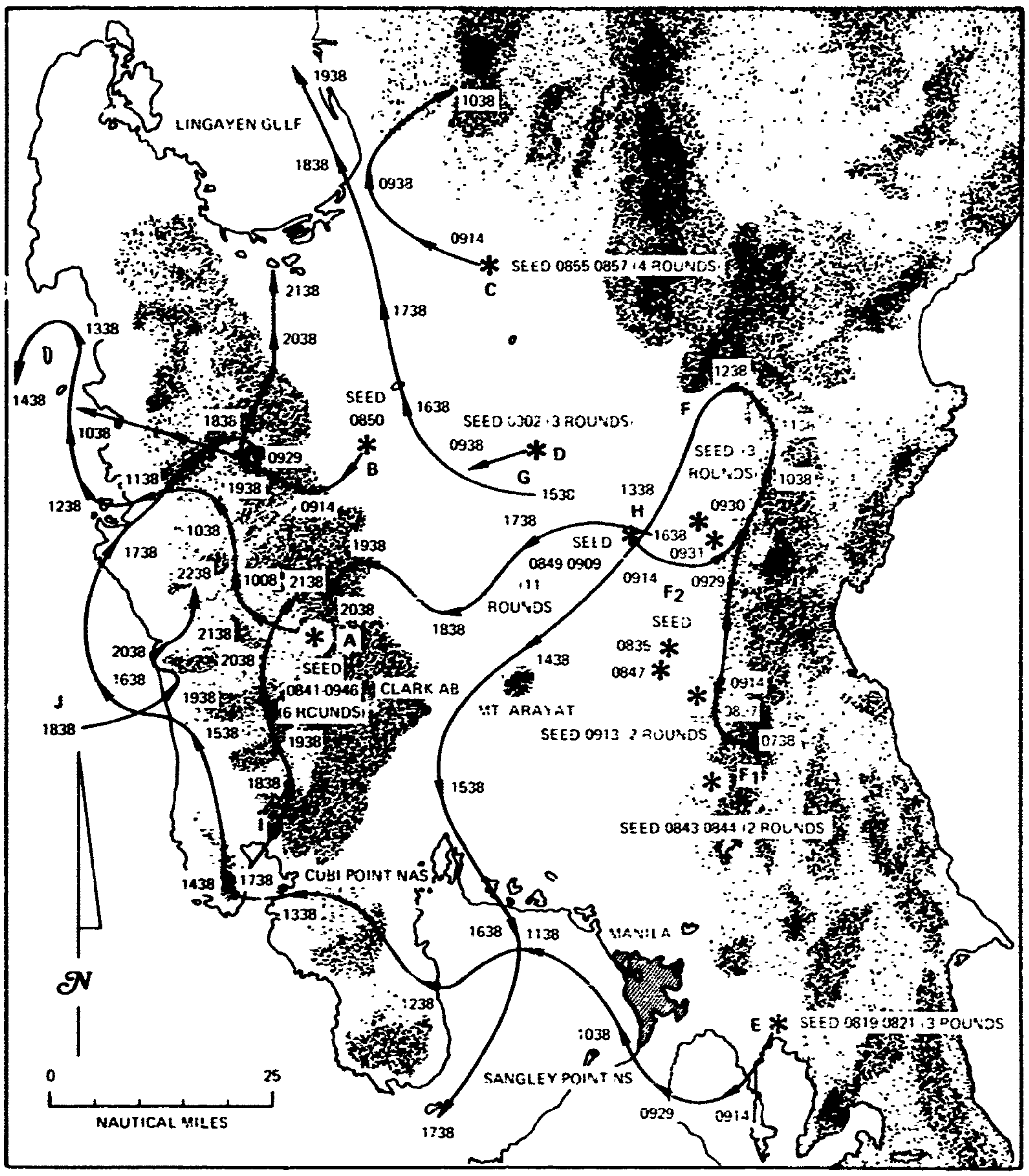



FIG. 52. Storm Paths Over Central Luzon, Evening of 13 May 1969 (Missions 22 and 23). Times are Greenwich mean time, for local standard time add 8 hours. Position of Storm F at 1438 is hypothesized. Presumably Storm F was not detected at 1438 because of the proximity of Mt. Arayat.

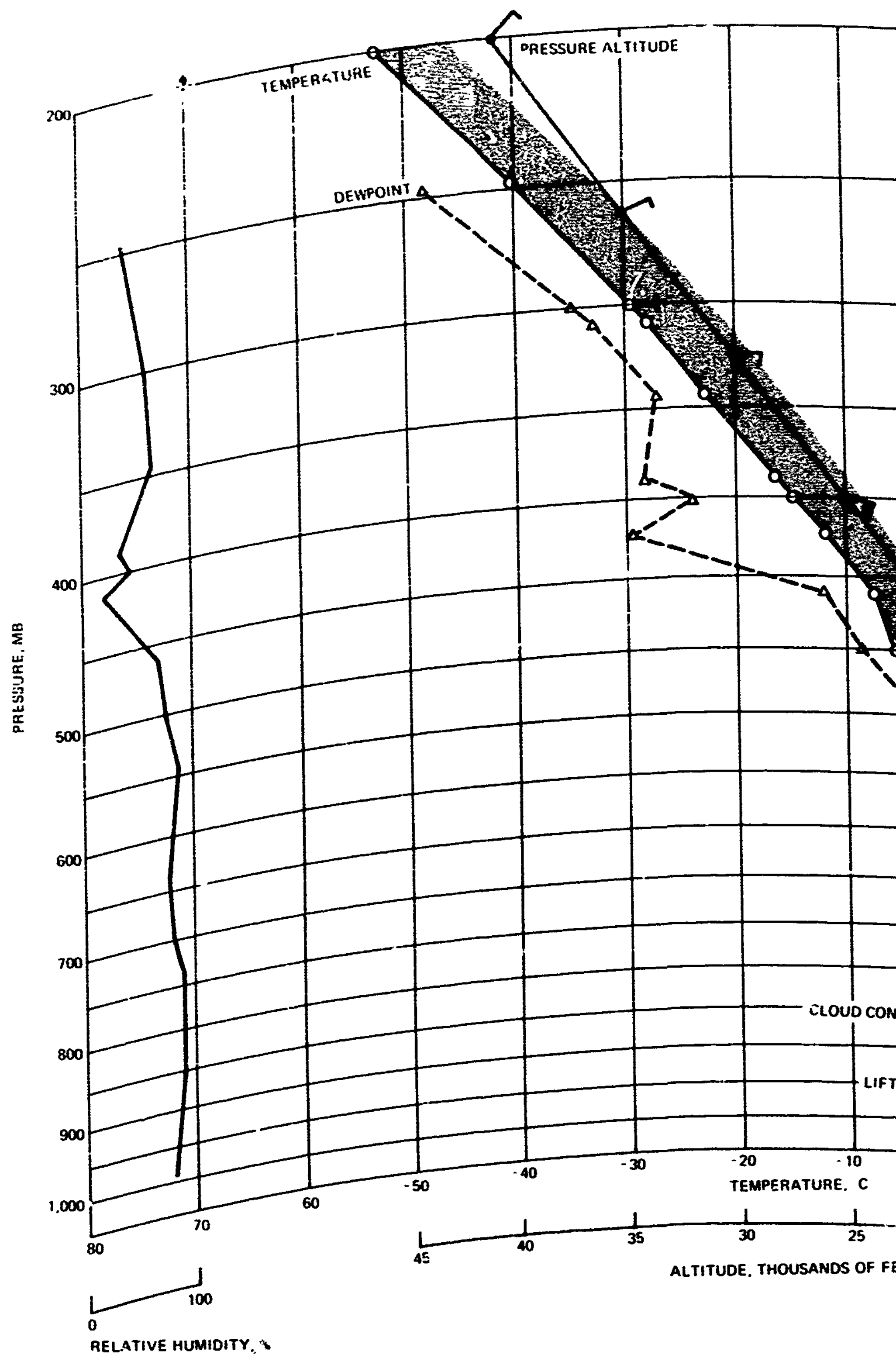

PRESSURE ALTITUDE
TEMPERATURE
DEWPOINT
PRESSURE, MB
200
300
400
500
600
700
800
900
1,000
CLOUD COND
LIFTIN
TEMPERATURE, C
-50
-40
-30
-20
-10
ALTITUDE, THOUSANDS OF FEE
45
40
35
30
25
80
70
60
0
100
RELATIVE HUMIDITY, %

FIG. 51. Rawinsonde Data, Clark AB, 13 May 1969, 2000 LST.

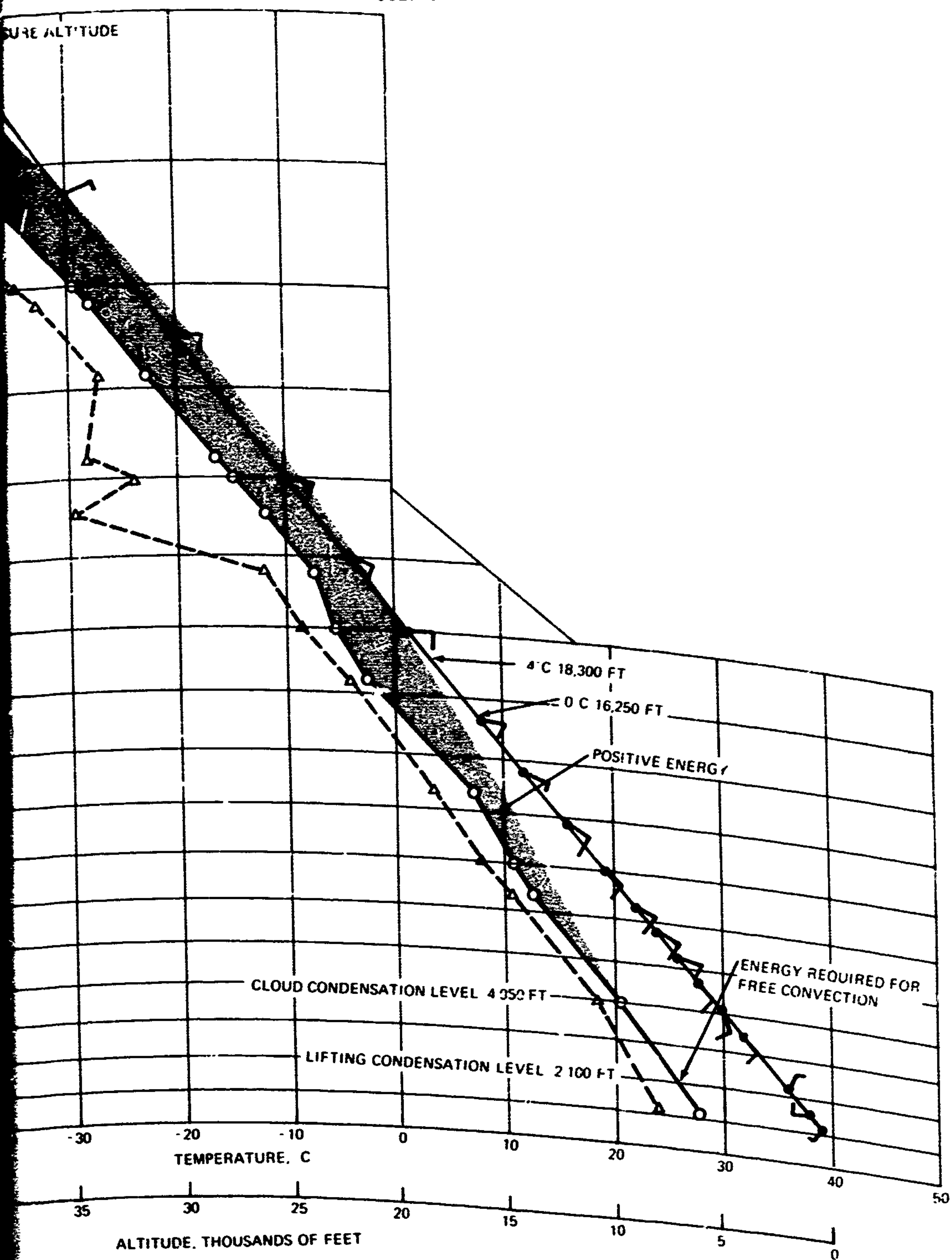


TABLE 14. Parameters for Seeded Storms Over Central Luzon on the Evening of 13 May 1969.

| Storm | Duration, hr | Rainfall, acre-ft | Length of storm path, nmi | Implied average depth of rainfall, in. |
|---|---|---|---|---|
| A | 5 1/2 | 49,500 | 75 | 1.13 |
| B | 1 3/4 | 15,800 | 45 | 0.55 |
| C | 1 3/4 | 15,800 | 40 | 0.62 |
| D | 3/4 | 6,800 | 10 | 1.06 |
| E | 13 | 117,000 | 190 | 0.97 |
| $F_1$[a] | 3 | 8,300 | 40 | 0.59 |
| $F_2$[b] | 3/4 | 31,200 | 15 | 1.52 |
| F[c] | 8 | 355,400 | 145 | 1.73 |
| Total | | 599,800 | | . . . |

[a] Radar records indicate a diameter of about 5 nmi.

[b] The diameter of "$F_2$", about 19 nmi, was determined so that the sum of the cross sections of "$F_1$" and "$F_2$" equalled the cross section of "F".

[c] "F" was formed by joining "$F_1$" and "$F_2$", and its diameter, as described in the text, is estimated to be about 20 nmi.

radar reports of storm widths were scant that day. One young storm was measured as 4 and later 5 nautical miles in diameter. A diameter of 9 nautical miles was reported for one mature storm, and this value is used for the remaining storms in Table 14, for lack of better information.

The rain depths shown in Table 14 (calculated as in Table 13 for Mission 29) may be compared with actual measurement. At Clark AB, 1.77 inches were recorded between 1150 and 1600 GMT, and 0.93 inch fell at Cubi Point NAS between 1200 and 1800.

Upon descent for landing at the return to Clark AB it could be seen that paddies and streams over the eastern part of the central valley of Luzon were full of water (Fig. 53).

A comparison of the Mission 22/23 rainfall estimates of Tables 14 and 15 (Appendix A) is enlightening. Radar interpretations of Storms A and B, corresponding to particularly intense portions of entry 22a of Table 15, clearly underestimate the rainfall for the Zambales area west of Clark AB, while the methods of Table 15 almost certainly overestimate the rainfall. On the other hand, entry 23b of Table 15 severely underestimates the rainfall from Storms $F_1$, $F_2$, and F, because aerial observation of this storm stopped after 2 hours, while radar indicates the storm lasted at least 8 hours. Storms C, D, and E, with a minimum rainfall of almost 140,000 acre-ft, do not contribute to the total rainfall of Table 15 since entries 22b and 23a were not sufficiently observed by the seeding teams to provide a basis for estimation of rainfall. For a more detailed discussion of the methods of Table 15, see Appendix A.

It is, of course, impossible to estimate the amount of rainfall added by seeding as compared to what would have fallen naturally, but the authors feel that the augmentation by cloud seeding was an important percentage of the rain that fell.

Assuming $20 per acre-ft as the value of the water, the integrated rainfall from the eight storms in Table 14 would be valued at $12,000,000. The

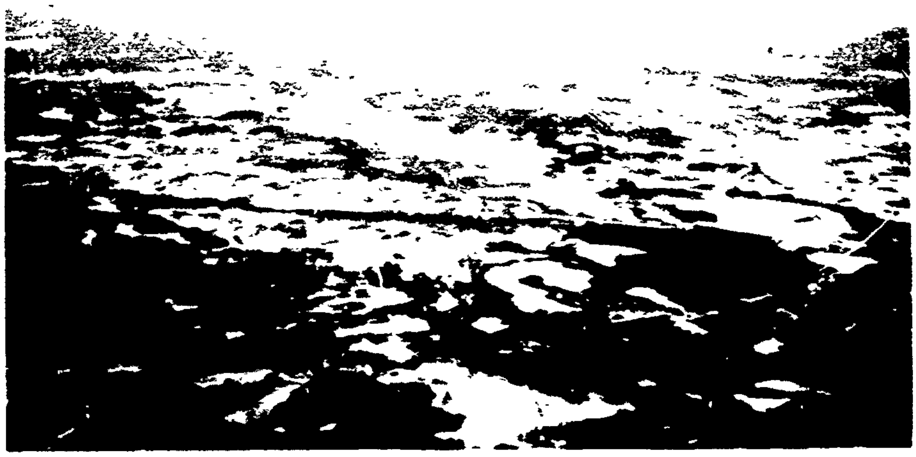


FIG. 53. Flooded Paddies in Southeast Central Luzon Valley. Note low clouds and rain in distance.

ammunition cost was under $600, and a reasonable rental fee for aircraft and pilot for a small plane capable of doing this would have been under $400. Hence the benefit to cost ratio on this day might approach 10,000 to 1.

