# Background data for the warm rain project[1]

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ABSTRACT

A brief description is given of the area in Hawaii where a cooperative study of rain mechanisms in warm clouds was conducted during July and August 1965. The nature of the project and its general objectives are outlined, and local weather and atmospheric structure is characterized in order to provide background information for discussions of specific project results.

## Introduction

The Island of Hawaii, rising to a height of about 4200 m, presents a formidable obstacle to the northeast trade winds which move over at least 4000 km of open ocean before this encounter. The influence of the island, however, is usually insufficient to disrupt significantly the control which the persistent trade inversion exerts on the depth of cumulus clouds in the lower moist layer. Thus, the copious rainfall which characterizes the windward coast of the island is provided by clouds whose tops are seldom higher than 3.5 km above sea level where temperatures are of the order of 5 C.

The high frequency of rain and the guarantee that it would be generated by "warm rain" mechanisms provided major reasons for selection of this locale for a joint measurement program undertaken by cloud physicists from Japan, the United States, and Australia during the summer of 1965. Many of the features which make the region attractive for aerosol and cloud physics studies have been described by Woodcock (1953). Some pertinent comments on the geography and the meteorology of the area will be given here in order to provide a background for the individual project results discussed in the following pages. The reader is referred to an article by Mordy (1957) for a complementary discussion of some of these topics. More general notes on the climate of the area are available in a U.S. Weather Bureau publication (Blumenstock, 1961).

## Project locale

Two volcanic domes dominate the topography of the Island of Hawaii. Mauna Kea rises to 4202 m and the summit of Mauna Loa, about 40 km to the south-southwest, is 4172 m above sea level (see Fig. 1). Between the two mountain masses is a col region, known as the Saddle, with an elevation at about 2000 m. With the trade inversion of about 2500 m forming an effective vertical lid, most of the airstream which strikes the mountain massif is forced around the barrier at low levels; very little escapes through the Saddle. From the 2000 m level, the terrain slopes quite smoothly and regularly towards the windward coast at a rate of about 1:20. The three roads shown on the map allow access to the slopes, and, what is perhaps more important from the point of view of cloud physics, they lie along the direction of the northeast trades so as to make feasible the sampling of rain characteristics during the life history of individual showers as they move upslope.

During the day, orographic lifting combines with convection induced by heating of the land to produce, typically, a widespread cloud cover over much of the windward slopes. Under conditions of strong trade winds and well developed cumulus clouds over the sea, this cloud cover can extend to the coastline and even beyond, a few kilometers out to sea; then it usually forms a nearly continuous blanket extending into the

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Saddle and mounting the upper slopes to well above the 3 km level. Squires & Warner (1957) have reported on the characteristics of this cloud layer. The well-developed orographic cloud spawns frequent showers near its upwind edge, and these often appear to merge into light but more nearly continuous rain farther upslope.

The night time cloud and rain distribution has been less well studied, but it is characterized by showers along the coast and gradual clearing over the upper slopes. The downslope drainage flow which prevails at night undoubtedly plays a significant role in the nocturnal cloud and shower production.

The major field site for the joint project was set up near the Saddle Road at the 760 m level (2500 ft) about 9 miles from the coast. The site was selected because it is in the maximum rainfall zone with an open view both upslope and downslope and because it is generally very near cloud base level. The latter characteristic allows essentially in-cloud precipitation measurements to be made by ground-based equipment.

The locations of other facilities which played key roles in the measurement program are designated in Fig. 1. The Cloud Physics Observatory is a research establishment operated by the University of Hawaii to capitalize on the many unique features which the island offers as a natural cloud physics laboratory. It served as headquarters for the summer project and is the site of the M-33 surveillance and tracking radar which, in addition to providing important data on the behavior of showers, was a valuable aid in coordinating the activities of the various groups working on the slopes. Mauna Loa Observatory MWO, a facility dedicated to the study of numerous aspects of atmospheric physics and operated by the Environmental Science Services Administration (ESSA), is located at an elevation of 3400 m (11,150 ft) on the northern flank of Mauna Loa. The measurement program and the local climate at this site have been described by Price & Pales (1963). The Hilo Airport is the site of a U.S. Weather Bureau Office which maintains a continuous weather observing and recording program. Two rawinsonde and two pibal soundings per day are routinely available but special ascents were also made for the benefit of the project.

