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# OPERATION GREENHOUSE

## METEOROLOGICAL

TECHNICAL REPORT

**1951**

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# METEOROLOGICAL TECHNICAL REPORT

by


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Commander, USN

and

GEORGE F. TAYLOR
Colonel, USAF





Joint Task Force Three

September 1951


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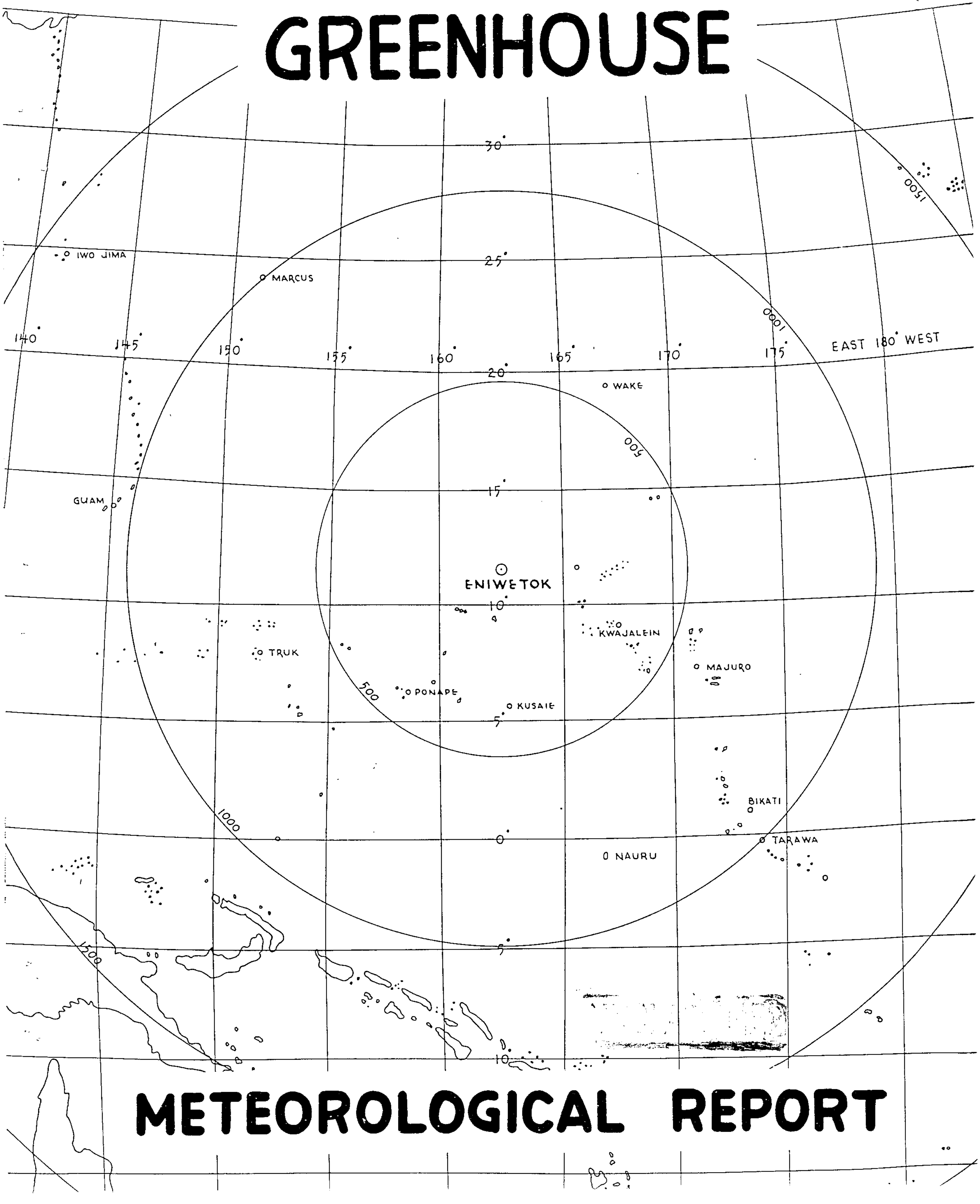
# OPERATION GREENHOUSE




# METEOROLOGICAL REPORT

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# FOREWORD

The mission of the Joint Task Force meteorological organization was set forth in Field Order Number 2 (Revised), dated 1 December 1950, as follows:

> ". . . to provide:
>
> a. Weather forecasts to assist the Commander, Joint Task Force THREE in reaching decisions concerning the firing of weapons.
>
> b. Weather information for aircraft operations.
>
> c. Weather information to be used in the meteorological research program of Task Group 3.1 (Scientific Task Group)."

The successful accomplishment of this mission involved the full time assignment of over 500 officers and men for variable periods, but averaging about 5 months, not to mention the time and effort expended by various divisions, branches and individuals of the Air Weather Service, the Air Materiel Command, the Naval Aerological Service, Headquarters, USAF, the Commander in Chief, Pacific and U. S. Pacific Fleet, the Commander Service Force, Pacific Fleet, the U. S. Coast Guard, the Pacific Trust Territories Administration, the Civil Administrator at Nauru, the Manager of the British Phosphate Commission, that lonely bearer of the white man's burden at Kusaie—Mr. Herman, and many other agencies and individuals too numerous to enumerate.

Another milestone in the development and test of atomic weapons has been passed successfully. This report—part narrative, part technical outline, and part "lessons learned"—is both a technical history and, for what it may be worth, a guide for those who may be concerned with weather and the testing of atomic weapons.

Meteorological data collected during Operation GREENHOUSE is being published as a separate unclassified annex to this report.



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# Chapter 1

# ORGANIZATION

## 1.1 Task Force

The Task Force Staff Weather Officer was responsible directly to the Task Force Commander for providing all necessary meteorological information for the Task Force.

## 1.2 Task Group 3.4

The Commander, Task Group 3.4 (Air Force) exercised operational control over the fixed weather units (Task Unit 3.4.5) which included the Eniwetok Weather Central and the four (4) outlying JTF-3 weather observation stations, and the Weather Reconnaissance Unit (Task Unit 3.4.4).

## 1.3 Task Group 3.3

The Commander, Task Group 3.3 (Navy), exercised operational control over the P2V antisubmarine squadron which furnished special weather reports at each regular position report.

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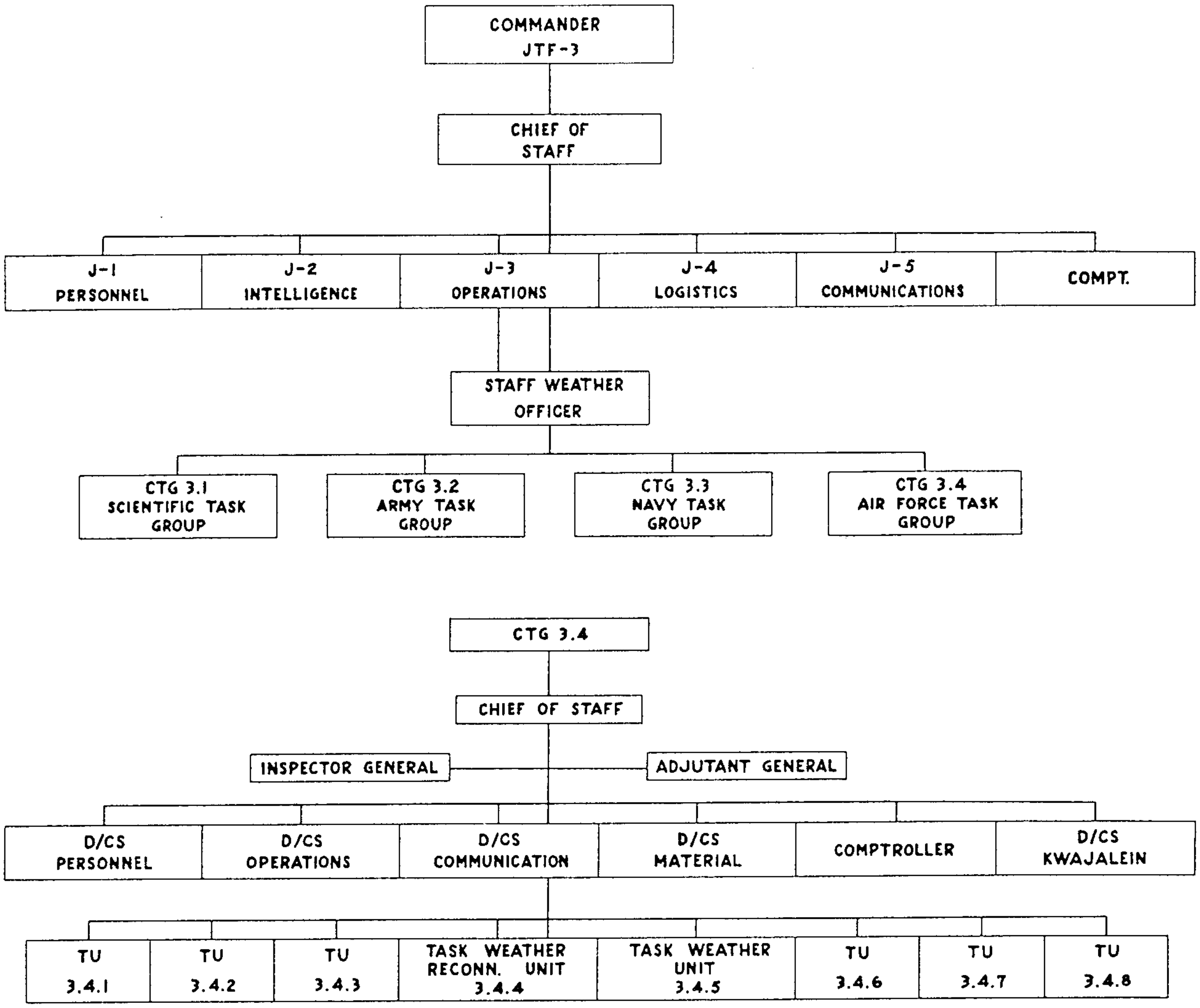


ORGANIZATION CHART



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# Chapter 2

# PLANNING

## 2.1 Original Planning

Planning for the necessary weather facilities for Operation GREENHOUSE began early in 1950 when the Staff Weather Officer, Col. George F. Taylor (then Lt. Col.), was assigned to duty with Joint Task Force THREE (JTF–3) Headquarters in Washington, D.C. Col. Taylor was on duty in Headquarters, Air Weather Service, Andrews Air Force Base, as Chief of the Weather Analysis Division at the time of his assignment to JTF–3 on 6 February 1950.

Plans for the forthcoming operations were discussed with Col. B. G. Holzman, Lt. Col. Delmar Crowson, and other meteorologists who had been associated with Operations TRINITY, CROSSROADS, and SANDSTONE, as well as with Dr. C. E. Palmer of the University of California at Los Angeles (UCLA) and other meteorologists of the Air Force, Navy, and U.S. Weather Bureau. A comprehensive plan for the meteorological facilities necessary for Operation GREENHOUSE was drawn up in March and arrangements were made with the Navy to furnish a Deputy Staff Weather Officer. Cdr. Elbert W. Pate (then Lcdr) reported for duty in that capacity on 5 April 1950. Prior to his assignment he was on duty as Instructor in Meteorology in the U.S. Naval School (General Line), Monterey, California.

The original comprehensive meteorological plan was adhered to, with the exception of some reduction in scope caused by the Korean War, throughout the operation. This plan called for a weather central at Eniwetok, a weather reconnaissance squadron, and seven outlying weather observation stations, together with necessary communications and the augmentation of a few existing Air Force and Navy weather stations in the Pacific Ocean.

## 2.2 Training

Early in April, Col. Taylor visited Dr. Palmer at UCLA concerning general meteorological problems of the tropical Pacific area and training of JTF–3 personnel in the latest techniques of tropical weather analysis and forecasting. It was decided then that six to eight Air Weather Service officers would receive specialized training with Dr. Palmer during the fall of 1950. Detailed planning of the operation of the weather central was also completed at this time.

## 2.3 Survey Trips

Communications and logistics plans were discussed with representatives of the Commander in Chief, Pacific and U.S. Pacific Fleet (CINCPAC), Air Weather Service (AWS), and Airways and Air Communications Service (AACS) during a trip to the Pacific area by Col. Taylor during April. At this time it was decided that a detailed survey of proposed sites for the outlying island weather stations should be made as soon as possible. As a result, Cdr Pate accompanied a Navy survey party that visited all proposed sites during May and June and obtained invaluable planning data. Each proposed site was studied with regard to boat approaches, beaching facilities, weather station and living sites, available local assistance, landing facilities, etc. The trip was made in the USS DEAL (AKL–2).

## 2.4 Operational Planning

Detailed planning at the operational level commenced in April when both the AWS and the AACS issued operation plans and began to organize the units that would be involved in Operation GREENHOUSE.

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Since it was evident from the first that accurate wind aloft observations to very high levels would be extremely desirable, steps were taken early in the planning to utilize the recently developed AN/GMD-1, automatic tracking wind aloft equipment. The use of this equipment at the JTF-3 weather observation stations resulted in upper wind coverage that was unparalleled in the tropics and it contributed greatly to the success of weather analysis and forecasting at the weather central.

## 2.5 Weather Central

In early discussions with the Head of the Naval Aerological Service it was agreed that the Navy would furnish about half of the meteorological personnel for the Eniwetok Weather Central. As a result, six aerologists and thirteen aerographers were assigned to the Weather Central and contributed in large measure to the successful accomplishment of its mission. Other Weather Central personnel consisted of the AWS forecasters specially trained by Dr. Palmer, several AWS forecasters who had been on duty in the Pacific area, as well as several AWS observers and rawinsonde technicians.

## 2.6 Cloud Photography

In early discussions with Dr. Palmer it was decided that the photography of tropical clouds was important and should be carried on at the various observation stations. This was done with considerable success and it is hoped that a fairly comprehensive tropical atlas will result. In addition, a large number of lapse-time motion pictures were taken of cloud development.

## 2.7 Radio-Facsimile

In the initial concept for the operations of the Eniwetok Weather Central it was decided that attention there would be focused primarily on weather conditions in the Central Pacific Ocean and that necessary weather analyses of the northern hemisphere for long range forecasts would be prepared at the Weather Analysis Division at Andrews Air Force Base and be transmitted to Eniwetok by radio-facsimile. Although a great deal of effort was put into this service by the AWS and the AACS, it did not function satisfactorily until almost the end of Operation GREENHOUSE because of numerous radio transmission difficulties. The charts which were received, however, were very useful.

## 2.8 AFOAT-1 Requirements

During all phases of the planning the special requirements of AFOAT-1 at certain of the outlying weather stations were considered and incorporated in the detailed plans.

## 2.9 Detailed Planning

Detailed planning of the weather units was carried on by the 2060th Mobile Weather Squadron of the 2059th Air Weather Wing, and by the 308th Reconnaissance Group, VLR, Weather. These units worked closely with Headquarters, Task Group 3.4 (Air Force), on logistic and personnel matters. Actual control of the units remained with the AWS until they moved overseas, when they were taken over by Task Group 3.4. The 2143rd Air Weather Wing also assisted materially in the planning within the Pacific area.

## 2.10 Outlying Weather Stations

Because of the geographic location, physical characteristics, and factors of governmental jurisdiction, each outlying station presented individual problems in establishment and maintenance.

*Majuro:* Agreement was reached with the Naval authorities at Majuro to feed, house, furnish medical care and provide other services within the capabilities of the station, subject to reimbursement from JTF-3 funds.

*Bikati:* The Commandant of the U.S. Coast Guard (USCG) agreed to arrange for joint use of facilities at the Long Range Navigation (LORAN) transmitting station at Bikati and to provide logistic and other support within the capabilities of the station. Due to the nature of this remote location, the agreement by the USCG to provide messing facilities and resupply services was most valuable.



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*Kusaie:* Arrangements were made through the Trust Territories Administration to provide native labor for trail clearing and other assistance to the unit. As the station at Kusaie was to be entirely self-sufficient, planning considerations were rigorous, and extreme effort was made to provide all necessary items for independent operation.

*Nauru:* As Nauru is a United Nations Trust Territory under Australian mandate, requirements for security imposed restrictions upon negotiations which were somewhat awkward. The survey party visited Nauru under a cover plan of, "investigating conditions for the possible establishment of a weather station concerned with research in tropical meteorology." As this cover proved convenient, it was retained throughout the operation. Negotiations were accomplished by the U.S. Attaché for Air, attached to the diplomatic mission in Melbourne, Australia. Governmental permission for landing the unit, along with authority to operate necessary radio equipment, was obtained without difficulty.

Perhaps the major individual economy in the weather programs was accomplished by contracting with the British Phosphate Commission on Nauru to feed and house all personnel and thus eliminate the problems of housing, food and medical attention.

## 2.11 Checking Equipment

Teams of an officer and several airmen were sent to the Naval Supply Center (NSC), Oakland, California, and to Hickam Air Force Base, T. H., in October 1950 to check supplies and equipment as they moved westward. This proved very helpful, as these teams were familiar with the specialized materiel and could check on actual operation and completeness of equipment before it arrived at the various isolated island sites.

## 2.12 Modifications in Plans

Shortly after the Korean War started, it became apparent that shipping in the Pacific area would be difficult to obtain and the Task Force was directed by the Joint Chiefs of Staff to reevaluate all programs and supporting services with a view to reduction in shipping requirements wherever possible. As a result of this reevaluation it was decided that the proposed weather service could be cut down somewhat without affecting the operation of the Task Force too greatly. It was recognized and accepted that a reduction in the number of reporting stations would reduce somewhat the valid forecast period from about forty-eight hours to thirty hours, or less. Accordingly, the number of outlying weather stations was reduced from seven to four and personnel and equipment allowances were reduced to the minimum. The outlying stations finally settled on were Nauru, Kusaie, Bikati, and Majuro. At this time, Baker, Kapingamarangi, and Rongerik were eliminated from the original plan, the first two because they posed great supply and resupply problems, and the latter because it was in an area rather well covered by regular weather reconnaissance tracks.

No reduction in any component of the reconnaissance squadron was considered feasible.

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# Chapter 3

# WEATHER OBSERVATION STATIONS

## 3.1 Reduction in Observation Stations

In complying with the July 1950 directive of the Joints Chiefs of Staff to reevaluate the entire GREENHOUSE program with a view toward reducing logistic requirements, 3 outlying weather stations (Rongerik Atoll, Baker Island, and Kapingamarangi Atoll) were eliminated from the original GREENHOUSE program. In addition, supply and equipment lists along with personnel tables of organization for the remaining four stations at Majuro, Bikati, Nauru, and Kusaie were critically examined with the view of effecting maximum reduction whenever possible and using existing facilities to the maximum extent. This attempt to reduce overall obligations to the minimum consistent with the accomplishment of the mission was the subject of considerable discussion. Eventually, however, agreement was reached and equipment and personnel lists were finalized. Arrangements also were completed at this time for the establishment of special teams of officer and enlisted weather specialists at the Naval Supply Center in Oakland and at Hickam Air Force Base to check all equipment being assembled or in transit through those locations.

## 3.2 Establishment of Stations

It was recognized that a more efficient operation could be conducted directly from the port of embarkation at Oakland, and CINCPAC was requested to consider a headquarters proposal to that effect. A reply was received that due to the Korean conflict the only available shipping (LST 859) required minor overhaul and because of distance and time factors to be considered that the overhaul could be completed only in Pearl Harbor if the ship was to become available at the required time. A prospective sailing date of 10 January 1951 from Pearl Harbor was established, and materiel, equipment and personnel were scheduled from the Zone of the Interior (ZI) to meet that date. Commander Pate reported to CINCPAC on 4 January 1951 to represent Headquarters, JTF–3, in monitoring the departure from Pearl Harbor of personnel and equipment embarked in LST 859.

### 3.2.1 Assembly of Equipment and Supplies

On 5 January 1951 all personnel had arrived in the Hawaiian area and were billeted aboard the LST. Of great concern, however, was the fact that only about 50% of the technical equipment and 60% of miscellaneous supplies were on hand in the Pearl Harbor area. It was determined, however, that over 95% of the equipment had been received and dispatched from Oakland, and shipping manifests on hand indicated that the greater portion was then waterborne and en route to the forward area. As a result of conferences between the Commander, Task Group 3.3 (who had assumed operational control of LST 859 on 1 January), the JTF–3 representative, and a representative of the Commander, Task Unit 3.4.5, it was agreed that the sailing of LST 859 on the scheduled date of 10 January would be highly uneconomical and, in fact, a subsequent trip would be required in order to establish the units ashore properly. Accordingly, it was agreed that the sailing date would be postponed until 20 January 1951. Headquarters concurrence with this action was received from the Commander, Joint Task Force THREE (CJTF–3), who arrived in the Hawaiian area on 14 January 1951 en route to Eniwetok on an inspection trip. By 19 January, 95% of all supplies and equipment had been received and placed aboard the LST, and definite information had been received that

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the remainder of the cargo would be delivered before noon of 20 January in time to be loaded aboard and permit the sailing of the LST by 1600 hours.

### 3.2.2 Majuro

No particular problems were encountered in establishing the station at Majuro, the first stop, although a change in command at that location had produced some minor misunderstandings in exactly the agreements made the previous summer by the survey party. Eventually, however, almost precisely the same agreements were made between the unit commander and the commander of the naval station. The naval base provided housing, messing, medical attention, native labor, engineering assistance and such other services within the capability of the base, subject to reimbursement from JTF–3 funds. The weather station at Majuro was set up in an ideal clear location near the east end of the runway on Dalap Island.

### 3.2.3 Bikati

The second station to be established was Bikati in the northern Makin group. Many difficult problems arose, the solution of which reflected great credit upon the Commanding Officer of the USS LST 859. The survey party of the previous year, acting upon the guidance received from the Commander, Service Force, Pacific Fleet (COMSERVPAC), that the weather stations would be established by standard cargo type ships using LCMs for the anchorage to beach movement, had surveyed the prospective anchorage and boat lanes with that type of movement in view. With the substitution of the LST, however, an entirely different unloading method had to be developed. As the LST had only two LCVPs to unload approximately 500 long tons of cargo it became apparent that use of the previously surveyed anchorage and boat lanes was highly impracticable. A second beaching area, which had been declared undesirable for LCM operations by the survey party, was found to be usable by LCVPs after minor clearing and rock removal. The choice of this second beaching area permitted a much shorter boat run and a more expeditious removal of cargo to the beach. Much ingenuity was demonstrated by the ship's force—cargo which would float and not be adversely affected by salt water was towed into the beach. All available native labor was used to the maximum extent. Had this labor not been available, establishment of the station would have been extremely difficult and time consuming. As an interesting sidelight to the employment of native labor and associated problems, the diplomatic skill of the ship's crew cannot be ignored. At one time during the unloading operation the Commanding Officer of the Coast Guard at Bikati notified the Commanding Officer of the LST that the natives were about to quit, as the wives were without food in the village. As the LST happened to be anchored in good fishing water, off-duty members of the ship's crew soon eliminated the food shortage and peaceful labor relations were immediately restored.

Although agreement in writing had been reached with the Commandant of the USCG at Headquarters in Washington with respect to the joint use of the facilities at Bikati, the Commanding Officer of the LORAN station had not been completely informed of those agreements. This imposed a definite handicap and, although major items of disagreement were immediately reconciled by TWX from JTF–3 on Eniwetok through the Commandant of the 14th Coast Guard District in Honolulu, arrangements were never entirely satisfactory.

### 3.2.4 Nauru

No particular problems were encountered in establishing the station at Nauru as contract arrangements with the British Phosphate Commission had been negotiated. Lighterage from ship to shore, warehouse storage, and trucking services were provided in a very efficient manner. There was a short delay in site selection as concurrence of the native council was required, but this imposed no handicap upon the operation.

### 3.2.5 Kusaie

For a number of reasons establishment of the station at Kusaie presented a difficult problem; it is not served with regular Trust Territory shipping, there is no military base or civilian enterprise capable of supporting the unit, the only feasible location for a weather station is on top of a 380 foot hill presenting a difficult access problem, and there are no local utilities of any sort. Of beneficial aspect, however, was the existence of a large and capable native labor supply. Arrangements had been made by the survey party of the previous summer for clearing the trail to, and levelling the site on top of the hill. Steps were also taken to appoint the Commanding Officer of the unit a special accountable officer and to provide him with funds and an accounting system whereby native labor could be paid. In January, instructions were dispatched to Mr. Herman to proceed with trail clearing and site preparation in anticipation of the arrival of the unit in February.

The LST arrived on schedule and unloading operations proceeded expeditiously as the LST was able to beach and there was no requirement for off-loading into small boats for transportation of cargo ashore. The LST remained at Kusaie until housing had been constructed ashore and all required facilities were operating.

All four of the outlying weather stations were fully established and operational on 22 February 1951.

## 3.3 Resupply

### 3.3.1 Majuro

Resupply at Majuro was accomplished both by water and by air. Because of the short distances involved, and the fact that Majuro was in air communication with Kwajalein and Eniwetok at frequent intervals, resupply and command administration of the unit offered no particular problem.

### 3.3.2 Bikati

Of all the outlying locations, Bikati presented the greatest resupply problem. As there is no enclosed lagoon or protected harbor, any communication with Bikati by seaplane would involve a hazardous open sea landing. The USCG advised strongly against any operations of that nature and indicated that it would be only because of extreme emergency that such an operation should be attempted. All resupply at Bikati, therefore, was handled by the USCG on their regular run by the NETTLE, a converted AKL, which operated on a semi-monthly schedule. This method proved to be entirely satisfactory.

### 3.3.3 Nauru

Resupply of the unit at Nauru involved a 700 mile C–47 flight and the use of an abandoned Japanese Air Strip on the island. This proved to be entirely satisfactory, as feeding and housing of the unit had been undertaken by the British Phosphate Commission.