## IMPACT OF GROMET II ON PHILIPPINE ECONOMY

When the project began, in late April after many months of drought, the fields in central Luzon were brown, and the sugarcane and other plants were dying. By the time the project was completed in June, the islands were verdant.

An analysis of rainfall records is not easy to accomplish. Therefore, the Philippine Sugar Institute assembled agricultural information from which they tried to estimate the impact on the economy. Rice planting was begun 3 weeks earlier than in the previous year. Alfredo Montelibano, Sr., of the Rice and Corn Administration stated: "The country will not have to import rice and corn in 1970, as a result of the rain that fell during May and June. This leads to a saving of 25 million U.S. dollars in foreign exchange."

Based on predicted sugarcane production corrected for area planted, type of cane, fertilizers used, etc., the Philippine Sugar Institute estimates the annual sugar crop. For the last 10 years, these estimates proved optimistic, being a little over the actual production. The 1970 crop was 10% in excess of the estimate. Had the drought conditions persisted, production would certainly have fallen low. The gain estimated for this increase is 43 million U.S. dollars.

The Filipinos were pleased with the effort and with the results. Vice President Fernando Lopez, acting as Secretary of Agriculture, presented plaques of appreciation to the agencies involved. He said in part, "On behalf of the Philippine Government, I wish to express our sincere appreciation for the help extended us by the U.S. Government This is probably one of the few projects jointly undertaken by the two governments whose benefits slipped down from the large-scale agricultural producers to the smallest farmer in the field."

It would be rash to say that the project really was responsible for all the things reported as agricultural gains or even to claim that all the rain that fell following seeding was the result of the efforts of the GROMET II team. However, the fact that the Filipinos continued the work at their own expense the succeeding year and made further plans for 1971 speaks well for the faith they placed in it.

It now remains to conduct a carefully planned, well-executed experiment using the techniques of GROMET II to evaluate the method and determine the cost-benefit ratios as well as to learn more about this potentially useful ecological tool.

## CONCLUSIONS

1. The materials and techniques discussed in this report, namely those developed at NWC for the stimulation and enhancement of rainfall from cold cumulus clouds, are well suited to tropical cumulus.

2. Seeding-agent requirements vary from an average of a few pyrotechnic rounds for single clouds to an average of almost two dozen for large systems.

3. Joining two or more clouds into a continuous, raining system not only greatly increases rainfall over what could be obtained from the clouds as individual raining units, but also sharply reduces the seeding-agent cost per unit of water yield.

4. The water yield of seeded tropical storms correlates well with rain intensity. This suggests that those conditions that permit the development of a certain intensity also largely determine the lateral extension and duration of a storm.

5. In the absence of an adequate water management system, the rain encouragement methods described in this report are a valuable tool for the alleviation of agricultural problems associated with drought.

## RECOMMENDATIONS

### GENERAL

The methods described in this report should be employed at agricultural locations around the world where (1) drought and the state of water management combine to provide a need and (2) suitable clouds exist. Some suggestions for the conduct of such operations appear in Appendix B.

## SPECIFIC

Project GROMET II was by need and by instruction not a scientific experiment. No time was available to set up the operation as such, and even if there had been time, the cost would have been tripled without adding much to the rainfall. We would not willingly have conducted the operation as an experiment because the water need was so great.

Had it been conducted as a carefully planned experiment, however, the results would have shown unequivocally that rain augmentation processes are successful in that climate. Such an experiment could be performed in the Philippines, perhaps to better advantage than almost anywhere else. We recommend that such an experiment be conducted and here set down our ideas as to a useful way to proceed.

### Location

The Visayan Islands (Fig. 54) are recommended as a favorable site. The weather conditions are excellent, the agricultural need is present, and because of the nature of the soil it is almost impossible to deposit too much rain. Panay, Negros, and Bohol have flat areas and hills. Cebu is mostly hilly so that a choice between orographic and air mass clouds is usually available.

Operations could be based at Mactan. A good airport, hangars, storage magazines, and fuel are available, as is a very pleasant city. Secondary bases are available at Bacolod, Iloilo, and Roxas A safe airfield is within gliding distance at all times.

One well-calibrated radar should be put on one of the two mountain peaks, at 8,000 or 6,200 feet, on northern Negros.

### Aircraft

Two turbocharged Cessna 210s or two turbocharged Cessna 337s should be based at Mactan. They should be equipped with seeding racks, Very pistols, and Minilab or other cloud physics apparatus, including a rain-rate indicator.

### Evaluation Equipment

Several thousand plastic rain gauges should be strategically placed on the islands. Reporting should be done daily by means of franked postcards. This reporting is to supplement the main determination to be made by the ground radar. The radar, equipped to measure rain and record aircraft position, would run day and

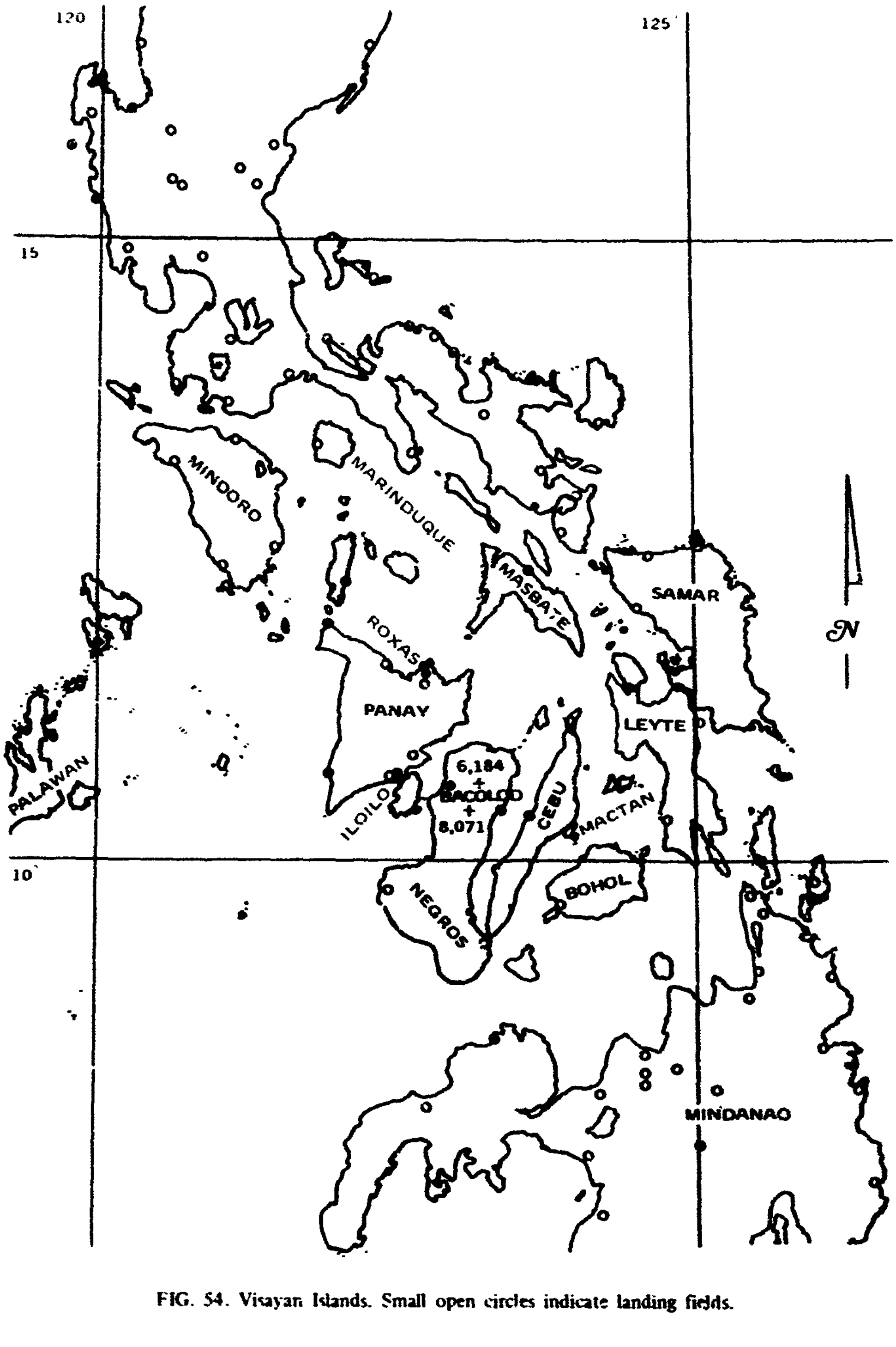



FIG. 54. Visayan Islands. Small open circles indicate landing fields.

night throughout the whole period of the experiment.

A few automatic recording rain gauges and anemometers should be available for installation in places where experience indicates showers occur frequently. Ground meteorological devices (GMD) should be installed at Bacolod and at Mactan and soundings should be made at frequent intervals.

## Procedures

In February or March the GMD and radar should begin surveillance of natural conditions. About 1 April seeding should begin and continue through July. The GMD and radar should continue in operation through August. A small computer, adequate to process mathematical models, should be placed at Mactan.

Seeding would be done on one or, at the most, two islands in 1 day. For example, if Panay were chosen for seeding one day, then Negros, Cebu, and Bohol would go unseeded. The next day Negros would be worked, the third day Cebu, and the fourth day Bohol. The fifth day Panay would be revisited.

All seedable targets on a given island would be worked unless some developments were for some reason to be favored over others. On all days all rainfall would be measured by radar and confirmed by rain gauges.

Thus, target and control situations would be on an island-to-island basis rather than a cloud-to-cloud basis. Because it now seems clear that a good soaking down on one day leads to better cloud development the next, the 4 days between seedings would permit an evaluation of long term effects induced by seeding.

This scheme would probably yield adequate rainfall for agriculture and offers the advantage of three control areas for each target area. Meanwhile, the islands of Leyte and Masbate could serve as constant control areas as might northern Mindanao, provided some rain gauges were made available.

## Cost of Experiment

A crude estimate of the costs of such an experiment follows.

This cost schedule assumes that no cost will be levied for use of local facilities and that the radars, GMD, and similar devices will be furnished from military or other government stores. Write-up, analysis, and computer time are included under overhead.

Seeding:

| | |
|---|---|
| Aircraft rental (2) | $ 30,000 |
| Pilots (2) | 10,000 |
| Mechanic (1) | 5,000 |
| Ammunition, 6,000 rds | 90,000 |
| | $135,000 |

| | |
|---|---|
| Evaluation: | |
| Manager | $ 10,000 |
| Meteorologist | 6,000 |
| Seeding assistant | 5,000 |
| Radar men (6) | 24,000 |
| Clerks (2) | 6,000 |
| | $ 51,000 |
| Supply: | |
| GMD expendables | $ 5,000 |
| Rain gauges | 5,000 |
| Postcards | 1,000 |
| | $ 11,000 |
| Total | $197,000 |
| Contingency and local labor | 20,000 |
| | $217,000 |
| Overhead | 217,000 |
| | $434,000 |

## Results

Analysis would reveal the normal rainfall rate, the augmentation achieved for each island, the time variations due to seeding, and the cost effectiveness of the operation; the analysis would also furnish data for computer evaluation of various models. Cloud-physics data would be collected by the aircraft.

Such a definitive experiment is clearly needed and should be performed soon in order to obtain data on attainable rain yields and cost effectiveness.

## ACKNOWLEDGMENT

Project GROMET II was made possible through the strong support and help of many people at home and abroad. To list them all is impossible.

Mr. R. M. McClung and staff at NWC procured all seeding supplies and equipment, and Mr. R. G. S. Sewell of NWC gave valuable technical help with the ordnance.

Mr. Francisco Baltazar of the Philippine Civil Aeronautic Administration and Mr. D. Tierney, U.S. Air Traffic Control Representative, did a fine job in arranging air traffic control procedures. Director Roman Kintanar of the Philippine Weather Bureau made available current weather data for the archipelago.

Major Thomas Studor, USAF, Air Weather Service Headquarters, enthusiastically shared his knowledge of meteorology and cloud physics.

Lieutenant Colonel Theodore Mace, USAF, Commander of Detachment 2, 9th Weather Reconnaissance Wing, and his Operations Officer, LTCOL Frank Ross, USAF, did an exceptional job of supervising the myriad operational details necessarily a part of a project of the scope and intensity of GROMET II

The U.S. Air Force flight crews from the 54th Weather Reconnaissance Squadron (MAC), Andersen Air Base, Guam, were outstanding in the performance of their duties and in the skills they were repeatedly called upon to demonstrate. Their can-do spirit and professional zeal and their sense of camaraderie were an inspiring asset to the program.

Major F. Yount, USAF, of Detachment 2, 9th Weather Reconnaissance Wing, and his maintenance team, including 1LT M. R. Hollobaugh, USAF, of the 54th Weather Reconnaissance Squadron (MAC) should be commended for their uncompromising maintenance work, which permitted us to keep each of two WC-130 aircraft in the air up to 8 hours a day for periods of several days.

Base weather (Detachment 5, 1st Weather Wing) under LTCOL W. B. Hellkamp sted in numerous ways in the provision of working space for the NWC technical n, the acquisition and interpretation of various meteorological data, and the il-time loan of an enlisted man. They are most remembered, however, for the willingness and cheerfulness with which they helped in innumerable small tasks, often on short notice. U.S Air Force CAPT L. L. Hawkins, MSGT W. J. Scott, and SSGT D. A. Pukall stand out among many.

GROMET II greatly benefited by the guidance and broad meteorological background of CAPT E. L. Snopkowski, USN.

Dr. D. R. Booker, Weather Science, Inc., Norman, Okla., provided the Minilabs and nucleus counter, supervised their installation, and trained Air Force personnel in their use. In addition, both he and Dr. E. X. Berry of Desert Research Institute, Reno, Nev., shared freely and frequently of their wide experience and expertise in cold cumulus seeding.

Dr. Hugh W. Hunter, Head of the Research Department at NWC, contributed to the program by his strong support and guidance.

Particular recognition is owing to CAPT Robert B. Mottern, USN (Ret.), who gave so unselfishly of his time, talent, and health to the development of techniques used in this venture. That GROMET II should have been an important step forward in using the technology he so skillfully and wholeheartedly helped develop as a tool in furthering human welfare and diplomatic relations is a credit and tribute to his outstanding career.

# Appendix A
# SUMMARY OF OPERATIONS

Table 15 is a tabulation of all GROMET II operations by date, mission and target number, geographic location, and preseed and postseed condition. The headnote to the table provides a key to the abbreviations used.

**Targets.** Individual targets may be a single cloud, a cloud complex, or several such occurring in the same general area and responding similarly to treatment.

**Locations.** The locations named in the "Place" column are the nearest geographical features that could be identified (Fig. 55).

**Rain Intensity.** For a discussion of rain intensities see the section Project Findings, page 50.

**Radar Echoes.** Preseed and postseed radar echoes are estimated or measured from the radar in the WC-130 aircraft.

**Rain Area.** The area experiencing rain is estimated from radar or from topographic features and navigational data. P means only a part has been estimated and that the area is larger. In some cases the dimensions of the major and minor axes of the area are given.

**Rain Duration.** Duration is time from onset following seeding to the last observation. If possible, estimates to the nearest tenth of an hour are given. Most storms were not observed over their full course, and the actual duration of the larger storms is almost invariably longer than shown.

**Rain Rate.** Rain rates other than the standard L, M, or H are determined from rain runs made through a portion of the shower. When the Weather Science, Inc., rain-rate meter data were used, a drop size of 2.5 millimeters was assumed in order to convert rainwater content to rain rate. This corresponds to the volume mean determined for several showers in the United States. Since Philippine drops were generally larger, the estimated rain rate is probably low. Where no numerical value is shown, the assumed values are L = 0.5 in/hr, M = 1.5 in/hr, H = 2.5 in/hr.

**Estimated Rainfall.** Calculated amounts of rainfall are shown for all cases sufficiently well observed to make a reasonable estimate of area, duration, and rain rate. Calculated rainfall values tend to be overestimates in the sense that it generally was not raining over the whole area at the indicated intensity for the entire time. More usually, each of several subareas received rain of a varying intensity for a portion of the period. While it is not possible to supply this detail, the overestimates implied by the gross accounting are partially compensated by the fact that most of the tabulated areas were raining at the termination of observations and continued to rain for an unknown time. The estimation procedure is consistent and provides a basis for the comparison of different cases.

We make no claim that all the rain that fell was produced by seeding. Our own experience leads us to believe that somewhat less than 50% would have fallen naturally and that less than 25% of the clouds would have developed heavy natural rainfall, but these values cannot be substantiated rigorously.