The nature and scope of the field project is illustrated by Table 1 which lists the special instrumentation utilized at the major field sites

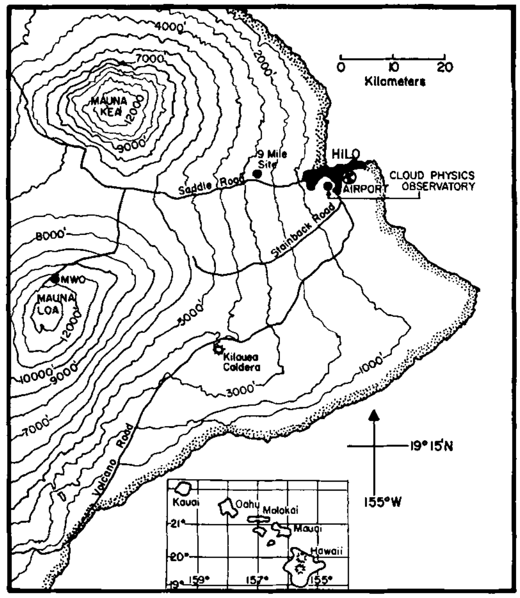


*Fig. 1.* Project locale, the eastern section of the Island of Hawaii, showing locations of major facilities and road network used during observational program. Terrain contour interval is 1000 ft (305 m).

and facilities. The research teams responsible for the equipment are identified by abbreviated names specified in the following brief synopsis of their main objectives.

The team from Nagoya University (Nag. U) and the Meteorological Research Institute (M.R.I.), both of Japan, were primarily concerned with the chemical and physical characteristics of raindrop populations. Measurements were made both on the ground and within the raincloud using a variety of specially designed instruments. The University of Illinois (Ill.) effort was centered on the modification and operation of the M-33 radar system together with data collection necessary to develop an understanding of the radar climatology of the area.

The group from Cornell Aeronautical Laboratory (C.A.L.) transported their Doppler radar system to Hawaii to provide a versatile tool for the 3-dimensional study of vertical air motions and drop-size distributions in the warm showers. In addition, Cornell undertook a study of the concentration of condensation nuclei and carried out aircraft measurements of such cloud variables as cloud droplet size distribution and liquid water content. The University of Hawaii (U.H.)

Table 1. *Primary instrumentation deployed in warm rain project*

| | | | |
|---|---|---|---|
| | *9-mile site* | | *Cloud Physics Obs.* |
| Nag. U | Raindrop spectrographs (for chemical analysis) | Ill. | M-33 Radar system (surveillance and tracking) |
| Nag. U | Electric field recorder | Ill. | GPG radar system |
| Nag. U | Raindrop electric charge recorder | Ill. | Time lapse cloud photography |
| Nag. U | Time lapse cloud photography | U.H. | Electric field recorder |
| Nag. U and M.R.I. | Radiosonde launching site (for drop size, salinity, and electric charge measurements in cloud) | U.H. | Flame photometer (for rain sample analysis) |
| | | U.H. | Constant level balloon launching site |
| M.R.I. | Raindrop size distribution recorders | C.A.L. | Thermal diffusion chamber (cloud nuclei measurements) |
| C.A.L. | Pulsed doppler radar system | Nag. U. | Ice nuclei counter-sampler |
| | *Hilo Airport* | Stanf. | Radioactive nuclei & rain samplers |
| U.S.W.B. | Conventional surface & upper air observations | | *Mauna Loa Obs.* |
| C.A.L. and C.S.I.R.O. | Cessna 336 aircraft (sampling of clouds and atmospheric structure) | Nag. U | Ice nuclei counter-sampler |
| | | Nag. U | Time lapse cloud photography |
| | | Stanf. | Radioactive nuclei & rain samplers |

contingent was involved partly with a study of time and altitude variations of the chemistry of raindrops using flame photometer and radioisotope analysis techniques. A pilot study of constant volume balloon trajectories was also undertaken to illucidate the horizontal and vertical air motions over the windward coast.