### 3.3.4 Kusaie

Resupply of and administrative contact with the unit on Kusaie was accomplished by PBM aircraft landing in Kusaie harbor. This method proved satisfactory until one aircraft ran aground early in May and upon advice from cognizant authority on Kwajalein, seaplane flights to and from Kusaie were discontinued. This resulted in severing of outgoing mail connections from Kusaie for a period of about a month, but did not unduly handicap the operation.

## 3.4 Difficulties Encountered

With exception of the unit on Bikati, no difficulties other than those which would be expected in any similar operation were encountered. Maintenance of technical equipment at all locations imposed many problems but this was a normal expectation, particularly when the hot, humid climate and its effect upon equipment was considered.

### 3.4.1 Bikati

The only real difficulty occurred at Bikati. Commander, Task Unit 3.4.5, made an inspection trip to that location in March and discovered that many standards of military conduct, and for that matter of ordinary civilized behavior, were being ignored and violated. Although specific instructions had been given to all personnel of outlying weather units, and commanding officers of the units had been particularly cautioned in matters pertaining to relations with the native population, the behavior and morale of the weather unit had clearly deteriorated and orders and instructions were being ignored. Corrective action was immediately undertaken by the Commander, Task Unit 3.4.5, and later by the

Commander, Task Group 3.4. The operation was completed without further incident of note at Bikati.

### 3.4.2 Nauru

Difficulties at Nauru were mainly centered around equipment failure, all of which were remedied within a reasonable time. Relations between the weather unit and the Australian civil population on Nauru left nothing to be desired. The conduct of the unit was exceptionally fine in all respects, and a lasting and favorable impression was created.

### 3.4.3 Equipment

Two reports of unsatisfactory equipment performance were forwarded through proper channels. One report involved the poor sealing of a metal can containing the humidity elements (a component of the upper air sounding equipment). The other equipment failure involved a connector in the Rawin set AN/GMD-1 in which driving rain or excess humidity shorted the connector, producing burning and subsequent failure.

## 3.5 Observations

Complete surface weather observations were taken every three hours and complete upper air soundings were made three times daily from all stations. In addition, special observations, both surface and upper air, were transmitted upon request, or when scheduled by requirements of the operation on Eniwetok. Standard international code forms were used in all reports, and the reports were made available immediately to the international network.

## 3.6 Communications

Communications between all the outlying stations and the weather central on Eniwetok was by CW transmission on a point to point duplex circuit. The system employed proved satisfactory throughout the operation.

## 3.7 Code Forms for Transmitting Additional Data (Extract from instructions)

Extra data to be added to surface weather reports and reconnaissance aircraft reports will consist of five items of information arranged in a five figure group. One or more groups may be sent depending on the number of cloud types observed. In the case of clear skies no extra groups will be sent. The form of this extra group will be *nCfsk*. An explanation with code tables for each item follows:

a. "n"—tenths of cloud as reported by "C" (table will be essentially the same as the aircraft reconnaissance code for N).

0—ten tenths
1—one tenth
2—two tenths
3—three tenths
4—four tenths
5—five tenths
6—six tenths
7—seven tenths
8—eight tenths
9—nine tenths

b. "C"—cloud type (same as C in aircraft reconnaissance code).

0—Stratus or fractostratus
1—Cirrus
2—Cirrostratus
3—Cirrocumulus
4—Altocumulus
5—Altostratus (thin)
6—Stratocumulus
7—Nimbostratus or Altostratus (thick)
8—Cumulus or fractocumulus
9—Cumulonimbus

c. "f"—area frequency of precipitation in tenths of cloud type reported by "C" with precipitation or virga visible (all visible precipitation from the cloud type reported by "C" should be included whether or not the precipitation reached the ground or sea surface).

0—no precipitation visible from the cloud type reported by "C".
1—less than two tenths of the cloud type reported by "C" showing precipitation.
2—from two tenths up to, but not including, three tenths of the cloud type reported by "C" showing precipitation.
3—from three tenths up to, but not including, four tenths of the cloud type reported by "C" showing precipitation.
4—from four tenths up to, but not including, five tenths of the cloud type reported by "C" showing precipitation.
5—from five tenths up to, but not including, six tenths of the cloud type reported by "C" showing precipitation.
6—from six tenths up to, but not including, seven tenths of the cloud type reported by "C" showing precipitation.

7—from seven tenths up to, but not including, eight tenths of the cloud type reported by "C" showing precipitation.

8—eight tenths and over of the cloud type reported by "C" showing precipitation.

9—representative area frequency of precipitation impossible to observe due to obscuration (such as observer being in a heavy shower himself, darkness, etc.).

d. "s"—maximum visible shear in the cloud type reported by "C".

0—no shear.

1—slight shear (clouds leaning less than 30 degrees from the vertical).

2—moderate shear (clouds leaning more than 30 degrees from the vertical, but cloud tops not obviously breaking off).

3—large shear (clouds leaning more than 30 degrees from the vertical, with cloud tops breaking off).

4—abrupt shear (clouds leaning less than 30 degrees from the vertical, with cloud tops breaking off sharply).

5-6-7-8—not used.

9—shear conditions not observed due to obscuration.

e. "k"—state of the sky (refers to the cloud type reported by "C").

0—no clouds to observe (normally not used).

1—clouds isolated with no connection between individual clouds.

2—clouds in groups or families, but not forming definite lines.*

3—clouds in groups or families and forming definite lines.*

4-5-6—not used.

7—clouds in layer not merging with other cloud forms.**

8—clouds in a layer merging with Cumulus and Cumulonimbus cloud forms.**

9—state of the sky not observed due to obscuration.

---

* Refer primarily to Cumulus or Cumulonimbus cloud types.

** Refer primarily to layer type cloud forms.

*Notes on "nCfsk" group:* The group is concerned with a detailed description of the cloud type "C", the second figure of the group. The "nCfsk" group should be sent at the end of surface and reconnaissance weather reports after the "19191" stop group; it should be repeated for each type of cloud observed, since one group refers to only one type of cloud as reported by the second figure, "C". Also, it may be repeated for the same type of cloud, if necessary, to show variations within one of the limited general cloud types that can be reported in the code for "C". (Example: Only one code figure, "8", is available for Cumulus, and this does not distinguish between small fair weather cumulus and large cumulus congestus.)

The amount, "n", and the type, "C", of cloud will have been already reported in the regular aircraft reconnaissance code message in the "$1KN_1N_2N_3$" and "ChhHH" groups; first two figures of the "nCfsk" group will then serve as a check on the regular cloud groups in the code message.

With clear skies the "nCfsk" group will not be sent. In order to insure consistency in cloud reporting, the following table classifying the usual 27 cloud types (9 low, 9 middle and 9 high cloud types) into the standard 10 types used for "C" will be helpful:

| "C" | *Low, L; Middle, M; or High, H clouds* |
|---|---|
| 0—St | $L_6$ |
| 1—Ci | $H_1$, $H_2$, $H_3$, $H_4$ |
| 2—Cs | $H_5$, $H_6$, $H_7$, $H_8$ |
| 3—Cc | $H_9$ |
| 4—Ac | $M_3$,$M_4$,$M_5$,$M_6$,$M_8$,$M_9$ |
| 5—As (thin) | $M_1$ |
| 6—Sc | $L_4$, $L_5$ |
| 7—Ns or As (thick) | $M_2$, $M_7$ |
| 8—Cu | $L_1$, $L_2$, $L_3$, $L_7$, $L_8$ |
| 9—Cb | $L_9$ |

[redacted]

# Chapter 4

# WEATHER RECONNAISSANCE

## 4.1 General

The importance of weather reconnaissance aircraft to Operation GREENHOUSE becomes immediately apparent when the size of the area in which a definite interest in the weather was necessary is compared with more familiar areas. While Eniwetok Atoll itself is only some 20 miles long by 10 miles wide, the entire Central Pacific as far west as Guam, as far east as Johnston Island, as far north as Wake Island, and as far south as Nauru Island must be subject to frequent critical examination even for short range weather forecasts of 30 hours validity. Even after the establishment of the four outlying weather stations at Majuro, Kusaie, Bikati, and Nauru there were only nine reliable weather reporting stations in this entire area which is much larger than the continental United States, including the Gulf of Mexico. It was the mission of the weather reconnaissance squadron assigned to Operation GREENHOUSE to provide detailed and accurate weather information from those wide areas over the ocean from which land station reports were not available.

## 4.2 Plans and Training

The weather reconnaissance mission was assigned to the Commander, Task Group 3.4. The 513th Reconnaissance Squadron, VLR, Weather (later Air Task Unit 3.4.4), based at Tinker Air Force Base, was assigned the mission in the summer of 1950. Detailed plans were made and intensive training programs were conducted through November 1950. Col. A. A. McCartan was the Commanding Officer of the 513th Reconnaissance Squadron and of Air Task Unit 3.4.4 throughout the operation.

## 4.3 Movement Overseas

Earliest elements of ground maintenance personnel, along with equipment, were staged overseas in December and January 1951, for Kwajalein. The first flight, composed of eight WB–29s, departed from Tinker Air Force Base on 3 February 1951 and arrived at Travis Air Force Base, California, without incident. The remaining four WB–29s of the squadron had been obligated for Operation RANGER, a continental atomic weapons test conducted at Frenchman Flat near Las Vegas, Nevada, in January–February 1951. The first of eight aircraft arrived at Kwajalein on 9 February. By the end of March the total strength on Kwajalein was 70 officers and 257 airmen.

## 4.4 Problems Encountered

During the month of February the name of the parent organization was changed to the 57th Strategic Reconnaissance Squadron (Medium), Weather. In addition to the expected and usual breaking in and settling down at Kwajalein, search for missing supplies and equipment, and general orientation to a new and strange environment, the squadron had the problems of effecting liaison with the Weather Central on Eniwetok to clarify procedure, and of preparing navigational charts for weather reconnaissance tracks to be flown.

By the middle of March, experience had uncovered most of the weaknesses in the organization and equipment which were to be encountered during the entire operation, methods and procedures had been established to take care of most contingencies, and the squadron was considered to be in routine operation.

The greatest handicap to an efficient operation was ineffective and slow communication

[redacted]

with Eniwetok from which directives for tracks had to be originated. Although the problem was recognized, it was not solved until later on in the operation. In addition, experience with the dropsonde apparatus aboard the planes had been very discouraging during the earlier weather reconnaissance flights. Continued experience in the squadron and the adoption of a categorical "we can make it work" attitude provided a solution, and by the middle of March dropsonde runs were approaching 100% success.

During the night of 20 March the island of Kwajalein was threatened by winds of over 50 knots accompanied by torrential rains. All precautions with parked aircraft were taken and every effort was made to keep equipment dry—as a result no damage was suffered. Regular reconnaissance tracks were abandoned and the major interest of the squadron was diverted to reconnaissance of typhoon GEORGIA. Maximum effort with respect to GEORGIA took place on 23 March when four fixes were taken on the typhoon center in addition to regular commitments.

During the month of March, total flying time for the squadron was 608 hours of which 566 were weather reconnaissance and special calibration flights.

## 4.5 Reporting Procedures

With respect to weather reporting methods, the report form devised for the operation was generally successful. It was found necessary to put a special heading indicating the track on all weather reconnaissance reports as a means of identification and to insure that the report would be placed upon the teletype circuit to Eniwetok. In addition, it was found desirable to obtain winds while ascending or descending at the turning points of the track at 2,000 foot intervals by double drift methods. Since there were no provisions in the code usually used in weather reconnaissance for reporting such winds, a new method was devised using a modification of the standard pilot balloon upper wind code.

## 4.6 Shot Effort Summary

### 4.6.1 DOG Shot

As DOG Day approached, the weather reconnaissance effort increased abruptly. Starting on 5 April three weather missions were flown in addition to special flights for AFOAT-1. From 1 April through 8 April a total of 278 hours were logged by reconnaissance aircraft.

### 4.6.2 EASY Shot

One additional and new demand for weather reconnaissance was instituted for EASY shot due to the importance of shower reporting near and around Engebi Island. A low level reconnaissance flight approached Engebi from a position 300 miles upwind making frequent reports of low clouds and showers in the area. The aircraft arrived at a point five miles upwind from Engebi at H minus 10 minutes at which time it reversed course and left the area.

### 4.6.3 GEORGE Shot

Typhoon JOAN was picked up on 7 May by two reconnaissance flights and, based upon the information obtained, a special reconnaissance flight was ordered for 8 May and both morning and afternoon fixes were obtained. Another mission went out on 9 May and also obtained morning and afternoon fixes. It was the information obtained by these two reconnaissance flights which permitted the deliberate use of a typhoon to detonate an atomic weapon under perfect conditions of radiological safety.

### 4.6.4 ITEM Shot

Because of experience obtained in previous tasks, ITEM shot was considered to be routine in all respects.

### 4.6.5 AFOAT-1 Missions

Following all shots the primary mission of the squadron was directed to tracking the atomic cloud and reporting results to AFOAT-1 as part of the world-wide detection project. Airborne RADIAC equipment and filter collectors were employed with marked success on all shots except GEORGE, where the major portion of the cloud apparently spiraled into

[redacted]

typhoon JOAN. Some of the airborne debris from GEORGE shot was encountered several days after the shot at a considerable distance from the Eniwetok area.

The employment of a weather reconnaissance squadron in a mission of this nature is highly effective and falls into the normal operational techniques and capabilities of such an organization very conveniently.

## 4.7 Tracks Flown

In order to simplify the navigation problem, a number of tracks for weather reconnaissance missions were established. The major considerations in the construction of these tracks were: efficient utilization of aircraft, coverage of important areas where weather "forms", coverage of areas of immediate and critical operational interest, and availability of navigational aids and positive geographic landmarks.

Because of the length of the missions (average 12 hours) it was also necessary to give some consideration to the human factor. Long tracks at low altitudes (1,500 feet) produce great fatigue due to the heat, humidity, and effort required for aircraft control. For these and additional important meteorological reasons such as obtaining temperature, humidity and wind soundings, altitudes on most tracks included at least one leg to be flown at the 700 millibar (approximately 10,000 feet) level.

Tracks to be flown were ordinarily determined by noon of the day before the missions at the Weather Central and transmitted to the squadron on Kwajalein. Ordinarily, tracks were selected by the Chief of the Weather Central on meteorological considerations based upon analysis of the current situation and expected developments. The final tracks are illustrated in Figures 4.1 to 4.6.

### 4.7.1 Upwind Special Track

Experience gained in the early part of the operation emphasized the difficulty in shower forecasting. In an effort to determine areas of "speed convergence" in the trades, and the existence of large shower areas approaching Eniwetok, a special track known as UPWIND SPECIAL was established. UPWIND SPECIAL started from a point near Eniwetok ordinarily at sunrise and flew directly upwind at an altitude of 1,500 feet for varying distances, 300 to 500 miles. A plot of the tracks gave an immediate indication of any "direction convergence" in the wind field in addition to "speed convergence" outlined by analysis of the wind velocities reported.

### 4.7.2 Downwind Special Track

Because of the extreme importance of showers during EASY shot, a DOWNWIND SPECIAL mission was flown during darkness to report showers in the area east of Eniwetok. DOWNWIND SPECIAL arrived at a point five miles upwind from Engebi Island 10 minutes before detonation, at which time it left the area. Reports from this DOWNWIND SPECIAL flight were most valuable in affording assurance concerning showers which could cause a delay in the schedule. This special night mission was conducted most efficiently and accurate observations were made possible by good visibility and moonlight.

### 4.7.3 Typhoons

Typhoons GEORGIA and JOAN were also the objects of special effort by the squadron. Both were of critical importance as they imposed a distinct threat to the entire program. Information furnished was accurate and timely and made accurate diagnosis possible. In the case of JOAN, reports from the squadron permitted the deliberate use of a typhoon to provide ideal radiological safety conditions for GEORGE shot.

## 4.8 Observations

Observations were taken at one hundred nautical mile intervals and each was a complete record of all weather elements present at the time. This included surface pressure and wind; flight level temperature, humidity and wind; cloud bases and tops and types; visibility; precipitation; height of standard pressure surfaces; turbulence and flight conditions, and significant weather, both past and present.

[redacted]

### 4.8.1 Wind Data

Particular emphasis was placed on obtaining flight level wind data since wind is an important parameter in tropical forecasting. During low and high level flight every possible means was used to obtain accurate flight level wind data (normally double drift winds).

### 4.8.2 Altimeter Calibration

Altimeter calibration was performed over Kwajalein Island at 1,500 feet immediately after take-off by comparing the calculated value of surface pressure with the existing value. No further calibration was necessary to make an atmospheric sounding and determine layer thickness on which to calibrate.

### 4.8.3 Additional Data

Additional data groups were added to the end of the individual CAW-C-5D Aircraft Weather Report Form to give forecasters additional detailed information on cloud formations. The additional information included shear, the arrangement of clouds, and amounts of precipitation. (See paragraph 3.7.) In order to report orientation of groups or families of clouds forming lines, as reported in these additional data groups, a third optional group was included. The orientation of the clouds was encoded in clear text, i.e., 19191 38113 NW-SE.

## 4.9 Atmospheric Soundings

Two aircraft soundings of the atmosphere were normally made on each track; one ascent and one descent. The normal rate of climb or descent was 300 feet per minute.

For the specific purpose of providing winds aloft data for tropical analysis, wind readings were taken on all ascent and descent soundings where drift measurements could be taken. These measurements were taken at 2,000 foot intervals by double drift methods. Since there was no provision for reporting such winds in the present codes being used by weather reconnaissance units, additional groups were added to the CAW-C code immediately after the sounding data as follows: RECWN ODDFF 2DDFF, etc.

In addition to two aircraft soundings, one droppable radiosonde (AN/AMT-3, dropsonde) release was made on each track at position "ten". Many improvements were made in dropsonde procedures and improved methods and modifications increased the reliability of successful runs to nearly 100%.

## 4.10 Reporting Procedures

Reports were transmitted to the Eniwetok ground station where the report was given to the weather monitor. Each report was monitored for consistency and correctness of observation. Where some doubt existed the monitor contacted the aircraft and queried the aerial observer. Correct reports were sent to the Eniwetok Weather Central and also given to AACS for transmittal over teletype circuits to the Anderson Weather Central at Guam for general broadcast. The average time delay between the observation and receipt of the report at the Eniwetok Weather Central was 30 minutes.

Reports for each mission were recopied in final draft and transmitted to the AWS Data Control Unit at New Orleans, Louisiana. This included the CAW-C-5D Aircraft Weather Report Form, the in-flight data, and the dropsonde data.

## 4.11 Typhoon Reconnaissance

The squadron conducted five special typhoon reconnaissance missions to reconnoiter typhoons GEORGIA and JOAN.

Typhoon reconnaissance at first was dually controlled by Anderson Weather Central and Task Group 3.4, but this arrangement was not entirely satisfactory. It was determined that the responsibility for the direction of typhoon reconnaissance should be vested in one organization and final agreements placed the responsibility with Anderson Weather Central. This prevented duplication of effort and effectively controlled the aircraft flying in the storm area.

## 4.12 Navigation

All methods of navigation common to the latitudes of operation were employed by the squadron. It was soon determined that the radar installed in the aircraft was nearly useless for navigation because of range and def-

[redacted]

inition deficiencies. Reliance was primarily on LORAN. There were practically no reports submitted during the operation which were suspected of containing large position errors.

SUMMARY OF WEATHER RECONNAISSANCE OBSERVATIONS

| | WEATHER MISSIONS | AERIAL OBSERVATIONS | AIRCRAFT SOUNDINGS | DROPSONDE SOUNDINGS |
|---|---|---|---|---|
| February | 7 | 132 | 13 | 4 |
| March | 48 | 908 | 83 | 40 |
| April | 56 | 1,045 | 99 | 51 |
| May | 47 | 876 | 87 | 46 |
| TOTAL | 158 | 2,961 | 382 | 141* |

* To obtain 141 successful dropsonde soundings approximately 175 instruments were required.

## 4.13 P2V Observations

The Navy P2V Squadron, VP 931, also based at Kwajalein, had been assigned the secondary mission of transmitting weather reports while on anti-submarine patrol. A special code was devised which was short, concise, and required no instrumentation other than that already in the plane. This code is illustrated in figure 4.7 and 4.8.

Reports from patrol planes were extremely valuable and made possible a more complete description of detailed weather conditions within an area of 300 miles radius around Eniwetok than would have been otherwise possible.

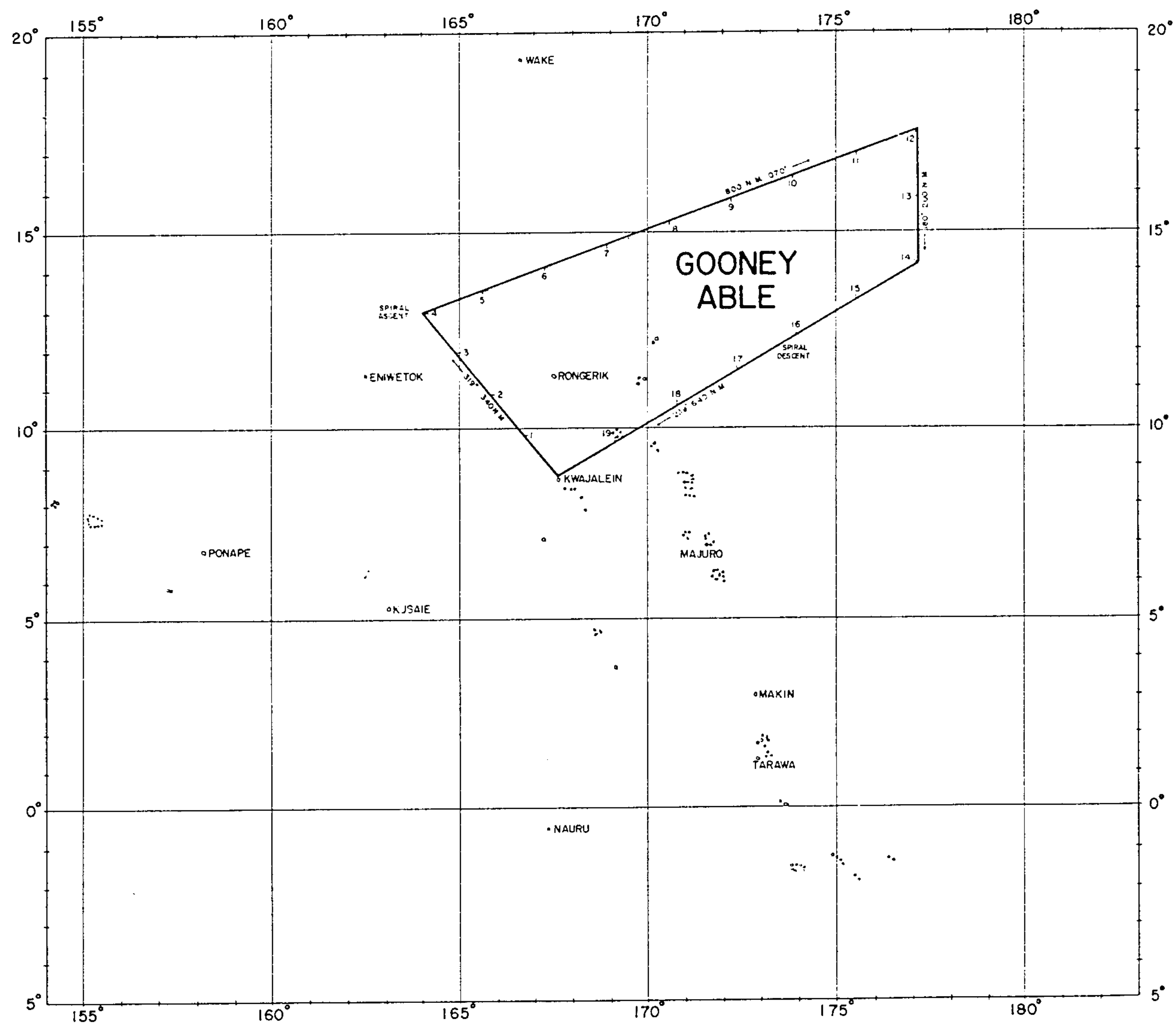


FIGURE 4.1—GOONEY "ABLE" Track

[redacted]

[redacted]