**Comments.** The comments in the last column are from observers' notes.

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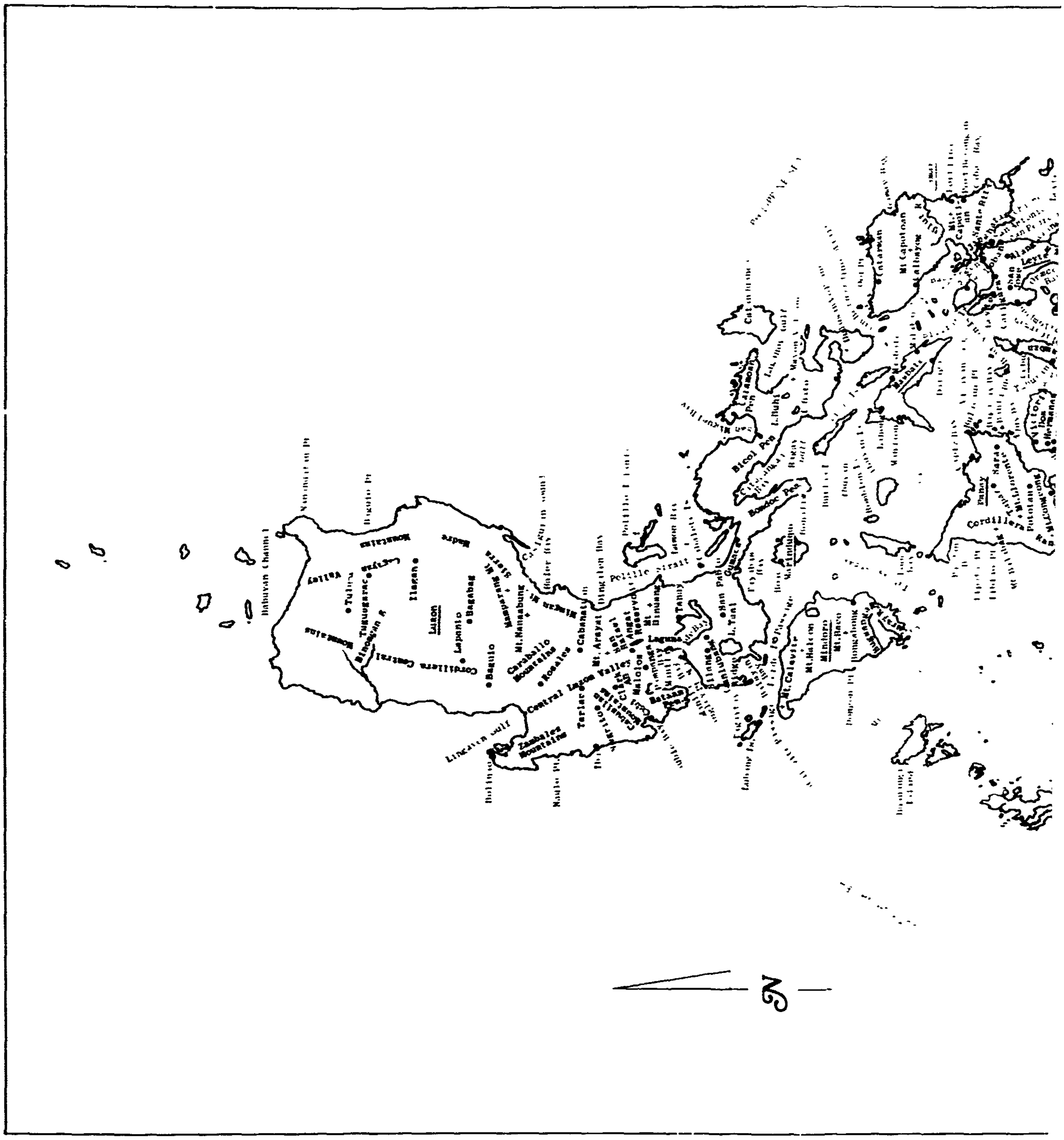
Luzon
Baguio
Cordillera Central
Caraballo Mountains
Mt.Arayat
Tarlac
Zambales Mountains
Polillo Strait
Bicol Pen.
Bondoc Pen.
L.Taal
Mindoro
Mt.Halcon
Mt.Calavite
Panay
Cordillera

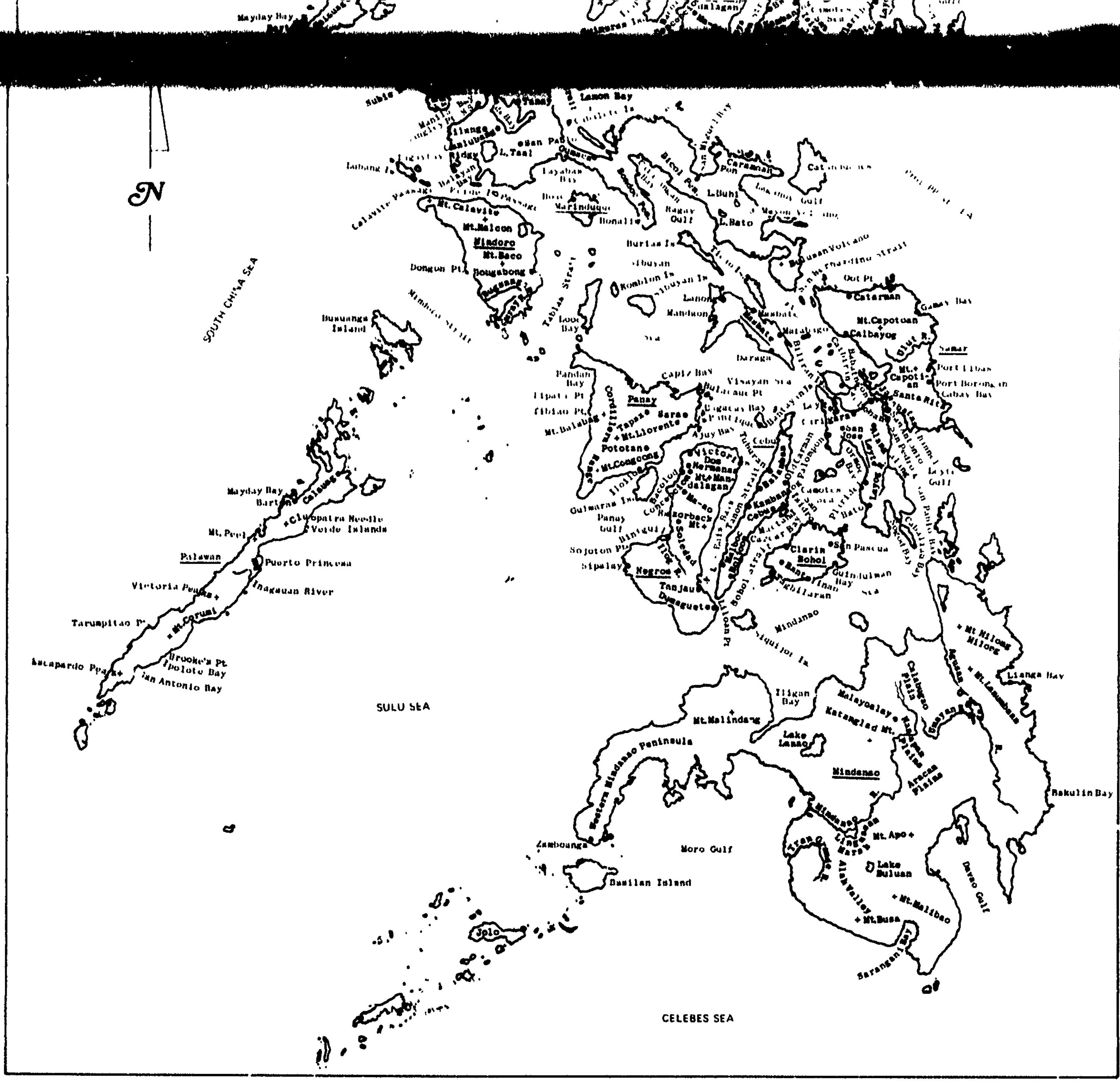


FIG. 55. Ta. ·t Locations Cited in Table 15.

TABLE 15 Summary of C

| Key | | | | | |
|---|---|---|---|---|---|
| AB | Air base | CU | Cumulus | L | Light |
| B | Between | D | Diameter | LWC | Liquid water con |
| C | Central | E | East | M | Moderate |
| CB | Cumulonimbus | H | Heavy | N | North |

Temperature and rain duration values

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft X 10³ | Temp., °C | No. of units | Rain intensity | Radar e nm |
| 28 Apr | 1 | Reconnaissance | | U | U | . . | . | . . | | |
| 29 Apr | 2 a | Panay | B Mt. Balabag and Mt. Congcong | L | U | 18 5 | U | 5 | M | U |
| | b | Negros | E of Biniguil | No | U | 18 6 | U | 2 | L | U |
| | 3 a | Mindoro | B Mt. Halcon and Mt. Calavite | No | U | 19.2 | -6 5 | 5 | L | + |
| | b | Luzon | W of Lake Taal | No | U | 18.5 | -6 5 | 9 | L | + |
| 30 Apr | 4 a | Mindanao | V Lake Lanao | No | 7 X 3 8 (D) | 19 2 | -5 5 | 12 | H | 24 ( |
| | b | Do. | N of Davao Gulf | No | U | 18.5 | -3.5 | 10 | L | U |
| | 5 a | Do. | S Tran Grande R. | No | U | 17.0 | -3.0 | 7 | M | 10 ( |
| | b | Do. | Mt. Malibao | No | 1.5 (D) | 20.6 | -7.5 | 4 | L | + |
| | c | Do. | S of Mt. Busa | No | U | 19.3 | -6.0 | 3 | L | + |
| 1 May | 6 a | Panay | C Cordillera Range | No (L V) | No | 21.2 | -10.5 | 4 | H | + |
| | b | Negros | SE of Sipalay | No (L V) | 6 X 3 | 19 5 | -5.5 | 4 | H | 5 X<br>3 X |
| | c | Cebu | V Malboc | No | U | 18.0 | -2.5 | 1 | No | Nc |
| | d | Bohol | SW of Bantolinao | No | U | 18.8 | -4 5 | 1 | L | U |
| | e | Luzon | V Lake Taal | No | No | 18.2 | -2 0 | 3 | L | + |
| | f | Do. | B W Coast and C Zambales Mt. | No | U | 17.3 | -2 0 | 2 | No | U |
| | g | Do. | S Zambales and N Cabusilan Mt. | No | U | 17.9 | -2.5 | 4 | L | + |
| | h | Do. | V Baguio | No | + | 21.3 | -9 0 | 1 | L | + |
| 2 May | 7 a | Samar | V Janabatas Channel | No | U | 18.2 | -2 0 | 6 | L | 4 X 2 |
| | b | Mindanao | V Katanglad Mt. | No | + | 20.8 | -8 0 | 11 | H | U |
| | c | Do. | Nanapan and Aracan Plains | No | U | 19 5 | -3 0 | 11 | H | U |
| | d | Do. | E of Alah Valley | No | U | 21 5 | -8.0 | 2 | H | U |
| | e | Do. | E of Sarangani Bay | No | U | 20.9 | -7 0 | 7 | H | U |
| 3 May | 8 a | Luzon | W Cordillera Central | M | + | 20.4 | (-6.0) | 28 | H | 7 X 17 |
| | b | Do. | V Rosales | L | U | 20.1 | (-6.0) | 14 | M | 2 X 1 |
| | c | Do. | Zambales and N Cabusilan Mt. | No | U | 20.5 | (-8.0) | 23 | M | U |
| 4 May | 9 a | Luzon | C Bicol Pen. | No | No | 19.5 | 6.0 | 16 | H | + |
| | b | Do. | N Bondoc Pen. | No | No | 17.0 | -3.5 | 13 | H | + |
| | c | Do. | Cabusilan Mt. | No | No | 17.9 | -2 0 | 17 | No | Nc |
| | d | Do. | NW of Baguio | L | + | 20.0 | -8.0 | 6 | M | + |
| | e | Do. | N and C Zambales Mt. | L | + | 17.8 | -2.5 | 15 | M | + |
| | f | Do. | W Mamparang Mt. | No | No | 18.0 | -2 5 | 2 | No | + |

15 Summary of GROMET II Operations

L Light
C Liquid water content
M Moderate
N North
NAS Naval Air Station
No (V) None from target, but from vicinity
P Partial
S South
U Unobserved
V Vicinity of
W West
\+ Noted but not measured

d rain duration values in parentheses are estimates

| Postseed | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rain intensity | Radar echoes, nmi | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft X $10^3$ | Comments |
| | | | | .. | .. | .. | ... |
| M | U | 15 x 5 | 75 | 1 8 | M | 14 3 | Precipitation increased, limited by strong wind shear |
| L | U | 3 x 5 | 15 | 0 8 | L | 0.4 | Cloud top blew off |
| L | + | U | U | U | ... | . | Low wind shear |
| L | + | 5 (D, P) | 20 (P) | U | . | . . | One of three shafts |
| H | 24 (D) | U | 4,000 | >3 | H | 2,120 | ... |
| L | U | U | U | 0 2 | ... | ... | ... |
| M | 10 (D) | 8 x 10 | 80 | >1 | M | 8 5 | ... |
| L | + | 8 x 10 | 80 | U | ... | . | ... |
| L | + | 8 x 4 | 32 | U | . . | | ... |
| H | + | 25 x 16 | 400 | >2 | H | 141 | Joined two nonraining clouds to two adjacent CB |
| H | 5 x 12<br>3 x 4 | 5 x 20 | 100 | 2 | H | 35.4 | Light precipitation over coastal farmlands |
| No | No | U | U | U | . . . | ... | Clouds too warm |
| L | U | U | 10 | 0 2 | L | 0.1 | Dissipated rapidly |
| L | + | U | U | 0.5 | . . | . . | Top separated |
| No | U | U | U | U | ... | ... | Clouds too warm |
| L | + | 1 (D) | 1 | 2 | L | 0.1 | 20-nmi drift; cyclic collapse and reformation |
| L | + | U | U | 0.3 | .. | .. | Cloud collapsed |
| L | 4 x 2 (P) | U | U | U | . . | ... | Two light showers; Clouds too warm |
| H | U | 30 x 10 | 300 | >1 | H | 53.0 | ... |
| H | U | >10 (D) | >80 | >1 | H | 14.1 | Farmland |
| H | U | 5 (D) | 20 | >1 | H | 3.5 | Farmland |
| H | U | 10 (D) | 80 | >1 | H | 14.1 | ... |
| H | 7 x 17 (P) | 180 x 50 | 9,000 | >1 | H | 1,590 | Joined clouds along range: storm grew to east |
| M | 2 x 1 5 (P) | 5 (D), 20 (D) | 330 | (1) | M | 35.0 | Scattered showers |
| M | U | 15 x 55 | 825 | >1 | M | 87.5 | Scattered showers; joined to target 8b |
| H | + | 40 (D) | 1,250 | >6 | H | 1,330 | Fields wet |
| H | + | 30 (D) | 700 | >6 | H | 742 | ... |
| No | No | U | U | U | ... | . | Clouds too warm |
| M | + | 20 x 14 | 280 | (1) | M | 39 8 | Extended natural precipitation |
| M | + | 5 x 30 | 150 | >1 | M | 15.9 | Joined CU to make CB |
| No | + | U | U | U | ... | ... | Clouds too warm |

TABLE 15. (Contd.)

