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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum PR-4

TROPICAL NUMERICAL WEATHER PREDICTION IN HAWAII

- A STATUS REPORT -

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PACIFIC REGION
TECHNICAL MEMORANDUM PR-4

HONOLULU, HAWAII
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ABSTRACT

Tropical Numerical Weather Prediction in Hawaii - A Status Report

In 1962 experiments began in Hawaii to analyze and forecast large scale upper wind and temperature fields in tropical Pacific areas using numerical methods. Computations were carried out on large digital computers. Based on the success of these experiments, a group of meteorologists in Hawaii has developed procedures to produce operationally useful products based on these analyses and prognoses.

The area of interest covers 24°S to 37°N, 75°E to 90°W. Extensive use is made of aircraft reports to define wind fields in normally "data-sparse" areas. Data processing, analysis, forecasting and distribution products are described. Examples of products are shown.

TROPICAL NUMERICAL WEATHER PREDICTION IN HAWAII - A STATUS REPORT

I. INTRODUCTION

Operational numerical weather prediction in the tropics has a history that can be traced, in part, to the original Joint Numerical Prediction Weather Unit (JNWP) which began routine operations in 1955 at Suitland, Maryland. JNWP initially developed the techniques from which many present operational procedures at various numerical weather facilities are patterned. These techniques involve matters such as automatic processing of semi-formatted "raw" meteorological reports, objective analysis, graphical depiction of charts by machine plotters, automatic high-speed dissemination of products via data-links, and facsimile map transmission. General descriptions of some of these processes have been published by Thompson (7) and Burnett (2). In particular, early successes in automatic processing of routine meteorological data have been described by Cressman and Bedient (4). An objective analysis system in common use today is due to Cressman (3).

II. TROPICAL ANALYSIS AND PROGNOSIS

Since nearly all of the early numerical efforts were concentrated in middle and higher latitudes, the possibility of development of analogous procedures suitable for the Tropics has always interested tropical meteorologists. Fortuitously, a few experienced numerical meteorologists were reassigned from Mainland United States numerical centers to duties in the Hawaiian Islands in the late 1950's and early 1960's. At the same time small amounts of computer time for meteorological purposes were available on various computers in the Hawaiian area permitting certain experiments in tropical numerical weather prediction to be conceived and undertaken.

In January 1962 U. S. Air Force and Weather Bureau personnel, using a U. S. Navy-owned computer, commenced experiments designed to develop operational numerical weather techniques for use in the Tropical Pacific. These efforts led to the development of wind analyses, through objective (computer) analyses of the u, v scalar components of the wind on a Cartesian grid.

Concurrently with this wind analysis effort, a group of University of Hawaii and Weather Bureau personnel were developing an experimental barotropic forecast scheme. Vederman, Hirata and Manning (8) reported that reasonable forecasts of a barotropic non-divergent atmosphere were possible in the Tropics. Because these barotropic forecasts were made by advecting computed wind field vorticity values with a non-divergent streamfunction wind field, a considerable effort was further undertaken by Bedient and Vederman (1) to develop a method to produce the necessary streamfunction analyses of the Tropical Pacific upper wind fields required by the barotropic forecast model. Their technique included an analysis

of the scalar components of the reported winds, as well as the computation of stream function values of the corresponding non-divergent portion of these wind fields. These two types of analyses were carried on more or less simultaneously to permit usage of the non-divergent wind field to provide a first approximation for the analysis of the actual wind fields. This system was run semi-operationally during the period 1963 through 1965. A considerably expanded effort following this approach is being undertaken at NMC at this time.

In mid 1965 Weather Bureau, Air Force and Navy meteorologists commenced cooperative efforts to program a tropical wind and stream function analysis and forecast system to exploit the availability of limited time on a medium size Navy-owned computer. This computer is a Control Data Corporation (CDC) 3100 and is located at Fleet Weather Central, Pearl Harbor, Hawaii. This particular computer center is connected to the Fleet Numerical Weather Facility, Monterey, California, by a high speed data link. This permits coupling of the tropical wind analyses with higher latitude numerical products, as available.

III. PRESENT COOPERATIVE EFFORT

A. Working Arrangement

Navy, Weather Bureau, and Air Force meteorologists in Hawaii have combined their limited resources of skilled manpower and equipment to permit continuous operation of the tropical numerical weather system. No single agency alone had enough skilled manpower and equipment to do the necessary job of data acquisition, objective analysis, forecasting, output and to provide for continuous monitoring supervision. However, by combining tasks all of the computer programming and operation of the computer center was accomplished using locally available personnel. Early experimental programs written in the FORTRAN compiler system for an International Business Machines (IBM) 704 computer were rather quickly converted to the CDC 3100 computer with minimum effort and loss of time. Since compiled programs tend to be relatively inefficient in terms of memory space allocation and in running time for numerical weather purposes, efforts to optimize and streamline program operation and running times are underway at present.

