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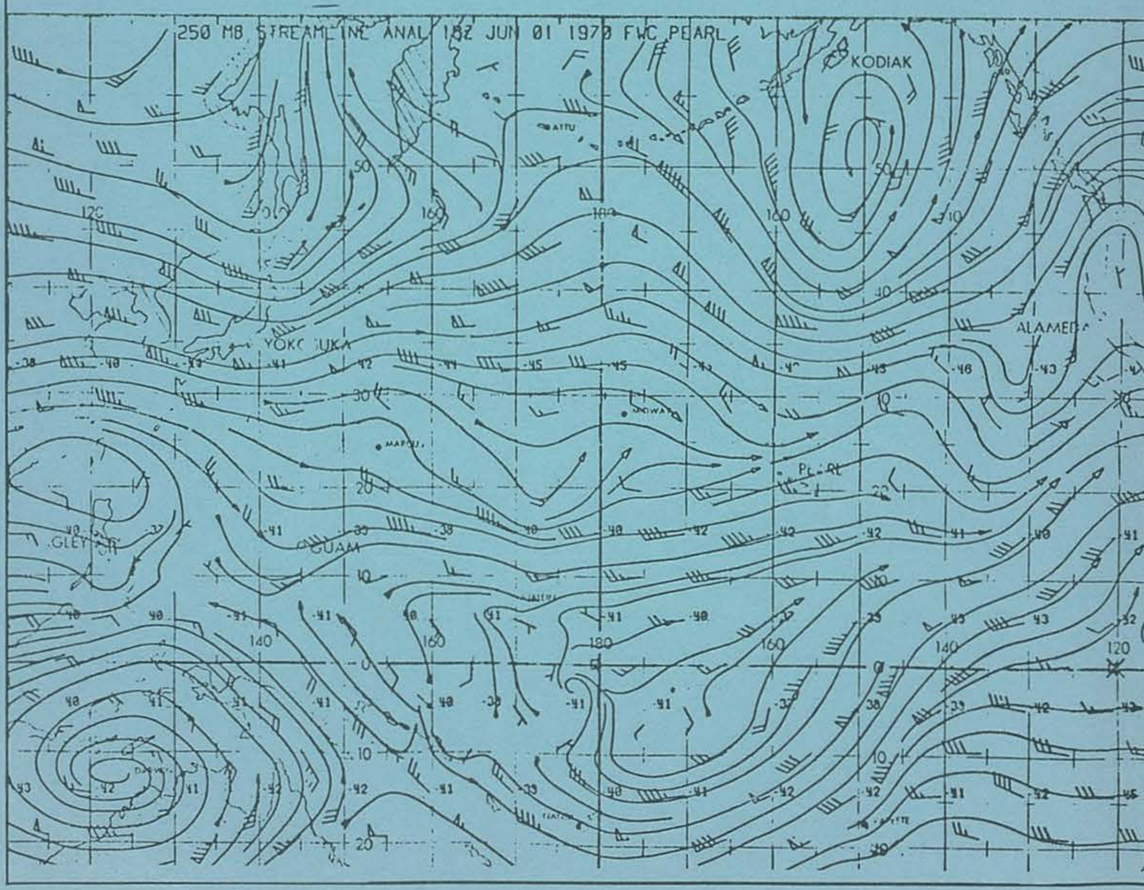
Tropical Numerical Weather Prediction In Hawaii—1971



PACIFIC REGION
HONOLULU,
HAWAII

MARCH 1971

CONTENTS

TROPICAL NUMERICAL WEATHER PREDICTION IN HAWAII - 1971

1. Background

Numerical weather prediction has been in existence for a number of years. The advent of the large scale digital computer in the early 1950's led to the establishment of centers on the Mainland designed to process, analyze, prognosticate, and disseminate operational meteorological products. The first of these was the Joint Numerical Weather Prediction (JNWP) unit established at Suitland, Maryland, in 1953. This unit has evolved through the years into the major production facility of the National Meteorological Center. In 1953 this unit had one IBM 701 computer. Today, two Control Data Corporation 6600 computers are used. Since the era of the IBM 701, computer speeds at NMC have increased by a factor of perhaps 500 times while storage capacity has increased 50 or more times. Use of larger computers is contemplated.

Unfortunately, most of the advances in NWP have been confined to the higher latitudes where basic relationships between the density distribution and the wind hold reasonably well and the data network is concentrated. The Tropics have been largely ignored, as far as NWP procedures are concerned, however, the tropical NWP picture is not all bleak. Experiments have been undertaken and progress made. Most of this effort had its beginning in Hawaii.

The author (4) prepared a status report on this subject in 1967 and these notes represent an updated revision of that report. The National Meteorological Center (NMC) in Suitland, Maryland, is increasingly active in the field of tropical NWP and their contribution to the effort will be covered, in part, in this report.

2. The Hawaii Cooperative NWP Effort

During 1962 in Hawaii, "alumni" of the original JNWP (Bedient and Vederman) perceived that NWP procedures might be developed to support weather service activities in the Tropics. At that time, they commenced to develop large scale wind and temperature analyses for the tropical Pacific. Objective wind field analyses from realtime data had not been seriously attempted prior to this time. Bedient (1) developed an analysis system based on the successive approximation technique (SAT) and extended this to the formation of streamfunction values to represent the nondivergent portion of the wind field. These procedures will be described later.

In 1965, progress was such that local weather service agencies of the Navy, Air Force and National Weather Service agreed to pool their manpower resources into a cooperative effort to produce and distribute tropical win and temperature products for the tropical Pacific. This pooling was required because no one agency had the resources to "go it" alone in such a venture. Further, the products provided by this group were basic in nature and could be utilized by all agencies.

Approximately 24 persons are directly involved in the Hawaii cooperative effort. Equipment and facilities are provided by the U. S. Navy at Fleet Weather Central, Pearl Harbor. The computer system, very highly automated, is built around a two CDC 3100 medium scale digital computers.