The Commonwealth Scientific Industrial Research Organization (C.S.I.R.O.) of Australia sponsored a program of aircraft measurements of the structure of the trade wind layer. The Stanford University (Stanf.) experiments dealt with the sampling of air and rain for concentration of radioactivity at various elevations on Mauna Loa. These were directed toward a better understanding of mechanisms by which radioactive contamination is delivered to rain and of the role of the trade wind inversion as a dynamic barrier to the transport of radioactive material to the ground.

## Project weather

The total rainfall observed over the windward side of the island during the project period was only about 60 per cent of normal; but rainfall still averaged over 0.3 inch (8 mm) per day over the area in which field measurements were concentrated. The island-wide distribution of total rainfall during this period is shown in Fig. 2. In spite of the "relatively" dry conditions on the windward slopes, the isohyetal pattern closely resembles that which is normally observed.

The inter-diurnal variability of rainfall is demonstrated in Fig. 3 which shows the progression of 12-hourly totals (periods ending at

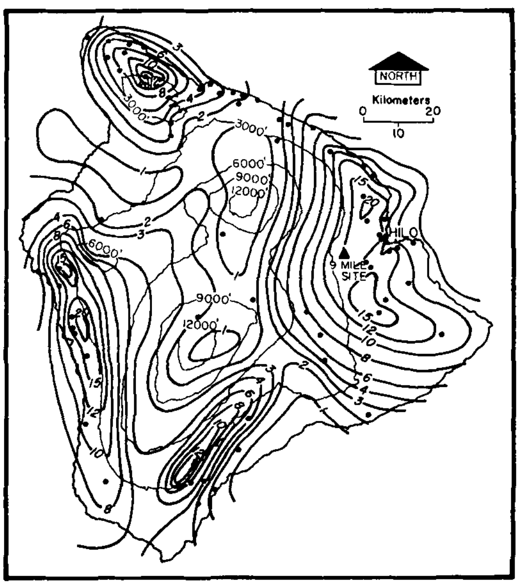


*Fig. 2.* Total rainfall for the Island of Hawaii during the 45-day period, 11 July to 24 August 1965. Terrain contours are at 3000-foot intervals. Isohyets, in inches, are based on daily reporting stations (shown by dots) and guided by totals from a few monthly recording stations and climatology.