B. Data Input

A reasonable question usually arises about the adequacy of data coverage in the Pacific which is one of the world's great sparse data areas. As far as upper wind analyses are concerned, a surprising amount of data exists in the form of aircraft reports (AIREPS). Smith, et al, (6) have reported on the operational uses of AIREPS in detail in Pacific Regional Technical Memorandum PR-3. It is sufficient here to relate that there is usually enough AIREP and other data available to provide reasonable objective analyses of the large scale wind flow in the Tropical Pacific. See Figure 1 which is a typical coverage chart for one level.

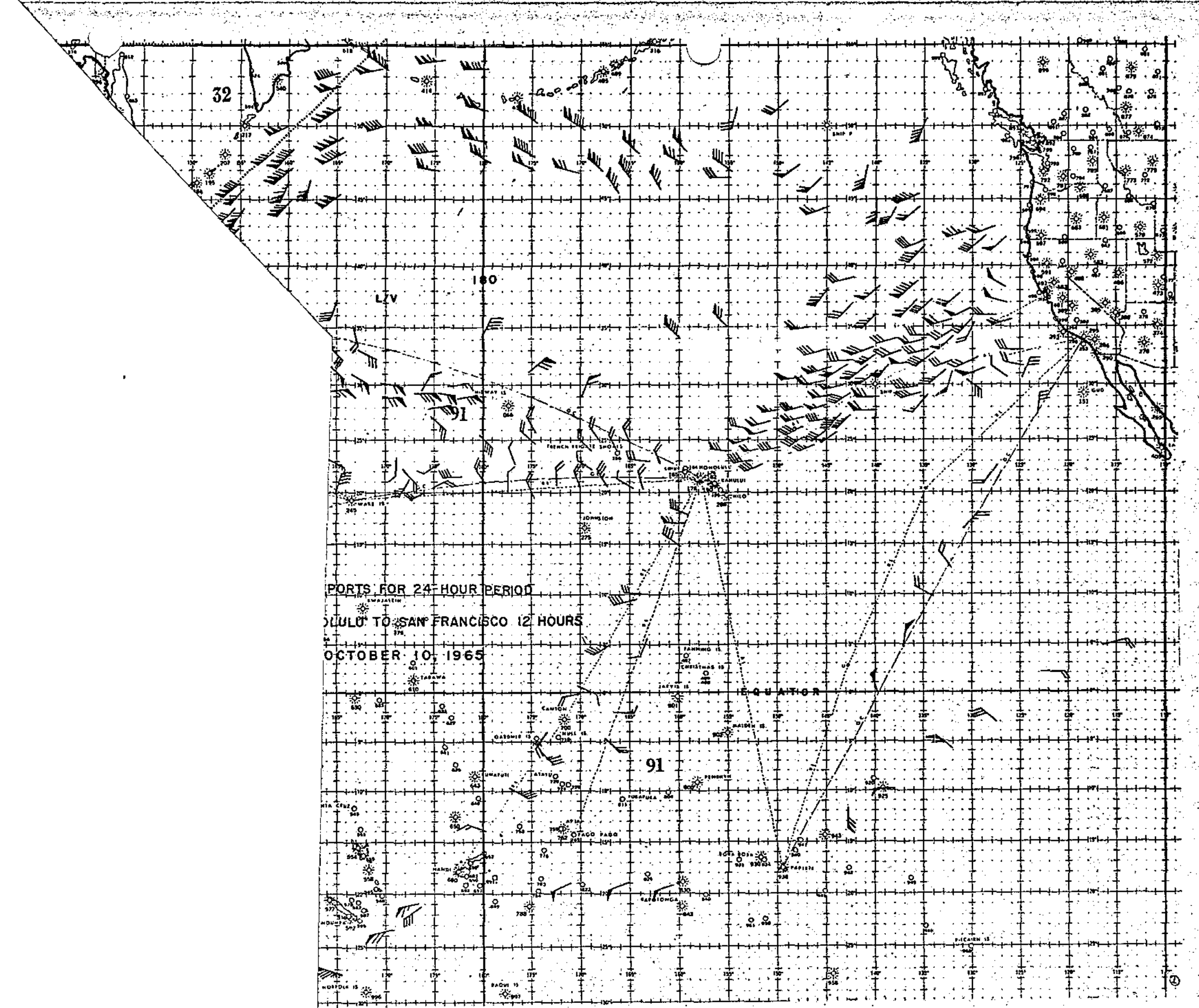

PORTS FOR 24-HOUR PERIOD
OLULU TO SAN FRANCISCO 12 HOURS
OCTOBER 10, 1965
EQUATOR
HONOLULU
KAHULUI
HILO
JOHNSON
MIDWAY IS
WAKE IS
FRENCH FRIGATE SHOALS
CANTON
TARAWA
FANNING IS
CHRISTMAS IS
JARVIS IS
MALDEN IS
PENRHYN
PAPEETE
RAROTONGA
PITCAIRN IS
NORFOLK IS
NANDI
PAGO PAGO
APIA
SHIP P
180
91
32
LZV

Fig. 1

C. Objective Analyses

Following the system used by Cressman (3) and Bedient and Vederman (1), an objective analysis of available wind data is made using the successive approximation technique (SAT). The SAT technique is applied over a 40 x 14 point rectangular grid of 560 points. Geographically, the grid is related to the Earth through a modified Mercator projection true at 22.5° latitude. The distance (mesh length) between grid points at the equator is 5° of longitude or 300 nautical miles. See Figure 2. The geographic boundaries of the grid range from 24.2°S to 37.1°N and 90°W to 75°E. Scan radii presently used by the SAT program are shown in Figure 2.