3. Flow of Data Through the NWP System

The flow of data from "raw" teletype form through automatic processing, analysis, prognosis, output and operational delivery to customers is shown in fig. 1. Let's look at certain parts of this system.

a. Data Collection. Data are collected automatically on "auto-collectors" or are received in binary form via a high-speed data link. Data are in the form of conventional upper air reports, special edited collectives or in the form of aircraft reports (AIREP). The local unit has developed special techniques to handle semi-formatted AIREPS. The availability of over 2000 AIREPS per day over the Pacific has made real-time objective wind analyses in this region feasible. Hence, ability to utilize irregular AIREP data is vital to the success of any tropical NWP effort.

All observation reports are processed directly by the computer from auto-collector tapes. Data are identified, key parameters decoded, an initial error checking accomplished by a complex program called "ADP" for automatic data processing.

b. Analysis. From these data SAT analyses of wind and temperature are performed for the 700 mb., 500 mb., 400 mb., 300 mb., 250 mb., and 200 mb. pressure surfaces. Statistical prognoses are made. Fig. 2 shows a sample of an analysis traced automatically by an incremental plotter. Such charts are reproduced at the National Weather Service forecast office and at other local weather service offices by off-line computer driven remote plotters connected by telephone lines or via facsimile. Special fine mesh 850 mb. analyses are produced as well as experimental 1000 mb. analyses.

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

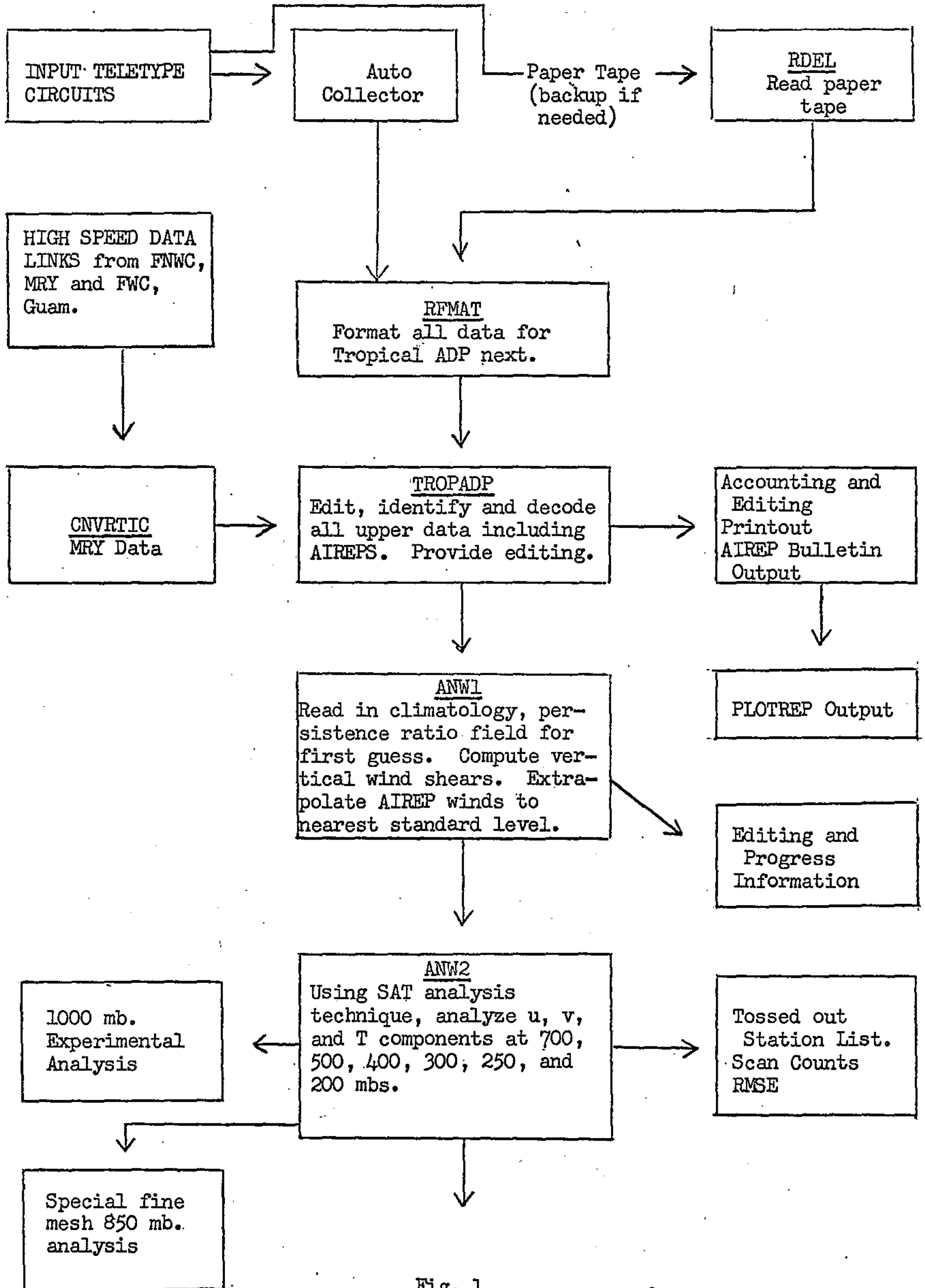


Fig. 1

Merge high latitude analysis and reanalyze

CLIMFCST

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

Merge with high latitude prog

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

<u>Plotter maps:</u>

700	winds (0,24 hr),	streamlines,	temperatures
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 150 at present).