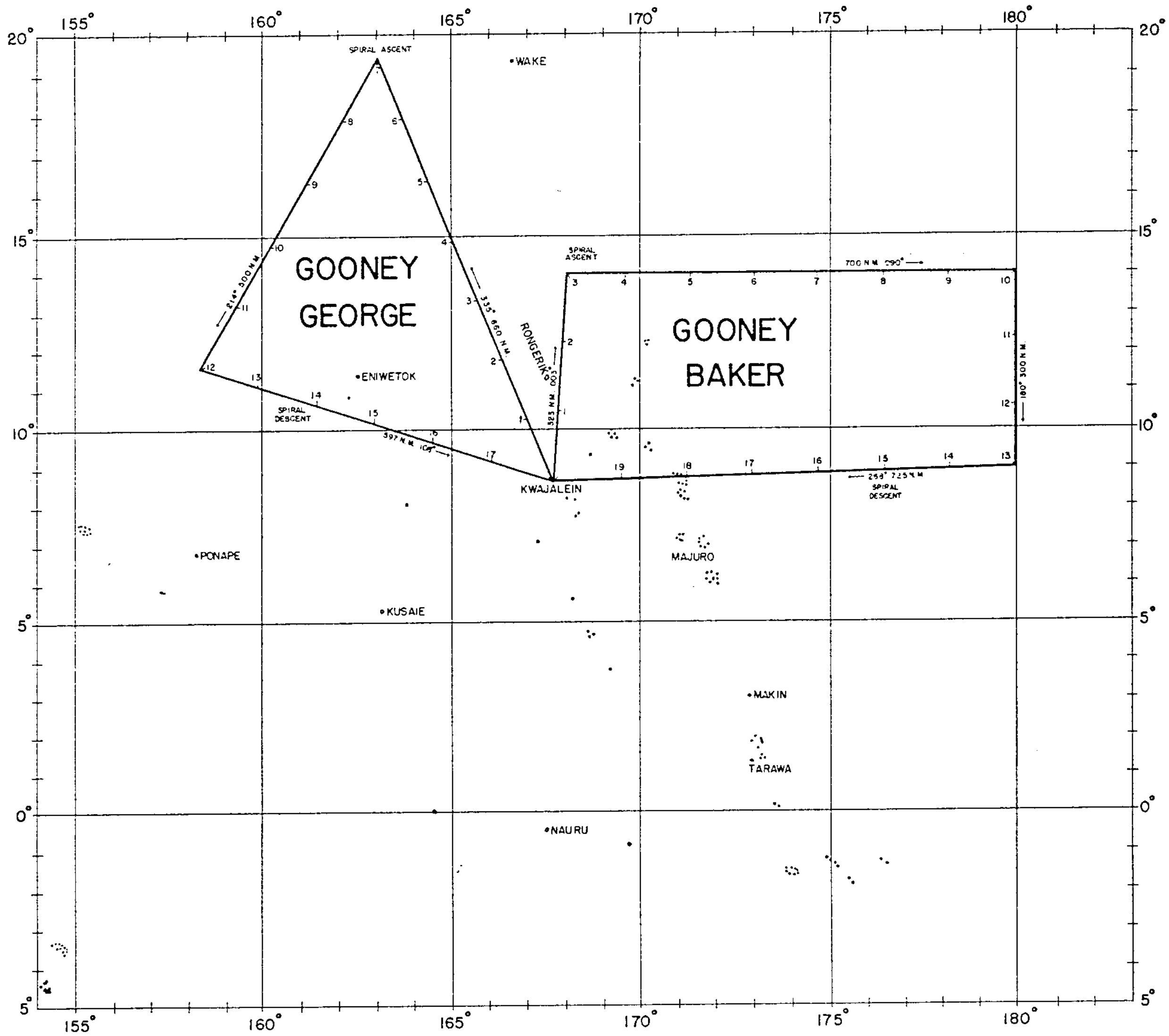


FIGURE 4.2—GOONEY "BAKER" and "GEORGE" Tracks



[redacted]

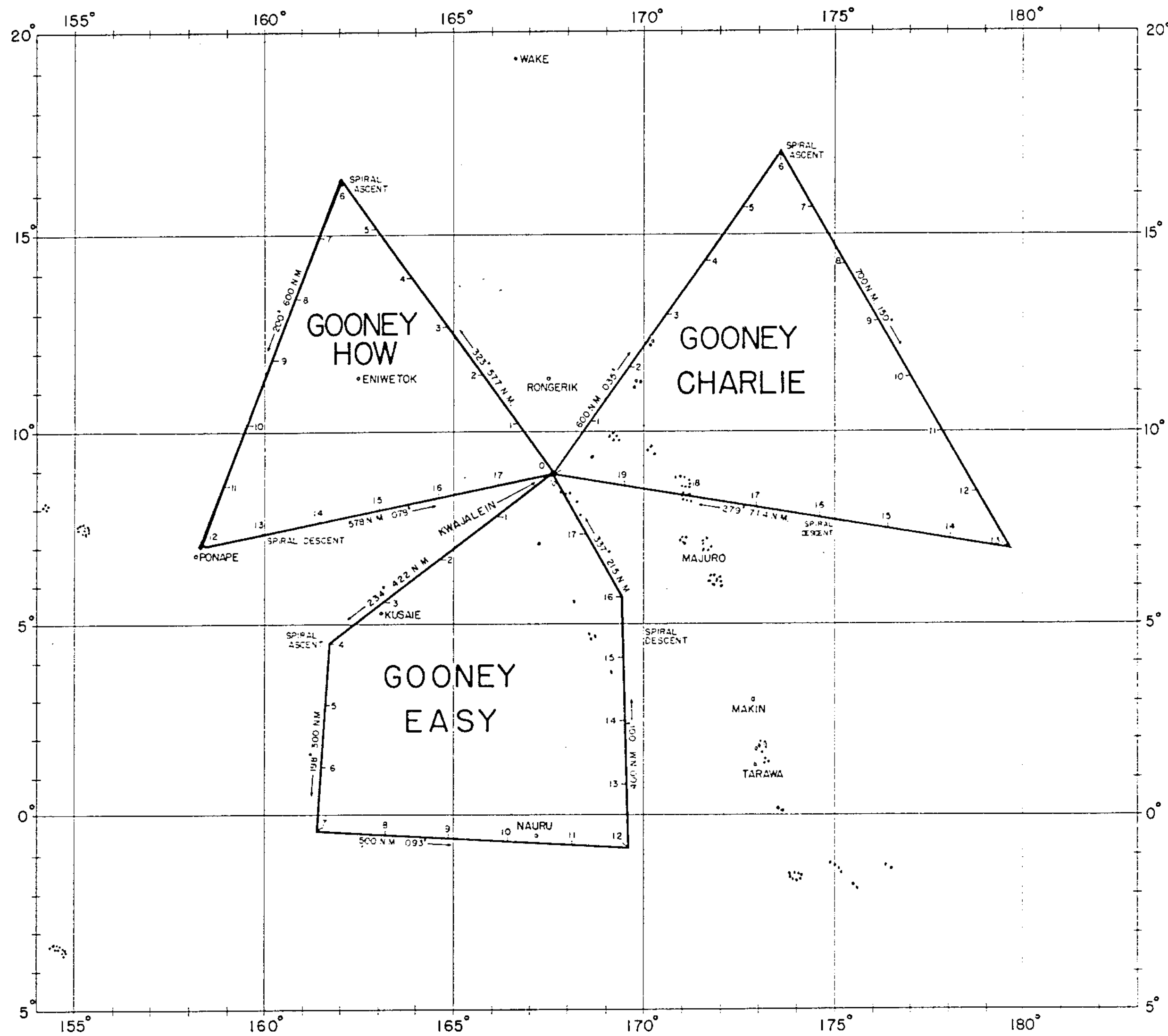


FIGURE 4.3—GOONEY "CHARLIE", "EASY", and "HOW" Tracks

[redacted]

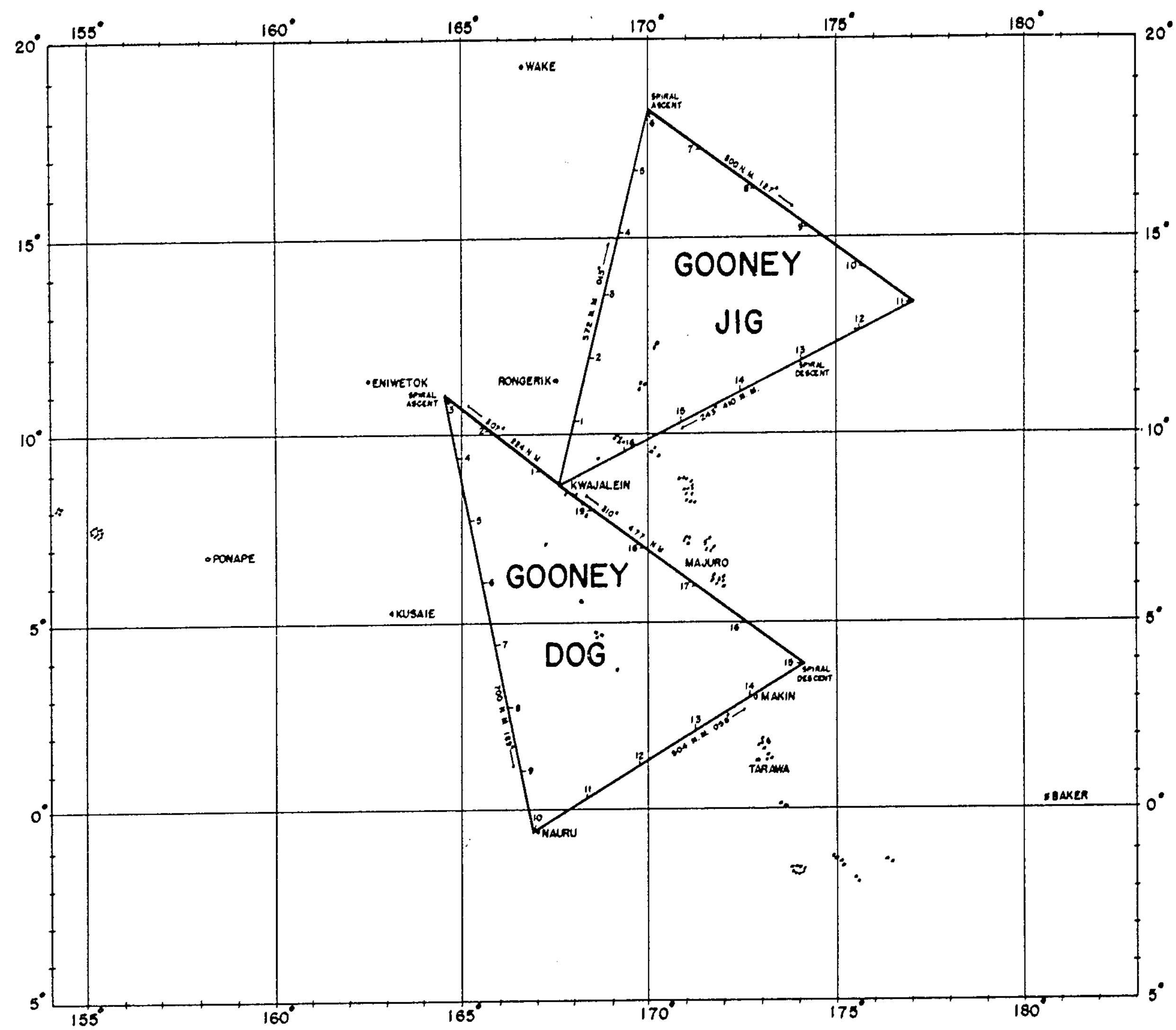


FIGURE 4.4—GOONEY "DOG" and "JIG" Tracks



[redacted]

[redacted]

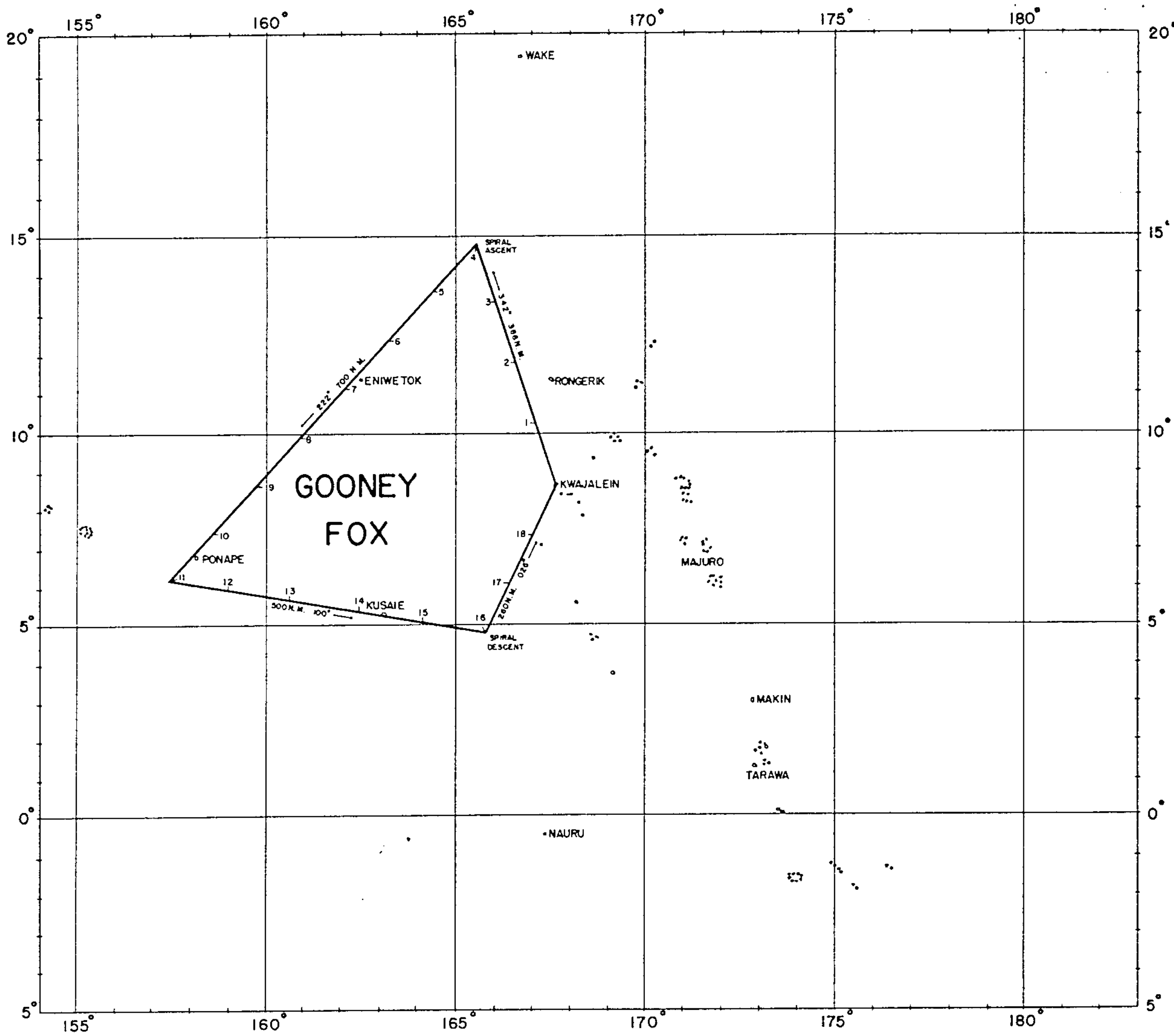


Figure 4.5—GOONEY "FOX" Tracks

[redacted]

[redacted]

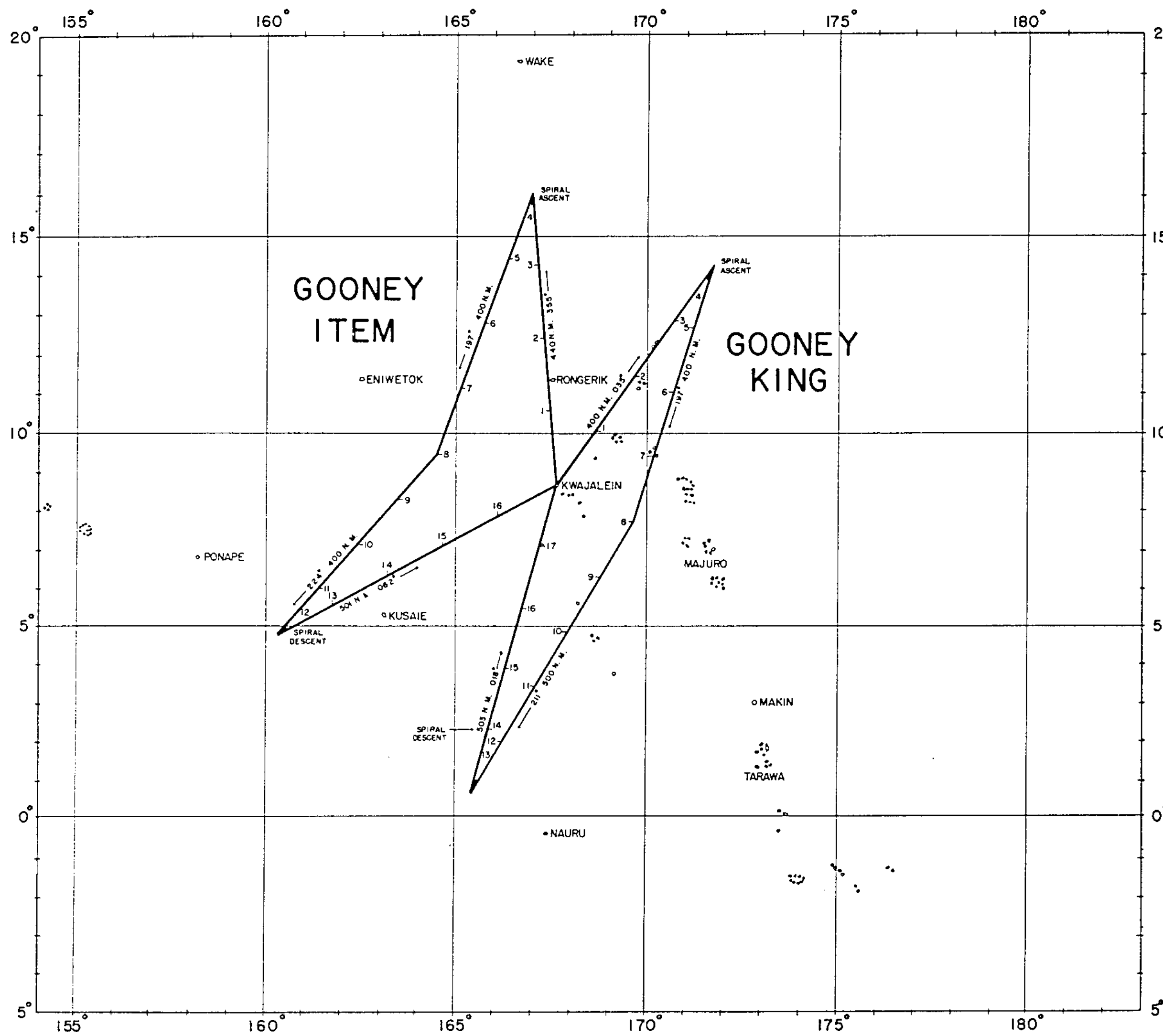


FIGURE 4.6—GOONEY "ITEM" and "KING" Tracks



[redacted]

[redacted]

## SPECIAL WEATHER REPORTING CODE
## OPERATION GREENHOUSE

| POSIT AND TIME | | WWPDD | FFVAA |
|---|---|---|---|
| ☐☐☐☐☐ | ☐☐☐☐☐ | ☐☐☐☐☐ | ☐☐☐☐☐ |

### POSIT AND TIME
(position and time)

**WW** COMPREHENSIVE WEATHER DESCRIPTION (TWO NUMBERS).

**P** PRECIPITION; SECTOR OF VISUAL OR SCOPE OBSERVATION COVERED BY RAIN, REPORTED DIRECTLY IN TENTHS FROM 0 TO 9.

**DD** SURFACE WIND DIRECTION, 10's OF DEGREES, ESTIMATED, (DAYLIGHT ONLY; TRANSMITT 99 AT NIGHT).

**FF** SURFACE WIND SPEED, KNOTS, ESTIMATED (DAYLIGHT ONLY; TRANSMITT 99 AT NIGHT).

**V** VISIBILITY (TABLE)

**AA** ALTITUDE, HUNDREDS OF FEET.

TRANSMIT REPORT BY RADIO
MAIL THIS TO HQ, CTU 3.4.5 A.P.O. 187

FIGURE 4.7—Special P2V Reporting Code

[redacted]

[redacted]

## VISIBILITY TABLE

0 UNDER 50 YD.
1 50-200 YD.
2 200-500 YD.
3 500-1000 YD.
4 1000 YD.-1 MILE
5 1-2 MI.
6 2-5 MI.
7 5-10 MI.
8 10-30 MI.
9 30 MI. OR OVER

| | | RANDOM Cu OR Cb | Cu OR Cb IN GROUPS, NO LINES | Cu OR Cb, DEFINITE LINES | MIDDLE OR HIGH CLOUDS, NOT MERGING | MIDDLE OR HIGH CLOUDS, MERGING | RANDOM Cu OR Cb | Cu OR Cb IN GROUPS, NO LINES | Cu OR Cb, DEFINITE LINES | MIDDLE OR HIGH CLOUDS, NOT MERGING | MIDDLE OR HIGH CLOUDS, MERGING |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CLEAR (< 1/10) | | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 |
| SCATTERED 2/10 - 6/10 | NO SHEAR | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | MOD. SHEAR | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| | MARKED SHEAR | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| BROKEN 6/10-9/10 | NO SHEAR | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| | MOD. SHEAR | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| | MARKED SHEAR | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
| OVERCAST 9/10+ | NO SHEAR | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 |
| | MOD. SHEAR | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 |
| | MARKED SHEAR | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 |
| | | SMALL TO MODERATE VERTICAL DEVELOPMENT "IN Cu OR Cb." | | | | | GREAT TO EXTREME VERTICAL DEVELOPMENT "IN Cu OR Cb." | | | | |

FIGURE 4.8—Table of Visibility (V) and Weather (WW) used in Special P2V Code



[redacted]

[redacted]

# Chapter 5

# ENIWETOK WEATHER CENTRAL

## 5.1 General Remarks

The Eniwetok Weather Central was located in the Task Group 3.4 Headquarters building on Eniwetok Island. A room 24 x 48 feet (1,152 square feet) was used to house the weather central as well as the administrative section of Task Unit 3.4.5, the CW and facsimile intercept positions, several teletype machines, and an ozalid machine. Conditions were somewhat crowded but not to the extent of reducing general efficiency appreciably. Compared to shipboard aerological installations, there was ample space. The large airy, unpartitioned room contributed to good ventilation, and working conditions were generally very comfortable.

Standard Air Weather Service weather station furniture was used for weather data and chart displays, supplemented by a light table and a few locally constructed display devices.

The location of both the facsimile receptors and the CW intercept positions in the Weather Central was a definite mistake because sparking from the styli on the facsimile drums produced severe interference with the CW receivers. For this and other reasons, it is definitely recommended that the CW intercept positions be located remotely from the weather central in this and similar installations in the future.

Operation of the weather central was under the supervision of Major Alfred R. Crisi, assisted by LCDR Harvey F. Smith. Eleven forecasters and aerologists (7 Air Force and 4 Navy) performed the analysis and forecasting work. Seventeen observers and aerographers (5 Air Force and 12 Navy) took surface observations and plotted weather. The observer section was headed by AGC R. D. Ackerman, U.S. Navy.

The rawinsonde section, under the supervision of 1st Lt. C. G. Campbell, USAF, was located some two hundred yards to the west of the weather central.

Headquarters of Commander, Task Unit 3.4.5, was located in one corner of the weather central. This practice is not recommended for future operations, as unavoidable interference between functions is an inevitable result.

## 5.2 Training

The results of investigations of meteorological data from Operation CROSSROADS by the tropical Pacific research group under Dr. C. Palmer at the Institute of Geophysics, University of California at Los Angeles, were carefully considered. It was decided to incorporate many of the techniques used by this research group into the operation. Special charts and codes were designed to fit the proposed operation. New codes for reporting 1,500 foot winds, turning of the wind in the vertical, and characteristics of tropical clouds received the greatest attention; a simple weather code was devised for use by patrol aircraft to increase the density of data close to Eniwetok.

Six of the Air Force officers worked with the research group on the CROSSROADS data at the Institute of Geophysics, University of California, Los Angeles, for at least two months prior to assignment to duty in the weather central. It was also planned to train on the job for a few months as soon as enough data became available at Eniwetok, so that teamwork among the forecasting staff could be fully developed before the final phase of Operation GREENHOUSE. As the remainder of the Air Force forecasters and all naval personnel assigned to the Weather Central were unfamiliar with Dr. Palmer's methods, a two

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weeks lecture and laboratory course was conducted at Eniwetok. Dr. Palmer spent about a month at Kwajalein during the middle of the operation supervising the research work of project 4.5 (Research on Tropical Meteorology). He also performed an invaluable service in conducting personal conferences with forecasters from the weather central. Most of the forecasters visited Kwajalein during Dr. Palmer's visit and worked with him for several days each between shots.

Several forecasters from the weather central also went on scheduled weather reconnaissance flights and acquired an excellent first hand knowledge of the problems and techniques of weather reconnaissance in the tropics.

## 5.3 Sources of Weather Data

All types of weather data were collected including surface reports (hourly, three-hourly, six-hourly), upper air reports (pibals, raobs, rawinsondes), weather reconnaissance reports, POMARS, terminal forecasts, storm bulletins, and miscellaneous reports. The sources of data are listed below with brief explanations as to the method of transmission and scope of data available.

### 5.3.1 Intercept of Radioteletype Broadcast from Guam

This collection contained all types of weather data from the central and western Pacific which included Hawaii, Japan, Philippines, ships at sea, and key island stations such as Wake, Marcus, Johnston, Ponape, and Truk.

### 5.3.2 Intercept of CW Weather Broadcast from Nandi, Fiji Islands

This collection contained all types of data from the south Pacific islands including New Zealand, but chiefly surface reports with only a few pibals and raobs.

### 5.3.3 Intercept of CW Weather Broadcasts from Townsville, Australia

This collection contained all types of weather data from Australia and the islands north of Australia, but chiefly surface reports from Australia proper.

### 5.3.4 Scheduled CW Transmissions from GREENHOUSE Network

This collection included three-hourly surface reports and six-hourly rawinsonde reports (0300Z, 1500Z, 2100Z only) plus additional surface and upper-air reports on request.

### 5.3.5 Intercept of Weather Reconnaissance Observations

This collection contained all types of weather reconnaissance data at 1,500 feet, 700-millibar, 500-millibar, aircraft spiral ascent and descent soundings with winds and dropsondes, plus additional data on request.

### 5.3.6 Intercept of Patrol Aircraft Reports

These reports were intercepted from P2V aircraft and included weather, cloud data, and estimated surface winds within 300 miles of Eniwetok.

### 5.3.7 Miscellaneous Sources of Data

Weather data were received from GCI radar scope interpretations, reports from base and transient aircraft, de-briefings of aircrews, and from naval vessels in the area upon request.