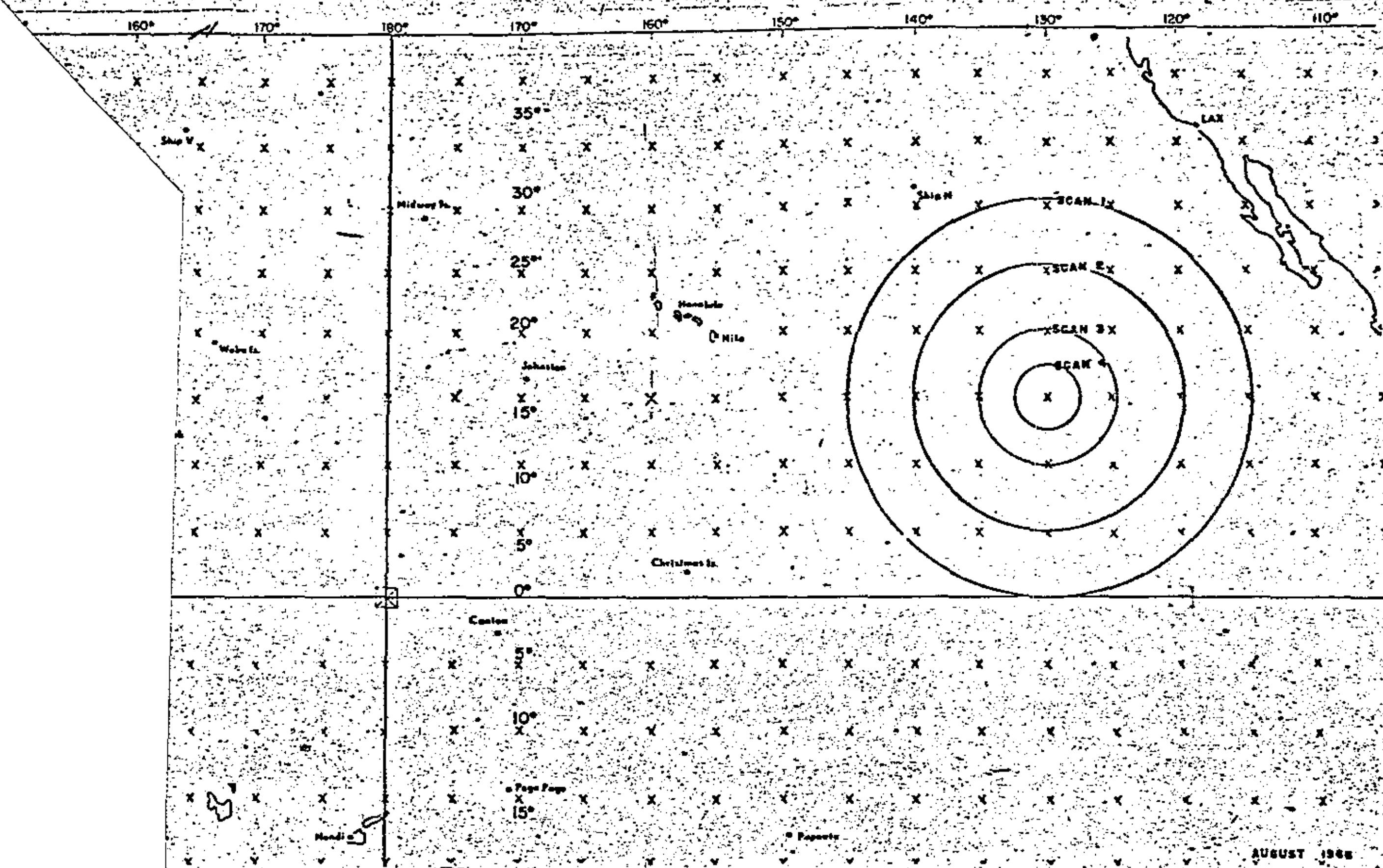
Data are processed automatically by the computer using teletype data and data that have been pre-processed by Fleet Numerical Weather Facility, Monterey, California and transmitted to Hawaii via digital data links. Data are identified, decoded, roughly checked for gross (improbable) errors and arranged in sequence to facilitate machine processing in the objective analysis programs.