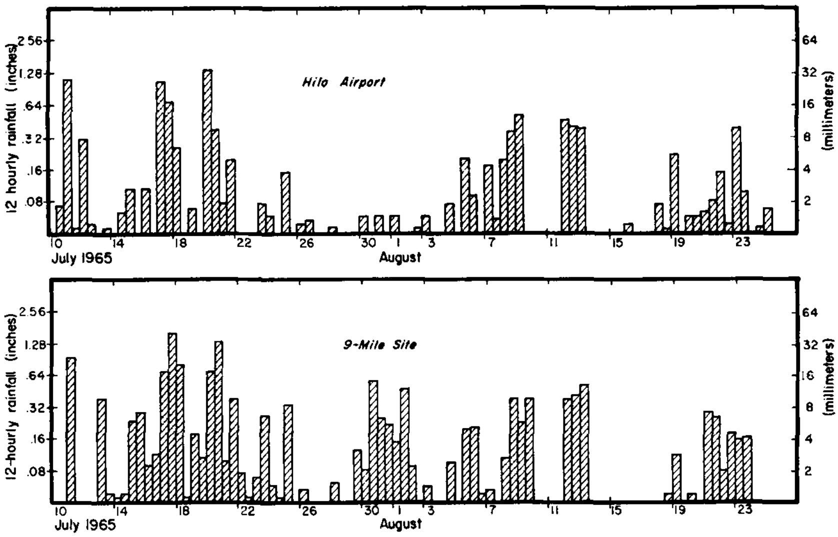


*Fig. 3.* Twelve-hour totals of rainfall for the project period, at Hilo Airport and at the 9-mile site. Totals measured at 8 a.m. and 8 p.m. Period totals, Airport: 10.61 inches (270 mm), 9-mile site: 15.76 inches (400 mm).

8 a.m. and 8 p.m.) at both the Hilo Airport and the "9-mile" site.

In order to characterize the vertical structure of temperature and moisture during the period of measurements, the mean radiosonde data for 1315 LST are shown in Fig. 4. The mean temperature sounding has been modified to include the median height and structure of the trade inversion whose features are smoothed out by the averaging process. The averaged sounding data are presented in more detail for both standard observing times in Table 2 where temperature, potential temperature, relative humidity, and mixing ratio are listed for each standard pressure level. The approximate heights of the pressure surfaces are included in the last column.

Since the inversion plays such an important role in the study of clouds and rainfall in this area, its median characteristics for the measurement period are listed in Table 3 which also includes estimates of cloud base altitude reported by weather observers on duty at Hilo Airport. The median height of the level in the

Table 2. *Mean Hilo radiosonde data—11 July to 25 August 1965*

| Pressure level (mb) | 00 GMT (1315) LST) T (°C) | θ (°A) | R.H. % | W (g/kg) | 12 GMT (0115 LST) T (°C) | θ (°A) | R.H. % | W (g/kg) | Z (m) |
|---|---|---|---|---|---|---|---|---|---|
| 1000 | 24.9 | 297.8 | 59 | 11.9 | 22.7 | 295.7 | 77 | 13.6 | 145 |
| 950 | 20.5 | 297.8 | 63 | 10.3 | 19.3 | 296.7 | 84 | 12.6 | 590 |
| 900 | 17.2 | 299.2 | 64 | 8.8 | 16.1 | 297.9 | 87 | 11.2 | 1055 |
| 850 | 14.0 | 300.8 | 65 | 7.7 | 13.0 | 299.8 | 87 | 9.7 | 1540 |
| 800 | 11.9 | 303.8 | 55 | 6.1 | 10.8 | 302.6 | 80 | 8.2 | 2050 |
| 750 | 10.1 | 307.7 | 41 | 4.3 | 9.4 | 306.9 | 53 | 5.3 | 2590 |
| 700 | 8.6 | 312.0 | 27 | 2.7 | 7.9 | 311.2 | 34 | 3.3 | 3160 |
| 650 | 6.0 | 315.9 | 25 | 2.3 | 5.1 | 314.9 | 25 | 2.2 | 3770 |
| 600 | 2.4 | 319.1 | 20 | 1.5 | 1.8 | 318.3 | 26 | 1.9 | 4420 |
| 550 | −1.6 | 322.4 | 21 | 1.3 | −2.4 | 321.5 | 25 | 1.5 | 5110 |
| 500 | −6.6 | 325.3 | 20 | 0.9 | −7.3 | 324.4 | 23 | 1.0 | 5865 |

Table 3. *Median values of cloud layer parameters (Hilo)*
11 July to 25 August 1965.

| | 00 GMT (1315 LST) | 12 GMT (0115 LST) |
|---|---|---|
| Cloud base | 670 m (2200 ft) | 610m (2000ft) |
| Inversion base | 765mb or 2415m | 768mb or 2385m |
| Inversion depth | 27mb or 290m | 27mb or 290m |
| Inversion strength | 1.5°C | 2.1°C |
| 50% R.H. height | 771mb or 2350m | 754mb or 2535m |

sounding at which the relative humidity fell below 50 per cent is also given; this humidity value usually coincides with the top of the moist layer (whether capped by an inversion or not) and is found to correlate well with mean cloud tops (see e.g. Woodcock & Friedman, 1963).