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No. of units | Rain intensity | Radar echoes, nmi | Li… o… |
| 5 May | 10 a | Luzon | Bicol Pen. and N Bondoc Pen. | No | U | 18.6 | –5.0 | 16 | H | 20 × 4 (P) | |
| | b | Samar | N of Calbayog | M | U | 19.1 | –6.5 | 5 | H | U | |
| | c | Leyte | B Babatngon and San Jose | M | U | 18.5 | –6.5 | 11 | H | U | |
| | d | Masbate | E Mandaon | No | U | 18.3 | –5.0 | 5 | H | U | |
| | 11 a | Luzon | Cabusilan Mt. | L | U | 20.0 | –8.0 | 12 | L | U | |
| | b | Do. | NE of Manila | L | U | 22.5 | –13.5 | 4 | L | U | |
| 6 May | 12 a | Luzon | S Central Luzon Valley | No | U | 18.8 | –5.0 | 14 | L | 3 (D, P) | |
| | 13 a | Do. | V Naulo Pt. | No | U | 18.7 | –5.0 | 11 | L | + | |
| | b | Do. | V Lake Taal | No | U | 17.9 | –2.5 | 9 | H | + | |
| 7 May | 14 a | Panay | Cordillera and Central Valley | No | No | 18.9 | (–3.5) | 41 | M | + | |
| | b | Negros | V Sipalay | No | No | 18.4 | –3.0 | 10 | M | 12 (D) | |
| | c | Luzon | SE of Lake Taal | No | No | 18.5 | –3.5 | 7 | M | + | |
| | d | Do. | B Manila and Negrito | No (V) | No (V) | 19.1 | (–4.5) | 27 | L | + | |
| | e | Do. | NE of Rosales | No | No | 19.5 | (–5.0) | 6 | M | U | |
| 9 May | 15 a | Masbate | S of Lahong | No | No | 20.0 | –6.0 | 3 | H | + | |
| | b | Panay | W of Bagacay Bay | No (V) | + | 19.7 | –7.5 | 3 | H | + | |
| | c | Luzon | N Bondoc Pen. | No | + | 20.0 | –6.5 | 2 | U | U | |
| | d | Do. | E of San Rafael | No | + | 19.7 | –5.5 | 3 | U | U | |
| | 16 a | Sibuyan | W | L | U | 19.2 | (–5.5) | 4 | H | + | |
| | b | Tablas | S | No | + | 19.1 | (–5.5) | 3 | L | U | |
| | c | Panay | V Mt. Congcong | L | U | 18.9 | (–5.5) | 7 | H | 7 × 10 | |
| | d | Guimaras | S | No | U | 19.0 | (–5.5) | 3 | M | U | |
| | e | Negros | B Soledad and Dos Hermanas | H | + | 19.3 | (–5.5) | 4 | H | + | |
| | f | Panay | B Tibiao Pt. and Lipata Pt | No | U | 19.2 | (–5.5) | 2 | U | U | |
| | g | Mindoro | V Bugusanga | L | + | 19.0 | (–5.5) | 5 | L | U | |
| | h | Luzon | V N Ragay Gulf | L | U | 18.9 | (–5.0) | 23 | M | U | |
| | i | Do. | N of Pampanga Bay | L | U | 18.9 | (–5.0) | 4 | M | U | |
| 10 May | 17 a | Tablas | Whole island | H | U | 20.0 | (–6.5) | 5 | U | U | |
| | b | Luzon | W of Lingayen Gulf | No | U | 18.8 | (–5.0) | 2 | U | U | |
| | 18 a | Tablas | V Looc Bay | No | No | 19.3 | –5.5 | 3 | L | + | |
| | b | Mindoro | Bugusanga and Caguray Valleys | No | No | 19.5 | –5.5 | 12 | H | + | |
| | c | Do. | NE of Dongon Pt. | No | No | 19.3 | –4.5 | 5 | H | + | |
| | d | Panay | B Tibiao Pt. and Sara | No (V) | U | 19.0 | –4.0 | 11 | H | U | |
| | e | Negros | SE of Concepcion | No | No | 18.6 | –3.5 | 1 | H | U | |
| | f | Do. | NE of Razorback Mt. | L | + | 19.6 | –[illegible] | 4 | H | U | |
| | g | Cebu | B Tuburan and Carcar Bay | L | + | 19.0 | –4.5 | 13 | H | + | |
| | h | Luzon | V San Pablo | No | No | 20.2 | –5.0 | 3 | U | U | |
| | i | Do. | B Iba and Angat Reservoir | No | No | ... | ... | .. | L | U | |

15 (Contd)

| echoes, mi | Postseed: Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | Comments |
|---|---|---|---|---|---|---|
| 4 (P) | 150 × 20 | 3,000 | >1 | 1 8 | 382 | Widespread, scattered storms built to major storms |
| U | 30 × 12 | 360 | (1) | H | 64.6 | Enhanced natural rain |
| U | 25 × 12 | 300 | (1) | H | 53 0 | Enhanced natural rain |
| U | 4 5 × 2 7 | 12 | >0.8 | 4.4 | 3.0 | Downwind cells developed from seeded cell |
| U | 11 (D) | 100 | 2 3 | L | 8.1 | Ordnance rack functioning poorly; many misfires |
| U | U | U | U | . . . | . . . | Ordnance rack functioning poorly, many misfires |
| D, F | 45 × 10 | 450 | (1) | 1 6 | 50.9 | . . . |
| + | 10 (D) | 80 | 0 3 | L | 0.8 | . . . |
| + | U | 200 | 5 | H | 177 | . . . |
| + | 60 × 17 | 1,020 | >2 | M | 216 | . . . |
| (D) | 11 (D) | 100 | >0 5 | M | 5.3 | Over farmland |
| + | 5 (D) | 20 | 4 | M | 8.5 | . . . |
| + | 50 × 10 | 500 | >1 | L | 17.7 | . . . |
| U | U | U | 4 | . . | . . . | . . . |
| + | 8 (D) | 50 | >1 | H | 8.8 | Rack failure over Bantayan, Panay, Negros, Cebu, Bohol, and Camotes |
| + | U | U | U | . . | . . . | . . . |
| U | U | U | U | . . | . | Growth suggested at least light rain would eventually fall |
| U | U | U | U | . . . | . . . | Approaching CB condition |
| + | U | U | <1 8 | . . . | . . . | Extended rain from coast inland |
| U | U | U | >1.8 | . . | . . | . . . |
| 10 | U | U | U | . . | . | Increased rain area and moved over lowlands |
| U | 10 × 20 | 200 | >0.3 | M | 1 4 | . . . |
| + | U | U | U | U | . . . | . . . |
| U | U | U | U | U | . . | . . . |
| U | 10 × 20 | 200 | >2 | L | 14.1 | . . . |
| U | 20 × 40 | 800 | >2 | M | 170 | Merged into a large storm |
| U | 5 (D) | 20 | 1.5 | M | 3.2 | Augmented rain |
| U | U | U | U | . . . | . . . | Large CB later in day |
| U | U | U | U | . . . | . . | No growth, little moisture |
| + | U | U | U | . . . | . . . | . . . |
| + | 12 (D), 5 (D) | 134 | >1 | 1.75 | 16.6 | Good growth |
| + | 10 (D) | 80 | >1 | H | 14.1 | . . . |
| U | 10 × 60 | 600 | >2 | H | 212 | . . . |
| U | 20 (D) | 310 | >2 | H | 110 | . . . |
| U | 5 (D) | 20 | >1 | H | 3 5 | Worked edge of natural storm |
| + | 10 × 48 | 480 | >2 | H | 170 | Grew storm towards Cebu |
| U | U | U | U | . . . | . . | . . . |
| U | U | U | U | . | . | Rack failed; no seeding; small natural showers developed |

TABLE

| Date, 1969 | Mission no and target | Geographic location | | Preseed | | Seeding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No. of units | Rain intensity | Radar [illegible] |
| 11 May | 19 a | Mindoro | Caguray Valley | No | U | 18.0 | -3.0 | 8 | L | |
| | b | Tablas | N of Looc Bay | No | U | 18 0 | -3.5 | 1 | L | |
| | c | Marinduque | V Bonaliw | No | U | 15.0 | +3 | 1 | L | |
| | d | Luzon | V Tagaytay Ridge | No | U | 18 7 | -3 0 | 3 | L | |
| | e | Do. | V Angat Reservoir | No | U | 19 5 | -5.0 | 18 | L | |
| | f | Do | S Zambales and Cabusilan Mt. | No | U | 19.6 | -5.5 | 27 | H | |
| | g | Do. | SW of Rosales | No | U | 20.1 | -5.5 | 2 | H | |
| | h | Do. | V Baguio | No | U | 19.2 | -4.5 | 10 | H | |
| | i | Do. | N of Dingalan Bay | M | U | 19.7 | -5.0 | 20 | H | |
| 12 May | 20 a | Luzon | Cabusilan Mt. | No | No | 18.9 | -6.0 | 5 | M | |
| | b | Marinduque | Whole island | No | No | 18.9 | 5.5 | 9 | H | 5 |
| | c | Luzon | S of Gumaca | No | No | 18.8 | -3.5 | 3 | H | |
| | d | Do. | B Lake Taal and Lamon Bay | No | No | 18 9 | -3 0 | 49 | L | |
| | e | Do. | NE of Tanay | No | No | 18.6 | -3 0 | 2 | U | |
| | f | Do. | W of Angat Reservoir | No | U | 19.1 | -5.0 | 1 | L | |
| | g | Do. | SE of Mt. Arayat | H | + | 19.0 | -4.5 | 6 | H | 2[illegible] |
| | h | Do. | E of Angat Reservoir | No | U | 19.0 | -5.5 | 2 | L | |
| | 21 a | Do. | W of Clark | No | + | 19.8 | -5 5 | 9 | M | 2 (D[illegible] |
| | b | Do. | SE Central Valley | L | No (V) | 20.0 | -5.5 | 7 | L | |
| | c | Do. | N Bataan Pen. | No | U | 20.0 | -6.0 | 3 | No | |
| | d | Do. | V Tarlac and Cabanatuan | L | U | 20.5 | -5.5 | 17 | M | |
| | e | Do | V Clark AB | No | U | 18.8 | -2.5 | 13 | No | |
| 13 May | 22 a | Luzon | S Zambales and Cabusilan Mt. | No (V) | U | 19.2 | -4.5 | 6 | H | |
| | b | Do. | V Rosales | No (V) | U | 18.5 | -3 5 | 7 | H | |
| | c | Do. | S Cagayan Valley | L | U | 20.8 | -9.5 | 22 | M | |
| | 23 a | Do. | B Angat Reservoir and Laguna de Bay | No | + | 19.0 | -3.5 | 5 | U | |
| | b | Do. | B Cabanatuan and Angat Reservoir | L | + | 19.8 | -7 5 | 29 | H | |
| 14 May | 24 a | Panay | B Lipato Pt. and Tapaz | L | U | 20.1 | (-6.0) | 7 | L | |
| | b | Negros | V Bacolod | No | U | 19.7 | -5.0 | 3 | L | |
| | c | Do. | SE Sipalay | No | U | 19.6 | -3.0 | 3 | L | |
| | d | Mindoro | NE of Mt. Baco | No | U | 19.0 | -6.0 | 4 | U | |
| | e | Luzon | B Cubi and Clark AB | L | U | 20.3 | (-6.5) | 3 | H | |
| | f | Do. | B Tarlac and Baler | No | U | 19 6 | (-5.0) | 6 | H | |

TABLE 15 (Contd.)

| Postseed | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rain intensity | Radar echoes nmi | Linear dimensions of rain area nmi | Rain area nmi² | Rain duration, hr | Rain rate in hr | Estimated rainfall, acre-ft × 10³ | Comments |
| L | • | 10 (D P) | 80 (P) | 2 | 0 2 | 2 3 | . . . |
| L | U | U | U | U | | | . . . |
| L | U | U | U | U | | | No growth; clouds too low |
| L | U | U | U | U | | | . . . |
| L | U | 10 × 30 | 300 | >3 | L | 31 8 | . . . |
| H | U | 20 × 60 | 1,200 | 2 5 | H | 530 | . . . |
| H | U | 10 × 20 | 200 | 2 5 | H | 88.4 | . . . |
| H | U | 10 (D) | 80 | <1 | | | Tops to 50,000 ft |
| H | U | 10 (D) | 80 | U | | . . | Could not estimate rain |
| M | • | U | U | U | | | . . . |
| H | 5 × 7 | U | U | 2 | . . | . . | 3 cells merged to form CB; tops at 40,000 ft; rain run aborted because of heavy rain |
| H | • | 30 × 15 | 450 | >3 | H | 239 | 2 cells merged to form CB |
| L | • | 20 × 50 | 1 000 | (>2 5) | L | 88.4 | Many cells merged together |
| U | • | U | U | U | . . | . . | . . . |
| L | U | U | U | U | . | | . . . |
| H | 25 × 6 | 20 × 40 | 800 | >3 | H | 424 | Aborted rain run due to lightning |
| L | . | . | | | . . . | . . | . . . |
| M | 2 (D), 12 (D) | 25 × 15 | 375 | >3 | M | 1 9 | . . . |
| L | U | 20 × 30 | 600 | 2 5 | L | 53.0 | 50,000-ft tops; same as target 20g |
| No | U | | . . | | . | . . . | Cloud dissipated |
| M | • | 30 × 50 | 1,500 | >4 | M | 636 | . . . |
| No | • | . | | . | . | . . . | . . . |
| H | U | 60 × 20 | 1,200 | >3 | H | 636 | . . . |
| H | U | | | . | . | . . . | . . . |
| M | U | 85 × 20 | 1,700 | >3 | M | 541 | Extended storm ESE over Cagayan Valley; widespread gentle rain from stratus deck in addition to showers |
| U | • | | . | . . | . . | . . . | . . . |
| H | • | 5 × 30 | 150 | >2 | H | 110 | Worked earlier by Mission 22, joined two cloud systems, thunder and lightning; storm too intense at center for rain run penetration |
| L | • | U | U | U | . . | . . . | No suitable targets |
| L | • | U | U | U | | . . | No suitable targets |
| L | U | 2 5 (D) | 5 | (0 5) | 0.9 | 0.2 | Most precipitation fell over water |
| U | U | U | U | U | . . | . | Seeded in passing |
| H | U | 5 × 25 | 125 | (1) | H | 22.1 | Increased and extended line of cells |
| H | U | 10 × 40 | 400 | (1) | H | 70.7 | Explosive growth; lightning |

T

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No of units | Rain intensity | Radar echoes, nmi |
| 15 May | 25 a | Luzon | E of Lake Taal | No | No | 19.0 | -5.5 | 3 | L | U |
| | b | Mindoro | B Mt. Halcon and Calavite Passage | L | + | 19.3 | -6.5 | 15 | H | + |
| | c | Luzon | V San Rafael | No | No | 19.0 | -6.5 | 12 | H | + |
| | d | Do. | B Malolos and Mt. Arayat | No | No | 19.2 | -6.5 | 28 | L | 5 × 30 |
| | e | Do | B Rosales and Cabanatuan | No | No | 19.0 | -6.5 | 11 | H | U |
| | 26 a | Panay | Cordillera Range and W Plain | No (V) | U | 19.5 | -7.0 | 22 | L | U |
| | b | Negros | V Ma-ao | No (V) | U | 19.0 | -7.0 | 10 | H | 12 (D) |
| | c | Do. | V Bacolod | No (V) | U | 20.0 | -7.0 | 5 | L | 2.5 (D) |
| | d | Bohol | B Clarin and Guindulman Bay | No | U | 23.0 | -12.0 | 2 | U | U |
| | e | Cebu | E of Balamban Bay | No (V) | U | 20.0 | -8.0 | 2 | U | U |
| | f | Luzon | V Lake Taal | L | U | 19.0 | -4.0 | 7 | No | U |
| 16 May | 27, 28 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 19 May | 29 a | Luzon | C and E Central Valley | No | No | 19.2 | -6.4 | 28 | H | + |
| 21 May | 30 a | Negros | V Bacolod | No | No | 20.0 | -5.5 | 8 | M | + |
| | b | Bohol | SW of San Isidro | No | 1 D | 20.0 | -6.0 | 1 | L | U |
| | c | Mindanao | N and E of Calabugao Plain | No (V) | No (V) | 20.0 | -6.0 | 4 | M | U |
| | d | Do. | E C Agusan Valley | L (2 of 3) | + | 19.9 | -5.5 | 5 | M | U |
| | e | Leyte | SE of Bato | No | + | 20.1 | -6.5 | 1 | L | U |
| | f | Do. | S Layog R. | No | No | 19.5 | -4.5 | 1 | No | U |
| | g | Do. | V Palompon | No (V) | U | 19.7 | -6.0 | 3 | M | U |
| | h | Masbate | V Daraga | No | + | 19.3 | -5.0 | 2 | U | U |
| | i | Luzon | B Caraballo Mt. and Angat Reservoir | L | + | 20.0 | -7.0 | 10 | H | U |
| | j | Do. | W of Clark AB | No | No | 19.4 | -6.0 | 2 | No | U |
| | k | Cebu | V Kambangog | No | + | 20.0 | -5.0 | 1 | U | U |
| 22 May | 31 a | Mindanao | B Mt. Lanuinbaan and Calabugao Plain | No (V) | No (V) | 19.0 | -6.0 | 4 | L | + |
| | b | Do. | C Umayan R. | No (V) | No (V) | 19.0 | -6.5 | 2 | No | U |
| | c | Do. | V Tren Grande R. | No (V) | No (V) | 19.0 | -6.0 | 6 | H | + |
| | d | Do. | V Mt. Malindang | No | + | 19.0 | -6.5 | 5 | H | + |
| | e | Samar | N of Calbayog City | No | No (V) | 19.0 | -6.0 | 7 | H | U |
| | f | Luzon | SE of Angat Reservoir | No | No | 19.0 | -7.0 | 1 | No | No |