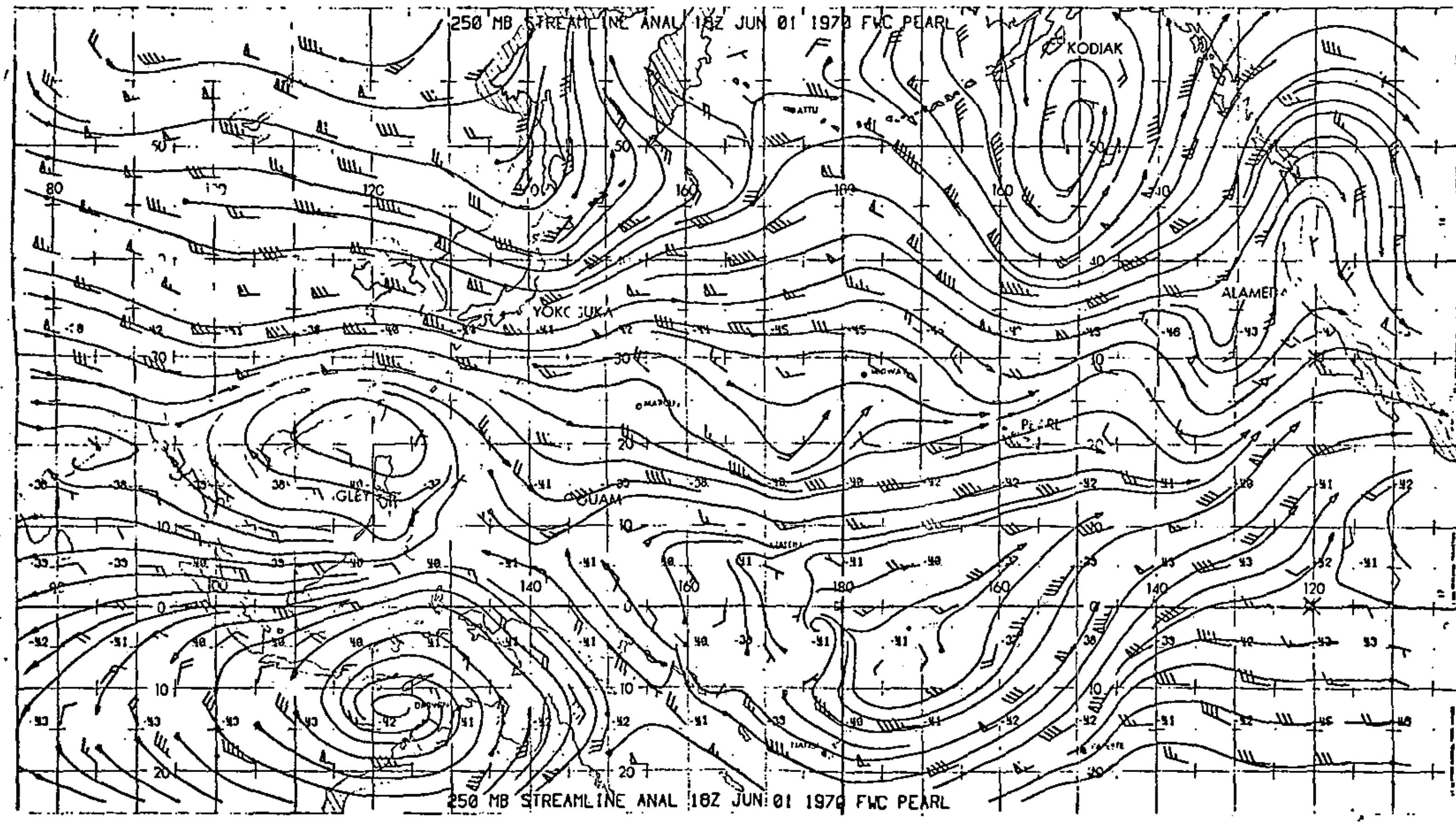


FIGURE 2. 250 MB COMPUTERIZED STREAMLINE ANALYSIS

c. Derived Products. Flight plans of the form shown in fig. 3 are produced for teletype distribution throughout the Pacific. Similarly, "paper doll" charts of analyzed data are teletyped throughout the Pacific Basin. A sample "paper doll" is shown in fig. 4. Many other products are derived from basic NWP grid data.

4. Tropical Analysis

a. SAT Technique. The successive approximation technique (SAT) is a well known method of objective analysis of a scalar value field. The term "objective analysis" refers to the process of transforming data at irregularly spaced points into data at points in a regularly spaced grid by use of predetermined procedural rules. Since little or no subjectivity enters into this system, objective techniques can be computerized. The present version in use is a modification of the technique due to Cressman (5).

The SAT technique essentially allows data to modify an initial approximate field (called a "guess" field in the parlance of the trade) which is usually the last available analysis or an applicable prognostic field.

In the Hawaii cooperative effort, the previous six hourly analysis modified slightly (5%) by climatology is used. Table 1 shows the formulae used to obtain values in various "guess" fields. The use of some climatology prevents unwanted "pollution" of values in normally "data silent" areas.

The technique of analysis used can be divided into three steps; guess construction, data evaluation, and adjustment. The end result of the procedure is to produce three scalar values, u (west-east wind component), v (south-north wind component) and temperature at each point of the grid. A general flow diagram of the analysis is shown in fig. 5.

For purposes of guess construction, the analysis can be divided into two basic areas with a "blend" area between. First, a guess is computed for values at points south of 40N in the following way:

(1) At 700, 300 and 200 mb. a combination of 95% of the previous analysis value plus 5% of the climatological value is computed.

(2) At the intervening levels, values are computed by applying shear values between the previously computed levels. For winds, 20% of the 700-300 mb. shear is assigned up to 500 mb. and 50% to the 400 mb. level. For temperatures, the computation is made for these levels using