A final ingredient of the mean atmospheric structure during the project is presented in Fig. 5 which portrays the mean profile of the east-west component of the wind measured at the airport. Resultant wind direction is plotted for each reporting level, demonstrating the small magnitude of the north-south component.

The foregoing mean data are, of course, only of limited use in describing conditions during a typical project day in spite of the often-quoted high values of constancy appropriate to trade wind regimes. Nevertheless, the data form a reasonable reference for specific daily values incorporated in the papers which follow this one.

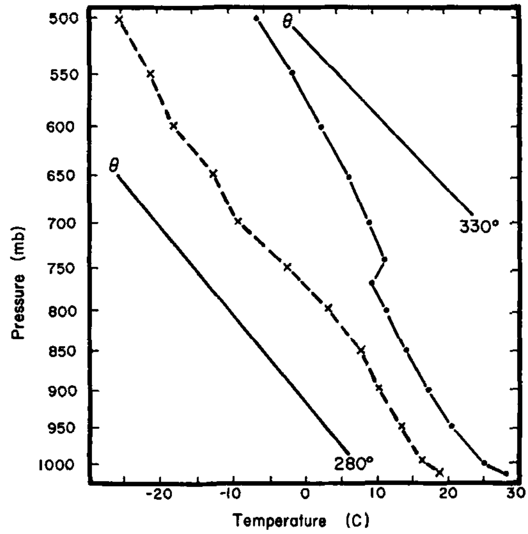


*Fig. 4.* Mean temperature and dewpoint sounding for 1315 LST at Hilo Airport during the project period, 11 July to 25 August 1965. Thin straight lines depict dry adiabats.

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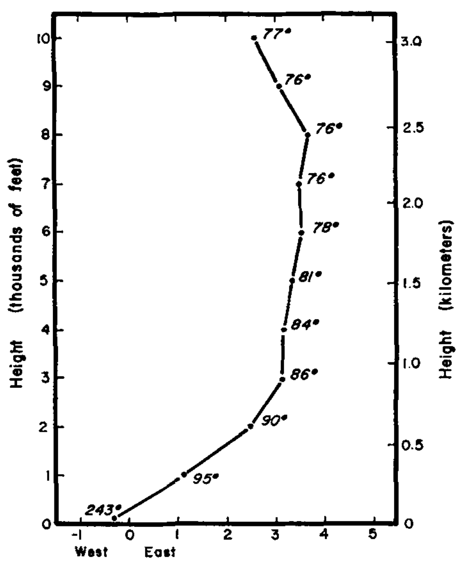


*Fig. 5.* Vertical profile of the mean zonal component of the wind at Hilo Airport for the period 11 July to 25 August 1965. Numbers entered along the profile show resultant wind direction.

and especially to Mr. Jack Tefft and his staff of the Radar Facilities Section, for the loan, modification, and installation of the M-33 radar system in Hilo. Field site equipment was made available by the Honolulu Office of the U.S. Atomic Energy Commission and by Holmes and Narver, Inc., their local contractors. The National Science Foundation provided considerable material for the field work under Grant No. GF 192.

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## ОСНОВНЫЕ ДАННЫЕ ДЛЯ ПРОЕКТА ПО ИССЛЕДОВАНИЮ ТЕПЛОГО ДОЖДЯ

Дается краткое описание местности на острове Гавайи, где проводилось изучение механизма дождя в теплых облаках в июле и августе 1965 года. Излагаются суть проекта и его главные цели; дается характеристика местной погоды и атмосферной структуры, чтобы обеспечить основную информацию для дискуссии о специфических результатах проекта.