TABLE 15. (Contd )

| | Postseed | | | | | Comments |
|---|---|---|---|---|---|---|
| ...choes ...i | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre ft $\times 10^3$ | |
| | 2 (D), 2 (D) | 6 | (0 2) | L | . | . . . |
| | 20 (D) | ~310 | >3 | H | 164 | Rain run aborted due to rain intensity; clouds merged to CB |
| | 15 (D) | 175 | (>3) | H | 92.8 | . . . |
| 30 | 5 x 30 | 150 | (>2) | 1 6 | 33 9 | Seeded over Clark first at 1648; heavy rain at 1749; 2 towers were overseeded and collapsed |
| | 6 (D), 6 (D), 6 (D), 6 (D) | 115 | >6 | 3 4 | 166 | . . . |
| | 15 x 45 | 675 | >3 | L | 71.6 | Good runoff in streams; scattered and intermittent rain over farmland |
| (D) | U | 150 | >1 | H | 26.5 | Bacolod confirmed rain |
| (D) | U | 15 | >2 | L | 1.1 | . . . |
| | U | U | U | . . . | . . . | . . . |
| | U | U | U | . . . | . . . | . . . |
| | U | U | U | . . . | . . . | Initial light rain due to Mission 25; overseeded; cloud tops blew off |
| | | . . . | . . . | . . . | . . . | Mission aborted; no seeding accomplished |
| | 100 x 50 | 5,000 | >3 | H | 2,650 | Lightning prevented rain run under CB |
| | 16 (D) | 200 | >1 | M | 21.2 | Bacolod reported rain 25 min. after seeding |
| | 2.5 (D) | 5 | >1 | L | 0.2 | . . . |
| | 5 (D), 5 (D), 8 (D) | 90 | >1 | M | 9.5 | . . . |
| | 25 x 10 | 250 | >0.3 | M | 8.0 | . . . |
| | 1 (D) | 1 | >0.2 | L | . . | . . . |
| | U | U | U | . . . | . . . | . . . |
| | 20 x 10 | 200 | >1 | M | 21.2 | . . . |
| | U | U | U | . . | . . . | . . . |
| | 10 x 15 | 150 | >1.5 | H | 39.8 | Cloud group rejuvenated; good growth |
| | U | U | U | . . . | . . | . . . |
| | U | U | U | . . . | . . . | . . . |
| | 5 x 5 | 25 | (0.5) | L | 0.4 | . . . |
| | U | U | U | . . . | . . . | . . . |
| | 50 x 30 | 1,500 | (>2) | H | 530 | . . . |
| | 10 x 20 | 200 | (>2) | H | 70.7 | . . . |
| | 10 x 30 | 300 | (>2) | H | 106 | . . . |
| ...o | U | U | U | . . . | . . . | Cloud top blew off |

TABLE 15 (Contd.)

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft X $10^3$ | Temp., °C | No of units | Rain intensity | Rada |
| 23 May | 32 a | Panay | V Mt Llorente | No | U | 18.6 | 4 5 | 2 | L | 5 |
| | b | Do. | NE Pototan | No (V) | U | 19 0 | 6 5 | 11 | L | 3 |
| | c | Do. | B Capiz and Ajuy Bays | No (V) | U | 18.8 | -6 5 | 5 | U | |
| | d | Negros | B Victorias and Razorback Mt. | No | U | 18 8 | -6 5 | 2 | U | |
| | e | Cebu | V Cebu City | No | U | 18.8 | 5 5 | 6 | L | |
| | f | Do. | N of Carcar Bay | No (V) | U | 18.7 | -5.5 | 3 | M | |
| | g | Masbate | S of Masbate | No | 1 D | 18.1 | 6.0 | 3 | H | 12 |
| | h | Luzon | W of Tarlac | L | U | 19.1 | -6.5 | 3 | L | |
| | i | Do. | SW of Cabanatuan | No | U | 19.1 | 6 0 | 5 | M | |
| 24 May | 33 a | Luzon | B Silang and Dingalan Bay | No | No | 18.0 | -2.5 | 22 | L | |
| | b | Do. | V Subic Bay | No | + | 19.4 | -6.0 | 1 | L | |
| | c | Do. | V Cabalete Island | No (L V) | + | 19.1 | -5.5 | 5 | M | |
| | d | Do. | N of Rosales | No | No | 19.5 | -7.0 | 4 | M | |
| | e | Do. | W of Tarlac | No | No | 19.2 | -6.0 | 2 | L | |
| | f | Do. | E of Iba | No | No | 19.3 | -6.0 | 1 | U | |
| 26 May | 34 | ... | ... | ... | ... | ... | ... | ... | ... | |
| 27 May | 35 a | Mindoro | NE of Mt. Baco | No (L V) | U | 19.8 | -8.0 | 2 | H | |
| | b | Negros | E of Dos Hermanas | L | + | 19.1 | -7.0 | 4 | M | |
| | c | Mindanao | W Zamboanga Pen. | L | + | 19.0 | -6.5 | 21 | H | |
| | d | Luzon | B Tarlac and Rosales | No | + | 18.0 | -4.5 | 9 | M | |
| 28 May | 36 a | Palawan | V Calauag | L | U | 18 5 | -5.5 | 5 | M | |
| | b | Do. | NE of Cleopatra Needle | L | U | 18.7 | -6.0 | 5 | H | |
| | c | Do. | W of Verde Islands | No | U | 18.8 | -6.0 | 1 | U | |
| | d | Do. | N W of Puerto Princesa | No (L V) | No (V) | 18.6 | -5 0 | 6 | M | |
| | e | Do. | NE of Victoria Peaks | No | + | 18.5 | -5.0 | 6 | L | |
| | f | Do. | N of Mt. Corumi | No (V) | No (V) | 18.8 | -5.5 | 3 | No | |
| | g | Do. | V Escapardo | No | No (V) | 19.3 | -7.0 | 2 | U | |
| | h | Do. | E of Brooke's Pt. | L | U | 19.2 | -8.0 | 3 | U | |
| | i | Do. | B Ipolote and San Antonio Bays | L | U | 18.2 | -4.5 | 4 | M | |
| | j | Luzon | B Laguna de Bay and Sangley Pt. NAS | L (1.5 nmi$^2$) | U | 19.0 | -6.5 | 4 | L | |
| | k | Do. | V Silang | L (3 nmi$^2$) | U | 18.9 | -6.5 | 2 | H | |
| 30 May | 37 a | Tablas | N of Looc Bay | No | No | 16.5 | -0.5 | 2 | L | |
| | b | Bohol | V Bantolinao | No (L V) | + | 18.6 | -4.5 | 5 | H | |
| | c | Mindanao | E of Lake Lanao | L | + | 19.5 | -5.5 | 12 | H | |
| | d | Do. | B Linguasan Marsh and Mt. Apo | No | No | 18.9 | -4.5 | 18 | L | |
| | e | Do. | B Alah Valley and E of Sarangani Bay | L | + | 19.0 | -5.0 | 5 | H | |
| | f | Do. | Nanapon Plain | No (V) | No (V) | 19.5 | 6.0 | 1 | U | |
| | g | Do. | N of Malaybalay | No | No | 19.2 | -5.0 | 4 | L | |
| | h | Luzon | B Angat Reservoir and Cabanatuan | L | + | 19.5 | -5.5 | 13 | H | |

(Cont'd)

| Postseed | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rain intensity | Radar echoes nmi | Lineal dimensions of rain area nmi | Rain area, nmi$^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | Comments |
| L | 5 × 1 | 5 × 2 | 10 | <1 | L | 0.4 | ... |
| L | 3 × 4 | 5 (D) | 20 | 1 | L | 0.7 | ... |
| U | U | U | U | U | . | . | ... |
| U | U | U | U | U | . | .. | ... |
| L | U | 4 (D) | 13 | 3 | L | 1.3 | Extended to Mactan |
| M | U | 50 | 20 | ( 1) | M | 2.1 | ... |
| H | 12 × 4 | 12 × 4 | 48 | 0.3 | H | 2.5 | ... |
| L | U | 5 (D) | 20 | 0.5 | L | 0.4 | ... |
| M | U | 3 × 6 | 18 | <1 | M | 1.9 | ... |
| L | + | 50 × 16 | 800 | 3 | L | 84.8 | Variable LMH rain |
| L | U | 11 (D) | 100 | 0.5 | L | 1.8 | ... |
| M | U | 5 × 20 | 100 | 0.8 | M | 8.5 | ... |
| M | U | 16 (D) | 200 | 1 | M | 21.2 | ... |
| L | U | 8 (D) | 50 | 0.8 | L | 1.4 | ... |
| U | U | U | U | U | ... | ... | ... |
| ... | ... | ... | ... | ... | ... | ... | Mission aborted; no seeding accomplished |
| H | + | 20 × 40 | 800 | >5 | H | 707 | ... |
| M | + | 20 × 5 | >100 | <2 | M | 21.2 | 3 seeded towers merged into CB |
| H | + | 10 × 150 | 1,500 | >3 | H | 795 | ... |
| M | U | 10 × 15 | 150 | 2.5 | M | 39.8 | ... |
| M | U | 2.5 (D), 2.5 (D)<br>2.5 (D), 2.5 (D) | 20 | <0.3 | M | 0.6 | ... |
| H | U | 5 × 10 | 50 | 2.8 | H | 24.7 | ... |
| U | U | U | U | U | ... | ... | ... |
| M | U | U | U | U | ... | ... | Growth added to area |
| L | + | 5 (D) | 20 | >2 | L | 1.4 | ... |
| No | U | U | U | U | ... | ... | ... |
| U | U | U | U | U | ... | ... | ... |
| U | U | U | U | U | ... | ... | ... |
| M | U | 3 × 10 | 30 | >0.5 | M | 1.6 | Extended rain area inland |
| L | U | 2.5 (D) | 5 | >2 | L | 0.4 | Extended rain area |
| H | U | 3 × 10 | 30 | >0.5 | H | 2.7 | ... |
| L | U | 5.5 (D) | 25 | >0.5 | L | 0.4 | Demonstration |
| H | U | 15 × 10 | 150 | 4 | H | 106 | 2 towers merged into CB |
| H | U | 40 × 20 | 800 | >3 | H | 424 | ... |
| L | U | 30 × 10 | 300 | 0.8 | L | 8.5 | ... |
| H | U | 40 × 5 | 200 | <1 | H | 35.4 | Lowlands |
| U | U | U | U | U | ... | ... | ... |
| L | U | 5.5 (D) | 25 | 0.5 | L | 0.4 | Stratiform |
| H | + | 50 × 20 | 1,000 | 6 | H | 1,060 | Increased area and duration of natural storm; lightning |

TABLE 15. (Contd.)

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No. of units | Rain intensity | Radar echoes, nmi |
| 31 May | 38 a | Luzon | V Cubi | L | + | 19.3 | −6.0 | 7 | H | 3 › 10 |
| | b | Do. | V Negrito | No | No | 18.2 | −3.5 | 3 | No | No |
| | c | Do. | S of Claveria | L | U | 18.6 | −4.5 | 11 | H | 5.5 (D, P) |
| | d | Do. | B Tarlac and N of Malolos | No (V) | No (V) | 19.£ | −7.0 | 17 | H | U |
| | e | Do. | NE Manila Bay | No (V) | No (V) | 19.8 | −7.0 | 4 | H | U |
| | f | Do. | B Cabanatuan and S Cagayan Valley | L | + | 18.5 | · 4.5 | 8 | No | U |
| 1 Jun | 39 a | Luzon | V Clark AB | No | U | 19.0 | −5.0 | 3 | L | U |
| | b | Do. | V Malalos | No (V) | U | 19.6 | −5.5 | 7 | H | U |
| | c | Do. | NW Cabusilan Mt. and SW Zambales Mt. | No ( V) | U | 18.4 | −3.5 | 13 | H | U |
| | d | Do. | NW Lingayen Gulf | No | U | 18.5 | −3.0 | 2 | L | U |
| | e | Do. | SW of Baguio | No (V) | U | 19.5 | −5.5 | 13 | H | U |
| | f | Do. | Caraballo Mt. | No (V) | U | 18.8 | −3.5 | 6 | H | U |
| | g | Do. | Extreme S Cagayan Valley | No (V) | U | 18.7 | −3.5 | 6 | L | U |
| 2 Jun | 40 a | Luzon | Sierra Madre B Casiguran Sound and Baguio Pt. | No (V) | U | 19.2 | −5.5 | 14 | H | U |
| | b | Do. | V Binongan R. | No | U | 19.0 | −5.5 | 5 | L | U |
| | c | Do. | NW of Baguio | No | U | 19.0 | −5.5 | 3 | L | U |
| | d | Do. | SW of Baguio | L | U | 17.6 | −3.0 | 4 | L | U |
| 3 Jun | 41 a | Negros | V Sojoton Pt. | No | U | 19.5 | −6.5 | 1 | M | U |
| | b | Do. | E of Soledad | No (L V) | U | 19.5 | −5.5 | 2 | M | U |
| | c | Bohol | V San Isidro | No (L V) | U | 19.6 | −6.0 | 5 | H | U |
| | d | Cebu | S of Tuburan | No | U | 18.2 | −3.0 | 1 | L | U |
| | e | Do. | E of Copton Pt. | No | U | 19.4 | (−5.5) | 1 | L | U |
| | f | Do. | S of Malboc | No | U | 18.4 | (−3.5) | 1 | L | U |
| | g | Negros | N, W, and E of Bais Bays | No (L V) | U | 19.4 | (−5.5) | 7 | M | U |
| | h | Leyte | B E of Ormoc Bay and N of Palompon | No | U | 19.5 | (−5.5) | 5 | L | U |
| | i | Masbate | W of Malabago | No | U | 19.5 | (−5.5) | 2 | M | U |
| | j | Luzon | NW Bondoc Pen. | No (V) | U | 19.1 | (−5.0) | 4 | H | U |
| | k | Marinduque | E of Boac | No (L V) | U | 19.6 | (−5.5) | 1 | H | U |
| | l | Luzon | B Laguna de Bay and Mt. Mayon | M | U | 18.8 | (−4.5) | 14 | H | U |
| | m | Do. | B Zambales and Cabusilan Mt. | H | U | 19.1 | (−5.0) | 6 | H | U |

| | Postseed | | | | | |
|---|---|---|---|---|---|---|
| der echoes, nmi | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | Comments |
| 3 × 10 | 15 (D) | 175 | >5 | H | 155 | . . . |
| No | U | U | U | . . . | . . . | . . . |
| .5 (D, P) | 7 (D) | 40 | >1 | H | 7.1 | . . . |
| U | 35 × 5 | 175 | >1.5 | H | 46.4 | Clark AB weather radar indicated tops of 62,000 ft |
| U | 8 (D) | 50 | >1.5 | H | 13.2 | Included demonstration of blowing cloud apart |
| U | U | U | U | . . . | . . . | . . . |
| U | 8 (D) | 50 | 0.3 | L | 0.5 | . . . |
| U | 5 × 5 | 25 | 2 | H | 8.8 | Increased rainfall |
| U | 10 (D) | 80 | >2 | H | 28.3 | . . . |
| U | 2 (D) | 3 | 0.2 | L | . . . | Single tower grew and then collapsed |
| U | 20 (D) | 310 | (2) | H | 110 | Massive storm |
| U | 5 × 2 | 10 | 2 | H | 3.5 | . . . |
| U | 10 × 3 | 30 | >2 | L | 2.1 | . . . |
| U | 5 (D), 10 (D) 5 (D), 2 (D) | 120 | (2) | H | 42.4 | Developed isolated clouds in line of CB |
| U | . . . | 8 | (1) | L | 0.3 | Good growth |
| U | 2.5 (D) | 5 | >0.3 | L | 0.1 | Good growth |
| U | 2.5 (D) | 5 | (1) | L | 0.2 | Good growth |
| U | 3.5 (D) | 10 | >2 | M | 2.1 | Isolated cell |
| U | 5 (D) | 20 | >1 | M | 2.1 | . . . |
| U | 10 × 30 | 300 | >3 | H | 159 | . . . |
| U | 3.5 (D) | 10 | 1 | L | 0.4 | . . . |
| U | 3.5 (D) | 10 | >1 | L | 0.4 | . . . |
| U | 3.5 (D) | 10 | >1 | L | 0.4 | . . . |
| U | 10 × 20 | 200 | 2 | M | 42.4 | . . . |
| U | 5 × 20 | 100 | >1 | L | 1.8 | . . . |
| U | 5 (D) | 20 | >1 | M | 2.1 | Excellent growth |
| U | 5 × 20 | 100 | >1 | H | 17.7 | . . . |
| U | 5 × 15 | 75 | 2 | H | 26.5 | . . . |
| U | 10 × 50 | 500 | >3 | H | 265 | Enlarged raining area (probably reached Manila) |
| U | 20 (D) | 310 | 3 | H | 164 | Merged 2 CB into major storm |