PHNL-KLAX GC

ZN	9000 FT	11000 FT	13000 FT	15000 FT	17000 FT
	DDFFFTTTWWWW	$DFFFTTTWWWW	DDFFFTTTWWWW	DDFFFTTTWWWW	DDFFFTTTWWWW
32	8013 8 -13	8012 7 -12	8007 2 -7	9004 -1 -4	36001 -4 -1
31	7012 7 -12	6011 6 -11	5008 1 -8	4006 -2 -6	1005 -5 -3
30	9004 5 -4	8004 3 -4	3004 -1 -3	1005 -4 -3	36007 -7 -3
29	18002 2 1	18001 1 -1	3005 -4 -5	3009 -7 -7	3013-10 -10
28	36001 1 0	3003 0 -3	4010 -5 -9	4015 -8 -14	4019-11 -18
27	2006 4 -4	2006 2 -5	4010 -3 -8	4012 -6 -9	4013 -9 -11
26	28005 7 5	27005 5 5	26004 0 4	24004 -3 4	22004 -7 4
25	22014 10 12	22015 8 12	21016 2 12	21018 -1 13	20019 -5 13
24	20018 11 11	20018 9 11	19019 4 11	19020 0 12	19022 -4 12
1/2	-7/ 4	-7/ 3	-6/ 0	-5/ -1	-4/ -3
TWF	-1	-1	-2	-3	-3

ZN	19000 FT	21000 FT	23000 FT	25000 FT	27000 FT
	DDFFFTTTWWWW	DDFFFTTTWWWW	DDFFFTTTWWWW	$DFFFTTTWWWW	DDFFFTTTWWWW
32	27003 -9 3	27005-13 5	25007-18 7	25011-22 11	26016-26 16
31	34005-10 -1	33008-14 1	33010-19 2	32014-22 5	31020-26 10
30	35009-12 -2	32014-16 4	31020-20 9	31027-24 13	30029-28 17
29	2015-14 -9	34015-19 0	31022-23 10	31024-27 12	31023-31 11
28	4024-15 -20	2019-20 -13	36017-25 -6	1018-29 -9	2020-33 -15
27	4015-14 -13	3016-18 -11	2017-23 -10	2018-26 -10	2019-30 -11
26	21005-12 4	22007-16 6	22008-21 8	23010-24 10	23014-28 13
25	20021-10 14	20025-15 17	20029-20 20	21036-24 25	21043-28 31
24	19024 -9 13	20028-14 17	20032-19 20	20037-23 24	20043-28 28
1/2	-2/ -3	3/ 1	6/ 5	10/ 6	13/ 7
TWF	-3	2	6	8	10

ZN	29000 FT	33000 FT	37000 FT	41000 FT
	DDFFFTTTWWWW	DDFFFTTTWWWW	DDFFFTTTWWWW	DDFFFTTTWWWW
32	26021-30 21	25026-40 26	24032-50 30	24033-55 32
31	30025-29 14	30028-40 18	29028-50 21	29030-55 23
30	30034-31 21	30037-41 24	30040-51 25	29039-55 27
29	31021-35 10	30026-44 16	29037-52 27	29044-56 33
28	4027-38 -22	1019-46 -10	31029-53 15	29037-56 27
27	2019-34 -12	35011-42 -2	29016-50 13	28021-54 20
26	23018-32 16	24022-40 22	23028-49 26	23029-53 27
25	21049-32 37	21052-40 40	21054-49 40	21055-53 41
24	20050-32 34	20052-41 36	20053-49 38	20055-53 39
1/2	17/ 7	21/ 14	25/ 25	27/ 30
TWF	11	17	25	29

BT

Fig. 3. Sample of computer derived flight wind and temperature information for the Honolulu-Los Angeles track.

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COMPUTER ANALYSES ARE QUALITY CHECKED BY ORIGINATOR FOR ERRORS.
SEE -UPA NPM FOR AMENDMENTS/COMMENTS. REPLIES INVITED.
SXN 3         145E        150E        155E        160E        165E        170E

   37.1
-18 28011 -17 24018 -19 25022 -21 26022 -23 27019 -23 25016 -24 23018
-07.33007 -05.26012 -07.26020 -10.27022 -11.29017 -11.31010 -12.21008
 09 04016  10 02004  08 26011  05 27017  03 30014  02 33007  02 18005

   33.0
-16 30007 -17 21007 -18 12007 -19 10019 -20 08025 -18 11013 -20 21011
-05.30013 -06.23016 -07.23010 -07.11001 -06.03012 -06.33013 -07.17008
 10 33010  11 24012  10 23009  08 18000  08 03012  07 03012  07 16007

   28.7
-16 36004 -18 12005 -18 10007 -19 13009 -19 05004 -18 26009 -19 26019
-06.31004 -07.18011 -08.19006 -07.26004 -06.33010 -06.33010 -07.19008
 09 03002  09 17013  09 18005  09 31002  09 35011  10 01010  09 14008

   24.2
-15 32004 -16 08005 -17 09010 -17 13010 -17 17001 -17 28007 -18 26007
-06.25003 -06.15009 -07.12009 -06.10005 -05.35004 -06.32005 -07.19004
 10 20005  09 16013  08 13011  09 08009  10 05011  11 04010  10 11006

   19.6
-15 31002 -16 32004 -16 29002 -15 20004 -15 19003 -16 03002 -17 09004
-05.22006 -06.22005 -05.22005 -04.27008 -04.28010 -05.30002 -06.07006
 10 22010  10 22009  10 20010  11 34001  12 04005  11 05008  10 06008

   14.8
-16 21001 -16 36002 -16 06002 -15 13002 -16 15003 -16 09003 -17 06005
-05.18004 -05.13002 -05.12003 -04.34001 -04.30003 -05.02004 -06.03013
 10 20006  10 32001  10 20010  11 27000  11 08005  10 07008  09 04012