Analyses are made of temperatures and winds for the 700, 500, 400, 300, 250, and 200 millibar constant pressure levels. AIREP data not at a standard level are "moved" up or down to the nearest mandatory level and modified by a wind shear factor that has been determined from the previous analyses. Temperatures are similarly modified by lapse rates also determined from the previous analyses. Wind analyses are obtained by analyzing the u and v scalar components of the wind separately and recombining in the final output to obtain velocity.

Most objective analysis scheme utilize a first approximation of the scalar field being analyzed. The Tropical analysis field uses the previous analysis, modified by the monitoring analyst on duty to account for known errors and late data, as a first approximation, or "guess" field. In our particular application, the "guess" is a combination of climatology and persistence. The percentage of climatology is increased five percent for every six hours elapsed since the previous analysis. Data that differ from this "guess" more than a certain threshold value are discarded and identified. The monitoring meteorologist may reinsert these data at a later time if other considerations dictate. The monitoring meteorologist may insert certain types of data based on non-digital information such as the location of a typhoon. Subjectively determined winds surrounding the disturbance using tropical storm model reasoning are inserted as "psuedo" observations.

D. Quality Control Monitoring

The key to successful day-to-day operation of these tropical wind analyses and prognoses may be attributed to the quality control exercised by a qualified meteorologist who monitors the progress of the system from



D SCAN RADII. AREAS 75° E TO 105° E AND 105° W TO 90° W NOT SHOWN.

initial input to final distribution of products. A number of special aids are available to the monitor. One such aid is depicted in Figure 3 which lists grid points with vertical shear exceeding certain values. When shear values are clearly out of line, the monitor can revise the analysis to reduce shears to more reasonable values. The monitor also examines the final output and may issue a correction bulletin, if needed. An example of a correction bulletin is found in Figure 4. A special program called FIXPERS can be run between scheduled operational analysis runs to correct errors at grid points or to permit changes in the analysis made advisable by late data. This procedure provides the best available "guess" fields for the next analysis and forecast run.

Recent operational experience has resulted in modification of values used in a number of procedures which existed under the original analysis system operated by Bedient and Vederman. First, the scan radius has been reduced and the gross error checks have been modified. At present these following criteria obtain:

Scan number	1	2	3	4
Scan radius (mesh lengths)	3.0	2.0	1.0	.5
700 mb wind (knots)	60	50	40	30
500 mb wind (knots)	80	60	50	40
300/250/200 mb wind	100	80	70	50
Temperature (all levels) °C	12	10	8	6

These are set values in the program, but can be changed for a run by the monitor. The above values are for winds at points where the first approximation is 30 knots or less. The values double at 90 knots or above and vary linearily at values between. A new version of the analysis is being introduced that will normally bypass the above table values in favor of a limit of three standard deviations of a computed RMSE determined by the data.

Limited experience to date has indicated that "feedback" between stream function field and wind field analyses mentioned in Section II is often damaging to the final analysis. This seems to be caused by the uncertainty of the non-divergent winds on the boundary of the grid. Errors on the boundaries may "pollute" the stream function solutions in the interior of the grid. Consequently, computation of stream function fields has been temporarily suspended. A smoother of u/ x and v/ y is used after each scan to smooth the divergence field. All wind observations, RAWIN, PIBAL, and AIREP are given equal weight in the analyses program. Consideration is being given to weighting RAWIN reports heavier than other observations.

E. Forecasting Wind and Temperature Fields

An objective wind forecast technique described by Lavoie and Wiederanders (5) provides wind forecasts using the following relationships:

$$u_F = (1-r_u)\ u_c + r_u\ u_p$$

$$v_F = (1-r_v)\ v_c + r_v\ v_p$$

where the subscript $_F$ refers to the forecast values of u and v, the subscript

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where the subscript $_F$ refers to the forecast values of u and v, the subscript

NALYSIS VERTICAL WIND SHEAR VALUES BETWEEN 700 MB AND 500 MB AT 000Z ON 24/ 9/67

(ONLY SHEARS EXCEEDING 40 KNOTS ARE PRINTED)

WIND SHEAR VALUES BETWEEN 500 MB AND 400 MB AT 000Z ON 24/ 9/67

ARS EXCEEDING 40 KNOTS ARE PRINTED)

SHEAR VALUES BETWEEN 400 MB AND 300 MB AT 000Z ON 24/ 9/67

EXCEEDING 40 KNOTS ARE PRINTED)

SHEAR VALUES BETWEEN 300 MB AND 250 MB AT 000Z ON 24/ 9/67

EXCEEDING 40 KNOTS ARE PRINTED)

SHEAR VALUES BETWEEN 250 MB AND 200 MB AT 000Z ON 24/ 9/67

EXCEEDING 40 KNOTS ARE PRINTED)

Figure 3

tout for monitor use listing points, by II JJ numbers and
g possibly abnormal vertical shear values. The monitor
rmines the causes and makes corrections, if warranted.