### 5.3.8 Data from Other Weather Centrals

This collection contained facsimile weather maps and charts received by radio facsimile from Washington, D. C.; Tokyo, Japan; and Hickam AFB, Hawaii.

### 5.3.9 Kwajalein Data

Special mention must be made of Kwajalein as a source of data. The weather station at Kwajalein was not part of Task Unit 3.4.5 GREENHOUSE network. However, all Kwajalein data was sent directly to Eniwetok by radioteletype. This procedure insured prompt receipt of valuable data including special added data not available throughout the Guam broadcast, which was the usual source for Kwajalein data.

## 5.4 Comments on Reports

The rawin data and surface reports from fixed land stations in and near the Marshall Islands were the most useful information received. Wind and weather reports from reconnaissance aircraft filled in the blank spaces between fixed stations and proved invaluable for determining the composition of the atmosphere. Patrol aircraft reports, radar observations, and reports from local base aircraft filled in the details of local weather distribution (200 to 300 mile radius from Eniwetok). The large and varied amounts of data from the Guam broadcast and the southern hemisphere data from the Townsville and Nandi broadcast served as background data for analysis of the overall Pacific weather situation.

### 5.4.1 Special Data

Additional data on winds and clouds were available from all stations in the GREENHOUSE network, Kwajalein, and the reconnaissance aircraft. The 1,500 foot wind data from these stations were used for the 1,500 foot streamline chart together with the reported 1,500 foot doubledrift winds from reconnaissance aircraft. The 1,500 foot level is the standard operating level for most low-level weather reconnaissance flights; thus, it was selected as the primary and lowest level for streamline analysis. Data on wind turning with height were used by forecasters to more accurately analyze the upper wind structure. The additive cloud data from land stations supplemented the regular synoptic code in describing tropical cloud characterizations. The best use of additive cloud data was made in the reconnaissance reports; the added cloud code groups were utilized to describe conditions off-course and in-between regular reporting positions over and above the usual limited code for past weather and weather-off-course.

### 5.4.2 Radio Facsimile

The radio reception of facsimile charts from other weather centrals left much to be desired. It had been planned to rely on the USAF Weather Central for northern hemisphere charts for overall background analysis, so that maximum effort could be devoted to detailed analysis of the Marshall Islands area. The unreliability of reception from Washington prevented the realization of such a plan; however, reception from Hickam and Tokyo was fair to good, but the charts available from those sources were not as useful as the northern hemisphere charts from Washington. The quality of all facsimile analyses was very good when legible charts were received, and they were of great value as a check on the area covered by local analysis and as a description of boundary conditions in the areas beyond the local analysis area.

### 5.4.3 Coverage

The weather information received at the weather central gave generally excellent coverage on all types of charts plotted, although the individual map coverage was not always complete due to poor radio reception and/or other causes beyond reasonable control.

## 5.5 Charts and Graphs Used

The charts and graphs used were selected to obtain maximum utilization of all useful data. The most useful and important data were usually plotted on several different charts in various forms to insure thorough consideration and evaluation by all forecasters. A list of the charts prepared follows:

| | |
|---|---|
| Surface map | Weather distribution chart |
| 700-millibar chart | Weather Recon cross sections |
| 1,500 foot chart | Wind-time graphs |
| 10,000 foot chart | Adiabatic diagrams |
| 20,000 foot chart | Wind tabulation sheets |
| 30,000 foot chart | Three-hourly station logs |
| 40,000 foot chart | Patrol aircraft reports chart |
| 50,000 foot chart | |

### 5.5.1 Base Charts

Three special base charts were used in the Task Force Weather Central for studying weather conditions. These were: a 1:10,000,000 chart of the Pacific Ocean area extending from 25°S to 48°N latitude and from North America to Asia, a 1:5,000,000 chart of the Central Pacific area, and a 1:1,000,000 chart of the Eniwetok area. These charts were all provided by special arrangement with the Cartographic Branch of the Air Weather Service and were published by the USAF Aeronautical Chart Service.

The charts proved to be extremely satisfactory for the purposes for which they were designed. The 1:10,000,000 (AWS–WPC–5–6–1) chart is drawn on a Mercator Conformal

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projection and is printed on tracing paper. It was used for general wide area weather analysis both at the surface and in the upper atmosphere. Ozalid copies of these maps were used extensively at Joint Task Force THREE Headquarters on Parry Island.

The 1:5,000,000 (AWS–WPC–5–6–2) chart is also drawn on a Mercator Conformal projection and it is printed on regular weight bond paper. It was used for detailed streamline analysis, for plotting weather reconnaissance reports, and for constructing weather distribution charts.

The 1:1,000,000 (AWS–WPC–5–6–3) chart is drawn on a Lambert Conformal Conic projection, and is printed on tracing paper. This projection was used for this chart since a similar base chart was already in existence and the preparation of a new base grid was thus obviated. For the small area concerned, this projection is very little different in appearance from the Mercator projection used on the other weather charts. It was used for detailed plotting of reports of the P2V Aircraft, and for plotting showers detected on the AN/FPS–3 radar installation on Eniwetok Island.

### 5.5.2 Thermodynamic Diagrams

Radiosonde data were plotted on skew T-log P charts. These charts are thermodynamic diagrams first proposed by Herlofson in Norway, and adopted for trial use by the USAF Weather Central. They were entirely satisfactory for the rather limited use made of radiosonde data in the forecasting at the Task Force Weather Central.

### 5.5.3 Polar Coordinate Diagrams

Polar coordinate diagrams (such as the standard Navy "Mooring and Maneuvering Board") were used extensively by the Joint Task Force THREE Staff Weather Officer and the Radiological Safety Officer in computing areas of radioactive fall-out.

## 5.6 Streamline Analysis

Streamline analysis for constant levels from 1,500 feet up to 50,000 feet was carried on daily from 0300Z, 1500Z and 2100Z, which were the times when the most rawin data were available. The method of streamline analysis used was that described by Bjerknes [1] and applied to tropical situations by Palmer.[2] Remarks about the individual charts will be made separately, although some general remarks can be noted for all the streamline charts. The lack of forecasters and trained supervisors with experience in this type of analysis resulted in poor continuity of analysis both in the vertical and with time. Of course, very little previous work has been done on high level analysis in the tropics, and what has been accomplished must be subject to considerable doubt due to the sparsity of data. The analysis improved, however, as forecasters developed more skill and confidence in evaluating the data. According to original plans, only the Marshall Islands area was to be analyzed. Facsimile charts, especially of the upper levels, from the USAF Weather Central in Washington were to furnish the overall background and continuity. Due to the poor and unreliable radio facsimile reception the original plan had to be abandoned when the demands for greater accuracy in wind forecasts increased. Midway through the project the chart area for the upper levels was increased. Continuity improved immediately, and the added overall understanding of air flow aloft was reflected in the improved accuracy of upper wind forecasts.

The main part of the streamline analysis was for the latitude strip between 5°S and 35°N. The several cells of the north Pacific anticyclone were usually in this belt and made the analysis quite complex because of their erratic movements. Cols or neutral points in the velocity field also showed very erratic movements. Frequent cases of closed lows or cyclonic singular points in the velocity field were noted in the regions from 10°N to 20°N; most of these distrubances were best developed in the upper troposphere and associated with extensive sheets of cirrus and cirrostratus above 25,000 feet. In such cases the base of the upper westerlies was lower at Eniwetok than at Wake and also lower at Kwajalein and

[1] Bjerknes, V., and others: Dynamic Meteorology and Hydrography, Part II, Kinematics, Washington, Carnegie Institution, 1911.

[2] Palmer, C. E., and H. Elsasser: Notes on Tropical Meteorology, Technical Bulletin, 2143rd Air Weather Wing, Tokyo, 1949.



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Majuro than at Eniwetok. These situations were characterized by great persistence.

## 5.7 The Surface Map

Each day four surface maps were plotted and analyzed for the area from 120°E to 150°W and from 25°S to 45°N, using the 1:10,000,000 charts.

The principal value of these maps was the generalized weather picture presented, especially in the equatorward portions of the temperate latitude storm tracks. The surface map was used for background briefing and for the construction of prognostic charts, which were also used for briefing purposes. The movements of fronts and pressure systems in the temperate latitudes were carefully checked to detect direct or indirect influences on tropical weather. The position of the equatorial pressure trough was determined, when possible, from the surface map, although in many cases no clean-out trough was evident.

## 5.8 The 700-Millibar Chart

Two 700-millibar charts on 1:10,000,000 base maps were plotted and analyzed each day for 0300Z and 1500Z covering the same area as the surface maps. By plotting a selection of POMARS for appropriate times and altitudes in addition to the regular 700-millibar upper-air reports, an excellent coverage of data was usually obtained for this chart. Conventional contour analysis was used in the westerlies, but in most cases the area south of 20°N in the equatorial regions was analyzed by streamline methods. No serious problems were encountered in combining the two methods of analysis on the same chart, since the transition zone was nearly always in the main anticyclonic belt across the Pacific. The large area covered by this chart made it a valuable background chart. The 700-millibar chart aided in the analysis and prognosis of the surface map, and was the best chart for forecasting flight level winds for long-distance MATS operations. It also enabled forecasters to determine direct and indirect influences on weather in the Marshall Islands of trough passages in the westerlies to the north of Eniwetok.

## 5.9 The 1,500-Foot Chart

This chart was plotted and analyzed for an area from 150°E through 180° to 175°W and from 5°S to 25°N centering on the Marshall Islands. The 1:5,000,000 base maps were used. When data permitted, a detailed isogon-isovel-streamline analysis was made. Continuity on this chart was usually fair to good. The best results were obtained during periods of unusual weather during which well-developed waves, vortices, and tropical storms showed up clearly on this chart. During periods of normal trade flow the analysis was not too significant, and minor variations in velocity divergence could not be detected. Good correlation could usually be found between this chart and the structure of the atmosphere as shown by the weather distribution chart. Forecasting from the 1,500 foot chart by pure extrapolation for twenty-four hours or less proved to be fairly accurate. The forecasters' lack of experience and confidence in streamline analysis undoubtedly limited the utilization of this chart for forecasting purposes.

## 5.10 The 10,000-Foot Chart

This chart was plotted and analyzed for an area similar to that covered by the 1,500 foot chart, and the larger 700-millibar chart was used for necessary background. The 1: 5,000,000 base maps were used. Usually the flow pattern at this level fitted well with the pattern at 700-millibars, and showed details of the wind field over the Marshall Islands more clearly than the small scale 700-millibar chart. Unfortunately, during February, March, and most of April the 10,000 foot level was in the main shear or transition layer between the trade wind and the upper westerlies, and the analysis was very complex and difficult to interpret. Later in the season, however, after mid-April, the 10,000 feet level was mostly in the easterlies and showed good correlation with the 1,500 foot chart.

## 5.11 The 20, 30, 40, and 50 Thousand Foot Charts

Due to a general lack of data the 50,000 foot chart was limited to the Marshall Islands area during the entire project. The other charts

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were plotted to cover a larger area from 120°E through 180° to 150°W and from 10°S to 40°N after facsimile reception was found to be unreliable. This larger area was comparable to that of the surface and 700-millibar charts and the same 1:10,000,000 base maps were used for this series of charts.

### 5.12 The Weather Distribution Chart

The area covered by this chart was the same as that of the 1,500 foot and 10,000 foot charts, and the 1:5,000,000 base maps were used. All reports of clouds and precipitation (present and past weather) plus additive data groups were plotted for a twelve-hour period centering around 0000Z, or Eniwetok local noon. This procedure included plotting all the regular weather reconnaissance reports for each day, all land station reports, and all POMARS for the appropriate times. The weather distribution chart gave an excellent picture of the composition of the atmosphere over the Marshall Islands. It was usually easy to correlate with the surface, 1,500-foot and 10,000-foot charts. Areas of poor weather could be watched and sometimes tracked on this chart. Extensive areas of middle cloud cover and precipitation indicated by this chart were usually associated with marked areas or zones of velocity convergence in the lower levels of the troposphere. The weather distribution chart was an excellent briefing tool, especially when separate overlays, in different colors, were constructed for low clouds, middle clouds, high clouds, and precipitation.

### 5.13 Weather Reconnaissance Cross Sections

For each regular reconnaissance track these charts were plotted and analyzed in the form of a vertical cross section of the weather observed. They were helpful for briefing purposes and as a supplement to the weather distribution chart.

### 5.14 Wind-Time Graphs

A graph was maintained for each of the GREENHOUSE network stations except Nauru. A graph was also kept for Kwajalein. Graphs for other stations were plotted as required. These wind-time graphs were essentially the same as the more common wind-time cross sections. The graphs provided a readily available representation of wind structure at stations in a continuous log form.

### 5.15 Wind Tabulation Sheets

A complete tabulation of winds was kept for each of the GREENHOUSE network stations plus Kwajalein, Wake, and Ponape. The plotting of wind tabulation sheets preserved the accuracy of the original data and provided a quick, and easy reference for wind data from key stations.

### 5.16 Adiabatic Charts

The upper air temperature, pressure, and humidity data from certain key stations were plotted on Herlofson diagrams. Weather reconnaissance aircraft ascents, descents, and dropsonde data were plotted on ML–124 adiabatic charts. These charts were used to check the height of the tropopause, the height of the surface "moist layer," and the temperatures aloft.

### 5.17 Three-Hourly Logs

Logs of three-hourly surface reports from twenty key land and ship stations in the Pacific were maintained. Events at any one station could be analyzed quickly and the result applied to the surface map analysis.

### 5.18 Patrol Aircraft Reports Charts

Weather reports from patrol aircraft (P2V) were plotted on a large chart (1:1,000,000) covering an area within a radius of 300 miles of Eniwetok. This chart supplemented the weather distribution chart and gave an up-to-date picture of weather conditions close to Eniwetok.

### 5.19 Forecasting

The forecasts required for Operation GREENHOUSE comprised detailed wind and temperature forecasts from the surface to 60,000 feet as well as the more usual types of planning and operational forecasts. Temperature structure and the tropopause height



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showed only small changes with time. The forecasting of clouds, precipitation, and winds was more difficult. Apparently, it required only very small changes in the field of motion to produce pronounced changes in cloud structure and shower activity. The winds aloft were highly variable, much more so than previous experience and perusal of available literature would indicate, although this had been suggested by Lt. Col. Crowson as a result of data obtained on Operation SANDSTONE.

In forecasting for the Marshall Islands, the weather central forecasters tried most of the known methods used in tropical regions. It was necessary to reconcile variations in interpretation and application of various methods by individual forecasters. Therefore, most of the planning and operational forecasting was done by a few supervising forecasters, who took all methods and opinions into account before making a final decision. This system proved very effective from an operational standpoint. It should be noted that often the differences in methods and opinions proved to be only differences in nomenclature.

Fundamentally, extrapolation of trends based on complete and accurate analysis was the main forecasting tool. Recognition of certain flow patterns and of phenomena models usually accepted as useful for tropical forecasting was constantly sought. In many cases, it was extremely difficult to find any definite physical basis or logical sequence upon which to base forecasts. Apparently, many of the changes in cloud and wind structure from day to day were caused by variations of meteorological elements that could not be measured or observed even with all the data from the increased network of land stations and aircraft reconnaissance flights activated for Operation GREENHOUSE.

Further details on weather conditions in the Eniwetok area appear in Appendix "B."

## 5.20 Conferences

During the period that Dr. Palmer was at Kwajalein, regular twice daily radiotelephone conferences were held between the weather central on Eniwetok and the research group on Kwajalein. This group consisted of Dr. Palmer, Capt. Orin W. Stopinski, and 1st Lt. Forrest R. Miller, with several plotters furnished by the Kwajalein weather station. At these conferences the general weather situation in the tropical Pacific region was discussed in some detail, future trends were examined critically, and plans for the next day's weather reconnaissance tracks were made final. The conferences were very useful for both groups.

## 5.21 Reproduction of Charts and Forecasts

As the demand for Weather Charts and Forecasts was extremely variable, both as to types and numbers, practically all available reproduction methods were employed at one time or another: verbal briefings, typed and "dittoed" forecasts, hand traced charts, and ozalid reproduction.

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# ORGANIZATION CHART
# TASK UNIT 3.4.5

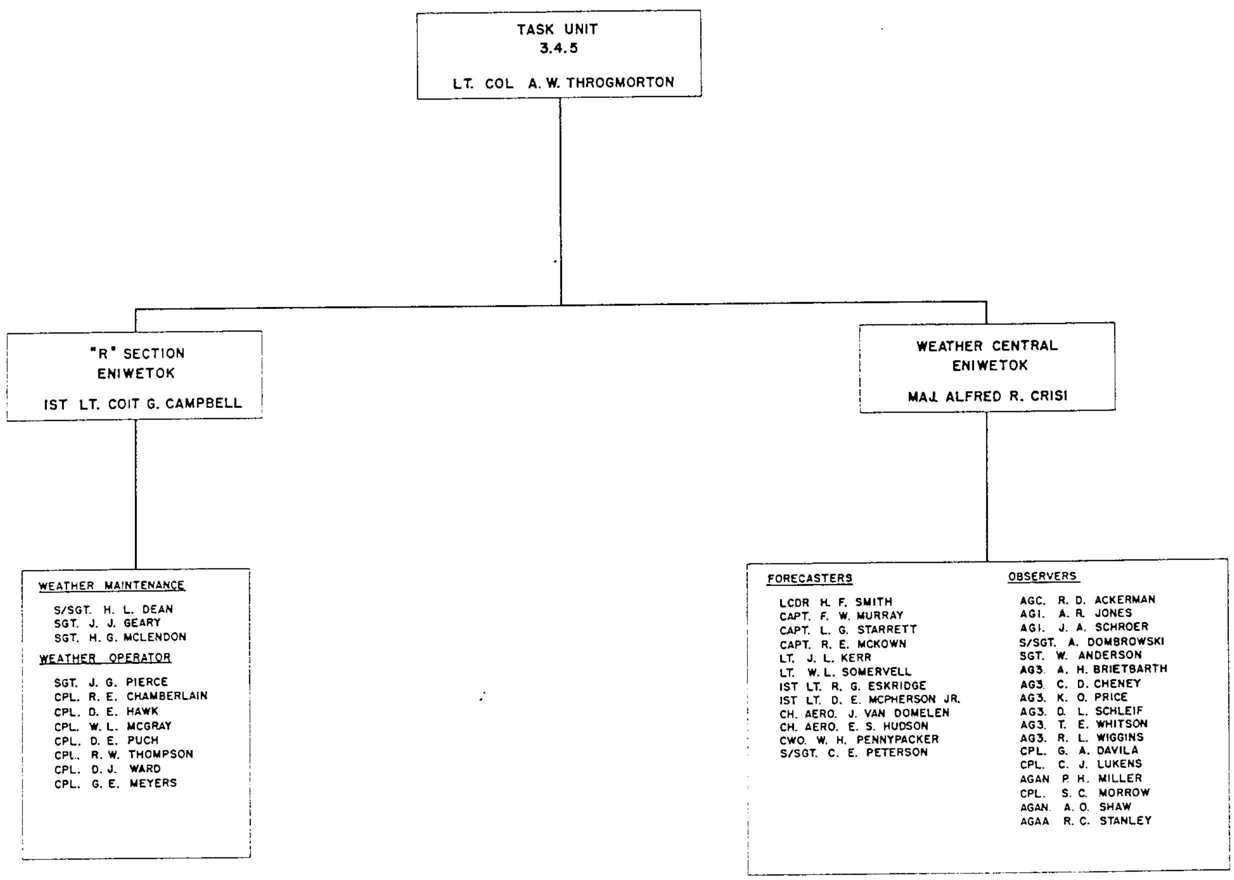


FIGURE 5.1—Organization Chart



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# Chapter 6

# HEADQUARTERS WEATHER SECTION

## 6.1 General Remarks

The Weather Section of Headquarters, JTF–3, was organized under the Technical Operations Branch, J–3 Division. It was assigned the tasks of coordinating the entire GREENHOUSE weather program, and advising the Commander, Deputies, interested members of his staff, and the Scientific Director in all matters with respect to weather. Throughout the operation in the forward area, Col. George F. Taylor, USAF, was Chief, Technical Operations Branch, and Cdr Elbert W. Pate, USN, was Staff Weather Officer.

It soon became obvious that weather and radiological safety considerations were inseparable from an operational standpoint. The Task Force Radiological Safety Officer, Cdr. Russell H. Maynard, USN, had previously been trained and had served as an aerologist. In practice, the Weather and Rad-Safe Sections were combined, and the three officers many times performed dual functions.

## 6.2 Communications

As Task Force Headquarters and the Scientific Task Group (TG 3.1) were located on Parry Island, the problem of communication with the Weather Central from which all basic data came was soon apparent. Experience with the rehearsal for DOG shot, during which typhoon GEORGIA was an added attraction, pointed out the deficiencies in communications, and resulted in the establishment of a workable (but not ideal) communication syssstem between the headquarters Weather Section and the Central.

### 6.2.1 Liaison Aircraft

Arrangements were made through CTG 3.4 to provide standby aircraft at specified times, and emergency aircraft at all times upon request of the Weather Section. These aircraft were used to transport Weather Officers to and from the Central for detailed conferences and to pick up command briefing charts.

### 6.2.2 Teletype

A land-line teletype link was established between the Operations Control Center in the Headquarters building and the Weather Central. The value of this installation cannot be over-emphasized.

### 6.2.3 Command Telephone

A special "hot line" was established between Headquarters and the Weather Central.

## 6.3 Command Briefings

A briefing schedule for DOG shot rehearsals was set up for "test" purposes. Essentially, briefings were scheduled at H minus 66 hours, and every 12 hours thereafter, with the last conference at H minus 6 hours.

Typhoon GEORGIA proved rather categorically that weather does not wait for scheduled conferences. During the same period it was also established to the satisfaction of all that formal briefings prior to H minus 30 hours serve no real purpose unless there are critical changes forecast. Gradually, as more experience was gained, a far more efficient briefing and advisory schedule was evolved: the weather Section informally advised interested Commanders and staff officers at unscheduled intervals prior to H minus 30 hours, and beginning at that time formal command briefings were conducted at 12 hour intervals. Technical considerations advanced by the Deputy Commander for Scientific

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Matters produced minor changes and variations to this schedule during specific periods, but no particular problem was created by minor departures.

Formal briefings were conducted by the Weather officers (alternately) in the Command Post at Task Force Headquarters. Attendance was restricted by order of the Commander. While the number present varied somewhat, the Commander, Military and Scientific Deputies, Chief of Staff, Special Advisor for Radiological Safety, and JTF–3 Operations Officer were invariably present or represented. In general, the following charts were employed:

North Pacific Surface.
North Pacific 700 millibar.
Central Pacific Stream Line Chart (1,500 feet plus higher levels when needed).
Weather Distribution Chart.
Prognostic Charts (variable in number as required).

Charts were posted by the Weather Officer, explained in detail, forecasts issued, and questions answered.

The Weather Briefing was followed by a discussion of Rad-Safe considerations. Surface and Air Radex Charts were introduced by the Rad-Safe Officer, along with the complete fall-out diagrams. (See Appendix "C".)

An Operational Weather Summary, including significant command decisions predicated upon weather briefings, is contained in Appendix "A."



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# Chapter 7

# CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

7.1.1 It is quite definitely within the interests of the individual Services, as well as serving the principles of unification, that operation of the Task Force Weather Central be a joint effort.

7.1.2 The functions of the Weather Officer and Radiological Officer are completely interrelated. Their responsibilities are unique and little related to other staff functions.

7.1.3 The physical location of the Weather Central on Eniwetok Island, with Task Force Headquarters on Parry Island, gave rise to an awkward system of providing weather information to the high command. While difficulty was overcome to some extent by establishing an elaborate communication system between the two locations, it is felt that the difficulty should be eliminated in future operations. The primary interest in the weather as a component of, and contributor to, major decisions lies at the top command level, as was repeatedly demonstrated during Operation GREENHOUSE. The clearance of aircraft, and the advising of any command on Eniwetok Island, could be the function of a small satellite organization under the weather central.

7.1.4 It is doubtful that the meteorological science will develop a method of forecasting in the tropics which will enable accurate particle fall-out predictions as far in advance as 30 hours. Upper wind patterns in the tropics can and do change radically within a short time, often from causes which cannot be diagnosed. Much of the success in adhering closely to the original firing schedule during Operation GREENHOUSE can be attributed to the acceptance of a fluid situation by the high command.

7.1.5 Although some radioactive particle fall-out was experienced on inhabited islands after ITEM shot, the decision to advance shot time from 0930M to 0617M was sound. The decision was based upon an upper-wind forecast that resultant winds at 0630 were acceptable, while winds for later detonation were forecast to be distinctly unfavorable.

7.1.6 Employment of aircraft of Task Group 3.3 assigned to the antisubmarine mission to provide additional weather reports proved sound, and permitted a precise and detailed description of the weather near Eniwetok.

7.1.7 Location of outlying weather stations should be examined critically. It appears highly desirable to eliminate Bikati and possibly substitute Tarawa, for many reasons; opinion with respect to the usefulness of Nauru should await evaluation at UCLA.

## 7.2 Recommendations

7.2.1 That personnel of the Air Force and Navy, who are to be in the Weather Central, be assigned and be trained within the ZI as a unit for not less than ninety (90) days before leaving for the forward area. This will permit education and training in common methods, and the separation of unqualified or undesirable personnel prior to an expensive overseas movement.

7.2.2 That the Weather Central be located at Task Force Headquarters and operated as a headquarters command function.

7.2.3 That research and development continue in the field of obtaining accurate upper-wind information to extreme levels. An important contribution can be made by the production of better balloons.