    9.9
-16 10010 -17 08010 -16 09010 -16 10012 -17 09014 -17 09014 -18 07012
-06.11009 -06.08010 -05.09011 -05.09009 -06.08007 -07.05012 -07.03022
 09 11004  09 06007  10 12008  09 10006  08 11004  08 05006  07 03014
```

Fig. 4. Computer derived analysis for teletype transmission. Scale 1/20M. Mercator. Plotting model

Lat.		
TT	DDVVV	400 mb. data
TT •	DDVVV	500 mb. data
TT	DDVVV	700 mb. data

• is location of grid position.

PRESSURE LEVEL	WIND GUESS	TEMPERATURE GUESS
200	$V_{200} = .95\,(V_{200})p + .05\,(V_{200})c$	$T_{200} = .95\,(T_{200})p + .05\,(T_{200})c$
250	$V_{250} = V_{300} + \frac{(Z^*_{250} - Z^*_{300})}{(Z^*_{200} - Z^*_{300})}(V_{200} - V_{300})$	$T_{250} = T_{300} + \frac{(T^*_{250} - T^*_{300})}{(T^*_{200} - T^*_{300})}(T_{200} - T_{300})$
300	$V_{300} = .95\,(V_{300})p + .05\,(V_{300})c$	$T_{300} = .95\,(T_{300})p + .05\,(T_{300})c$
400	$V_{400} = V_{700} + .5\,(V_{300} - V_{700})$	$T_{400} = T_{700} + \frac{(T^*_{400} - T^*_{700})}{(T^*_{300} - T^*_{700})}(T_{300} - T_{700})$
500	$V_{500} = V_{700} + .2\,(V_{300} - V_{700})$	$T_{500} = T_{700} + \frac{(T^*_{500} - T^*_{700})}{(T^*_{300} - T^*_{700})}(T_{300} - T_{700})$
700	$V_{700} = .95\,(V_{700})p + .05\,(V_{700})c$	$T_{700} = .95\,(T_{700})p + .05\,(T_{700})c$

Table I. Computation of guess values south of 40N (notation: p refers to persistence, c to climatological value , * indicates standard atmosphere values)

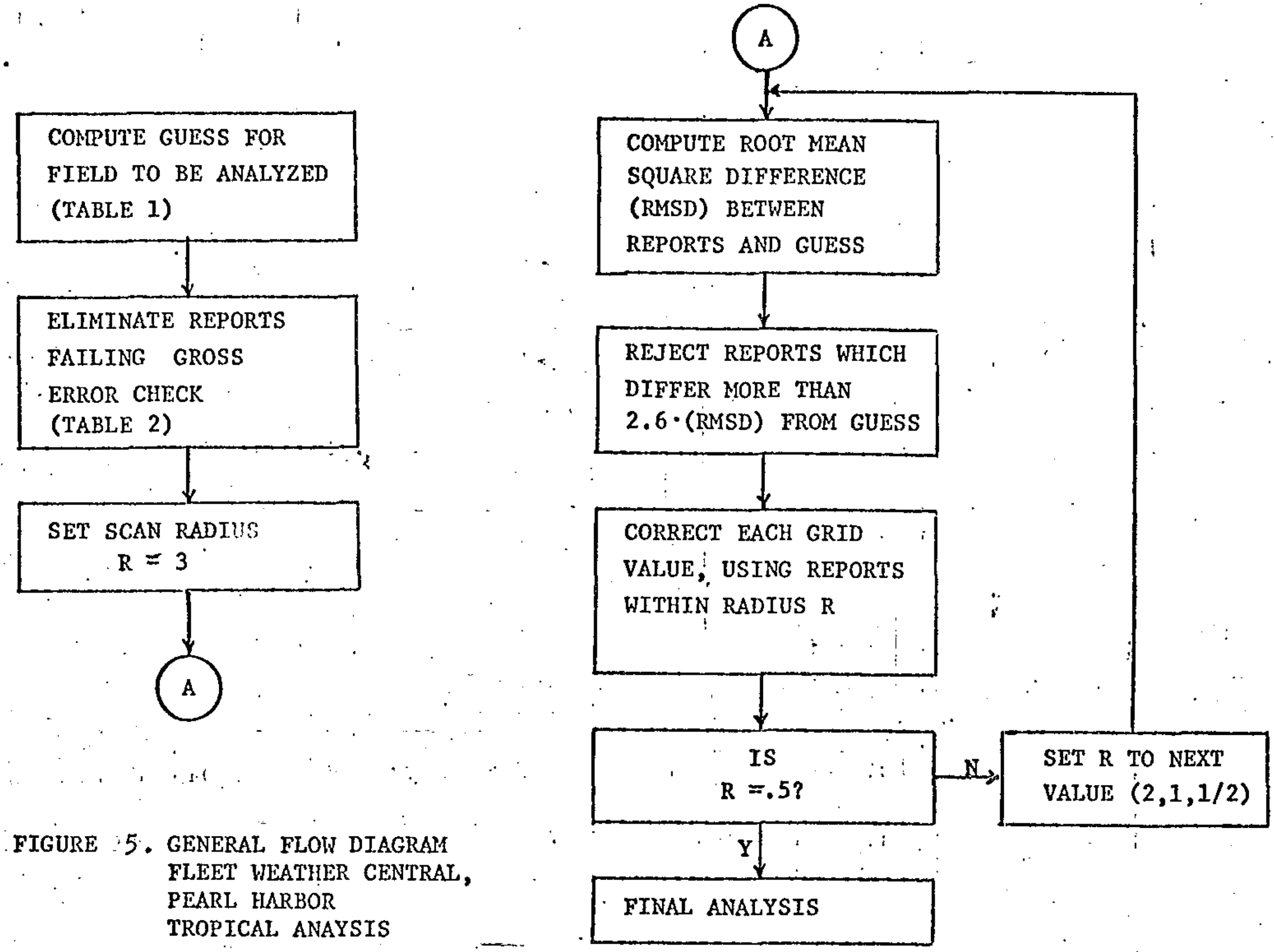

FIGURE 5. GENERAL FLOW DIAGRAM
FLEET WEATHER CENTRAL,
PEARL HARBOR
TROPICAL ANAYSIS

the ratios of standard atmosphere thickness to interpolate between 700 and 300 mb. The thickness ratio is used also in interpolating between 200 and 300 mb. values to obtain the 250 mb. wind and temperature guesses. These computations are summarized in Table 1.

For the points north of 30N, geostrophic winds are computed for each grid point using the latest Fleet Numerical Weather Central height prognoses verifying at analysis time. (These are prognoses produced on a polar stereographic projection for mid and high latitudes) For the grid points lying between 30N and 40N, (33N and 37N) a smooth transition is obtained by blending a combination of the values obtained through the two methods.

The resulting guess thus provides a vertically consistent set of values, consisting of a dynamic prognosis in mid latitudes combined with a persistence/climatology forecast in the tropics.

The second and third steps of the analysis procedure are performed alternately in cycles. In the adjustment step, at each cycle a scan of radius R is made around each grid point and an individual correction value is computed for each report encountered. This value, C_i, is computed from the equation

$$C_i = W\,(u-u_i)$$

where u is the reported value, u_i is the interpolated value of the guess field at the point of the report, W is a weighting function

$$W = \frac{R^2-d^2}{R^2+d^2}$$

based on the distance, d, of the report from the grid point. The total correction at each grid point is then obtained as a simple mean of the respective individual corrections. This correction is applied to the guess value to obtain either the guess for the next cycle or the final analyzed value, as the case may be. This correction technique remains unchanged from that described by Bedient and Vederman (1) in 1964 except that the scan radii, R, have been shortened. These radii are now 3, 2, 1 and $\frac{1}{2}$ grid mesh length for the four successive scans.

Prior to each correction scan an evaluation is made of each reported datum and some values are rejected and removed from further consideration in the analysis. For winds, an initial evaluation (Gross Error Check) is made before the analysis is begun based strictly on scalar wind speed difference between the guess value and the reported value. Reports are rejected if they differ from the guess more than the amount shown in Table 2.

300, 250 and 200 mb. 400 mb 500 mb 700 mb	80 knots 70 knots 60 knots 50 knots

Table 2. Speed Variation Allowed Between Reports and Guess for Gross Error Check

The evaluation prior to each scan is made using a root mean square difference computed between all reported data not previously rejected and the guess value. Any report varying from the guess by more than 2.6 times the root mean square difference is rejected from further consideration. This test is applied to both wind and temperature reports.

b. Data Utilization. Data input to the Fleet Weather Central analysis model is accomplished through computer decoding of reports received via both teletype and high speed data circuits. The techniques used in decoding these reports were discussed by Davis at the recent Symposium on Tropical Meteorology (4). Reports can be divided into three categories-aircraft reports, meteorological sounding reports and satellite observations. At this time both winds and temperatures are obtained from the first two report types while only winds have been utilized from satellite observations.