20 JUL -- 06 25 Z

AUPA NPM 200000Z
COMPUTER TROPCIAL ANALYSIS VALIDATION
1. ANALYSIS WITHIN REASONABLE LIMITS EXCEPT FOR THE
FOLLOWING GRID POINT-WINDS:
14.8N 140E 7/10015
33.0N 145E 7/25010
24.2N 155E 7/09015
24.2N 170E 7/09015
19.6N 170E 7/08015
5.0N 160E 7/08020
33.0N 145W 5/28010
28.7N 135W 5/28015
24.2N 140W 5/09020
24.2N 145W 5/05010
28.7N 145E 5/26010
37.1N 170W 3/26025 25/31030 2/32020
9.9N 120W 5/11010
2. FUPA FLOW PATTERNS SHOULD BE MODIFIED ACCORDINGLY.
BT

NNNN

$_c$ to the monthly climatic value, $_p$ to persistence, and $_r$ to the lag correlation coefficient determined by climatological wind records from observations at Tropical Pacific stations.

Such a simplified technique has proved to be difficult to improve upon by a subjective forecaster in the Tropics except in the area of a jet stream and is easily adapted for computation on the computer. A 24-hour forecast is presently prepared every six hours.

Vanderman (9) has described work on a forecast model using a barotropic primitive equation model to forecast stream function values on an around-the-world tropical belt. Analyses and forecasts of stream function values on this complete equatorial belt grid are computed on a routine basis by the National Meteorological Center, Suitland, Maryland. NMC is experimenting with a two-level tropical model at this time.

While an operational version of a barotropic forecast model is available at Honolulu, it is not being used at present because of the present inability to form a reasonable stream function field by which to advect computed vorticity values.

F. Output Products

Output products are generated for distribution to users and include machine plotted charts and teletype bulletins of upper air winds and temperatures. Plotted charts automatically produced on an incremental plotter have proven popular. Users find that streamlines are readily sketched on such charts and wind values are easily picked off by eye without resorting to wind scales or other tools.

1. Program flow diagrams

An interesting program to plot streamlines derived from analyzed and forecast wind fields has been developed by Mr. Roger Davis, ESSA Weather Bureau. A sample of this type of output display is seen in Figure 6. Figure 6 is a 250 mb. analysis chart consisting of machine plotted wind barbs and streamlines. Figure 7 is a sample of flight wind and temperature data produced for military use.

Plotter products are distributed locally and to certain computer stations on the Navy computer system network. Teletype products, such as Figure 5 are distributed to military and civilian centers locally and throughout the Tropical Pacific, including Manila, P.I.; Auckland, N.Z.; Nandi, Fiji Islands; Papeete, Tahiti; Mexico City, Mexico.

IV. NEW DEVELOPMENTS

In addition to improving present techniques, the following programs are under active development and are expected to be operational shortly:

1. An objective sea level wind, pressure, temperature, and dew point analysis.

2. A "melded" wind forecast field made by interpolating a statistical low-latitude forecast into a higher latitude dynamic forecast.

COMPUTER ANALYSES ARE QUALITY CHECKED BY ORIGINATOR FOR ERRORS.
SEE AUPA NPM FOR AMENDMENTS/COMMENTS. REPLIES INVITED.