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No. of units | Rain intensity |
| 7 Jun | 46 a | Luzon | NE of Pampanga Bay | L | 2.5 (D) | 18.8 | -4.5 | 2 | M |
| | b | Do. | E of Cabanatuan | No | U | 19.0 | -5.0 | 1 | L |
| | c | Do. | S of Mt. Nanaabung | L | U | 19.0 | -5.0 | 3 | M |
| | d | Do. | V of Mt. Nanaabung | No | U | 19.1 | -5.0 | 2 | No |
| | e | Do. | NE of Rosales | No (V) | U | 19.1 | -5.5 | 6 | M |
| | f | Do. | NW of Mt. Arayat | No (V) | U | 20.0 | -7.0 | 9 | M |
| | g | Do. | V Tarlac | No (V) | U | 19.2 | -5.5 | 13 | L |
| | h | Do. | V Negrito | No (V) | U | 19.8 | -6.0 | 3 | M |
| | i | Marinduque | NC | L (2 nmi$^2$) | U | 19.0 | -5.5 | 4 | L |
| | j | Luzon | B San Pablo and Verde Island Passage | No | + | 19.1 | -5.5 | 4 | U |
| | k | Do. | S of Mt. Binuang | No | U | 19.0 | -5.5 | 4 | L |
| | l | Do. | W of Mt. Binuang | No | U | 19.3 | -6.0 | 3 | U |
| | 47 a | Panay | E Iloilo and Pototan | No | U | 20.3 | -8.0 | 10 | M |
| | b | Do. | B Topaz and Sara | No | U | 19.4 | -4.0 | 15 | H |
| | c | Negros | S of Mt. Mandalagan | No | U | 18.6 | -4.0 | 8 | M |
| | d | Cebu | B Carcar Bay and Boljoon | No | U | 20.0 | -6.5 | 16 | H |
| | e | Do. | SW of Balamban Bay | No | U | 20.1 | -6.5 | 2 | U |
| 9 Jun | 48 a | Luzon | SE of Manila | No | U | 19.3 | -3.5 | 14 | H |
| | b | Do. | B Tagaytay Ridge and Salang | No | U | 18.6 | -2.5 | 9 | M |
| | c | Do. | B Angat Reservoir and Rosales | No | U | 19.3 | -3.5 | 27 | H |
| | d | Do. | B Mt. Arayat and Manila Bay | No | U | 18.9 | -2.5 | 14 | H |
| | e | Do. | NW of Casiguran Sound | No | U | 20.0 | -4.5 | 6 | M |
| | f | Do. | Angat Reservoir | No | U | 20.7 | -7.0 | 4 | M |
| | g | Do. | E of Laguna de Bay | L | U | 18.8 | -3.0 | 1 | M |
| | 49 a | Samar | W Gamay Bay | No | No | 19.0 | -6.0 | 8 | H |
| | b | Do. | S of Oot Pt. | L | 1 (D) | 19.0 | -6.0 | 7 | M |
| | c | Do. | B Mt. Capoti-an and Port Libas | L | 2 × 2 | 18.4 | -5.0 | 6 | H |
| | d | Do. | NE Cabay Bay | No | No | 18.3 | -4.5 | 2 | No |
| | e | Leyte | S of Alangalang | L | 3 × 1.5 | 18.5 | -5.0 | 3 | H |
| | f | Do. | NE of Leyte | No | No | 18.5 | -5.0 | 2 | L |
| | g | Biliran | NW of Caibiran | No | No | 18.5 | -5.0 | 2 | L |
| | h | Leyte | NW of Tacloban City | No (V) | No (V) | 18.4 | -5.0 | 2 | L |
| | i | Samar | V San Antonio | No (V) | No (V) | 18.0 | -4.5 | 1 | No |
| | j | Do. | V Santa Rita | No (V) | No (V) | 18.4 | 5.0 | 6 | L |
| | k | Do. | NE of Santa Rita | No (V) | No (V) | 18.0 | -4.5 | 4 | H |
| | l | Do. | V Catarman | No | No (V) | 18.4 | -5.0 | 9 | M |

TABLE 15 (Contd)

| Postseed | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rain intensity | Radar echoes, nmi | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | Comments |
| M | U | 5 (D) | 20 | 0.5 | M | 1.1 | . . . |
| L | U | 2 (D) | 3 | 0.3 | L | . . . | . . . |
| M | 5.5 (D) | 5 (D) | 20 | 1.5 | M | 3.2 | . . . |
| No | U | U | U | U | . . . | . . . | Dissipated without significant precipitation |
| M | 6 (D) | 5 × 10 | 50 | 1.5 | M | 8.8 | . . . |
| M | U | 3 (D) | 7 | 0.6 | M | 0.4 | . . . |
| L | U | 5 × 2 | 10 | 1.5 | L | 0.5 | . . . |
| M | U | 3.5 (D) | 10 | 1 | M | 1.1 | . . . |
| L | U | 2.5 (D) | 5 | (1) | L | 0.2 | Dense cirrus overcast; seeded 1 of 2 identical towers; each grew and rained |
| U | U | U | U | U | . . . | . . . | . . . |
| L | U | U | U | U | . . . | . . . | . . . |
| U | U | U | U | U | . . . | . . . | . . . |
| M | U | 30 × 10 | 300 | 2.5 | M | 79.5 | . . . |
| H | U | 40 × 3 | 120 | 4 | H | 84.8 | LWC 3 $g/m^3$ on rain run; paddies, ponds, and streams full |
| M | U | 5.5 (D) | 25 | (>2) | M | 5.3 | . . . |
| H | U | 20 × 10 | 200 | >2 | H | 70.7 | . . . |
| U | U | U | U | U | . . . | . . . | . . . |
| H | U | 3 × 25 | 75 | 3 | H | 39.8 | Initially weak line of clouds became "wall of rain"; drifted toward Manila |
| M | U | 5 (D) | 20 | 3 | M | 6.4 | . . . |
| H | U | 60 × 20 | 1,200 | >5 | H | 1,060 | . . . |
| H | U | 50, 80 | 70 | (>1) | H | 12.4 | . . . |
| M | U | 15 × 5 | 75 | >1 | M | 8.0 | Heavy rain to east in mountain valleys; rain over main valley light to moderate |
| M | U | 2 × 10 | 20 | 0.5 | M | 1.1 | . . . |
| M | U | 2.5 (D) | 5 | >2 | M | 1.1 | Rapid development; enlarged raining area |
| H | 20 × 10 | 20 × 10 | 200 | >4.5 | H | 159 | . . . |
| M | + | 8 (D) | 50 | >3.3 | M | 17.5 | . . . |
| H | + | 5 (D) | 20 | >2.5 | H | 8.8 | . . . |
| No | U | U | U | U | . . . | . . . | Cloud top collapsed |
| H | + | 5 (D) | 20 | >1.8 | H | 6.4 | Top blew off after first seeding; subsequently worked into CB; rain run |
| L | U | U | U | U | . . . | . . . | . . . |
| L | U | U | U | U | . . . | . . . | . . . |
| L | U | 1.5 (D) | 2 | >1 | L | 0.1 | Rain run |
| No | U | U | U | U | . . . | . . . | Rain run |
| L | U | 1 (D) | 1 | >1 | L | . . . | Rain run |
| H | U | 3 × 5 | 15 | >1 | H | 2.7 | Rain run |
| M | + | 5 (D) | 20 | >0.5 | M | 1.1 | Rain run |

TABLE 15. (Contd)

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × 10³ | Temp., °C | No. of units | Rain intensity | Radar echoes, nmi | Lineal of rai |
| 5 Jun | 42 a | Negros | SW Ma-ao | No (V) | U | 18.6 | −5.0 | 9 | H | U | 1 |
| | b | Do. | V Mt. Mandalagan | No (V) | U | 18.6 | −4.0 | 8 | L | U | |
| | c | Do. | E Victorias | No (V) | U | 20.2 | −9.5 | 9 | M | U | [illegible] |
| | d | Do. | B Biniguil and Tarjau | No (H V) | No (V) | 18.7 | −4.5 | 10 | U | U | |
| | e | Siquijor | Whole island | No (M V) | No (V) | 18.9 | −4.5 | 2 | L | U | |
| | f | Bohol | B Tagbilaran and San Pascua | No (H V) | No (V) | 18.6 | −5.5 | 9 | L | U | |
| | g | Panay | S plain | No (H V) | U | 19.4 | −6.0 | 5 | U | U | |
| | h | Luzon | B Canlubang and Manila | No | U | 20.0 | −6.5 | 19 | H | 3 × 10 | 1 |
| | i | Do. | NE of Manila | No | U | 18.9 | −4.5 | 1 | L | U | [illegible] |
| | j | Do. | E of Angat Reservoir | L | 2 × 3 | 19.6 | −7.0 | 2 | U | 5 × 6 | |
| | k | Panay | N Pandan Bay | No | No | 18.2 | −5.0 | 1 | U | U | |
| | 43 a | Burias | NW | 2 No, 1 L | U | 20.0 | −7.0 | 3 | H | U | |
| | b | Masbate | B Lahong and Malobago | No (M V) | U | 19.5 | −6.0 | 17 | H | U | [illegible] |
| | c | Samar | B Catarman and W Ulut R. | No | U | 19.5 | −6.0 | 8 | H | U | [illegible] |
| | d | Luzon | V Bulusan Volcano | No (L V) | U | 19.5 | −6.0 | 1 | U | U | |
| | e | Do. | C Caramoan Pen. | No (L V) | U | 19.5 | −5.5 | 1 | U | U | |
| | f | Do. | V Cadig Mt. | No (L V) | U | 19.0 | −5.5 | 6 | M | U | |
| | g | Do. | SE Cagayan Valley and Sierra Madre B Baler Bay and Nanandatan Pt. | L | U | 19.5 | −6.0 | 21 | H | U | 5 × 5 (D), |
| 6 Jun | 44 a | Luzon | V Bolinao | No | U | 20.3 | −7.0 | 2 | M | U | |
| | b | Do. | W of Bagabag | No | U | 21.6 | −8.0 | 4 | M | U | |
| | c | Do. | NE of Ilagan | No | U | 19.1 | −5.0 | 5 | M | U | |
| | d | Do. | NE of Tuguegarao | No (V) | U | 20.0 | −5.5 | 9 | M | U | |
| | e | Do. | SE of Bagabag | No | U | 19.5 | −6.5 | 3 | M | U | |
| | f | Do. | S of Tulung | No | U | 18.7 | −5.0 | 1 | No | U | |
| | g | Do. | N of Lapanto | No | U | 19.2 | −5.0 | 6 | M | U | |
| | h | Do. | B S of Rosales and Caraballo Mt. | No | U | 21.1 | −7.5 | 12 | H | U | |
| | i | Do. | N of Mt. Arayat | No | U | 16.6 | −3.0 | 8 | H | U | |
| | j | Do. | S of Cabanatuan | No (V) | U | 20.4 | −7.5 | 4 | M | U | |
| | k | Do. | N of Canlubang | No (V) | U | 18.0 | −6.0 | 5 | U | U | |
| | 45 a | Panay | SW of Bulacaue Pt. | No (V) | U | 18.7 | −4.5 | 1 | L | U | |
| | b | Mindanao | B Bakulin Bay and SE of Mt. Lanumbaan | No (L V) | U | 18.4 | −4.0 | 29 | L | U | |
| | c | Do. | E of Lianga Bay | L | U | 18.5 | −4.0 | 4 | L | U | |
| | d | Do. | S of Mt. Lanumbaan | L | U | 18.5 | −3.5 | 4 | L | U | |
| | e | Leyte | NE of Cabalian Bay | No | + | 18.3 | −3.0 | 1 | U | U | |
| | f | Do. | S of Carigara | L | U | 19.1 | −4.5 | 2 | U | U | |

| Postseed | | | | | Comments |
|---|---|---|---|---|---|
| Areal dimensions of rain area, nmi | Rain area, nmi² | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × 10³ | |
| 12.5 (D) | 120 | 3 | H | 63.6 | . . . |
| 5 (D) | 20 | (0.5) | L | 0.4 | . . . |
| 2.5 (D) | 5 | 1 | M | 0.5 | . . . |
| U | U | U | . | . . . | . . . |
| 5 (D) | 20 | 0.5 | L | 0.4 | Cell dissipated |
| 5 × 35 | [illegible] | 1 | L | 6.2 | . . . |
| U | U | U | . . . | . . . | Worked upwind side of area between 2 raining cells |
| 10 × 20 | 200 | 2 | H | 70.7 | First worked by Mission 43. Joined to natural raining systems (heavy rain in Manila later) |
| 2.5 (D) | 5 | 0.6 | L | 0.1 | . . . |
| U | U | U | . . | . . . | . . . |
| U | U | U | . . . | . . . | . . . |
| 5 × 10 | 50 | >4 | H | 35.4 | 3 towers initially |
| 40 × 5 | 200 | >3 | H | 106 | . . . |
| 10 × 50 | 500 | >3 | H | 265 | . . . |
| U | U | U | . . . | . . . | Increased rain area |
| U | U | U | . . . | . . . | Increased rain area |
| U | U | U | . . . | . . . | Increased rain area |
| X 25, 2.5 (D) | 400 | 2 | H | 141 | Developed 5 CB |
| 0.5 × 20, 30 × 5 | | | | | |
| 3.5 (D) | 10 | 1 | M | 1.1 | . . . |
| 11 (D) | 100 | 1 | M | 10.6 | . . . |
| 16 × 5 | 80 | >1 | M | 8.5 | . . . |
| 22 (D) | 380 | >1 | M | 40.3 | . . . |
| 3 × 10 | 30 | . | M | 3.2 | . . . |
| U | U | U | . . . | . . . | Seeding under overhang; abandoned due to poor visibility |
| 20 × 10 | 200 | (1) | M | 21.2 | Revitalized large collapsing cloud mass |
| 20 × 30 | 600 | >3 | H | 318 | . . . |
| 11 (D) | 100 | 4.5 | H | 79.5 | Heavy rain from low unpromising clouds |
| 30 × 5 | 150 | (1) | M | 15.9 | . . . |
| U | U | U | . . | . . . | Attempt to revitalize old tower; no apparent success |
| 1 (D) | 1 | 0.1 | L | . . . | Cloud grew 1,000 ft and collapsed |
| 10 × 50 | 500 | >2 | L | 35.4 | Moved W over valley |
| 15 × 10 | 150 (see comments) | (1) | L | 5.3 | Precipitation in addition to that from naturally raining area |
| 2 (D) | 3 | (0.?) | L | . . . | . . . |
| U | U | U | . . | . . . | . . . |
| U | U | U | . . . | . . . | . . . |

TABLE 15. (Contd.)