Analyses are produced four times per day, with nominal base times at the main synoptic hours of 0000, 0600, 1200 and 1800 GMT. The actual analysis, however, is not synoptic in the usual sense of simultaneous observation due to the input of the aircraft reports with their random times. Data are collected until 3 hours 30 minutes past the nominal analysis time, at which time the data processing procedure is begun. Meteorological soundings are accepted for the analysis which have observation times less than 9 hours prior to analysis time while aircraft reports are accepted back to 4½ hours prior to analysis time, if north of 20N or 6½ hours prior to analysis time south of this latitude.

From the inception of the analysis project, the major factor in producing an acceptable analysis has been the data coverage provided by aircraft reports. For the tropical Pacific Ocean area covered by the Fleet Weather Central analysis, it would be impossible to produce an adequate analysis based on meteorological sounding data alone; this point cannot be over emphasized. Fig. 6 shows a computer plot of a typical collective of data

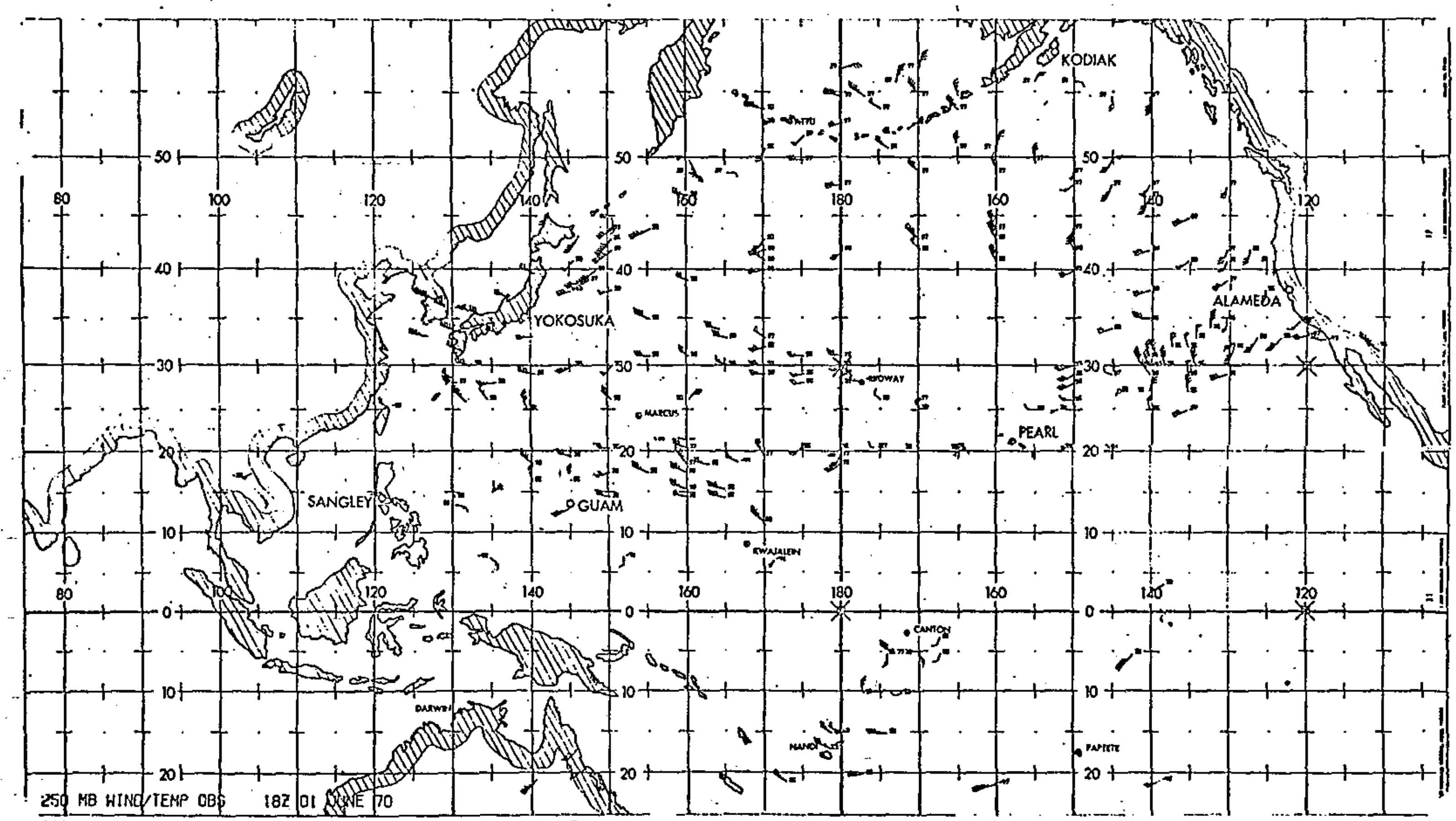

FIGURE 6. 250 MB DATA PLOTTED BY COMPUTER

at a single level. It can be seen that aircraft reports alone provide a reasonable basis for analysis over a great portion of the map.

As a practical measure, since aircraft reports seldom fall at standard pressure surfaces, each report is modified to provide a data value at nearby pressure surfaces. The procedure used to accomplish this is as follows:

First, using the first guess fields described above, linear wind shear and temperature lapse rates between the 700 and 300 mb. surfaces and between the 300 and 200 mb. surfaces are computed at each grid point. Using these values, each aircraft report is extrapolated vertically. For reports below 300 mb., extrapolated values are obtained for the nearest two levels in the analysis, while above 300 mb. values are extrapolated to each of the three levels, 300, 250, and 200 mb.

For the past several years, an additional source of data has begun to become available. Although still experimental, bulletins of cirrus level wind values taken from analysis of satellite pictures are being furnished by the National Environmental Satellite Center. The Fleet Weather Central analysis scheme, since it relies solely on winds rather than height values, is particularly adapted to utilizing this type of data. For purpose of analysis, the decoded winds are treated as individual reports of winds at the 200 mb. level. Each individual wind is then subjected to the same extrapolation and error detection procedures as an aircraft report.

c. Man-Machine Interface. In order to maintain control of the quality of analyses produced, a degree of human intervention is allowed in the computerized analysis cycle. This intervention is exercised in two ways-modification of the first guess fields used, and manual introduction of key observations. The process is controlled by a qualified analyst known as the Tropical Product Monitor (TPM).

The most important means available to the TPM for effecting changes in the computer analysis is through modification of guess fields. In accomplishing this, the TPM examines each completed analysis for areas which are likely to show major changes in the next six hours. He then examines later reports, as they are received, for evidence of such changes. Before the next analysis begins, he provides the computer operator with punched cards, containing corrections for the guess at individual grid points. These corrections are applied to the guess before the analysis program begins to consider reported data, thus providing a "running start".

The second means of manual intervention, introduction of key observations, is used by the TPM for insuring that critical reports which may have been garbled in communication are made available to the analysis in their correct form.

d. Wind Prognosis. Forecast wind fields are also produced at Fleet Weather Central, Pearl Harbor, for the same area and levels for which analyses are made. The forecast consists of a statistical climatology-persistence forecast south of 33N blended in the same manner as the analysis guess fields with dynamic mid-latitude prognoses provided by the Fleet Numerical Weather Central, Monterey, California. The tropical area forecast employs the lag correlation scheme suggested by Lavoie and Wiederanders (8) employing the prognostic equations

$$U_f = (1-r_u)\ U_c + r_u U_p$$

$$V_f = (1-r_v)\ V_c + r_v V_p$$

where U and V are the west and south wind components respectively. The subscript f refers to the forecast value, c refers to the monthly climatological value and p to persistence. The lag correlation coefficient r has been determined for each grid point and at each level through analysis of such coefficients obtained statistically for individual observing stations. Output is in a form similar to the form of the analysis shown in fig. 2.