7.2.4 *That the principle of "fluid attitude" in command decision be retained as one of the most valuable lessons from Operation GREENHOUSE. As weapon yields continue to increase, the importance of this principle will increase correspondingly.*

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# Appendix "A"

# OPERATIONAL WEATHER SUMMARY

## PART I

### Brief Summary

## A.1 General

Weather was a definite factor in the daily activities of the Task Force on Eniwetok, but there were five critical periods during which interest was intense, and during which success of the overall mission depended upon the weather:

| | |
|---|---|
| Typhoon GEORGIA | 17 March–25 March |
| DOG Shot | 4 April – 8 April |
| EASY Shot | 17 April –21 April |
| GEORGE Shot | 5 May – 9 May |
| ITEM Shot | 21 May –25 May |

While it would serve little purpose to attempt detailed reconstruction of all forecasts and advices given to the top command, several outstanding experiences persist which demonstrate the "fluid situation" philosophy adopted by the command. Typhoon GEORGIA and all test shots presented many and different weather problems. A summary of the significant elements entering the weather portion of major command decisions follow.

## A.2 Typhoon Georgia

During one of the DOG shot rehearsal briefings early warning had been given the Commander that a distinct possibility existed that GEORGIA could reverse course and take a new heading directly for Eniwetok. When GEORGIA did exactly that the next day, the situation at Eniwetok became extremely serious. Evacuation orders were prepared, routine work and construction activities were halted while personnel "battened down," and other Pacific Commands were alerted for large numbers of possible visitors in case Eniwetok had to be evacuated. Gloom prevailed at all echelons when the magnitude of destruction and subsequent delay in a vital program was visualized.

All components of the weather service were already alerted. Communication services gave priority to the delivery of all weather traffic and a deluge of weather information from many sources commenced. The reconnaissance squadron provided invaluable reports. Kwajalein, Guam, and Pearl Harbor issued frequent advisories. A system of numbered advisories to task group commanders was instituted and all echelons of command were informed at frequent intervals of Headquarters' analysis of the situation.

Fortunately, GEORGIA degenerated rapidly after passing north and west of Kwajalein and passed south of Eniwetok, producing maximum winds of 40 knots and torrential rains.

Time lost while battening down resulted in a two day delay in the DOG shot schedule. The experience produced a highly beneficial result: communication and organizational weaknesses were brought out before test operations began and corrective action was taken immediately.

## A.3 DOG Shot

Weather requirements for DOG shot were based upon demands for satisfactory wind and cloud conditions for a night take-off of drones, cloud and visibility conditions which would permit photography, and an upper wind

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structure of such a type that dangerous radioactivity levels would not be produced on populated islands from the fall-out of "hot" particles.

It was recognized that the expected yield of the weapon might produce many phenomena never observed in previous tests. This expectation was fully realized when ground monitors on Parry Island began to record radioactivity at H plus 2 hours (see Radiological Safety Report).

A detailed analysis of all available data and information began that day and continued for nearly a week. It was finally determined that particles of the sizes and densities observed must have had an origin in the 30,000–40,000 feet levels—an occurrence which had not been anticipated. Continued research produced a methodology which would permit prediction of such occurrences (Appendix "C", this report). This was one of the most valuable lessons in meteorology learned during GREENHOUSE.

## A.4 EASY Shot

Because of the importance of the structures, biological and radiation programs, a positive requirement that there be no precipitation over Engebi Island at shot time was established by the Scientific Director. This requirement was in addition to acceptable radiological safety conditions.

Since best weather (little cloud and precipitation) accompanies the typical trade wind condition (westerlies over northeasterlies), and ideal fall-out conditions exist with a southerly component in the winds aloft, it was pointed out that the conditions desired were almost mutually exclusive.

Many special precautions were taken to insure accurate and timely reports of showers in the Engebi area and an alternate schedule was issued to permit a possible last minute delay. Fortunately, all weather requirements were realized and the shot took place on schedule.

## A.5 GEORGE Shot

The expected yield of GEORGE demanded "absolutely safe" fall-out conditions; that is, southerly winds aloft at all levels, the stronger the better. All other requirements were reduced to a minimum.

Typhoon JOAN developed and moved as if it were a scheduled part of the operation. Zero hour was advanced to 0930 to permit drone operation during full daylight and thus allow for marginal cloud and visibility conditions.

GEORGE was detonated with strong southerly winds at all levels to 50,000 feet and excellent local weather conditions.

## A.6 ITEM Shot

There were no special requirements for ITEM approaching the stringent nature of demands for previous shots. Very slight fall-out on inhabited islands was predicted, and did occur, but not to any dangerous extent. The alternative would have been a long and costly delay.

# PART II

Detailed Summary

## A.7 Typhoon GEORGIA

### A.7.1 Origin

During the early part of March, the dominant upper level flow was from the south. At 40,000 feet the flow had been southwesterly in the region about Nauru, Kusaie, and Ponape, but shifted to a southeasterly direction about 11 March. At 30,000 feet the flow was also southeasterly by 14 March and at 20,000 feet after 141500Z a persistent cyclonic point was observed south of Kusaie. The strong southerly flow over the Marshall Islands appears to have been associated with an unusually large high pressure cell centered over northeastern Australia. Cyclonic shear along the



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border of this southerly current west of Kusaie may have contributed to the final development of the cyclonic circulation and deepening that developed into Typhoon GEORGIA.

On 17 March the VULTURE GEORGE flight reported a vortex about 3°N, 158°E, and on 19 March at 0500Z, VULTURE GEORGE again noted a pronounced but weak circulation at 7°18′N, 159°48′E. Between 0300Z and 1500Z on 18 March, Ponape reported a wind shift at 1,500 feet from northeast to northwest, consistent with the passage of a cyclone to the southeast with a path from south-southwest to north-northeast. Had the southern hemisphere vortex, after passing Nauru, been carried toward the northwest in accordance with the upper flow, it could have been the same vortex noted by the VULTURE Flight, now in the process of recurvature. A second possibility is that the southern hemisphere vortex which passed Nauru moved on to the west, south of Ponape and Truk. It could still have been the vortex noted by VULTURE GEORGE on 17 March.

One possible hypothesis (see figure A.1) is that the vortex originated in the southern hemisphere. On 15 March at 2100Z there was evidence of a vortex passing to the south of Nauru. The evidence consisted mainly of wind shifts at various levels, together with a thunderstorm observed at 151200Z. If a closed circulation existed at the 10,000 foot level it must have passed to the north of Nauru. In any case, the vortex was carried on the 1,500 foot streamline chart until 161500Z, after which it was dropped for lack of data.

The second hypothesis (see figure A.1) is that a minor wave had developed somewhere to the east of the Marshalls and was moving westward. There is fairly good evidence of a wave passage at Bikati at 151500Z, and somewhat more tentative indications of a wave at Majuro at 160300Z. This wave could have moved just south of Kusaie between 0300Z and 1500Z on 17 March. Unfortunately, no upper winds were available for Kusaie at that time, and so it is impossible to determine whether or not there was the northerly wind to be expected ahead of a wave. By 172100Z the coincidence of the wave and the southerly flow aloft might have resulted in the observed vortex whose later development is so well established.

Either of these hypotheses is tenable, although the first seems more in accord with the observation of the VULTURE flight and those at Kusaie and Ponape. If the second hypothesis is accepted it will have to be assumed that the vortex observed at 3°N, 158°E moved on off to the west, south of Ponape and Truk. It is also possible that the actual development of GEORGIA might have been a combination of the two, or some still different sequence of events.

### A.7.2 Early Stage

The principal feature of the pressure field during the early period, before 17 March, was the displacement of the equatorial pressure trough to a position unusually far to the north for the season. By 16 March it appeared to be between Kusaie and Nauru and between Majuro and Bikati. Kusaie reported a thunderstorm shortly before 170000Z, and at 171800Z a ship about one hundred miles southwest of Eniwetok reported lightning. No closed low pressure center was noted until 180600Z, when Ponape reported the somewhat low pressure of 1003.1 MB in a thunderstorm. As early as 170000Z the reports from Ponape and VULTURE GEORGE flight indicated a disturbance in that region. The VULTURE GEORGE 190000Z report showed that the disturbance was still to the east of Ponape, and therefore could not now be an ordinary wave. Also, a ship south of Eniwetok was still reporting thunderstorms.

An indication that the disturbance was gaining in intensity was given by the upper winds at Kusaie at 182100Z, when at 8,000 feet and above, winds of approximately fifty knots were observed from the southwest. On the 18th of March, Kusaie had 0.95 inch of rain; on the 19th, 0.74 inch; and on the 20th, 3.72 inches fell. During the period 180300Z–200300Z the surface winds were very gusty with gusts estimated to be more than fifty knots.

Up until this time the disturbance had not been considered to have particular significance for operations at Eniwetok. However,

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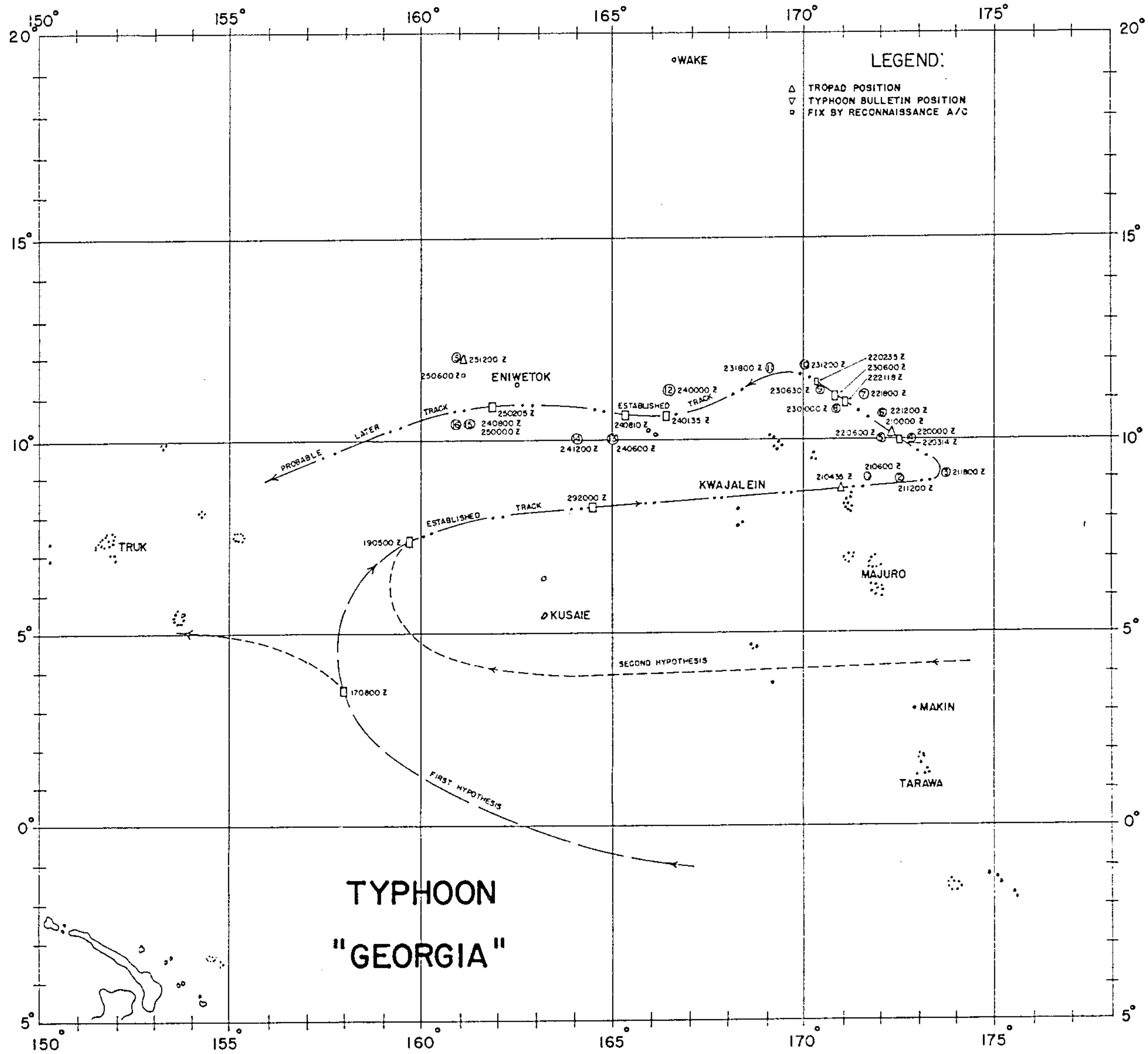


FIGURE A.1—Origin and Movement of Typhoon GEORGIA

on 19 March (GMT) a special GOONEY flight was dispatched to investigate the region between Eniwetok and Kusaie. This flight fixed the center of the storm and established that its movement was toward the east. The previous GOONEY flight had suggested that the associated hyperbolic point was to the northwest of the vortex, another indication of a basic eastward flow.

### A.7.3 Mature Stage

At 0600Z, 20 March the storm passed to the south of Kwajalein, very near the station. Strong surface winds and a maximum upper wind of sixty-five knots at 6,000 feet were reported at the time of storm passage and in addition 3.28 inches of rainfall occurred between 0000Z–1800Z. The storm was then moving in an easterly direction at approximately eighteen to twenty knots, but shortly afterward, decreased in speed of movement and became practically stationary, with a slight curvature to the north.

### A.7.4 Recurvature

The first typhoon bulletin was issued by the Guam Typhoon Warning Center at 210600Z.



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This placed the center at 9°N, 171.5°E on the basis of a reconnaissance fix by a special VULTURE flight. The maximum winds were reported at one hundred knots. At 210440Z a reconnaissance aircraft measured the central pressure at 978.2 MB. The typhoon was then moving northeastward about five knots or less, but it soon curved to the west or westnorthwest, reaching a position of 10°36′N, 171°18′E at 222118Z, according to a report from the VULTURE flight. At this time the eye was fifteen by twenty-five miles across, with light winds in the eye, but winds in excess of one hundred knots within fifty miles of the center.

The Guam typhoon bulletin for 231200Z gave a gale warning for Kwajalein, placing the center at 11.5°N, 170.0°E, with 110 knot winds within a radius of sixty miles. Observed winds at Kwajalein were exceptionally light, hardly exceeding 20 knots, except at 221500Z, when they reached a maximum of 45 knots at 6,000 feet. The lightness of the winds at Kwajalein was indicative of the fact that the hyberbolic point of the typhoon was in the vicinity of Kwajalein. The significance of this is twofold; first, the orientation of the hyperbolic point indicated a motion of the typhoon to the west or westsouthwest, and second, the proximity of the hyperbolic point and the vortex indicated decreasing intensity of the circulation. As a matter of fact, the reconnaissance flight at this time could not locate a definite eye and the maximum 1,500 foot wind reported was only 57 knots.

### A.7.5 Effects on Eniwetok

By 24 March, the storm had moved close enough to affect the JTF-3 mission in the next 24 hours. On the basis of the indicated dissipation of the typhoon, maximum winds of 30 to 40 knots with gusts to 45 were forecast. The center was forecast to degenerate into a wave, whose crest was to pass Eniwetok near 241500Z (250300 local time). The timing was based on a forecasted acceleration in the speed of the storm to 14 knots as compared with the previous speed of 11 knots. Actually, the closed circulation did not disappear so quickly and its speed of propagation remained 11 to 12 knots. As a result, the storm did not pass until sometime between 242100Z and 250300Z, with winds in the lower levels shifting sharply from northeast to southeast, and in the upper levels from northwest to southwest. Wind speeds were slightly lower than forecast, but 0.59 inch of rain fell on the 25th. Considerable improvement occurred on the 26th. On the 27th a line of convergence associated with the storm moved slowly over Eniwetok, resulting in 2.03 inches of rain.

The last typhoon bulletin issued by Guam was dated 250600Z. At this time the center was located by reconnaissance aircraft at 11.5°N, 162.0°E, although the circulation by now was so poorly defined that this position is open to some question. During the time the storm was near Eniwetok a large search radar was run continuously, and it failed to show a clearly defined vortex. This was possibly due to the fact that the clouds in the area covered by aircraft reporting the center were mainly stratiform and gave little or no radar echo. On the other hand, the clouds of vertical development giving the best echo were distributed in an indefinite pattern and mostly to the north of Eniwetok.

The movement of the disturbance after leaving the Eniwetok area is open to considerable question. Had the movement continued in a west-southwest direction at 12 knots, it would have reached a point northeast of Truk by 270300Z. A routine VULTURE flight actually showed a pronounced cyclonic circulation near this location.

### A.7.6 Dissipation of Storm

In connection with the dissipation of the typhoon GEORGIA it is of interest to note that this occurred simultaneously with the development of a new vortex between Kwajalein and Kusaie. This new vortex was first noted at 10,000 feet at 221500Z. It was first drawn on the 1,500 foot streamline chart at 240300Z and thereafter it showed a regular westward movement. It passed directly over Kusaie at 251500Z and continued on at twelve to fifteen knots to the vicinity of Truk. Although this vortex never caused much bad weather, it is conceivable that its formation drained energy from the typhoon GEORGIA hastening its dissipation. At one time the surface pressure map showed a small depres-

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sion north of Nauru but this did not develop and was not carried on later maps. Even as late as the 28th, however, the equatorial pressure trough was far to the north of its mean position for the season.

### A.7.7 Reconnaissance

In the initial detection and later tracking of GEORGIA, aircraft reconnaissance was invaluable. Among the first definite indications of a vortex between Kusaie and Ponape were the reports of the VULTURE GEORGE flight on the 17th and 19th of March. On the 20th, the GOONEY SPECIAL entered the vortex and definitely ascertained its position and motion. Thereafter there were two or more VULTURE or GOONEY SPECIAL flights per day to locate the center of the storm and to determine the wind velocity and weather distribution about it. In addition, there were the regular GOONEY CHARLIE and GEORGE tracks, which bracketed the storm area and gave an indication of the more widespread effects on the weather. The special flights were continued until 25 March, when it became no longer possible to locate a definite eye or any weather or winds considered to be operationally hazardous.

The Weather Central did not have the responsibility of directing the GOONEY and VULTURE special flights into the storm; this was handled from Guam in accordance with usual typhoon reconnaissance procedure. The principal departure from routine in the matter of reconnaissance flights arose from the availability of the 57th Reconnaissance Squadron aircraft and crews for typhoon tracking in addition to the usual 54th Reconnaissance Squadron facilities. The only special observations made by Task Unit 3.4.5 were a series of upper wind observations taken at Eniwetok at three hour intervals (rather than the normal six) from 230000Z to 242100Z, inclusive.

## A.8 Weather Conditions Preceding DOG Shot

Normal trade flow prevailed over the Eniwetok Atoll area during the whole time here discussed, i.e., from 4 April to 8 April 1951. The surface winds varied from east to north-northeast and from eight to twenty-eight knots, the tendency being to become more northerly and increase in speed during this time. The prevailing wind on 4 April was east-northeast at an average of 14 knots and it changed gradually to northeast at an average speed of 20 knots on 8 April. Low clouds moved from east to west during the entire period, also, indicating that the surface wind was representative. No major waves, perturbations, or fronts influenced Eniwetok during this time. A high pressure ridge lay north of the Marshall Islands and the equatorial pressure trough lay south of Kusaie.

Besides the usual scattered to occasionally broken cumulus and stratocumulus clouds, there was a great deal of cirrostratus, with occasional patches of middle clouds throughout the period. Scattered light rain showers increased on 7 April, but ended that night, none being reported at the station after 0200M, 8 April.

The wind structure in the tropics is highly variable and relatively little is known about it. The depth of the easterly trade winds decreased from 18,000 feet on 4 April to as low as 12,000 feet on 5 April, then increased steadily to over 25,000 feet by noon of 8 April. Above the easterlies, westerlies dominated the flow to at least 55,000 feet and possibly to 85,000 feet, though sufficient data were not secured to depict the higher levels. The two wind observations that exceeded 105,000 feet showed easterlies above 85,000 feet. The speed of the westerlies from about 30,000 feet to 55,000 feet was unusually high for this area, reaching 62 knots near 40,000 feet during the first of the period. The easterly trades were generally strongest in the first 6,000 feet from the surface.

### A.8.1 The Forecast

The final forecast was issued at 2300M, 7 April 1951, to cover the period from midnight to 1000M, 8 April. The forecast was as follows:

"2/10 to 4/10 Sc base 2000 top 3000 with few tops to 8000.
5/10 thin Cs layers 30,000 to 40,000.
Few widely scattered light showers.

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Visibility 12 miles reduced to 2 to 5 miles in showers. Surface wind 080 degrees 15 to 20 knots with occasional gust to 25 knots.

Height of tropopause 55,000 feet."

### A.8.2 Weather Conditions 8 April 1951, 0000M—1000M

Scattered low clouds at 1,800 feet and scattered high clouds above 30,000 feet prevailed until 0620M. After 0620M the low clouds increased for a few hours but were scattered again by 0900M. The high clouds also increased after daybreak.

There was no measurable precipitation during the period. A "trace" was recorded during a light shower from 0155M to 0159M.

Visibility was over ten miles.

Surface winds averaged northeast about 20 knots, with some speeds up to 30 knots toward the end of the period.

An extract from the official record of surface weather observations taken at Eniwetok for the period 0000M to 1000M on 8 April along with a report of control tower wind observations follows:

| LOCAL TIME | CLOUDS TENTHS AND TYPES | REMARKS |
|---|---|---|
| 0050 | 2 SC 18 3 CS 300 | |
| 0150 | 2 SC 18 2 CS 300 | |
| 0250 | 1 SC 18 3 CS 300 | Light rain shower 0155 to 0159 |
| 0350 | 1 SC 18 3 CS 300 | |
| 0450 | 2 SC 18 2 CS 300 | |
| 0550 | 3 SC 18 2 CS 300 | |
| 0650 | 9 plus SC 18 | |
| 0750 | 6 SC 18 9 plus 300 | |
| 0850 | 6 SC 18 2 AC 90 9 CS 300 | |
| 0950 | 4 CU 18 2 AC 90 9 CS 350 | |

Report of control tower wind observations (degrees true, speed in knots)

| | |
|---|---|
| 0050 ENE 21 | 0550 ENE 20 |
| 0150 ENE 25 | 0650 NE 23 |
| 0250 NE 18 | 0750 NE 25 |
| 0350 NE 25 | 0850 NE 25–30 |
| 0450 NNE 20 | 0950 ENE 25–30 |

### A.8.3 Forecast and Actual Winds for H-Hour

The tabulation below shows several wind forecasts prepared at different times but all valid for H-Hour. The observed winds at H-Hour are given in the final column at the extreme right. Winds are shown from the surface to 60,000 feet in tens of degrees and knots.

| | D–2 Fcst | D–1 Fcst | D–1 Fcst | D–1 Fcst | D–1 Fcst | D Fcst | H Actual |
|---|---|---|---|---|---|---|---|
| Prepared "M" Time | 2300 | 1100 | 1800 | 2200 | 2300 | 0400 | 0600 |
| Surface | 08/17 | 08/17 | 08/17 | 07/20 | 07/20 | 07/20 | 07/19 |
| 2 | 07/25 | 08/25 | | 07/25 | 07/25 | | 07/26 |
| 4 | 06/29 | 09/30 | | 08/28 | 08/28 | | 08/29 |
| 5 | | | 06/18 | | | 08/25 | |
| 6 | 07/27 | 09/30 | | 08/25 | 08/25 | | 08/23 |
| 8 | 09/21 | 09/20 | | 09/20 | 09/20 | | 08/23 |
| 10 | 10/16 | 09/15 | 07/15 | 08/15 | 08/15 | 07/20 | 08/19 |
| 12 | 12/08 | 09/20 | | 06/15 | 06/15 | | 08/23 |
| 14 | 09/06 | 08/20 | | 05/13 | 05/13 | | 07/18 |
| 15 | | | 08/14 | | | 05/15 | |
| 16 | 06/05 | 07/15 | | 05/10 | 05/10 | | 07/25 |
| 18 | 02/05 | 07/15 | | 01/05 | 01/05 | | 05/23 |
| 20 | 30/08 | 08/15 | 28/12 | 31/08 | 36/08 | 36/12 | 03/19 |
| 22 | 29/15 | 06/15 | | 31/10 | 34/10 | | 35/10 |
| 24 | 28/21 | 04/10 | | 30/12 | 34/12 | | 32/10 |
| 25 | | | 34/15 | | | 30/12 | 30/10 |
| 26 | 28/25 | 36/02 | | 30/15 | 30/15 | | 30/10 |
| 28 | 27/31 | 34/10 | | 29/18 | 29/18 | | 30/17 |
| 30 | 27/35 | 32/20 | 28/35 | 29/24 | 28/24 | 28/24 | 28/27 |
| 35 | 26/38 | 30/25 | 22/32 | | 24/25 | 24/25 | 23/25 |
| 40 | 25/42 | 29/30 | 24/35 | | 25/22 | 24/20 | 22/29 |
| 45 | 28/28 | 27/35 | 26/32 | | 28/28 | 26/25 | 28/23 |
| 50 | 31/15 | 32/20 | 21/28 | | 28/17 | 31/20 | 31/19* |
| 55 | 05/06 | 34/25 | 23/22 | | 28/17 | 32/15 | 34/27 |
| 60 | 09/10 | 04/20 | 08/15 | | 04/20 | 05/25 | 03/29 |

* 0000M

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## A.9 Weather Conditions Preceding EASY Shot

Normal trade winds prevailed over the Eniwetok Atoll area during the whole time here discussed, i.e., from 17 April to 21 April 1951. The surface winds varied from east to north-northeast and from 9 to 23 knots the tendency being toward steadier but lighter winds. The prevailing wind on 17 April was east-northeast at an average of 19 knots and it decreased to east-northeast at an average speed of 15 knots on 21 April. Low clouds moved from east to the west during the entire period indicating that the surface wind was representative. No major waves or fronts influenced Eniwetok during this time. A high pressure ridge lay far to the north and the equatorial low pressure trough lay south of Kusaie.