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft X $10^3$ | Temp., °C | No. of units | Rain intensity | Radar echoes, nmi | |
| 10 Jun | 50 a | Palawan | V Calauag | No | U | 19.7 | −5.5 | 6 | L | U | |
| | b | Do. | SE of Mayday Bay | No | U | 18.2 | −3.0 | 1 | L | U | |
| | c | Do. | S of Barton | No | U | 19.0 | −5.0 | 1 | M | U | |
| | d | Do. | V Cleopatra Needle | No | U | 19.3 | −5.0 | 2 | L | U | |
| | e | Do. | B Mt. Peel and Inagauan R. | No | U | 19.8 | −5.5 | 15 | H | U | |
| | f | Do. | V of Victoria Peaks | No | U | 18.6 | −4.0 | 5 | L | U | |
| | g | Do. | E and NE of Tarumpitao Pt. | No | U | 18.6 | −4.0 | 21 | H | U | |
| | 51 a | Luzon | S of Binongan R. | No | No | 18.3 | −4.0 | 11 | M | + | |
| | b | Do. | E and NE of Lapanto | L | + | 18.2 | −3.5 | 42 | H | U | |
| 11 Jun | 52 a | Cebu | NE of Old Carmen | No | No | 18.7 | −4.0 | 3 | No | U | |
| | 53 a | Bohol | W of San Isidro | No | No | 19.0 | (−4.5) | 2 | No | No | |
| 13 Jun | 54 a | Samar | SW of Catarman | No | No | 19.4 | −6.0 | 3 | L | U | |
| | b | Do. | S of Catarman and Oot Pt. | L | + | 19.3 | −6.0 | 7 | M | U | |
| | c | Do. | SE of Oot Pt. | L | 3 × 2 | 18.9 | −5.5 | 1 | H | 3 × 2 | |
| | d | Do. | V Mt. Capotoan | No (V) | No (V) | 19.0 | −4.0 | 11 | L | U | |
| | e | Do. | NW of Cabay Bay | H | + | 19.5 | −6.0 | 3 | H→L | U | |
| | f | Leyte | NE of Sogod Bay | No (V) | U | 19.0 | −5.0 | 1 | No | U | |
| | g | Do. | E of S Layog R. | No (V) | U | 19.2 | −5.0 | 2 | M | 1 (D) | |
| | h | Do. | E of Plaridel | No (V) | U | 19.4 | −5.0 | 4 | M | 2.5 × 1.5 | |
| | i | Do. | NE of Ormoc Bay | No (V) | U | 19.6 | −5.0 | 3 | U | U | |
| 14 Jun | 55 a | Luzon | N of Catabangan Bay | No (V) | No (V) | 19.7 | −5.5 | 15 | H | 15 × 6 | |
| | b | Do. | SE of Lake Buhi | L | 1 D | 20.6 | −7.0 | 2 | No | U | |
| | c | Samar | B Ulut R. and Pt. Borongan | L | + | 19.3 | −5.0 | 12 | H | + | |
| | d | Leyte | S of Babatngon | No (V) | No (V) | 19.8 | −5.0 | 8 | H | + | |
| | e | Samar | V Mt. Capotoan | No | U | 19.0 | −4.5 | 14 | H | + | |
| | 56 a | Marinduque | NE | No | U | 20.0 | −6.5 | 3 | L | U | |
| | b | Panay | Cordillera Range B Mt. Llorente and Lipata Pt. | No | U | 19.5 | −6.0 | 7 | H | U | |
| | c | Do. | N of Sara | No | U | 18.4 | −4.5 | 4 | M | U | |
| | d | Negros | NE of Victorias | No (V) | U | 19.3 | −6.0 | 1 | M | U | |
| | e | Do. | E of Maaso | No (V) | U | 19.6 | −6.5 | 4 | H | U | |
| | f | Cebu | B Tuburan and Liloan Pt. | No | U | 20.0 | −7.0 | 18 | H | U | |
| | g | Bantayan | V Bantique | No | U | 19.5 | −6.0 | 3 | L | U | |
| | h | Masbate | N of Masbate | No | U | 19.0 | −5.5 | 1 | L | U | |
| | i | Luzon | SW of Mayon Volcano | No | U | 18.0 | −4.5 | 5 | L | U | |
| 15 Jun | 57 a | Luzon | E Clark AB and Dingalan Bay | No | U | 19.5 | −5.0 | 22 | H | U | |
| | b | Do. | S of Baguio | No | U | 19.0 | −4.0 | 6 | H | U | |
| | c | Do. | E and N of Rosales | No | U | 18.7 | −4.0 | 16 | L | U | |
| | 58 a | Leyte | B Ormoc Bay and Leyte | No (V) | No (V) | 20.0 | −8.5 | 10 | H | 10 (D) | |
| | b | Samar | NE of San Pedro and San Pablo Bay | No | No (V) | 19.4 | −6.5 | 8 | L | 3.5 (D) | |
| | c | Do. | NE of Santa Rita | M | U | 18.7 | −5.0 | 2 | M | U | |
| | d | Leyte | E of Plaridel | No | No | 18.5 | −5.0 | 1 | No | U | |
| | e | Luzon | N and E of Lake Bato | L | 1.5 (D) 1.5 (D) | [illegible] | −7.5 | 5 | M | 6 (D) | |

| | Postseed | | | | | |
|---|---|---|---|---|---|---|
| ...ues, | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | Comments |
| | 16 (D) | 200 | 3 | L | 21.2 | Wind reversal at altitude |
| | U | U | U | . . . | . . . | . . . |
| | 8 (D) | 50 | 3 | M | 15.9 | . . . |
| | 3 × 10 | 30 | (?) | L | 1.1 | Fused two cells together |
| | 30 × 15 | 450 | ( 1) | H | 79.5 | . . . |
| | 8 (D) | 50 | 2 | L | 3.5 | Originally four towers |
| | 15 × 20 | 300 | 3 | H | 159 | . . . |
| | 5 (D) | 20 | 2 | M | 4.2 | . . . |
| | 40 × 15 | 600 | 2 | H | 212 | . . . |
| | U | U | U | . . . | . . . | Widespread natural rain over most of Philippines this day; this target marginal |
| | U | U | U | . . . | . . . | Poor target; demonstration only |
| | 3 (D) | 7 | 0.2 | L | . . . | . . . |
| | 2 (D) | 3 | 0.7 | M | 0.2 | Overseeded |
| | 4 (D) | 13 | 2 | H | 4.6 | . . . |
| | 5 × 15 | 75 | 2.2 | L | 5.8 | . . . |
| | 5 × 15 | 75 | >1.5 | M | 11.9 | Rain run |
| | U | U | U | . . . | . . . | Collapsed immediately after seeding |
| | 2.5 (D) | 5 | 0.3 | M | 0.2 | . . . |
| .5 | 2.5 (D) | 5 | 0.3 | M | 0.2 | . . . |
| | U | U | U | . . . | . . . | Good growth |
| 6 | 10 × 7 | 70 | 4.3 | H | 53.2 | . . . |
| | U | U | U | . . | . . . | Seeded too late |
| | 30 × 5 | 150 | 1.5 | H | 39.8 | Rejuvenated decaying system |
| | 6 (D) | 30 | 1.2 | H | 6.4 | . . . |
| | 25 × 12 | 300 | >1 | H | 53.0 | . . . |
| | U | U | U | . . . | . . . | . . . |
| | 5 × 30 | 150 | >2 | H | 53.0 | Joined; most of island covered by raining clouds |
| | 50 × 5 | 250 | >2 | M | 53.0 | Joined; most of island covered by raining clouds |
| | U | U | U | . . . | . . . | . . . |
| | U | U | U | . . . | . . . | . . . |
| | 5 (D), 10 (D), 15 (D) | 275 | >2 | H | 97.2 | . . . |
| | 5 (D) | 20 | 0.3 | L | 0.2 | . . . |
| | 2.5 (D) | 5 | 0.3 | L | 0.1 | Poor cloud; demonstration |
| | 8 (D) | 50 | >0.5 | L | 0.9 | Rapid growth |
| | 10 × 30 | 300 | 2 | H | 106 | Developed line of towers; rain run aborted due to heavy rain |
| | 8 (D) | 50 | >2 | H | 17.7 | Joined |
| | 30 × 5 | 150 | >2 | L | 10.6 | Joined |
| D) | 15 × 5 | 75 | 2 | H | 26.5 | Subsequent regeneration unassessed |
| D) | 3.5 (D) | 10 | 1 | L | 0.4 | . . . |
| | 5 (D) | 20 | 2 | M | 4.2 | Joined natural CB |
| | U | U | U | . . . | . . . | Marginal target |
| D) | 10 × 3 | 30 | 0.5 | M | 1.6 | Joined two cells |

| Date, 1969 | Mission no. and target | Geographic location | | Preseed | | Seeding | | | Rain intensi |
|---|---|---|---|---|---|---|---|---|---|
| | | Island | Place | Rain intensity | Radar echoes, nmi | Altitude, ft × $10^3$ | Temp., °C | No. of units | |
| 17 Jun | 59 a | Panay | Cordillera Range | No | U | 19.1 | −4.0 | 33 | H |
| | b | Do. | B Ajuy Bay and Cordillera Range | No | U | 18.6 | 5.0 | 21 | L, M, I |
| | c | Guimaras | SW of Iloilo | No | U | 19.6 | −5.0 | 9 | M |
| | 60 a | Luzon | Caramoan Pen. | No (V) | U | 19.5 | −6.0 | 11 | H |
| | b | Do. | Bicol Bay B San Miguel Bay and San Bernardino Strait | No (V) | U | 19.5 | −6.0 | 8 | M |
| | c | Ticao | N | No | + | 18.3 | −5.0 | 6 | L |
| 18 Jun | 61 a | Mindanao | B Mt. Hilong Hilong and Lianga Bay | No | U | 18.9 | −5.0 | 25 | H |
| | 62 a | Mindoro | W of B.ngabong | No | U | 19.6 | −7.0 | 1 | U |
| | b | Negros | E of Binaguil | No | U | 18.7 | −6.0 | 4 | L |
| | c | Do. | V S Ilog R. | No | U | 18.7 | −6.5 | 5 | U |
| | d | Do. | W of Dumaguete City | No | U | 18.6 | −6.0 | 10 | M |
| | e | Do. | B Razorback Mt. and Victorias | No | U | 19.0 | −6.0 | 20 | H |
| | f | Tablas | N of Looc | No | U | 20.5 | −8.0 | 2 | U |
| | g | Marinduque | C | No | U | 19.5 | −7.0 | 2 | U |
| | Total | ... | ... | ... | ... | ... | ... | 2,447 | ... |

TAB

ty

15 (Contd)

| Postseed | | | | | | Comments |
|---|---|---|---|---|---|---|
| dar echoes, nmi | Lineal dimensions of rain area, nmi | Rain area, $nmi^2$ | Rain duration, hr | Rain rate, in/hr | Estimated rainfall, acre-ft × $10^3$ | |
| U | 60 × 20 | 1,200 | ·3 | H | 636 | |
| U | 40 × 35 | 1,400 | ~3 | M | 445 | LWC 3.6 $g/m^3$; rain run |
| U | 3 × 5 | 15 | ~3 | M | 4.8 | Extended clouds inland from N coast |
| U | U | 60 | 3 | H | 31.8 | Filled in gaps among natural storms |
| U | U | 50 | >2.5 | M | 13.3 | Filled in gaps among natural storms |
| 3 × 10 | 10 × 15 | 150 | (1) | L | 5.3 | Partially over Masbate Strait |
| U | U | U | U | ... | ... | |
| U | U | U | U | ... | ... | |
| U | 5 × 2 | 10 | (0.2) | L | 0.1 | Cloud dissipated |
| U | U | U | U | ... | ... | Slow growth |
| 6 (D) | 2 × 10 | 20 | (1) | M | [illegible].1 | |
| U | 15 (D) | 175 | (2) | H | 6[illegible]8 | Entire island covered with CU; Bacolod confirmed rain |
| U | U | U | U | ... | ... | |
| U | U | U | U | ... | ... | |
| ... | ... | ... | ... | .. | [illegible],100 | |

# Appendix B
# OPERATIONAL CONSIDERATIONS

The seeding done by the GROMET II team was clearly adequate to augment rainfall from the type of clouds found over the Philippines and indeed in many places in the world. From these experiences it is well perhaps to suggest some guidelines for the use of rain enhancement techniques in areas outside the United States.

## Forecasts

With rawinsonde and other data available, a capable forecaster can predict cloud locations adequately to be of use in deciding on the seeding plan for the day's operations. Although helpful computer models exist, computers are not usually available or are too expensive to consider for routine use; nor are they necessary.

In general, a forecast will include the possibility of orographic cloud development, even under conditions unfavorable to purely convective cumulus growth.

Once the forecast is in hand, aircraft should be launched, even under marginal conditions, to take advantage of any clouds that may be found. There are usually some that can be worked. Conditions change with time and place, and often weather stations do not report clouds, even though they may be seen from the air at a little distance. In drought conditions, air pollution often precludes good sky observation.

## Aircraft

Although the WC-130 military aircraft used during GROMET II would be hard to surpass in safety, comfort, and convenience, the work could have been done with much less expensive equipment.

At NWC we have used the cheapest single-engine light aircraft available. In most areas of the world this is satisfactory, but in some situations a multiengine aircraft is preferable.

Frequently, the local military can furnish crews and aircraft capable of reaching the seeding altitude, but fuel costs for such aircraft may be prohibitive. Moreover, surplus reciprocating engine aircraft built in the 1940s and 1950s generally cannot operate effectively at the altitudes required because they do not have supercharged engines. Jets operate effectively at altitude but do not remain long enough on station and fly so fast that targeting is difficult. Their fuel consumption is also inordinately high.

Any supercharged reciprocating or turbine-powered aircraft capable of sustained operation at 25,000 feet will do. A reasonably high cruise speed at altitude and a high rate of climb are important.

The Cessna 210 is a good aircraft for the purpose. Two external seeding racks for droppable units can be carried, one under each wing. An excellent twin-engine aircraft is the Cessna 337. This model can be operated on one engine at 18,000 feet to conserve fuel while waiting for development of clouds. Operating cost for the Cessna 210 is about $45 per hour, and for the Cessna 337 the cost is about $60 per hour. One such aircraft can work an area about 100 miles in radius very effectively.

Careful consideration should be given to aircraft supplies and equipment:

1. Supplemental oxygen should be carried because the usual supplies are inadequate. Pressurized cabins are more comfortable but not necessary.

2. Dual navigation communication gear is necessary. A distance-measuring apparatus is desirable, but in most places is not very useful because of lack of ground facilities. If possible the aircraft should have dual automatic direction finders because most countries have many nondirectional beacons. An instrument landing system is desirable. In some areas high frequency communication gear is advisable. A transponder is generally required for high altitude flights, but is not necessary unless radar control is involved. Most air traffic control radar cannot track a light plane long without a transponder, especially if the plane is a Bellanca or Windecker aircraft.

3. Aircraft radar is a convenience and of great use in estimating distance to targets and effects of seeding on targets, but is not required. It cannot be installed easily in any single-engine aircraft and is usually not used in twin-engine planes because of cost.

4. Spare parts peculiar to the project aircraft should be brought along to the base of operations because, although most countries have good mechanics available, spare parts are not often found in abundance.

## Pilots

Local pilots who know and are interested in the country can serve very well. They should be instrument-rated or at least be capable of short periods of instrument flight in turbulence. If possible, after having listened to some lectures and chalk talks on the subject, they should be trained to seed by another pilot familiar with the technique.

## Evaluation

Evaluation of the results may not be required, but it is a most important factor and one of the most difficult to carry out. Because seeding projects are generally conducted in dry areas where the need for maximum water production is urgent, there is often little interest in a full-scale statistical experiment. Every aircraft is needed to seed every cloud possible. Randomization to acquire scientific information, so important to American experimenters, is generally not favored by local officials nor indeed is any evaluation process that exceeds 10% of the project cost.

Rainfall measurement is best done by well-calibrated radars, but these are rarely found in sufficient number in most countries because of the cost. Rain gauges are perhaps the most practical means of measuring rain, but an enormous number are needed. The observation and reporting are expensive even if the gauges are read only once a day.

The real proof of effectiveness is in benefits to agriculture and irrigation. In many cases estimates of this sort can be made, but so many variables are at work that one cannot always be sure the results isolated are indeed the ones needed.

## Local Participation

It is important to secure the active cooperation of local people in the rainmaking operations. They should be included in the work to as large an extent as possible and their advice and help should be sought. The irrigation, power, and water management people are usually enthusiastic. The weather people are not as a rule vitally interested and may even offer some resistance. There must be a continuous effort made to involve them in making the decisions that have to be made. Providing reprints from the seeding literature, holding seminars, and taking a few local people along on seeding missions are some ways of gaining their interest in the project. However, the people should be chosen with care, the activities limited to good seeding days, and the air work confined at first to only mild penetrations because most people unaccustomed to such flights get airsick under conditions that an experienced person would find dull.

## Hold Harmless Agreement

Before any seeding is done, a formal *hold harmless agreement*, a legal agreement limiting liability on the part of the seeding party, should be entered into by the participating governments and promulgated. Although there is little chance of extensive damage, natural occurrences such as typhoons, hail, lightning strikes, and similar phenomena of an unexpected nature, as well as complicated dis-benefits befalling certain, perhaps unsympathetic, groups could lead to interminable litigation and trouble.

The *hold harmless clause* together with intelligent restraint in the conduct of the operation and the wise use of local advice will preclude most such trouble.

## Water Management

Often the lack of water points up a less than adequate water management system. It must be emphasized to the recipients that cloud seeding alone is not enough to solve problems perhaps centuries in the making and that a proper storage and distribution system is often the real need.

## Appendix C

# PRELIMINARY CLOUD STUDIES IN THE PHILIPPINES-1969

# PRELIMINARY CLOUD STUDIES IN THE PHILIPPINES-1969

Report to

EARTH AND PLANETARY SCIENCES DIVISION
NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA

Contract N66001-69-C-1142

by

D. Ray Booker

Weather Science, Inc.
Norman, Oklahoma

28 December 1970

## 1.0 Purpose.

I was asked in April of 1969 to participate in the early phases of a cloud-seeding operation in the Philippines which became known as GROMET II. My purpose was

1. To install two airborne meteorological instrumentation systems on two Air Force C-130 weather reconnaissance aircraft.
2. To make preliminary observations of clouds and their environments.
3. To act as a scientific observer of seeding techniques and cloud reactions.
4. To train military personnel in the use of equipment and making of observations.

I departed Norman, Oklahoma, on 27 April and returned on 29 May 1969.