e. Fine Mesh Analysis. In addition to the main Tropical Pacific Ocean Area analyses, a fine mesh temperature and wind analysis is run at Fleet Weather Central, Pearl Harbor. The grid used for this analysis has a spacing one half that of the main analysis, two and one half degrees on a side. At present, this analysis is run for the 850 mb. level, an area covering Southeast Asia and the South China Sea, from the equator north to 44.5 and from 75.5E to 142.5E.

Guess fields for these analyses are formed in the same manner as for the main analysis. The previous analysis is returned to climatology by 5 percent for each six hours. Data evaluation is also the same, rejecting reports on the basis of a Root Mean Square Deviation check.

Other than the grid spacing, the distinctive feature of the fine mesh analysis is the method of weighting the observations of winds in modifying the guess. As in the main analysis, successive circular scans are made about each grid point, computing corrections from each report encountered. The scans are set at 6, 4, 2 and 1 mesh length in successive passes. The weighting, however, is based not only on distance but also on the direction and speed of the guess wind. The equation used for computing the correction at a grid point is:

$$C_u = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{R^2 - r_i^2}{R^2 + r_i^2} \right) e^{\frac{-s}{100} \sin \theta_i} (u_o - u_g)$$

where:

- N = number of observations within scan area
- R = scan radius
- r_i = distance of observation to grid point
- S = guess wind speed at the grid point (knots)
- θ_i = angle between a line from the observation to the grid point and the wind direction of the observation
- u_o = horizontal component of observed wind
- u_g = horizontal component of grid point wind

The added exponential term, developed by Major Jack G. Joern, USAF (7) results in an elliptical field of influence around each wind observation. Table 3 shows the ratio of weights along the axes perpendicular and parallel to the wind direction for several wind speeds.

WIND SPEED (knots)	RATIO $\frac{W_{\perp}}{W_{\parallel}}$
0	1.000
25	.779
50	.607
100	.368
150	.223
200	.135

Table 3. Ratio of weights along the axes perpendicular to the wind and parallel to the wind.

As can be seen, this modification to the correction equation results in less "spreading" of observations showing strong winds, thereby sharpening features in the isotach pattern.

f. Streamline Presentation. The output of the analysis and prognosis programs described above is in the form of scalar values of two wind components and temperature at each point of a grid. These values are normally output from the computer on magnetic tape as "binary data fields". Each of these fields contains a single scalar value for each grid point at one atmospheric level, e.g., the west-east component of wind at 700 mb. These fields provide the input to other computer programs that perform interpolations and other calculations which result in "tailored" products such as wind factors for specific routes.

For use in the forecast center however, the tropical meteorologist has traditionally used streamline charts. Thus a program was developed at Fleet Weather Central, Pearl Harbor, to produce such charts from the data fields. This program, which was the first such program known to be used operationally, was developed by Mr. Harry N. Farnsworth of the U.S. Navy and Mr. Roger Davis (6) of the National Weather Service. It has been programmed for the CDC 3100 computer and outputs a magnetic tape which drives a CALCOMP 565 incremental plotter to produce the desired chart. Fig. 3 is an example of the charts produced by this program.

The general technique used in the program is the approximation of individual streamlines by a connected set of vector increments, the slope of each increment being the ratio of the south-north (V) wind component to the west-east (U) wind component. The specifics of the program are closely tied to the characteristics of the plotter used. All plotting consists of a series of steps. In each step, the pen may be moved by 0.01 inches in either a positive or negative direction along two mutually perpendicular axes. Thus a single step may result in a movement in one of eight directions. (See Fig. 7).

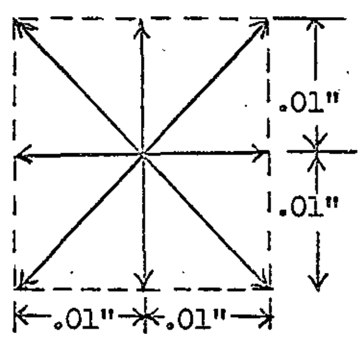

Fig. 7. The Eight Possible Plotter Pen Movements