Total cloudiness decreased from a mean of 5/10 on 17 April to a mean of 2/10 on 19 April, when no ceiling was reported for the entire 24 hour period. It then increased to a mean of 8/10 on 21 April, but most of the increase was in high cirrostratus which had no effect on operations. No ceiling below 30,000 feet was reported from 1800M, 20 April to 1320M, 21 April. Scattered light rain showers occurred each day of the period except the first, i.e., 17 April, but only on 18 April was there enough precipitation to measure—0.07 inch. A trace was reported for each of the following three days.

The depth of the easterly trade winds decreased from 20,000 feet on 17–18 April to as low as 5,000–6,000 feet on 20–21 April. Above the easterlies, northerlies dominated the flow to 50,000 feet on 17–19 April, giving way to westerlies the last two days of the period. A layer of southerlies from 8,000 to 14,000 feet separated the easterly trades from the higher westerlies on 21 April. Less than half the wind observations exceeded 50,000 feet, but the two highest, 90,000 feet and 115,000 feet, showed strong easterlies above 85,000 feet. The easterly trades were generally strongest from 2,000 to 4,000 feet.

### A.9.1 The Forecast

The final forecast was issued at 2300M, 20 April 1951 to cover the period from midnight to 1000M, 21 April. The forecast was as follows:

"1/10 to 3/10 Cu Sc base 2,000 top 3,500 with few tops to 5,000.
5/10 Cirrus at 40,000.
No showers or other precipitation.
Visibility 12 miles.
Surface wind 070 degrees 12 to 18 knots.
Height of tropopause 53,000 feet."

### A.9.2 Weather Conditions 21 April 1951, 0000M—1000M

Scattered low clouds at 2,000 feet prevailed throughout the period. Thin high clouds estimated at or above 30,000 feet were scattered at the beginning of the period and became overcast by the end of the period.

Visibility was good, exceeding 12 miles.

There was no measurable precipitation during the period.

An extract from the official record of surface weather observations taken at Eniwetok for the period 0000M to 1000M on 21 April 1951 follows:

| LOCAL TIME | CLOUDS TENTHS AND TYPE | | SURFACE WIND (KNOTS) |
|---|---|---|---|
| 0051 | 1 Cu E20 | 3 Cs E300 | ENE 12 |
| 0150 | 1 Cu E20 | 3 Cs E300 | ENE 15 |
| 0250 | 1 Cu E20 | 5 Cs E300 | ENE 13 |
| 0350 | 1 Cu E20 | 4 Cs E300 | ENE 14 |
| 0450 | 1 Cu E20 | 3 Cs E300 | ENE 13 |
| 0550 | 2 Cu E20 | 8 Cs E300 | ENE 14 |
| 0650 | 2 Cu E20 | 9 CS E300 | ENE 12 |
| 0750 | 2 Cu E20 | 7 Cs E300 | ENE 11 |
| 0850 | 2 Cu E20 | 7 Cs E300 | ENE 14 |
| 0950 | 2 Cu E20 | 10 Cs E300 | ENE 15 |

Remarks: Light rain shower 0902 to 0907 ("trace" recorded).

### A.9.3 Forecast and Actual Winds for H-Hour

The tabulation below shows several wind forecasts prepared at different times but all valid for H-Hour. The observed winds at H-Hour are given in the final column at the extreme right. Winds are shown from the surface to 60,000 feet in tens of degrees and knots.



[redacted]

[redacted]

| | E–2 Fcst | E–1 Fcst | E–1 Fcst | E–1 Fcst | E–1 Fcst | E Fcst | H Actual |
|---|---|---|---|---|---|---|---|
| Prepared "M" Time | 2300 | 1100 | 1800 | 2130 | 2300 | 0400 | |
| Surface | 06/18 | 07/18 | 05/18 | | | 07/17 | 05/14 |
| 2 | 07/20 | 06/21 | | 07/22 | 07/22 | | 07/18 |
| 4 | 09/25 | 07/18 | | 06/16 | 06/16 | | 08/12 |
| 5 | | | 08/12 | | | 07/12 | 10/08 |
| 6 | 10/15 | 07/15 | | 08/12 | 05/12 | | 16/06 |
| 8 | 12/15 | 06/13 | | 04/07 | 06/07 | | 15/05 |
| 10 | 12/20 | 06/08 | 07/15 | 06/14 | 06/15 | 05/10 | 07/07 |
| 12 | 10/18 | 07/08 | | 03/12 | | | 12/02 |
| 14 | 09/15 | 08/08 | | 03/10 | 03/10 | | 21/03 |
| 15 | | | 36/05 | | | 21/05 | 24/05 |
| 16 | 07/15 | 08/07 | | 30/07 | 30/07 | | 28/06 |
| 18 | 05/17 | 12/06 | | 31/13 | 31/13 | | 33/04 |
| 20 | 04/20 | 15/08 | 26/14 | 33/10 | 33/10 | 34/10 | 31/03 |
| 22 | 04/20 | 12/08 | | 02/03 | 34/03 | | 29/04 |
| 24 | 03/25 | 06/08 | | 35/04 | 35/04 | | 30/07 |
| 25 | | | 34/12 | | | 34/05 | 35/11 |
| 26 | 03/25 | 02/10 | | 33/08 | 33/08 | | 29/14 |
| 28 | 02/20 | 35/10 | | 27/08 | 27/08 | | 27/13 |
| 30 | 02/20 | 34/08 | 27/20 | | 25/20 | 28/20 | 27/24 |
| 35 | 36/25 | 34/26 | 27/20 | | 25/20 | 28/20 | 27/24 |
| 40 | 33/25 | 34/20 | 26/18 | | 25/15 | 25/20 | 28/28 |
| 45 | 32/25 | 30/24 | 27/25 | | 28/25 | 27/28 | 26/30 |
| 50 | 36/15 | 30/18 | 28/20 | | 30/15 | 25/25 | 27/24 |
| 55 | 09/10 | 06/10 | 06/10 | | 33/10 | 33/10 | 33/13 |
| 60 | 27/10 | 05/08 | 05/08 | | 33/10 | 33/10 | 33/13 |

## A.10 Weather Conditions Preceding GEORGE Shot

Typhoon JOAN dominated the weather over the Eniwetok Atoll area during the period discussed, i.e., from 5 May 1951 to 9 May 1951. The typhoon was nearest and only 170 miles from Eniwetok about noon of 8 May. (A detailed discussion of JOAN appears at the end of this section of the report.)

On 5 May there was still little effect of the typhoon at Eniwetok except for an unusual amount of intermediate and high cloudiness. During most of the day there was a cirrostratus or altocumulus overcast, with scattered cumulus below. The surface wind was east-northeast, varying from 14 to 28 knots decreasing to 10 to 15 knots at 25,000 feet. Above this level the winds became southwesterly and then northwesterly at 15 to 20 knots up to 50,000 feet. At still higher levels the direction was variable, with speeds of 7 to 10 knots. During the afternoon there were occasional showers which produced only a trace of precipitation.

On 6 May the weather deteriorated. There continued to be broken to overcast cirrostratus and altocumulus, the latter based at 12,000 feet. There were scattered cumulus at 2,000 feet in the morning, but by late evening there was a stratocumulus overcast at 1,000 feet with rain. The surface wind was east-northeast about 20 knots in the morning becoming east in the afternoon, and east-southeast by the end of the period. At higher levels the winds were southeast at 30 to 40 knots decreasing with height to 15 knots at 25,000 feet. Above this level were southwesterlies at 25 knots decreasing to almost calm with variable direction at 60,000 feet. During the day the base of the southwesterlies lowered to 20,000 feet and there were occasional rain showers. In the evening there was moderate and occasionally heavy continuous rain. Until 1800M there was only a trace of precipitation; in the next six hours from 1800M to midnight, 1.10 inches of precipitation were recorded.

During the first three hours of 7 May there was a stratocumulus overcast at 1,000 feet with rain. The low clouds then became scattered or broken fractocumulus, with some cumulonimbus observed during the afternoon of 7 May. The broken to overcast altostratus at 12,000 feet and the cirrostratus above 25,000

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feet continued. The surface wind was east-southeast about 18 knots, but occasionally was as high as 28 knots. The winds aloft were southeast at 30 knots at the lower levels decreasing to 15 knots at 12,000 feet. Above this level were southwesterlies at 20 to 35 knots. The base of the southwesterlies lowered progressively to 2,000 feet. Rain fell in various intensities during the day amounting to 2.20 inches in the first six hours; the total for the day was 2.93 inches.

On 8 May there were broken altocumulus with bases varying from 6,000 to 15,000 feet and cirrostratus near 30,000 feet. From time to time there was broken to overcast stratocumulus with rain. At 0100M lightning was reported to the north. The surface wind was south-southeast about 22 knots; it reached 32 knots in gusts and shifted to south at 18 knots after 1600M and then shifted to south-southwest after 2100M. The winds continued from the southwest at all levels to 50,000 feet with speeds of 20 to 40 knots. At the higher levels the speeds decreased and above 50,000 feet the winds were northeast at less than 10 knots. Rain showers and rain throughout the day produced 1.09 inches of measured precipitation.

### A.10.1 The Forecast

The final forecast was issued at 2300M, 8 May 1951, to cover the period from 0400M to 1200M, 9 May. The forecast was as follows:

Tropical storm JOAN was located at 081317M at 13.7°N, 160.8°E or approximately 175 miles northwest of Eniwetok. It is recurving to the northeast and is dominating the weather in this area.

3/10 Cu base 1500 top 5000. Few scattered tops to 15,000.
3/10 As base 12,000 top 13,000.
8/10 cirrus above 35,000.
Scattered showers.
Visibility 10 miles lowering to 1 mile in showers.
Light turbulence in cumulus clouds.
Surface winds variable 220 to 250 degrees 15–20 knots.
Height of tropopause 54,000 feet.

### A.10.2 Weather Conditions 9 May 1951, 0400–1200M

From 0400 to 0700 broken low clouds at 1800 feet with broken to overcast middle clouds at 14,000 feet prevailed. It is highly probable that nearly overcast high clouds existed at this same time at or above 30,000 feet. After 0700 the low and middle clouds became scattered and a high overcast was clearly visible.

Moderate rain showers occurred during the early part of the period but became light after 0500.

Visibility averaged 8 miles except in rain showers. During light showers the visibility was reduced to 5 miles; during the heavier showers the visibility was reduced briefly to 1 mile.

The surface wind was between SSW and WSW at an average of 17 knots.

An extract of the official record of surface weather observations taken at Eniwetok for the period 0400M to 1200M on 9 May 1951 follows:

| LOCAL TIME | CLOUDS TENTHS AND TYPE | | | SURFACE WIND (KNOTS) |
|---|---|---|---|---|
| 0350 | 2 Sc M20; | 8 Ac M140 | | SSW 19 |
| 0450 | 8 Sc M18; | 10 Ac E140 | | SW 23 |
| 0550 | 6 Sc M18; | 10 Ac E140 | | SW 23 |
| 0651 | 4 Cu E18; | 4 Ac E140; | 2 Cs E200 | SW 17 |
| 0751 | 3 Cu E18; | 3 Ac E140; | 9 Cs E300 | WSW 18 |
| 0851 | 2 Cu E18; | 3 Ac E140; | 10 Cs E300 | WSW 12 |
| 0951 | 4 Cu E18; | 1 Ac E140; | 10 Cs E300 | WSW 14 |
| 1051 | 5 Cu E20; | 10 Cs E300 | | SW 8 |
| 1151 | 4 Cu E20; | 10 Cs E300 | | SWS 13 |

Remarks: Moderate rain shower 0418 to 0427; light rain showers 0441 to 0452, 0520, and 1140 to 1145.

[redacted]

### A.10.3 Forecast and Actual Winds for H-Hour

The tabulation below shows several wind forecasts prepared at different times but all valid for H-Hour. The observed winds at H-Hour are given in the final column at the extreme right. Winds are shown from the surface to 60,000 feet in tens of degrees and knots.

| | G–2 Fcst | G–1 Fcst | G–1 Fcst | G–1 Fcst | G–1 Fcst | G Fcst | H Actual |
|---|---|---|---|---|---|---|---|
| Prepared "M" Time | 2300 | 1100 | 1800 | 2130 | 2300 | 0610 | |
| Surface | 15/10 | 20/16 | 24/10 | 18/15 | | 21/20 | 24/12 |
| 2 | 23/22 | 22/22 | | 23/29 | 23/29 | | 25/23 |
| 4 | 25/29 | 22/20 | | 24/33 | 24/33 | | 26/30 |
| 6 | 26/27 | 22/18 | 30/10 | 24/32 | 24/32 | 24/35 | 25/27 |
| 8 | 26/26 | 23/18 | | 25/31 | 25/31 | | 25/19 |
| 10 | 27/20 | 22/18 | 30/10 | 25/30 | 25/30 | 24/34 | 25/42 |
| 12 | 28/25 | 22/20 | | 26/30 | 26/30 | | 27/29 |
| 14 | 29/29 | 22/22 | | 26/29 | 26/29 | | 27/23 |
| 15 | 30/32 | | 30/12 | | | 24/28 | 26/23 |
| 16 | 30/32 | 25/24 | | 27/27 | 27/27 | | 25/24 |
| 18 | 30/29 | 26/20 | | 27/28 | 27/28 | | 25/20 |
| 20 | 29/26 | 26/20 | 30/15 | 28/24 | 28/24 | 24/16 | 23/20 |
| 22 | 29/26 | 26/26 | | 28/20 | 28/20 | | 21/22 |
| 24 | 31/28 | 26/28 | | 29/18 | 29/18 | | 20/21 |
| 25 | | | 33/20 | | | 26/20 | 19/22 |
| 26 | 32/32 | 26/30 | | 30/18 | 30/18 | | 17/18 |
| 28 | 30/33 | 26/32 | | 30/23 | 30/23 | | 20/16 |
| 30 | 28/35 | 26/30 | 33/25 | 28/25 | 28/25 | 28/20 | 23/21 |
| 35 | 27/30 | 27/25 | 33/25 | 23/20 | 26/22 | 27/23 | 27/17 |
| 40 | 24/20 | 27/20 | 30/20 | 16/12 | | 16/12 | 29/16 |
| 45 | 23/10 | 25/20 | 30/20 | 03/17 | | 36/15 | 17/03 |
| 50 | 29/06 | 11/10 | 27/15 | 30/18 | | 29/10 | 31/13 |
| 55 | 09/06 | 15/08 | 09/10 | 06/14 | | 06/12 | 02/10* |
| 60 | 30/14 | 23/06 | 09/10 | 03/10 | | 03/14 | |

* 3 hrs later.

## A.11 Typhoon JOAN

### A.11.1 Origin

The winds at Nauru indicated a disturbance in the vicinity as early as 2100Z, 29 April 1951. Analysis of the pressure field revealed a quasi-stationary trough extending from the north into the Nauru area. Small low pressure cells had appeared repeatedly in the Gilbert and Ellice Islands just prior to the quoted time, but no definite center of disturbance could be fixed.

On 27 April a pronounced equatorial wave passed Bikati, as evidenced by graphical wind time sections. This wave carried westward to a longitude of 168°E on 28 May, but it was not apparent after that time. Although this was the same longitude at which the disturbance which was to become JOAN first definitely appeared on 2 May (see figure A.2), it is believed that the time lag would preclude the possibility that the wave and JOAN were identical. The wave may have had some bearing on the movement of the disturbance northward across the equator.

JOAN was first analyzed as a vortex on the 1,500 foot streamline chart for 0300Z, 2 May 1951, at the position indicated in figure A.2. The low level wind shifts at Nauru suggested an indraft to the east, moving northwest. It is interesting to note that this location was on or near the position of a very strong and persistent line of streamline convergence that had extended northwestward toward an older vortex during the last days of April. The new vortex moved approximately as indicated in figure A.2 and developed slowly, reaching typhoon intensity probably about 7 May. Although the wind speeds were at first moderate, the associated weather was heavy throughout the life of the storm JOAN. The 24-hour rainfall at Nauru amounted to 8.16 inches for the period ending 0000Z, 2 May; this was followed by 1.16 inches in the next 24 hours.

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[redacted]

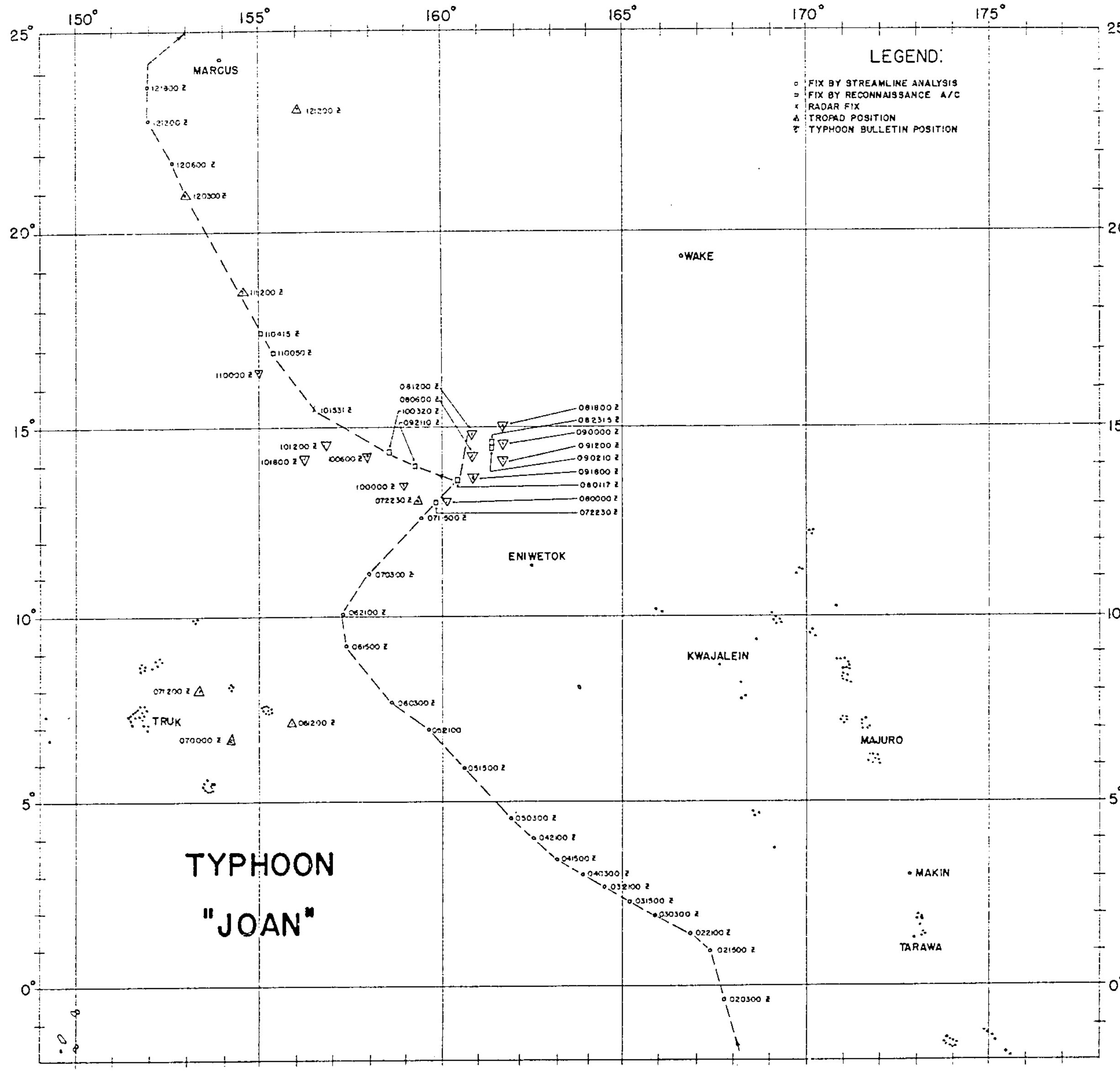


FIGURE A.2—Origin and Movement of Typhoon JOAN

### A.11.2 Early Stage

As the vortex approached within 200 miles of Kusaie, the surface wind shifted from southerly to east-northeast about 20 knots, with gusts exceeding 35 knots at 2100Z, 3 May. On 5 May thunderstorms with 1.61 inches of rain were reported at Kusaie. Extensive intermediate cloudiness with intermittent rain and southerly to westerly winds from the surface to about 20,000 feet prevailed at Kusaie from this time until 10 May, when the storm had moved far to the northwest, as shown in figure A.2.

At Ponape, winds remained moderate, although the vortex character of the approaching storm was becoming more pronounced. It should be noted that JOAN passed southwest of Kusaie, but northeast of Ponape. There was considerable rain on 5 May and by 0300Z, 6 May, the wind had shifted from easterly to southwesterly, continuing southerly, but very light, until 11 May. Thereafter, a period of calm was followed by light northerly winds. Throughout the area, the passing of JOAN was followed by unusually light winds.



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### A.11.3 Mature Stage

At Eniwetok on 7 May the surface wind became southeast with sustained speeds as high as 32 knots. Rainfall increased to 2.20 inches in the 18 hours from 0600Z, 6 May to 0000Z 7 May and 1.51 inches for the following 24 hours. Late on 7 May southwesterly winds appeared aloft and early on 8 May these extended down to the surface. On 8 May the Eniwetok rawinsonde station made runs every three hours in order to better track the storm while it was in the vicinity.

During the mature stage of typhoon JOAN aerial reconnaissance was invaluable in tracking the center and determining the intensity. The first special efforts to locate the storm by aircraft were made on 5 May. However, it was not considered necessary to dispatch special search missions, but instead the regular GOONEY HOW and VULTURE GEORGE tracks were called for. Neither flight, however, reached the storm center, although between Truk and Ponape VULTURE GEORGE reached what was first thought to be the center (note the first Tropad position in figure A.2), but was later analyzed as the neutral point. Certain sectors about a neutral point have light convergent winds just as in the eye of a storm and it was apparently such a sector that VULTURE GEORGE entered. The fact that no strong winds or especially bad weather were encountered while entering this region, combined with the definite cyclonic circulation noted to the northeast, leads one to the conclusion that the storm center had already moved to the north.

In the later stages of development, a number of regular and special reconnaissance flights entered the storm. On 7 May, at 2230Z, a GOONEY Special fixed the center. On 8 May both GOONEY HOW and GOONEY GEORGE entered the typhoon. On 9 and 10 May special GOONEY flights determined the storm center and on 11 May a special VULTURE flight entered the storm.

Heavy precipitation associated with the typhoon was concentrated in narrow bands which spiraled toward the center. These bands are asymptotes of streamline convergence. In the case of JOAN only one such band was positively identified, but it was very long, vigorous and persistent. This line ran from a neutral point at 4°N, 165°E, a bit west of north, then spiraled into the storm. At Eniwetok the heaviest rain occurred as this line moved eastward over the station. The line tended to rotate counterclockwise about the storm center and reached Kwajalein about 1200Z, 8 May. With its arrival, Kwajalein reported a shift from easterly to westerly winds and 2.75 inches of rain in six hours.

The upper flow during the early stages of development was easterly in the southern Marshalls. At 30,000 and 40,000 feet a belt of anti-cyclones near 10°N gave easterly winds over Nauru, becoming southeasterly near Kusaie and Ponape. A closed cyclonic circulation was detected at 10,000 feet on 3 May and at 20,000 feet on 5 May. In both cases it was approximately above the low level circulation. By this latter time, extensive southerlies had set in over the western Marshall and the eastern Caroline Islands. At 10,000 feet, the area covered by the cyclonic circulation increased until it dominated the greater part of the Marshalls and Carolines by 6 May. Thereafter the patterns at 10,000 feet and 1,500 feet remained quite similar. From 7 May to 9 May, JOAN dominated the circulation of the entire area. The normal easterlies were replaced by westerlies over all the Northern Marshalls and the Carolines at least up to 14,000 feet.

### A.11.4 Dissipation

Meanwhile, an upper trough in the polar westerlies, apparent at 20,000, 30,000 and 40,000 feet, had been approaching from the west. On 7 May it extended southward between Marcus and Wake and behind it was an anticyclonic cell bounded roughly by the Mariannas, the Philippines, the Ryukyus and the Bonins. The typhoon had been moving northward toward the upper trough, but on 9 May it came under the area of light winds at the southern end of the trough and it remained quasi-stationary there for about 40 hours. Meanwhile, the upper trough moved on toward Midway and the anti-cyclonic cell moved in behind it to the north of JOAN. This placed the typhoon in a deep easterly current and on 9 May it started moving WNW about 10

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knots. Reconnaissance reports indicated that it was weakening.

By 11 May, the storm had moved into an area where observations were too sparse for reliable analysis, but it appeared to have weakened considerably. The winds over the Northern Marshalls and Carolines had become very light and without a definite flow pattern. The storm curved clockwise around the eastward moving anti-cyclone, which had come between the storm vortex and the polar trough and was absorbed by the polar westerlies near Marcus Island on 12 May. By this time, normal trade flow had returned to all the Marshall and Caroline Islands and the storm showed no further influence in the tropics.

## A.12 Weather Conditions Preceding ITEM Shot

The Eniwetok Atoll area was under the influence of a relatively undisturbed east-northeast trade flow during the period discussed, i.e., 21 May to 25 May 1951.

On 21 May there were scattered cumulus at 2,000 feet which increased to broken occasional showers, and scattered to broken cirrus and cirrostratus near 30,000 feet. Early in the morning there were scattered altocumulus at 16,000 feet. The surface winds were ENE, averaging 18 knots. The winds aloft were ENE up to 20,000 feet with speeds of 25–30 knots at lower levels decreasing to 10–15 knots at the higher levels. Above 20,000 feet the winds were southwest at speeds up to 50 knots. There were occasional rain showers during the day, but only a trace of precipitation was recorded for the 24 hour period.