SXN 7	1ØØE	1Ø5E	11ØE	115E	12ØE	
↑46 Ø8Ø22	↑47 Ø8Ø14	↑47 Ø9ØØ7	↑48 Ø9ØØ9	↑49 1ØØ16	↑51 1ØØ31	
↑34 Ø8Ø21	↑37 Ø8Ø12	↑36 Ø7ØØ8	↑37 13ØØ7	↑37 15Ø13	↑38 Ø9Ø19	
↑25.Ø8Ø14	↑26.Ø9Ø12	↑25.Ø9Ø1Ø	↑27.Ø9Ø26	↑27.11Ø2Ø	↑29.Ø7Ø21	24.2
↑Ø1 22ØØ3	↑Ø1 Ø1ØØ2	↑Ø1 15ØØ6	+ØØ 16Ø2Ø	↑Ø1 Ø7Ø14	↑Ø3 Ø5Ø12	
+13 21ØØ4	+1Ø 16ØØ4	+12 25ØØ8	+11 16ØØ8	+12 12Ø1Ø	+11 Ø3Ø14	
↑51 Ø8Ø27	↑5Ø 1ØØ16	↑5Ø Ø7Ø13	↑49 Ø8ØØ9	↑51 Ø7Ø11	↑51 Ø7Ø28	
↑38 Ø8Ø23	↑38 Ø7Ø13	↑38 Ø6ØØ8	↑38 11Ø14	↑39 13Ø1Ø	↑37 Ø6ØØ9	
↑28.Ø8Ø21	↑28.Ø7Ø16	↑28.Ø7Ø1Ø	↑25.Ø8Ø1Ø	↑28.Ø7Ø11	↑24.1ØØ18	19.6
↑Ø3 17ØØ2	↑Ø2 22ØØ2	↑Ø2 15ØØ8	↑Ø2 19ØØ4	↑Ø3 15Ø19	↑Ø4 31ØØ2	
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↑52 Ø8Ø28	↑52 Ø9Ø14	↑51 Ø6ØØ8	↑53 12Ø15	↑52 Ø5Ø26	↑54 Ø4Ø17	
↑38 Ø7Ø19	↑37 Ø6ØØ6	↑38 Ø4ØØ5	↑4Ø 12Ø12	↑38 1ØØ19	↑4Ø Ø7Ø16	
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↑54 Ø7Ø37	↑53 Ø8Ø28	↑53 Ø5Ø28	↑53 Ø3Ø1Ø	↑53 Ø7Ø16	↑54 Ø3Ø14	
↑39 Ø6Ø24	↑39 Ø7Ø14	↑4Ø Ø4Ø24	↑39 Ø6ØØ9	↑38 12Ø19	↑39 1ØØ17	
↑3Ø.Ø7Ø23	↑31.Ø8Ø17	↑31.Ø4Ø15	↑26.Ø6Ø15	↑21.Ø9Ø15	↑19.Ø8Ø2Ø	9.9
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↑Ø5 17ØØ8	↑Ø6 19Ø1Ø	↑Ø5 22ØØ5	↑Ø5 3ØØØ1	↑Ø4 Ø8ØØ4	↑Ø4 Ø9ØØ9	
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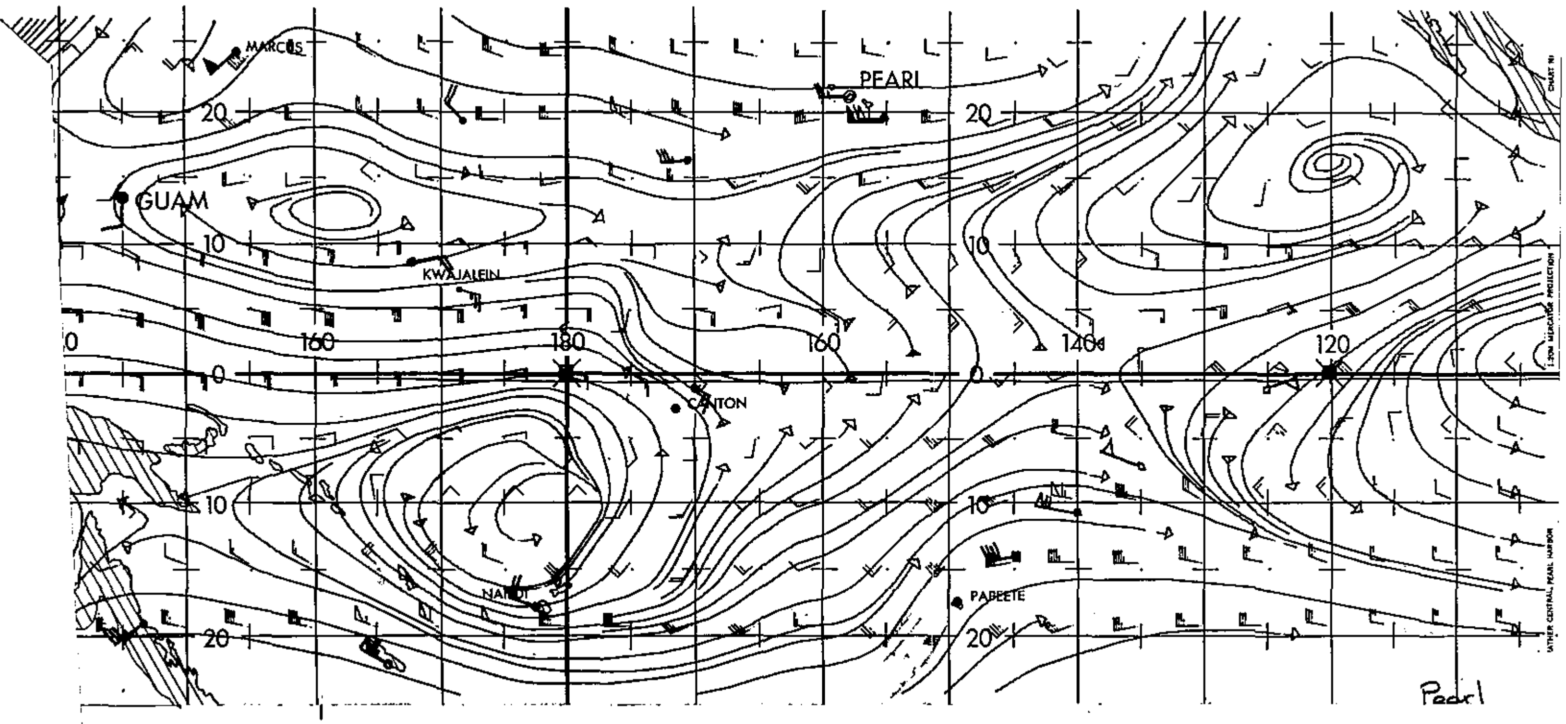

ımple of an objective 250 mb. wind analysis complete
machine plotted wind barbs and streamlines. Heavy
barbs represent actual reported winds at a few
omly selected stations and from certain doppler
-finding equipped aircraft in normally data sparse
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FXPA 2 NPM 18/1200Z