## 2.0 Equipment.

The equipment used for installation on the Air Force weather reconnaissance aircraft was removed from a Cessna 205 and a Piper Aztec where it had previously been used in similar measurements within the Continental United States. The equipment was reconditioned prior to shipment to the Philippines. The equipment, referred to as AMS-11 and AMS-15, was designed to measure various cloud and environmental parameters including rainrate, liquid water content, temperature, dewpoint and others. The AMS-15 was equipped with both analog and digital recording systems operating in parallel. The AMS-11 produced only analog records. The analog records were used for on-site preliminary analysis. The digital records were returned to the United States for processing and use in a more detailed analysis.

The AMS-15 was additionally furnished with a continuous ice nucleus counter of the NCAR-Bollay type. The ice nucleus counter produced printed digital records independent of the analog and digital recordings previously mentioned.

For both aircraft, the instrumentation installations were made in the forward right section of the cargo compartment. A shelf was improvised on the bulkhead to support the instruments and power supplies while providing a place for the operator to work. Sensors were mounted on the aircraft skin on the right side of the aircraft.

Six military technicians were trained in the techniques of installing, operating and maintaining the instrument systems. Nine weather observers and weather officers were trained in the use of the equipment and analysis of the data for meteorological purposes. Operation of the equipment was transferred systematically to military operators during my stay in the Philippines.

## 3.0 Preliminary Observations.

I participated in seeding flights on about half of the operational days while I was in the Philippines. I used the aircraft instrumentation systems and visual observations in coming to the following preliminary conclusions:

Even though the Philippine Islands were experiencing an unprecedented drought, we were able to find clouds suitable for seeding on every day on which I participated in flights. The clouds grew over the highest peaks in the mid- and late afternoons. Bases varied from 3,000-10,000 ft. The clouds tended to organize themselves along the mountain ranges. In general, they were extremely easy to operate on because of their relative isolation and a natural tendency to organize themselves in short lines. The liquid water content meters indicated rather wet conditions in most of the clouds. LWC values of 4 gm/m$^3$ were common near the tops of the cumuli. The clouds were generally slightly sheared. Almost all observations were made at or near the -7C level.

Very few rain measurements were made since the aircraft were used primarily for seeding. Therefore, no conclusive results regarding the character of the rain can be made from the rainrate measurements. However, the impression I have gained from the ooservations and data is that the rain was of high intensity, normally reaching peak values above 100 mm/hr. Droplet concentrations were considerably higher than those we experienced in seeding tests in New Mexico and Oklahoma.

Ice nucleus measurements were made on most of the flights. We generally found very few ice nuclei except in areas where we had been seeding. Most of the measurements were made at the -7C level. The environment, as might be expected, was essentially clean at that level. The occasional ice nucleus checks at lower altitudes indicated relatively few ice nuclei present.

I observed a great deal of smoke rising from cane fields on operational days. This smoke was frequently observed to enter the bases of cumuli growing nearby. The possibility that this air pollution was ineffective in modifying the clouds seems remote to me. Although we had no quantitative way of measuring, my impression was that the clouds became very much of Continental character by addition of condensation nuclei rather than the more efficient maritime type which normally prevails at these latitudes

## 4.0 Impression of Seeding Effectiveness.

Seeding was conducted by Dr. St.-Amand and various members of the China Lake team, and military trainees. A large number of military personnel and Philippine crew members were trained in the theory and practice of cold cloud seeding techniques.

The seeding material was placed carefully in the updraft. The number of rounds was varied according to the strength and width of the updraft encountered. The clouds were carefully observed for growth, organization and glaciation.

I was particularly impressed with the opportunity to enhance cloud organization. Since the clouds tended to occur in short lines, as determined by mountain ranges, the crews were able to watch the development carefully and to seed those turrets which would enhance this tendency by filling in or extending a line. My impression was that the seeding was effective in increasing cloud organization. Theoretically, this should greatly increase the available precipitation since increased cloud efficiency results from decreased entrainment and increased instability due to line orientation.

Subsequent related experiences in Project Hotshot, which has been conducted since returning from the Philippines, used the same seeding material. The ice nuclei were introduced from the base rather than the top because of aircraft limitations. The results indicated that rain at the cloud base was more than doubled as a result of seeding. These results were statistically significant. We found that the raindrop spectrum was significantly altered in a uniform manner as a result of seeding. Our results would tend to indicate that similar results could be expected from the cold clouds seeded in the Philippines.

## 5.0 Recommendations.

All evidence from the flights of GROMET II and subsequent Hotshot experiments would indicate significant positive results from seeding. This potential should have marked economic, military, and political significance. I would recommend that a long-term agreement for further development of this technology in cooperation with a friendly nation be devised. The results can and should be very beneficial to both nations.

## Appendix D

## OBSERVATIONS AT GROMET II

# OBSERVATIONS AT GROMET II

by
Edwin X. Berry

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Reno, Nevada

## ABSTRACT

The systematic seeding of growing cumulus towers in a localized area with pyrotechnic drops at about the −5C level regularly gave rise to large thunderstorms with heavy rain-showers, while unseeded cloud areas in the general vicinity produced little or no significant growth or rain. These are the qualitative conclusions of an independent observer present at the GROMET II seeding operation in the Philippine Islands during two weeks in June 1969.

## INTRODUCTION

The following is an account of the GROMET II cumulus seeding operation in the Philippine Islands during the period June 1969, as witnessed by the author who was invited to be an independent observer. Since the purpose of the operation was to make rain fall in designated drought areas as opposed to being experimental, there were no means available other than the qualitative judgments of the observers to measure the outcome of this project. Exceptions are the rainfall and crop growth data gathered by the farmers, which apparently showed a rainfall increase over the previous five years. This account will only be concerned with observations of the clouds and rain from aboard the C-130 seeding aircraft.

## METEOROLOGICAL CONDITIONS

The observations took place during a two-week period near the end of the transitional period during which the southwest monsoon was approaching. There were a few days during this period when the island of Luzon at least was obliterated with rain and the operation was cancelled. Otherwise during the operation over the southern Philippine islands there were scattered fair weather cumulus with bases around 3,000 ft. MSL and tops 16,000 to 18,000 ft. None of these produced any rain. They seemed to be only a momentary entity climbing rapidly to their peak then dissipating. Their lifetime seemed to be about 15 minutes; their diameters about half a kilometer. They were generally randomly scattered over the land areas with some predominance of occurrence near mountain ranges and upwind shores. Occasionally (i.e. about once per $10^4 km^2$ per day) a large cumulus cloud would form and grow to about 30,000 ft.

## SEEDING TECHNIQUE

A group of small cumulus clouds were selected which reached to at least the -2C level and preferably to the -5C level which were over an area that needed water. The aircraft was flown into the tops of the more active towers, which usually meant flying about 19,000 ft. MSL (-5C), and approximately one pyrotechnic flare per 500 m was dropped in each actively growing cloud top traversed. A few minutes later the tops of more clouds which grew to at least -2C were similarly seeded. This technique was repeated for 15 to 30 minutes as more and more cumulus tops in the designated area, usually no greater than 10 km X 10 km, began to grow near the seeded towers. The seeding proceeded by trying to fill in the gaps between the towers where growing cloud developed between them.

The intention was to expand the total area of cloud and updraft in the preferred region. If the whole cloud drifted with a wind only the towers on the upshear side were seeded in an attempt to make them grow together into one cloud.

As a larger cumulus cloud developed, perhaps now reaching 22,000 ft. and 1 km in diameter, the adjoining cumulus were seeded and frequently penetrations were made of the towers while doing so. When the cloud was about 26,000 ft. and 2-3 km in diameter the seeding was discontinued. Then either another area was sought at least 80 km away or the now growing storm was observed for about half an hour.

## OBSERVED RESULTS

Generally, a few minutes after a tower was seeded it was observed during a turn. There was seldom any difficulty in distinguishing the seeded tower from the others In virtually every case the seeded tower had grown approximately 2,000 ft. higher than nearby unseeded towers in 3 to 5 minutes after seeding and glaciation was usually apparent at the top of the seeded tower.

As more towers in the vicinity were seeded, more towers seemed to grow by comparison to other areas within signt that were similar before the seeding began. Whether by the influence of the seeding or by a clever anticipation of nature, when towers were seeded to fill in space between clouds these areas invariably filled in. Some 15 to 20 towers were seeded during the formation of each cumulo-nimbus. The observer witnessed some 8 cumulo-nimbus formations that developed subsequent to the seeding and only two cases when the seeding was not followed by a thunderstorm, and these were cases where the clouds were very scarce. When the storm was about 3 km in diameter, small cu growth was suppressed to at least 20 km from the storm and the very small cu that did grow within 5 km of the storms were noticeably tilted toward the storm. Most of these storms reached about 35,000 ft., developed anvils, and persisted actively for about one hour during which time moderate to heavy rain fell out the bottom. Four times the aircraft was flown down below the cloud and partially into the rain to verify that what was seen from above was indeed heavy rain. At times the visibility was less than one km in this rain.

Invariably the seeded storm was the most intense storm visible within about 100 km. About two hours after the seeding similar cu-nimbus sometimes developed about 50 km from the seeded cell.

In one case a group of scattered small cumulus clouds on one end of an island were purposely selected for the seeding by this observer while at the opposite end of the island about 20 km away a larger cumulus group was forming that would have been a better seeding target. The poorer target was chosen in order to see if the seeding technique could compete with nature when starting with a handicap.

The group chosen for seeding was marginal and only two towers were high enough for seeding on the first pass. It took ten minutes for another tower to come up and an additional five minutes for another. Each of these was given one flare. Although the group could still be classified as scattered cumulus, the convection seemed to be intensifying. Thirty minutes after seeding began there were about three towers topping at 20,000 ft. and perhaps six coming up to 18,000 ft. and the cloud

## INTRODUCTION

The following is an account of the GROMET II cumulus seeding operation in the Philippine Islands during the period June 1969, as witnessed by the author who was invited to be an independent observer. Since the purpose of the operation was to make rain fall in designated drought areas as opposed to being experimental, there were no means available other than the qualitative judgments of the observers to measure the outcome of this project. Exceptions are the rainfall and crop growth data gathered by the farmers, which apparently showed a rainfall increase over the previous five years. This account will only be concerned with observations of the clouds and rain from aboard the C-130 seeding aircraft.

## METEOROLOGICAL CONDITIONS

The observations took place during a two-week period near the end of the transitional period during which the southwest monsoon was approaching. There were a few days during this period when the island of Luzon at least was obliterated with rain and the operation was cancelled. Otherwise during the operation over the southern Philippine Islands there were scattered fair weather cumulus with bases around 3,000 ft. MSL and tops 16,000 to 18,000 ft. None of these produced any rain. They seemed to be only a momentary entity climbing rapidly to their peak then dissipating. Their lifetime seemed to be about 15 minutes; their diameters about half a kilometer. They were generally randomly scattered over the land areas with some predominance of occurrence near mountain ranges and upwind shores. Occasionally (i.e. about once per $10^4 km^2$ per day) a large cumulus cloud would form and grow to about 30,000 ft.

## SEEDING TECHNIQUE

A group of small cumulus clouds were selected which reached to at least the -2C level and preferably to the -5C level which were over an area that needed water. The aircraft was flown into the tops of the more active towers, which usually meant flying about 19,000 ft. MSL (-5C), and approximately one pyrotechnic flare per 500 m was dropped in each actively growing cloud top traversed. A few minutes later the tops of more clouds which grew to at least -2C were similarly seeded. This technique was repeated for 15 to 30 minutes as more and more cumulus tops in the designated area, usually no greater than 10 km X 10 km, began to grow near the seeded towers. The seeding proceeded by trying to fill in the gaps between the towers where growing cloud developed between them.

The intention was to expand the total area of cloud and updraft in the preferred region. If the whole cloud drifted with a wind only the towers on the upshear side were seeded in an attempt to make them grow together into one cloud.

As a larger cumulus cloud developed, perhaps now reaching 22,000 ft. and 1 km in diameter, the adjoining cumulus were seeded and frequently penetrations were made of the towers while doing so. When the cloud was about 26,000 ft. and 2-3 km in diameter the seeding was discontinued. Then either another area was sought at least 80 km away or the now growing storm was observed for about half an hour.

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As more towers in the vicinity were seeded, more towers seemed to grow by comparison to other areas within sight that were similar before the seeding began. Whether by the influence of the seeding or by a clever anticipation of nature, when towers were seeded to fill in space between clouds these areas invariably filled in. Some 15 to 20 towers were seeded during the formation of each cumulo-nimbus. The observer witnessed some 8 cumulo-nimbus formations that developed subsequent to the seeding and only two cases when the seeding was not followed by a thunderstorm, and these were cases where the clouds were very scarce. When the storm was about 3 km in diameter, small cu growth was suppressed to at least 20 km from the storm and the very small cu that did grow within 5 km of the storms were noticeably tilted toward the storm. Most of these storms reached about 35,000 ft., developed anvils, and persisted actively for about one hour during which time moderate to heavy rain fell out the bottom. Four times the aircraft was flown down below the cloud and partially into the rain to verify that what was seen from above was indeed heavy rain. At times the visibility was less than one km in this rain.

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The group chosen for seeding was marginal and only two towers were high enough for seeding on the first pass. It took ten minutes for another tower to come up and an additional five minutes for another. Each of these was given one flare. Although the group could still be classified as scattered cumulus, the convection seemed to be intensifying. Thirty minutes after seeding began there were about three towers topping at 20,000 ft. and perhaps six coming up to 18,000 ft. and the cloud cover in this group went from scattered to broken. Meanwhile, at the other end of the island, nature was still ahead with a strong group of clouds between 20,000 and 21,000 ft.

One hour after seeding began the target area contained a large cumulus cloud about 5 km in diameter and growing through 24,000 ft. The natural cloud seemed unchanged or even diminished during the previous half hour. Seeding was discontinued.

Ninety minutes after seeding began the target area contained a cumulo-nimbus cloud with heavy rainfall. The clouds at the opposite end of the island had all but dissipated, and convection in that area seemed hindered by the cumulo-nimbus in the target area. The target area clouds were the only ones to deliver rain to the island that day.

## IMPLICATIONS FOR THE FUTURE

Since the project was not an experiment, per se, there were no controls or statistics, and the sequence of events observed cannot be used to strongly imply a cause-effect relationship between the seeding and the rain. However, the evident possibility that such a relationship may have existed makes the seeding technique worthy of description and worthy of future testing in a controlled experiment.

If the above described seeding technique does indeed promote storms in certain circumstances, then the upward acceleration of an individual cumulus must modify the local air flow in such a way that nearby growth is encouraged; otherwise the result would be only higher single cells with the same area distribution as the natural case. The relative importance of increased horizontal convergence and the effect of vertical wind shear in causing mergers is not clearly known. If a way could be found to measure the airflow around the lower regions of cumulus clouds during a seeding experiment (or even in the natural case) much could be learned that might suggest better seeding techniques.

Investigations into the formation of cloud merges and their artificial simulation are indeed at the heart of the future problems in cloud modification.

## CONCLUSIONS

It is the author's opinion that this was an ideal situation for such a seeding operation. Although no precise measurements were available, the repetitive apparent success of each attempt to produce rain seems to be some evidence in itself that the seeding indeed formed the large cumulo-nimbus clouds when nature might not have done so. The design of the seeding technique to use latent heat release due to freezing and careful placement of the flares to generate and organize a large strong convective cell seems to make sense. It is the author's feeling that additional rain was produced by having the warm rain process operate in an organized intensive updraft of longer duration than nature was producing and that the ice crystals formed by seeding had a bearing on the precipitation only indirectly through their intensification of the updraft.

## REFERENCES

1. Yap, Edgardo F. Q., Project Coordinator. *Artificial Rain Stimulation in the Philippines. I. Performance Report on the 1969 Project. II. Proposed Work Program for 1969-1970.* Office of the Executive Secretary; Philippine Sugar Institute; National Federation of Sugarcane Planters. Quezon City, Philippine Islands, 15 July 1969.

2. St.-Amand, Pierre, Wm. G. Finnegan, L. Lee Wilson, Sheldon D. Elliott, Jr., and Paul T. Jorgensen. "Pyrotechnic Production of Nucleants for Cloud Modification: Part II. Pyrotechnic Compounds and Delivery Systems for Freezing Nucleants." *The Journal of Weather Modification* Vol. 2, No. 1 (May 1970), pp. 33-52.

3. Institute of Atmospheric Sciences, South Dakota School of Mines and Technology. *Final Report–Nucleation Efficiency Tests Conducted for the Naval Weapons Center Under Contract No. N60530-68-C-0006*, by John A. Donnan and Donald N. Blair. Rapid City, S. Dak., South Dakota School of Mines and Technology, July 1970. 20 pp. (Report 70-8.)

4. Warner, J. "A Reduction in Rainfall Associated with Smoke from Sugar-Cane Fires–An Inadvertent Weather Modification?" *APPL METEOROL*, Vol. 7, No. 2 (April 1968), pp. 247-51.