On 22 May conditions were little changed except for an increase in the amount of low clouds and precipitation. There were scattered to broken cumulus at 2,000 feet with scattered altocumulus at 8,000 feet and scattered to broken cirrus near 30,000 feet. The surface winds, and winds up to 10,000 feet continued ENE at 18 to 20 knots. However, from 10,000 to 20,000 feet there were southeasterlies at 10 knots. Above these were stronger southwesterlies reaching 45 knots. There were numerous light showers during the day bringing the total precipitation to 0.03 inches.

Throughout the 23rd of May the cumulus clouds at 1,800 to 2,000 feet were scattered, but there were broken to overcast cirrus and cirrostratus. The surface winds were ENE at 18 to 20 knots. During the first part of the day the upper winds were easterly at 25 to 30 knots becoming very light southerly between 18,000 and 20,000 feet; later, northeasterlies at 8 knots were established in this layer. At 30,000 feet and higher the winds were southwesterly at speeds up to 30 knots. Three very light showers resulted in only a trace of precipitation.

The conditions on 24 May were much the same as on the 23rd. There were scattered cumulus at 1,800 to 2,000 feet and broken to overcast cirrus near 35,000 feet. Surface winds continued ENE at 18 knots. Northeasterlies continued to 12,000 feet, but were very light except in the lowest layers. At higher levels the speeds became very light and the directions variable. One very light shower occurred in the early morning.

### A.12.1 The Forecast

The final forecast was issued at 2300M, 24 May 1951, to cover the period from 0000M to 1000M, 25 May. The forecast was as follows:

"2/10 to 4/10 Cu and Sc base 2,000 top 4,000 with few scattered tops 8,000.
1/10 to 3/10 As and Ac in thin patches at 8,000, 15,000 and 24,000.
4/10 to 7/10 cirrus above 30,000.
Scattered light showers.
Visibility 10 miles.
Surface winds 70 degrees 18 to 23 knots.
Height of tropopause 55,000 feet."

### A.12.2 Weather Conditions 25 May 1951, 0000M–1000M

Prevailing cloud cover was scattered low clouds at 1,800 feet with a few scattered middle clouds at 16,000 feet and scattered to broken high clouds above 30,000 feet. At the end of the period the high clouds became almost overcast at 35,000 feet.

One light shower occurred at the start of the period, giving only a trace of precipitation.

Visibility averaged 12 miles.

The surface winds averaged ENE at 16 knots.

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An extract of the official record of surface weather observations taken at Eniwetok for the period 0000M to 1000M on 25 May 1951 follows:

| LOCAL TIME | CLOUDS TENTHS AND TYPES | SURFACE WINDS (KNOTS) |
|---|---|---|
| 0050 | 5 Cu E18; 2 Ac E160; 3 Ci E350 | ENE 20 |
| 0150 | 2 Cu E18; 1 Ac E160; 3 Ci E350 | ENE 16 |
| 0250 | 3 Cu E18; 1 Ci E350 | ENE 13 |
| 0350 | 2 Cu E18 | ENE 17 |
| 0450 | 1 Cu E18; 1 Sc E20 | ENE 18 |
| 0550 | 3 Cu E18 | ENE 13 |
| 0650 | 2 Cu E18; 1 Ac E160; 1 Cs E350 | ENE 15 |
| 0750 | 4 Cu E18; 3 Ci E350; 2 Cs E400 | ENE 17 |
| 0851 | 4 Cu E22; 9 Cs E350 | ENE 18 |
| 0951 | 3 Cu E22; 9 Cs E350 | ENE 15 |

Remarks: A light rain shower occurred from 0044 to 0054 giving a trace of precipitation.

### A.12.3 Forecast and Actual Winds for H-Hour

The tabulation below shows several wind forecasts prepared at different times but all valid for H-Hour. The observed winds at H-Hour are given in the final column at the extreme right. Winds are shown from the surface to 60,000 feet in tens of degrees and knots.

| | I–2 Fcst | I–1 Fcst | I–1 Fcst | I–1 Fcst | I Fcst | H Actual |
|---|---|---|---|---|---|---|
| Prepared "M" Time | 2300 | 1100 | 1800 | 2300 | 0400 | |
| Surface | 07/18 | 07/18 | 07/18 | 07/18 | 07/18 | 07/13 |
| 2 | 08/18 | 08/25 | | 07/25 | | 06/26 |
| 4 | 08/20 | 08/19 | | 07/25 | | 09/21 |
| 5 | | | 08/19 | | 08/15 | 09/14 |
| 6 | 09/15 | 08/14 | | 06/20 | | 09/14 |
| 8 | 08/12 | 09/12 | | 05/15 | | 08/10 |
| 10 | 07/10 | 09/12 | 15/10 | 03/05 | 09/05 | 09/04 |
| 12 | 06/08 | 09/10 | | 36/05 | | 32/03 |
| 14 | 04/06 | 08/10 | | 30/05 | | 25/09 |
| 15 | | | 24/08 | | 30/05 | |
| 16 | 03/05 | 08/10 | | 30/05 | | 28/07 |
| 18 | 19/05 | 07'12 | | 33/05 | | 29/07 |
| 20 | 22/05 | 07/14 | 09/15 | 33/05 | 33/05 | 29/08 |
| 22 | 24/05 | 07/14 | | 33/05 | | 32/09 |
| 24 | 25/08 | 03/12 | | 36/05 | | 34/06 |
| 25 | | | 02/15 | | 03/10 | 25/10 |
| 26 | 24/12 | 36/10 | | 03/10 | | 03/14 |
| 28 | 24/17 | 33/10 | | 03/10 | | 03/12 |
| 30 | 24/20 | 29/12 | 30/15 | 36/10 | 35/10 | 36/09 |
| 35 | 23/25 | 26/20 | 26/20 | 18/15 | 25/10 | 25/08 |
| 40 | 22/35 | 24/25 | 21/25 | 15/10 | 15/10 | 28/07 |
| 45 | 21/26 | 26/15 | 26/18 | 18/05 | 12/05 | 15/07 |
| 50 | 24/14 | 30/12 | 26/15 | 36/10 | 36/10 | 33/09 |
| 55 | 26/10 | 02/10 | 02/10 | 36/10 | 36/10 | |
| 60 | 09/10 | 07/10 | 07/10 | 06/10 | 06/10 | |

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# Appendix "B"

# COMMENTARY ON ENIWETOK WEATHER

## B.1 General

Day to day variations of surface temperature, pressure, and humidity are so small at Eniwetok that they are insignificant in describing the weather. In fact, the changes during a particular day are ordinarily much greater than for any longer period. Fortunately, these elements have little operational significance compared to the day-to-day changes which do occur in winds, cloud, and precipitation.

## B.2 Troughs in the Westerlies (Polar Troughs)

No strong, clearly defined troughs in the westerlies were noted in the Marshall Islands area during the operation. Cold fronts had definitely lost their identity as such before they reached Wake Island. Weak, indefinite troughs were traced across Wake Island, but lack of data to the northwest, north, and northeast of Eniwetok made exact analysis of these situations impossible. It appeared that some of these weak troughs stagnated in the region between Wake Island and Eniwetok, i.e., 10°N to 20°N, and gradually assumed an east-west orientation. The passage or proximity of these ill-defined troughs lowered the base of the upper westerlies at Wake and Eniwetok. On many occasions, the base of the westerlies would lower more at Eniwetok than at Wake; closed cyclonic circulations often were suspected in such situations along the axis of the general east-west trough. Most of the troughs were more pronounced at the higher levels, especially above 20,000 feet. These trough situations did not produce any prolonged bad weather or extensive middle clouds and showers. Above 20,000 feet, however, the more pronounced troughs were usually associated with increased cirrus clouds, and it was suspected that, by some indirect influence on the lower easterly flow, small increases in middle clouds and shower activity could have been produced. Unfortunately, no definite relationships were discovered.

## B.3 Easterly Waves

Few, if any, easterly waves of the Caribbean type were found in the Eniwetok Area. Some forecasters attempted to follow pseudo-easterly waves on the surface pressure map, but little continuity could be maintained. Waves in the easterly flow could be found more easily on the 1,500 foot chart, where they appeared as weak waves of small amplitude. Most of them were sharply limited in extent, the majority remaining south of 5°N. A few seemed to bring increased precipitation to Kwajalein, but rarely could weather at Eniwetok be associated with their passage.

## B.4 Convergence Lines and Zones

Many lines and zones of convergence were found in the analysis of the streamline charts. Usually, poor weather was accompanied by obvious streamline convergence at the 1,500 foot level. Convergence at upper levels was not necessarily associated with any definite weather pattern.

The daily 1,500 foot and 10,000 foot streamline analysis indicated that, in general, the most pronounced line or zone of convergence extended westward from near Tarawa between the equator and 5°N. It varied from day to day in position, orientation, extent, and intensity. On some days it could not be found. Although the weather in this zone varied greatly, all strong zones of convergence were accompanied by extensive altostratus clouds. It is interesting to note that the preferred track of the small waves in the easterlies, described above, seemed to coincide with this mean line of convergence.

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Some forecasters referred to this main line of convergence as the "Intertropical Convergence Zone;" others recognized the convergent character of the line only when the streamline analysis and associated weather justified it. According to most studies, the "Intertropical Convergence Zone" should have been south of the equator during March, April and May. Whether it existed in the southern Marshalls during Operation GREENHOUSE was a matter of lively discussion among forecasters. It appeared that the mean line of convergence mentioned above marked the boundary between the strong, northeast trade winds and a wide belt of relatively light, variable winds that extended to approximately 15°S. In order to avoid misunderstandings and undesirable connotations, especially in weather briefings, it was decided that the terms, "Intertropical Convergence Zone," "Intertropical Front," or "Equatorial Front" would not be used, but rather that attention would be directed to individual lines of convergence.

Only two intense convergence lines influenced the weather at Eniwetok during March, April and May. Both were asymptotes of streamline convergence connected with well-developed vortices, the tropical storms "GEORGIA" and "JOAN." In each of these cases, broken to overcast clouds at all levels, rain, and heavy showers persisted for about 48 hours.

Extrapolation of the erratic displacements of convergence zones was attempted and proved to be of value in forecasting. It was noted that a pronounced southerly flow over the southern Marshalls at the middle levels aloft, i.e., 10,000 to 40,000 feet, was associated with a northward displacement of the strong convergence zones; while a pronounced northerly flow aloft was associated with southward displacement, weakening, and even dissipation of such zones. The usefulness of this principle was limited by the difficulty of predicting the general southerly and northerly currents.

## B.5 Surges and Areas of Convergence

Surges and areas of convergence in the northeast trade flow appeared to play a dominant role in causing shower activity at Eniwetok. In this report, the term "surge" means general speed convergence over a large area and applies only for such situations in the trades. Large-scale surges or sudden strengthening of the trades which progressed down-stream similar to compressional waves were most common following the passage of a polar anti-cyclone just north of the trade wind belt. The position, movement, and strength of polar anticyclones were all considered important in forecasting surges. Qualitative rules of thumb were applied by various forecasters with a fair degree of success. In general, surges were expected shortly after the passage of strong polar anticyclones north of Wake Island if the southern portion of the associated polar front had dissipated and the anticyclone was forecast to merge with the sub-tropical high pressure belt. Increased shower activity associated with these large scale surges persisted at Eniwetok about 12 to 36 hours.

Small areas of speed convergence were observed in trade flow that was otherwise uniform. The resulting small-scale shower areas were impossible to predict because the observations were too sparse or possibly because such situations were too short-lived. Several of these situations were observed on the AN/FPS-3 radar on Eniwetok Island. The showers were arranged in definite lines, 20 to at least 60 miles long, oriented approximately normal to the general trade wind flow. The activity along the lines waxed and waned rather rapidly, indicating that they were relatively local phenomena. It is suggested that many reported examples of so-called "multiple intertropical convergence zones" may have been this type of phenomenon. Analysis of the speed field left much to be desired even when special air reconnaissance missions took fifteen-minute observations on an upwind track from Eniwetok. Only limited success was achieved with such attempts to analyze the windspeed field. Shower activity associated with these smaller areas of speed convergence persisted usually for 4 to 12 hours.

At Eniwetok, both large surges and small areas of speed convergence in the trades resulted in similar weather activity. The trade cumulus increased in amount and vertical ex-



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tent, the tops reaching 8,000 to 12,000 feet. Showers became more frequent. Patches of altocumulus or stratocumulus were associated with the trade cumulus in the shower areas.

## B.6 Tropical Storms

According to known studies and previous weather data available, tropical storms are rare in the Marshall Islands during the months of March, April, and May. However, during Operation GREENHOUSE, two storms developed in this region and reached typhoon intensity. Both storms had marked effect on the weather and operations at Eniwetok. (See Appendix "A".) Although reports of typhoons in the Marshall Islands are very scanty it is believed that they actually do occur fairly frequently and are not reported because of the lack of sufficient observation stations. Probably neither typhoons GEORGIA or JOAN would have been reported, in their earlier stages for example, without the use of weather reconnaissance. Undoubtedly many cases of heavy, prolonged rain in the area actually are caused by undetected typhoons.

## B.7 Remarks on Miscellaneous Weather Phenomena

### B.7.1 Showers

Except under conditions of pronounced low-level divergence, showers were always prevalent in the area around Eniwetok. When very many reports were available, land station and "POMAR" reports being supplemented by patrol aircraft, local flights, and air reconnaissance, it was evident that scattered light showers were common. This type of shower covered only a small area, seldom, if ever, the whole of Eniwetok Island, which is only about two and one half miles in length. Such showers occurred as frequently over the ocean as over the lagoon. They fell from cumulus, usually ordinary trade cumulus grouped in a small family or short line with bases near 1,800 feet and tops above 10,000 feet and sometimes as low as 6,000 feet. Light sprinkles of very small drops fell frequently from low clouds no more than 2,000 to 3,000 feet thick. Due to the moderate to fresh prevailing wind, showers gave an impression of heavy rain, but their duration was usually short, five to ten minutes, and seldom did the rain gauge collect enough rainfall to measure; the amount was usually recorded as a "trace."

A particularly striking case of the complete precipitation of a tropical cumulus cloud was observed by three forecasters. In this case, a rainbow extended from a very small wisp of isolated cloud to the ocean surface. No other cloud was within several miles of this rainbow.

### B.7.2 Clouds

The normal cloud cover at Eniwetok comprised scattered trade cumulus at 2,000 feet with tops at 6,000 or 8,000 feet and scattered to broken cirrus above 30,000 feet. Relatively few middle clouds were observed. The middle clouds observed were above 10,000 feet, mostly in the 12,000 to 20,000 foot range. It was difficult to get measurements on the height of cirrus-type clouds, but in one case the base was checked by a reconnaissance aircraft as variable 26,000 to 28,000 feet. On another occasion, a jet fighter reported the base of the cirrus above his flight altitude of 38,000 feet.

Middle and high clouds appeared to increase and thicken with a prolonged southerly flow aloft. They appeared to decrease and dissipate with prolonged northerly flow aloft.

A marked increase in cirrus-type clouds was also observed with westerly winds aloft, especially when a sharp east-west shear line or trough existed near the station above 20,000 feet. This situation appeared many times between Eniwetok and Wake. Reports from reconnaissance aircraft showed a sharp boundary to the cirrus clouds at the trough axis or shear line, with no cirrus clouds appearing to the north of the trough. South of the trough axis, variable amounts of cirrus clouds from broken to overcast were found in an east-west band about 300 miles wide. On several occasions, when reliable reconnaissance wind reports were available near the east-west trough or shear line, it was apparent that this line consisted of small cyclonic eddies and related cols. Upper east-west troughs below 20,000 feet with variable amounts of associated middle clouds, usually altocumulus, were also observed. These lower level troughs appeared much less frequently than the higher ones.

### B.7.3 Diurnal Variations

Diurnal variations in cloud cover were small. When the trades in the local area were undisturbed, the low cloud cover frequently reached a maximum at, or just before, sunrise. A tendency for a maximum of showers between midnight and sunrise was also observed. Both of these maxima were much more pronounced when, above the surface moist layer, usually 4,000 to 6,000 feet thick, the following set of conditions were satisfied: (1) a temperature inversion existed immediately above the moist layer; (2) the air above the inversion was very dry; (3) there were no significant amounts of middle or high clouds. Apparently, the top of the moist layer was an effective radiating surface under these conditions. On several occasions, it was noted that the temperature at the top of the moist layer (which was also the base of the temperature inversion) decreased three to four degrees centigrade from afternoon to early morning. Therefore, it seems logical to assume that radiation played a large part in the diurnal maxima of cloudiness and precipitation at Eniwetok.

### B.7.4 Lagoon Temperatures

It has been suspected for some time by tropical meteorologists that the temperature of the sea surface in the relatively shallow lagoons of atolls is slightly higher than that in the open ocean. As a result it has been suggested that cloudiness and shower activity should be slightly greater in the vicinity of atolls, at least during periods of relatively slight air movement. This idea was investigated at Eniwetok on 16 May 1951. Sea surface temperatures were measured in the open ocean to the east of the atoll, and a series of temperatures was measured completely across the lagoon on a triangular course to eliminate any effects due to trans-lagoon currents. The total variation in temperature was only 0.8° C. The temperature in the open ocean was 27.6° C and in the lagoon it ranged from 27.1° C to 27.9° C. Cloudiness consisted of 1/10 to 2/10 trade cumulus. No showers were observed. The entire series of observations was made in the forenoon. Surface winds were from the NE to ENE 12–18 knots. Free air temperatures ranged from 27.0° C at 0800M to 28.0° C at 1100M.

It is concluded from this brief study that the sea surface temperatures in the lagoon did not differ appreciably from those in the open ocean during this period of more or less normal trade wind conditions. It is possible that some effect might be observed during periods of stagnant air flow, but this appears unlikely.

### B.7.5 Upper Winds

The upper wind structure above the trades seemed to be very complex. The North Pacific anticyclonic was usually split into several large cells at 10,000 feet and above. The movements of these cells and their associated cols or neutral points were difficult to follow with the limited reports available. The stagnation of the southern portion of troughs in the westerlies in this area and the formation of east-west troughs between 10°N and 20°N also complicated the upper flow patterns. Cyclonic circulations between Wake and Eniwetok were observed frequently above 20,000 feet. In spite of these difficulties, careful streamline analysis of the upper levels south of 25°N, using the increased amount of data available in the Marshall Islands area, enabled forecasters to use limited extrapolation in upper-wind forecasting with a fair degree of success.

## B.8 Forecasts

All forecasts issued at the weather central were verified by checking against the actual weather conditions at or during the verifying time. A rough check of the verification of forecasts against persistence showed that persistence was very good for 24 or 36 hours, but the forecasts issued were always better.

Most forecasters on Operation GREENHOUSE became aware of the fact that many of their previous concepts about tropical meteorology in the Central Pacific required revisions in light of the extensive data available for the Marshall Islands area. It appears that knowledge of tropical meteorology is indeed meager, and that much work remains to be done before satisfactory solutions can be found for specific and detailed forecasting problems. The large amount of weather data collected during Operation GREENHOUSE offers an excellent opportunity for continued research in tropical meteorology.

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# Appendix "C"

# RADIOACTIVE PARTICLE FALL-OUT PREDICTIONS

## C.1 General

A critical consideration in the detonation of atomic weapons is the ever present possibility of fall-out of radioactive particles from the atomic cloud. While it is strongly believed that the probability of accumulating a dangerous or lethal dose is extremely remote except in the immediate downwind area from zero point for a short period following detonation, there are other factors to be considered. Due to the nature of radioactivity, personnel have a strong aversion to exposure, however small and insignificant. In addition, various precision instruments and film used in scientific experiments are adversely affected if background intensity rises appreciably in the installation or storage areas.

Prior to the detonation of DOG shot, all evidence, thought and opinion pointed toward only two types of particle fall-out: (1) the immediate fall-out in the area downwind from zero of relatively large and dense particles of dirt, debris, and unfissioned particles containing large amounts of radioactivity, and (2) the much later (days and weeks) fall-out of small particles which had drifted in the rapidly dispersing atomic cloud to great distances from zero, and contained very low levels of radioactivity.

## C.2 DOG Shot Fall-Out

This concept remained valid until about 2 hours after the firing of DOG shot, when radiological safety monitors noted sudden increase in radioactivity from background to around 50 milliroentgens per hour. Although this amount of radiation presented no hazard whatsoever to personnel, considerable concern was felt concerning the possible effect upon film and delicate instrumentation. No plausible theory could be advanced immediately to explain the fall-out.

Detailed investigation of the phenomenon began immediately. The entire upper wind field above Eniwetok was analyzed carefully and it was found that any fall-out which occurred should have started from an elevation of 30,000–35,000 feet. Rates of fall of particles were then studied, assuming Stokes Law to be valid, and it was demonstrated that particles reaching the ground from 30,000 to 35,000 feet at about 2 hours after shot time should be in the size range of about 70–170 microns, depending on their density (around 2.5 if coral sand or 7.5 if iron). (See Table C.1.) These conclusions were reached by mid-afternoon of DOG Day, before any actual particles had been studied. By the morning of D plus 1 day, however, actual radioactive particles had been isolated and examined. These were light colored, irregular grains of coral sand ranging from 50 to 200 microns in diameter, with small, dark specks of radioactive material adhering strongly to their outer surfaces. The next day a number of dense, dark globules were discovered in a few areas where eddy currents in the surface wind had concentrated them in protected corners in buildings and vehicles. These globules were in the same general size range as the sand grains and appeared to be iron. The active radioactive material was in the form of minute, dark specks either included in the globules or attached to their outer surfaces.

It was apparent, therefore, that the basic theory concerning the mode of arrival of the radioactive material on Parry Island was essentially correct. The method developed for predicting fall-out was tested on subsequent shots and provided an entirely satisfactory solution of the fall-out problem.

## C.3 Basic Ballistic Concept

Any object falling freely in the atmosphere is affected by all winds from the initial altitude

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to the surface over the total time that the fall requires. Particles with diameters less than a few millimeters reach a nearly constant rate of fall very quickly after starting their descent. If a particle falls from point M at an altitude of 1,000 feet at the rate of 1,000 feet per hour, and the effective wind during the fall is from the west with a speed of 20 knots, the particle must reach the surface at N, 20 miles east of M.

Certain assumptions concerning the actual conditions enter into the problem. These assumptions are listed and evaluated below:

1. That the rate of fall of individual particles is constant.
2. That the measured wind at any altitude is representative of the total effective wind in a layer halfway to the measured winds at the levels below and above; i.e., if winds are measured at 5,000 feet intervals, the 35,000 foot wind is the effective wind from 32,500 feet to 37,500 feet.
3. That the wind field is unchanging in space and time.
4. That there is no precipitation.
5. That the effect of vertical air currents can be ignored.
6. That the atomic cloud rises instantaneously and vertically over zero point.

The validity of the assumptions varies somewhat with the actual situation:

1. The rate of fall of particles is slightly dependent upon the density and temperature of the air but this effect is relatively small and can be neglected for practical purposes.
2. If the layers through which the wind is assumed constant are kept fairly thin, no great error will be involved by assuming the wind at each level to be representative of a layer of finite thickness. In practice, 1,000 foot layers were used from the surface to 10,000 feet; 2,000 foot layers were used from 10,000 feet to 30,000 feet; and 5,000 foot layers were used above 30,000 feet. This is believed to be a fair compromise between accuracy and convenience.
3. The assumption that the wind field is static is the one most likely to lead to inaccuracy. For a localized area the assumption of no change in *space* is reasonably satisfactory. During periods of rapid local changes in the wind field, however, the local change with *time* should definitely be taken into account.
4. The effect of precipitation on falling particulate matter is to speed its descent. This usually results in a broadening of the area of fall-out.
5. The effect of vertical air currents can usually be ignored safely for relatively large particles—above perhaps 10–20 microns—because in the course of travel along a path of a few tens of miles while falling for a few hours particles will normally encounter about as many up-drafts as down-drafts. With very small particles, on the other hand, which fall only a few hundred feet per day, broad scale vertical currents of the same magnitude as the rate of fall may be encountered and these particles may remain in suspension for very long periods. This situation does not concern the present discussion, however, because the present technique is intended to cover only the period within a few hours or tens of hours from shot time.
6. For practical purposes, the atomic cloud may be considered to rise instantaneously and vertically over zero point, since it reaches its maximum height in less than fifteen minutes and during this time moves but a few miles.

The rate of fall of spherical particles below about 200 microns in diameter follows Stokes Law fairly closely. This empirically derived law may be written as:

$$\text{(a)} \quad c = \frac{2r^2 g(s_1 - s_2)}{9n}$$

$c$ is the velocity of fall in cm/sec.
$r$ is the particle radius in cm.
$s_1$ is the density of the particle.
$s_2$ is the density of air (very small relative to $s_1$).
$n$ is the dynamic viscosity of air in poises.
$g$ is the acceleration of gravity.

This equation may be rewritten in the following form after supplying constants and changing to English units:

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(b) $C = .00592\, s_1 D^2$ (for air at 70°F)
C is the velocity of fall in feet/min.
D is the particle diameter in microns.

Above about 400 microns up to about 5,000 microns the following empirical expression is fairly satisfactory:

(c) $C = 24.9 \sqrt{D s_1}$

Between 200 and 400 microns the rate of fall lies between (b) and (c).

The following table gives directly the time in hours required for spherical particles of various densities to reach the surface from various elevations, assuming that expression (b) is valid. The particle sizes are in microns.