PHNL-KSFO GC
VALID TO 19/0300Z See Code

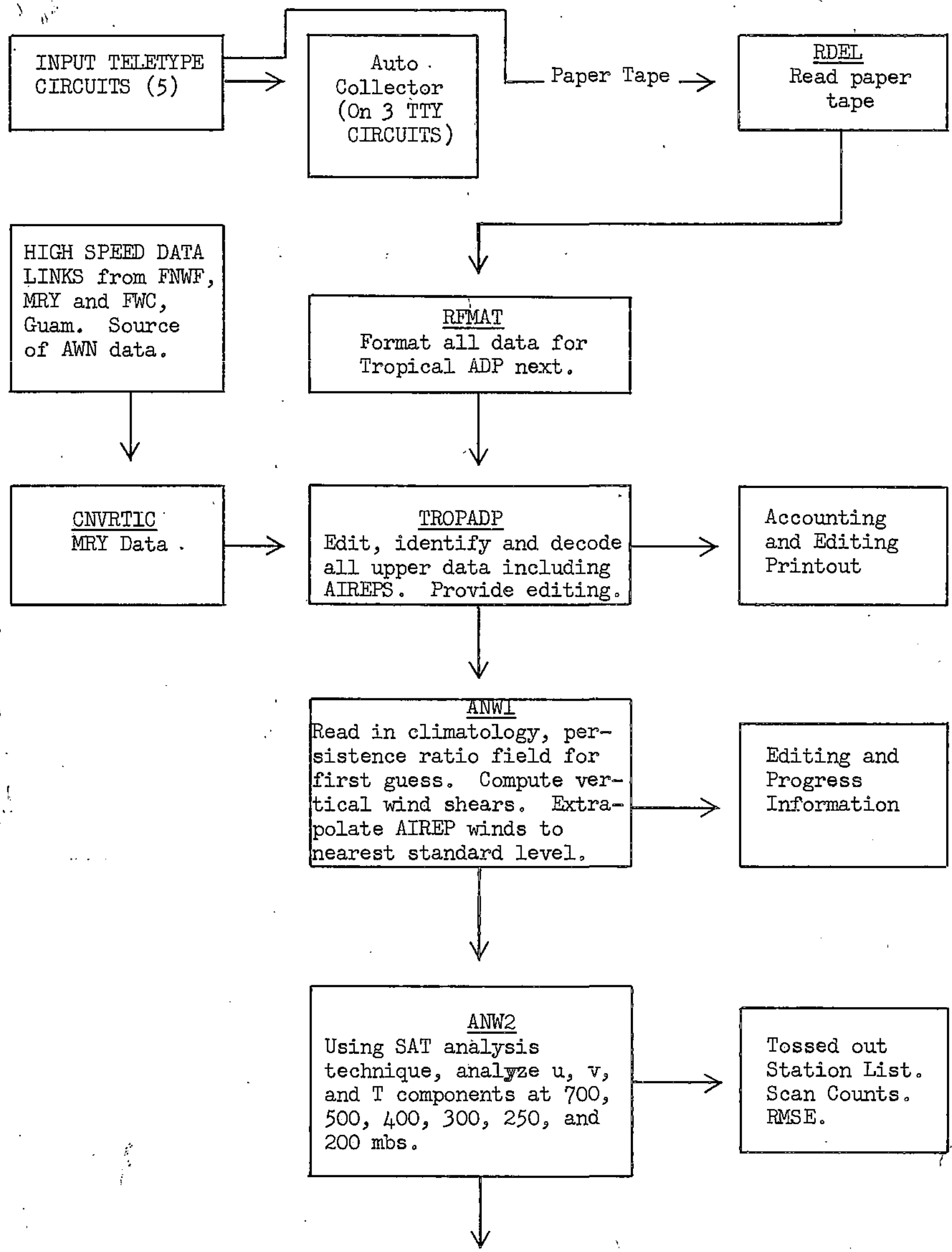
ZN	T	9000	T	11000	T	13000	T	15000	T	17000
32	4	13/ 13	3	13/ 10	1	13/ 5	-1	5/ 2	-3	35/ 3
31	6	13/ 8	4	13/ 6	2	13/ 6	-2	4/ 3	-4	34/ 5
30	7	29/ 1	5	30/ 2	3	31/ 4	-2	32/ 7	-4	32/ 8
29	6	28/ 6	4	27/ 7	2	27/ 8	-3	27/ 9	-6	26/ 11
28	5	25/ 7	4	24/ 8	2	23/ 11	-3	22/ 14	-6	21/ 16
27	6	24/ 7	5	23/ 7	3	22/ 9	-2	20/ 12	-3	19/ 14
26	8	25/ 8	7	24/ 7	5	22/ 8	0	20/ 9	-2	18/ 10
25	11	27/ 6	9	26/ 5	7	23/ 5	0	19/ 4	-3	15/ 6
1H/2H		1/ 7		1/ 7		2/ 7		3/ 7		4/ 7
TWF		4		4		4		5		5