TABLE C.1

| TIME | 10,000 FEET | | | | | 20,000 FEET | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DENSITY | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 1 | 167 | 118 | 97 | 84 | 75 | — | 167 | 137 | 118 | 106 |
| 1½ | 137 | 97 | 79 | 68 | 61 | 193 | 137 | 112 | 97 | 87 |
| 2 | 118 | 84 | 68 | 59 | 53 | 168 | 118 | 97 | 84 | 75 |
| 2½ | 106 | 75 | 61 | 53 | 47 | 150 | 106 | 87 | 75 | 67 |
| 3 | 96 | 68 | 56 | 48 | 43 | 137 | 96 | 79 | 68 | 61 |
| 3½ | 90 | 63 | 52 | 45 | 40 | 127 | 90 | 73 | 63 | 57 |
| 4 | 84 | 59 | 49 | 42 | 38 | 119 | 84 | 68 | 59 | 53 |
| 5 | 75 | 53 | 43 | 38 | 34 | 106 | 75 | 61 | 53 | 47 |
| 6 | 68 | 48 | 39 | 34 | 30 | 97 | 68 | 56 | 48 | 43 |
| 7 | 63 | 45 | 36 | 32 | 28 | 90 | 63 | 52 | 45 | 40 |
| 8 | 59 | 42 | 34 | 30 | 26 | 84 | 59 | 48 | 42 | 37 |
| 10 | 53 | 37 | 31 | 27 | 24 | 75 | 53 | 43 | 37 | 33 |
| 12 | 48 | 34 | 28 | 24 | 22 | 68 | 48 | 39 | 34 | 30 |
| 15 | 43 | 31 | 25 | 22 | 19 | 61 | 43 | 35 | 31 | 27 |
| 18 | 40 | 28 | 23 | 20 | 18 | 56 | 40 | 32 | 28 | 25 |
| 24 | 34 | 24 | 20 | 17 | 15 | 48 | 34 | 28 | 24 | 22 |
| 30 | 30 | 22 | 17 | 15 | 13 | 43 | 30 | 25 | 22 | 19 |
| 36 | 28 | 20 | 16 | 14 | 12 | 39 | 28 | 23 | 20 | 18 |
| 48 | 24 | 17 | 14 | 12 | 11 | 34 | 24 | 20 | 17 | 15 |
| 60 | 22 | 15 | 13 | 11 | 10 | 31 | 22 | 18 | 15 | 14 |
| 72 | 20 | 14 | 11 | 10 | 9 | 28 | 20 | 16 | 14 | 12 |

| TIME | 30,000 FEET | | | | | 40,000 FEET | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DENSITY | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 1 | — | 206 | 167 | 145 | 130 | — | — | 193 | 167 | 150 |
| 1½ | — | 167 | 137 | 118 | 106 | — | 193 | 160 | 137 | 125 |
| 2 | 206 | 145 | 118 | 102 | 92 | — | 168 | 137 | 119 | 106 |
| 2½ | 184 | 130 | 106 | 92 | 82 | 213 | 150 | 123 | 106 | 96 |
| 3 | 168 | 119 | 96 | 84 | 75 | 193 | 137 | 112 | 97 | 87 |
| 3½ | 155 | 110 | 90 | 78 | 70 | 179 | 127 | 104 | 90 | 80 |
| 4 | 145 | 103 | 84 | 73 | 65 | 168 | 119 | 97 | 84 | 75 |
| 5 | 130 | 92 | 75 | 65 | 58 | 150 | 106 | 87 | 75 | 67 |
| 6 | 119 | 84 | 68 | 59 | 53 | 137 | 96 | 79 | 68 | 61 |
| 7 | 111 | 78 | 63 | 54 | 49 | 127 | 90 | 73 | 63 | 57 |
| 8 | 103 | 73 | 59 | 51 | 45 | 119 | 84 | 68 | 59 | 53 |
| 10 | 92 | 65 | 53 | 46 | 41 | 106 | 75 | 61 | 53 | 47 |
| 12 | 84 | 59 | 48 | 42 | 38 | 97 | 68 | 56 | 48 | 43 |
| 15 | 75 | 53 | 43 | 38 | 34 | 86 | 61 | 50 | 43 | 39 |
| 18 | 68 | 48 | 40 | 35 | 31 | 79 | 56 | 46 | 40 | 36 |
| 24 | 59 | 42 | 34 | 30 | 27 | 68 | 48 | 39 | 34 | 30 |
| 30 | 53 | 37 | 30 | 27 | 24 | 61 | 43 | 35 | 31 | 27 |
| 36 | 48 | 34 | 28 | 24 | 21 | 56 | 40 | 32 | 28 | 25 |
| 48 | 42 | 30 | 24 | 21 | 18 | 48 | 34 | 28 | 24 | 22 |
| 60 | 37 | 27 | 22 | 18 | 16 | 43 | 30 | 25 | 22 | 19 |
| 72 | 34 | 24 | 20 | 17 | 15 | 39 | 28 | 23 | 20 | 18 |

[redacted]

[redacted]

TABLE C.1 (*Continued*)

| TIME / DENSITY | 50,000 FEET | | | | | 60,000 FEET | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 1 | — | — | 216 | 187 | 167 | — | — | — | 206 | 184 |
| 1½ | — | 216 | 177 | 153 | 137 | — | — | 193 | 167 | 150 |
| 2 | — | 187 | 152 | 132 | 118 | — | 206 | 168 | 145 | 130 |
| 2½ | — | 167 | 137 | 118 | 106 | — | 184 | 150 | 130 | 116 |
| 3 | 216 | 153 | 125 | 108 | 96 | — | 168 | 137 | 119 | 106 |
| 3½ | 200 | 142 | 115 | 100 | 90 | — | 155 | 127 | 110 | 98 |
| 4 | 187 | 132 | 108 | 93 | 84 | 205 | 145 | 119 | 103 | 92 |
| 5 | 168 | 119 | 97 | 84 | 75 | 183 | 130 | 106 | 92 | 82 |
| 6 | 153 | 108 | 88 | 76 | 68 | 168 | 119 | 97 | 84 | 75 |
| 7 | 141 | 100 | 82 | 71 | 63 | 155 | 111 | 90 | 78 | 69 |
| 8 | 133 | 94 | 76 | 66 | 59 | 145 | 103 | 84 | 73 | 65 |
| 10 | 119 | 84 | 68 | 59 | 53 | 130 | 92 | 75 | 65 | 58 |
| 12 | 108 | 76 | 63 | 54 | 48 | 119 | 84 | 68 | 59 | 53 |
| 15 | 97 | 68 | 56 | 48 | 43 | 106 | 75 | 61 | 53 | 47 |
| 18 | 88 | 62 | 51 | 44 | 40 | 97 | 68 | 56 | 48 | 43 |
| 24 | 77 | 54 | 44 | 39 | 34 | 84 | 59 | 48 | 42 | 37 |
| 30 | 68 | 48 | 39 | 34 | 30 | 75 | 53 | 43 | 37 | 33 |
| 36 | 63 | 44 | 36 | 31 | 28 | 68 | 48 | 39 | 34 | 30 |
| 48 | 54 | 38 | 31 | 27 | 24 | 59 | 42 | 34 | 30 | 26 |
| 60 | 48 | 34 | 28 | 24 | 22 | 53 | 37 | 31 | 27 | 24 |
| 72 | 44 | 31 | 25 | 22 | 20 | 48 | 34 | 28 | 24 | 22 |



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To expand the ballistic concept one more step, assume that a particle falls from 35,000 feet at a rate of 5,000 feet per hour and that the winds aloft are: 35,000—W 20; 30,000—NW 20; 25,000—N 20; 20,000—NE 20; 15,000—E 20; 10,000—SE 20; 5,000—S 20; then the particle must fall some such path as this (not to scale):

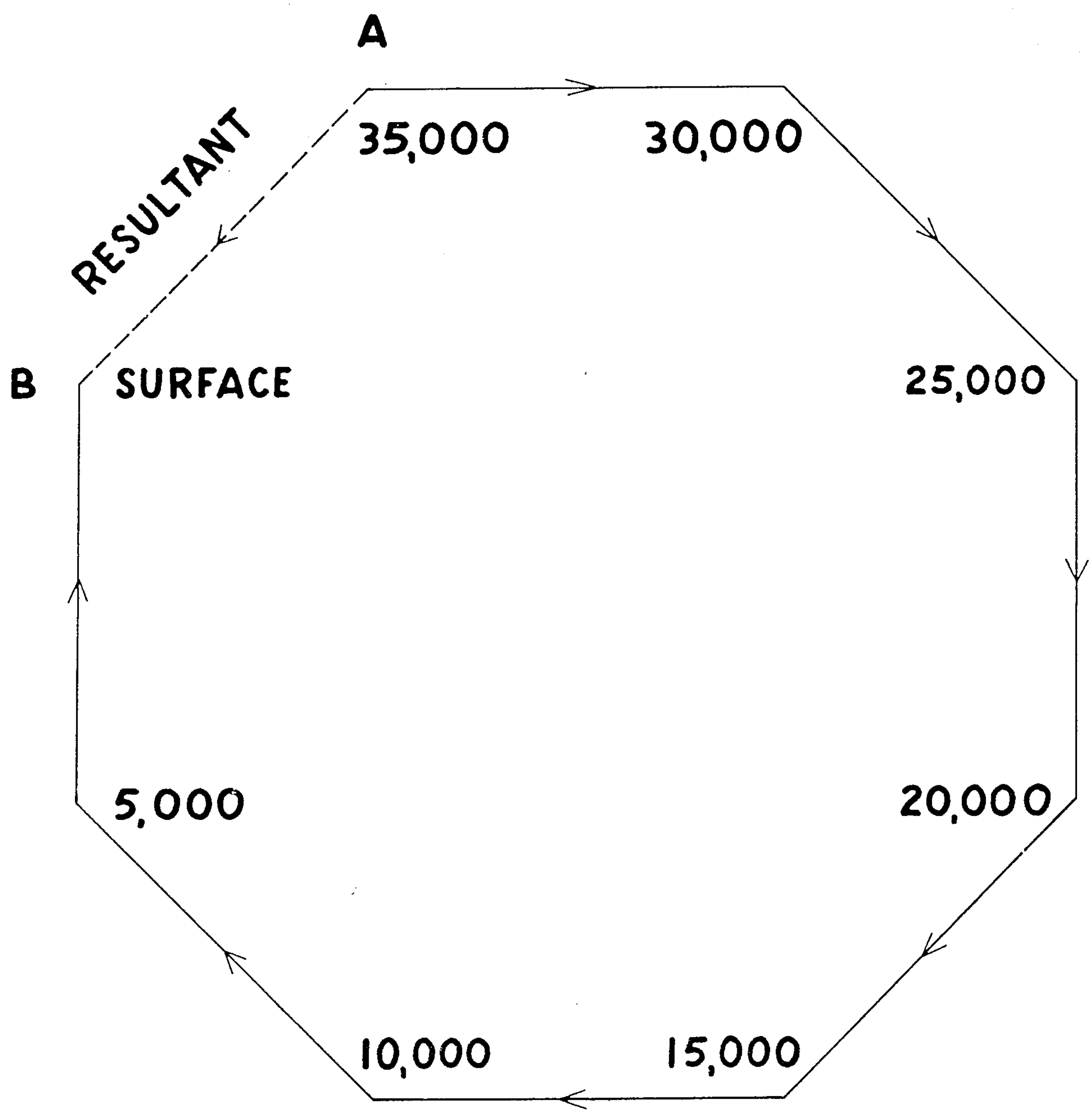


FIGURE C.1 Resultant Wind Diagram

or, in effect, travel along the resultant vector A–B. A convenient assumption in all cases of fall-out computation is that a particle will fall 5,000 feet per hour, since, when plotted to scale, this usually results in a diagram of convenient size.

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## C.4 Plotting

In practice it is most convenient to reverse the direction of plotting, i.e., plot winds from the surface up to the highest level desired, rather than from high levels down. This method is convenient for three reasons: (1) upper winds are transmitted in code form from the surface upward through the various levels; (2) the lower levels are available first and the diagram can thus be completed shortly after the last observation becomes available, and (3) most important of all, this method of plotting obviates the necessity of constructing separate vector diagrams *downward* for each level of interest.

The figure used in the example, when plotted from the surface *up*, then appears:

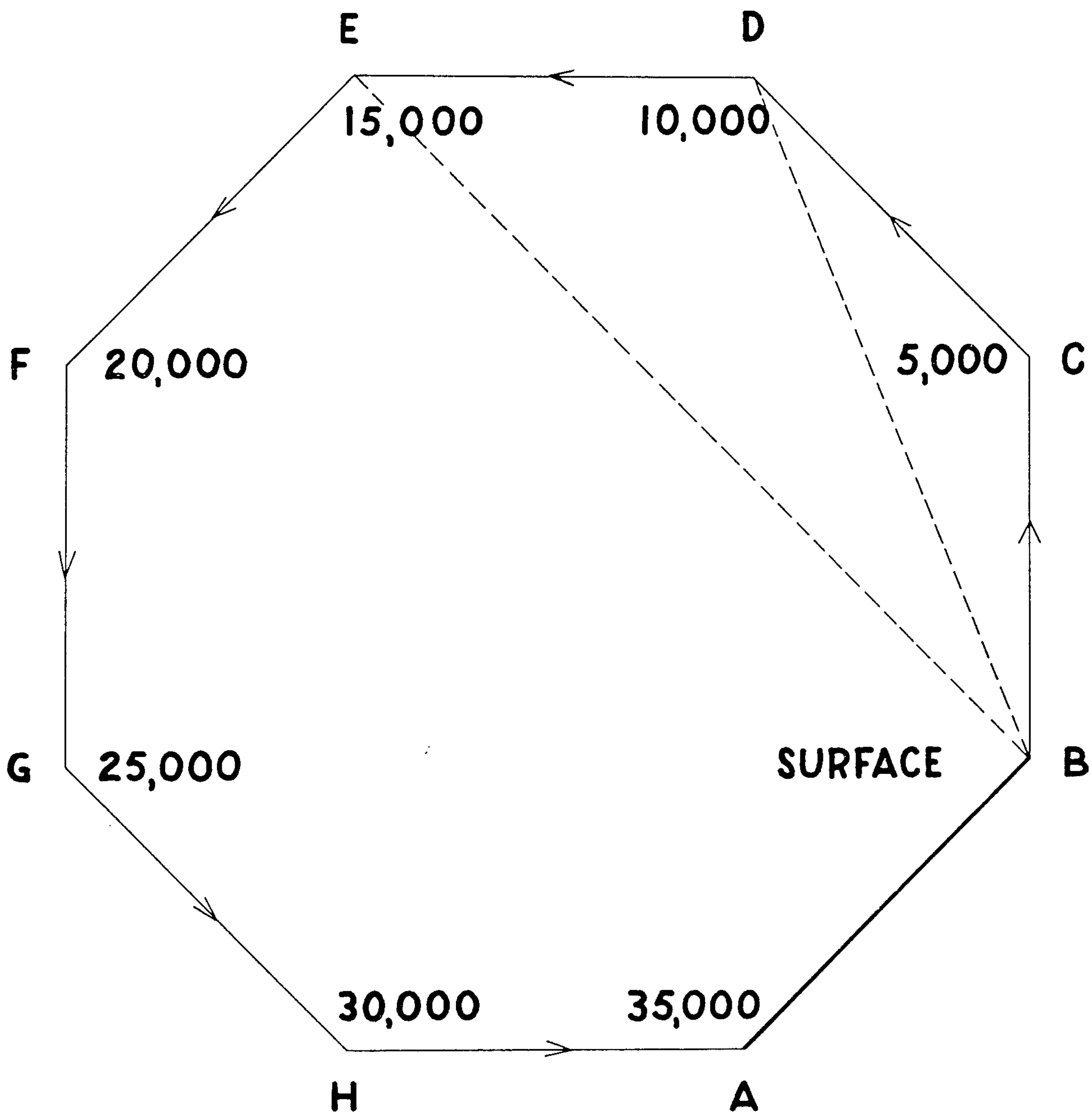


FIGURE C.2 Resultant Wing Diagram



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## C.5 Construction of Fall-Out Areas

Further refinement can be made with respect to time and distance by the construction of isolines of equitime fall-out from all levels. Fall-out which occurs in *one* hour from 35,000 feet will be observed at point "1" along line A–B. Point "1" is obtained by dividing A–B into 7 equal parts (35,000 feet at 5,000 feet per hour). Fall-out which occurs in *one* hour from 30,000 feet will be observed at point "1" along H–B, which is obtained by dividing H–B into six parts (30,000 feet at 5,000 feet per hour). By dividing G–B into 5 parts, F–B into 4 parts, E–B into 3 parts, D–B into 2 parts, and leaving C–B undivided, points "1" are obtained for all levels, and an *area* established by joining points "1," which describes the geographic area *to scale* in which fall-out will be observed one hour after detonation

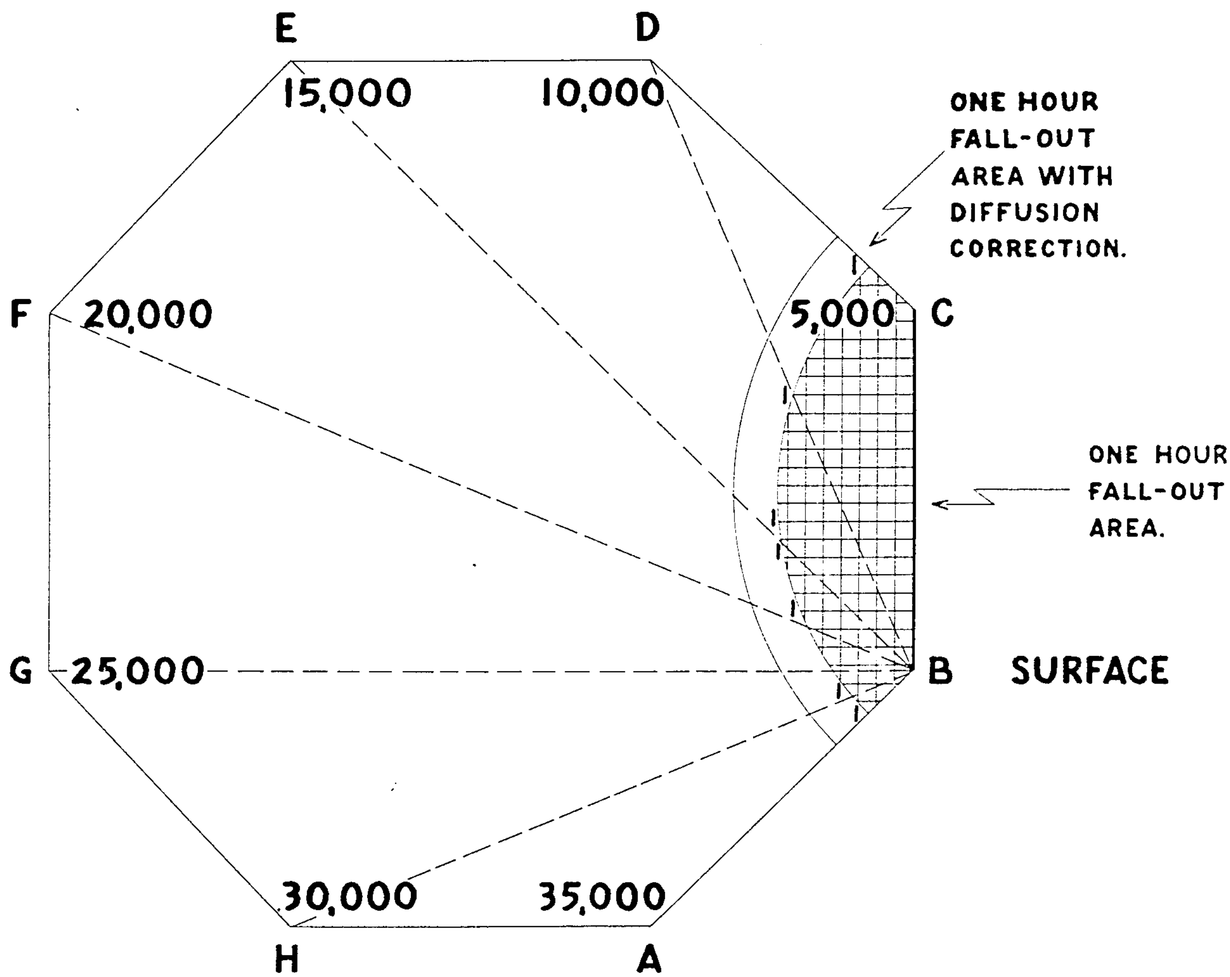


FIGURE C.3 Fall-out Diagram

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Isolines for any time desired can be constructed in exactly the same manner, and fall-out areas clearly delineated with the addition of one refinement to account for lateral diffusion. *An atomic cloud difuses laterally and longitudinally about one mile for each seven miles from zero it travels with the wind.* After all points "1" ("2," "3," or any other) have been connected, the final computed fall-out area would extend to a new line radially farther from zero, as shown on the diagram.

Now, if we construct an upper wind plot of more realistic nature, and conduct a detailed analysis, it will be found that a number of important questions can be answered; (1) will fall-out occur at a particular location?; (2) when will it occur?; and, (3) what will be the particle sizes?

Let points A, B and C represent critical installations (winds and distances to same scale).

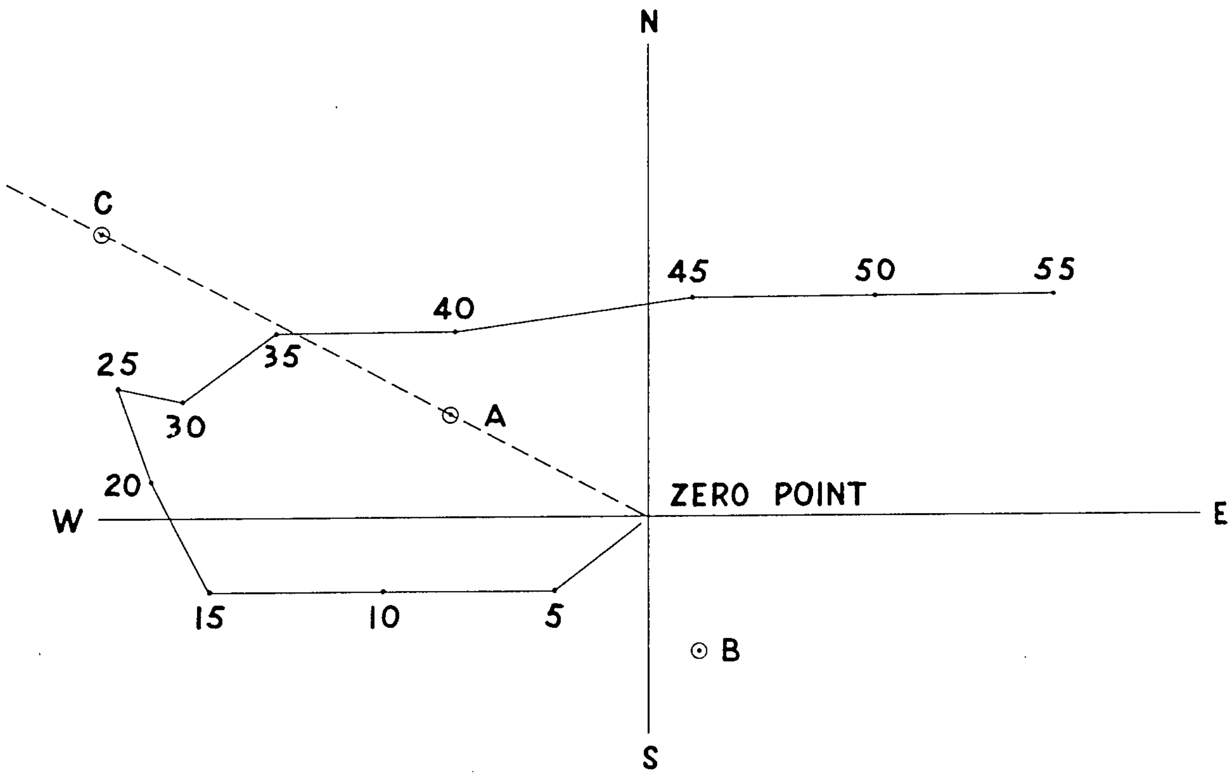


FIGURE C.4 Resultant Upper-wind Plot

With respect to point A, the following conclusions can be reached:

1. Fall-out will occur at point A.
2. Fall-out will be from the 35,000 foot level.
3. Fall-out will start about 3½ hours after detonation. (A is about half the length of vector from zero to the 35,000 foot level—5,000 feet per hour, ½ of 7 hours).
4. The particles will be of the order of 110 microns in diameter, if of coral sand. (See Table C.1.)

No fall-out will occur at point B.

With respect to point C:

1. Fall-out will occur.
2. Fall-out will be from the 35,000 foot level.
3. Fall-out will commence about 10 hours after detonation.
4. Particles will be about 63 microns in size, if of coral sand.

Comparison of arrival times and particle sizes for points A and C permits a general conclusion (in this case with respect to the 35,000 foot level fall-out).

Natural fractionation of particle size occurs along line ZERO—C, with the largest particles falling soonest, and being observed nearest zero, and the smaller sizes farther away, with longer falling times.

Certain basic assumptions must be kept in mind at all times if the limitations of the method are to be understood; *the wind field does not change with time or space, and no precipitation occurs.* Dispersion due to a number of factors will result in some spreading of the calculated area of fall-out.

## C.6 Trend Charts

Construction of trend charts for upper wind structure was added as a refinement and forecasting tool. These trend charts consisted simply of resultant wind tracings made for consecutive upper wind observations, and may be extended for any period desired. In practice, it was found that trend charts for two days were most useful.

## C.7 Conclusion

The upper winds observed at shot times are recorded in other sections of this report. Construction of resultant wind diagrams in accordance with the method outlined will show why fall-out was observed on Parry and Eniwetok after DOG and ITEM shots, while none was observed after EASY and GEORGE shots.