ZN	T	19000	T	21000	T	23000	T	25000	T	27000
32	-9	35/ 6	-10	35/ 10	-14	35/ 14	-21	36/ 17	-27	36/ 18
31	-8	34/ 8	-12	34/ 11	-16	34/ 14	-23	35/ 16	-29	35/ 16
30	-8	32/ 10	-12	31/ 12	-17	31/ 15	-24	32/ 17	-31	32/ 17
29	-10	26/ 13	-14	27/ 17	-19	27/ 20	-25	27/ 22	-30	27/ 21
28	-10	21/ 17	-15	22/ 18	-20	23/ 20	-25	24/ 21	-29	23/ 22
27	-9	19/ 15	-12	20/ 16	-17	20/ 17	-22	21/ 17	-27	21/ 23
26	-8	19/ 10	-12	20/ 11	-17	21/ 12	-22	22/ 12	-27	21/ 16
25	-9	18/ 6	-14	21/ 6	-18	24/ 5	-22	26/ 5	-26	24/ 6
1H/2H		4/ 8		4/ 9		5/ 11		4/ 14		4/ 17
TWF		6		7		8		9		10

ZN	T	29000	T	33000	T	37000	T	41000
32	-32	1/ 20	-39	0/ 21	-50	34/ 22	-57	33/ 29
31	-34	36/ 16	-41	36/ 16	-51	34/ 19	-58	33/ 26
30	-36	32/ 18	-43	32/ 18	-52	32/ 21	-58	31/ 28
29	-35	28/ 20	-42	29/ 19	-50	28/ 28	-57	27/ 37
28	-34	24/ 27	-41	24/ 32	-49	23/ 42	-56	25/ 48
27	-33	21/ 30	-40	21/ 37	-49	21/ 43	-55	23/ 50
26	-32	21/ 20	-39	22/ 35	-48	22/ 37	-55	23/ 50
25	-31	23/ 8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1H/2H		3/ 20		[illegible]		[illegible]		[illegible]
TWF		11		[illegible]		[illegible]		[illegible]

CODE
PHNL-KSFO GC

The following block flow diagrams describe the basic system from initial input to final output:



CLIMFCST

Using Lavoie - Wiederanders technique, make 24 hour forecast of u, v, and T.

<u>OUTPUT</u>. Generate following output:

<u>Plotter maps</u>:

700	Winds (0, 24 hr),	Streamlines
500	"	"
400	"	"
300	"	"
250	"	"
200	"	"

AUPA, FUPA (7 sections each level)
teletype formatted bulletins
Scale 1/20 M.
Total: 21 sections

FXPA

Flight route plans. Generate plans as required (about 138 at present).

3. Displaying high latitude contour analyses in Mercator projection form and automatically streamlining lower latitude wind fields. See Figure 6.

4. Developing a local meso-scale orographic precipitation model.

5. Computing fields of relative vorticity and horizontal divergence for subjective comparison with satellite cloud data.

6. A number of special systems computer programs to enable more versatile and efficient use of manpower and equipment.

V. PLANS

In addition to improving present techniques, it may be possible, in the course of the next few years, to explore such problems as follows:

1. Forecasting by advecting departure from normal anomalies.

2. Meso-scale wind, cloudiness, and temperature analyses and forecasts for selected areas in the Tropical Pacific.

3. Tsunami travel - time forecasts.

4. Sea surface condition analyses and forecasts in the Tropical Pacific.

5. Development of tropical moisture layer depth analyses and forecasts from which large scale cloudiness and precipitation forecasts for the tropics might be made possible.

6. Relationship of satellite cloud and infrared data to atmospheric parameters for input to analysis.

7. Special statistical studies to examine relationships between various observed parameters pertaining to Hawaiian weather.

VI. PROBLEMS

A number of problem areas have arisen during the developmental phases of the effort. These problems include the following:

1. Wind analyses are inherently more difficult in the regions of the Earth where the pressure height/wind relationship is weak and difficult to measure. This, in turn, means that vertical wind consistency will likely depend upon some vertical wind shear relationship rather than the usual hydrostatic relationship. This problem is considerably aggravated by the reality that the Tropics are normally data sparse areas.

2. Primary data used are AIREP reports. While normally reasonable, such data is not subject to "quality control" measures inherent in normal meteorological reports. The observers are not meteorologists or meteorological technicians and control and training of such personnel is through persuasion rather than direction.

3. AIREPS are not collected by meteorological agencies at the source and many reports seem to become "lost" prior to reaching an analysis center.

Problems 2 and 3 have been overcome partially through hard work and constant vigilance.

4. Teletype transmission errors and failure to follow coding practices exactly often causes data to be misinterpreted or disregarded by the data processing program. Also, some AIREP reports are not formatted, forcing manual formatting prior to processing.

5. Some communications links are overcrowded and too slow to permit timely receipt of data, thereby affecting the quality of the analysis.

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