For purposes of bookkeeping within the program, the chart to be streamlined is divided into squares, 0.1 inches on a side. The construction of streamlines begins at the square about an arbitrary origin point. Double linear interpolation is used to obtain the U and V values for the starting square. A line increment is then constructed, consisting of pen steps in the ratio of the U and V components, with 10 steps assigned in the direction of the larger component and an accordingly lesser number of steps in the direction of the smaller component. At the completion of this increment, the pen will have moved 0.1 inches in one (or possibly two) of the four cardinal directions and will be resting at the center of a new square. Each time a square is entered, the coordinate of the square is recorded. If the square has been entered before, two streamlines have converged and the plotting of the latest streamline is terminated. Otherwise, the process is repeated and new segments are constructed until the edge of the chart is reached or until a point is reached where the wind is calm.

When a streamline is terminated, its starting and ending points are saved and a search is conducted for an origin point for a new streamline. Origin points are initially selected at the west and east edges of the chart. Starting at the bottom (south) along these edges, an interval of constant length is checked for a square in which a streamline has previously been drawn. If such a square is found, a new check interval is initiated at this square and checking proceeds upward until the top of the chart is reached or an empty interval is found. When an empty interval is found, a new streamline origin is established at a specified plot interval (which is less than the check interval) from the last encountered occupied square.

When checks have been completed along both the east and west ends of the chart, checking is continued along lines one inch in from each end. When these checks are completed, the check lines are moved in another inch, until finally the center of the chart is reached.

By modifying the check interval and the plot interval, the density of streamlines on a chart can easily be controlled.

As a practical matter, since the computer determination of the streamline locations is much more rapid than the actual plotting of the lines, the movement of the plotter pen must be minimized by reducing the movement of the pen between streamlines. Thus the streamlines are not output to the plotter in the same order they are produced. When the output of each streamline is complete, a search is made in the list of terminal points to locate the nearest one which has not already been output. This one is then plotted next, optimizing the pen motion.

A more complete description of the streamline generation program may be found in reference (6).

5. National Meteorological Center Program

a. Streamfunction Analysis. NMC has considerably improved the original streamfunction analysis technique first developed by Bedient (1). First, a wind field is analyzed on a global band grid (cylindrical) of 72x23 points. The mesh length is 5^{o} lat. at the equator.

The technique described by Bedient (2), produces a field of streamfunction values from the analyzed wind component (u,v) fields. The streamfunction is determined from the relationship

$$\nabla^2 \psi = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = F(x,y)$$

and thus represents the non-divergent portion of the wind field.

Through a complex process involving solution of partial differential equations and deft handling of boundary values, a field of streamfunction values closely approximating the basic wind flow can be determined. This system is operational at NMC. The advantage of this method is that it merges well with higher latitude streamfunction fields and provides the basis for attempts at dynamic prognostication. An example of a streamfunction analysis is shown as fig. 8.

The format of these output charts is interesting in that all lines, labels, characters, etc., are generated in the computer. The digital records comprising the charts are converted to graphical form in two ways. A high speed electrostatic plotter can be used to generate depictions rapidly. An example of this output format is shown in fig. 9. Also, conventional facsimile charts can be prepared through a digital to analog converter. An example of a chart formed in this manner is fig. 8. Such a system as this has great inherent flexibility.

In the NMC system, data are handled automatically in a manner much as described in section 2 through an elaborate special communications computer system. The analyzed streamfunction fields are formed for each scan of the SAT analysis process and the resultant wind fields are used as a "guess" for the next scan. This procedure gradually removes the divergence from the wind fields. Analyses at 700, 500, 300, 250 and 200 mb. levels are produced twice daily at 0350 and 1550 GMT. "Clean up" runs at 0800 and 2000 GMT take care of late data and improve the guess for the next run. Extensive use is made of satellite derived winds. On the average, 125 satellite winds are used. More extensive use of inferred winds from satellite data is planned.

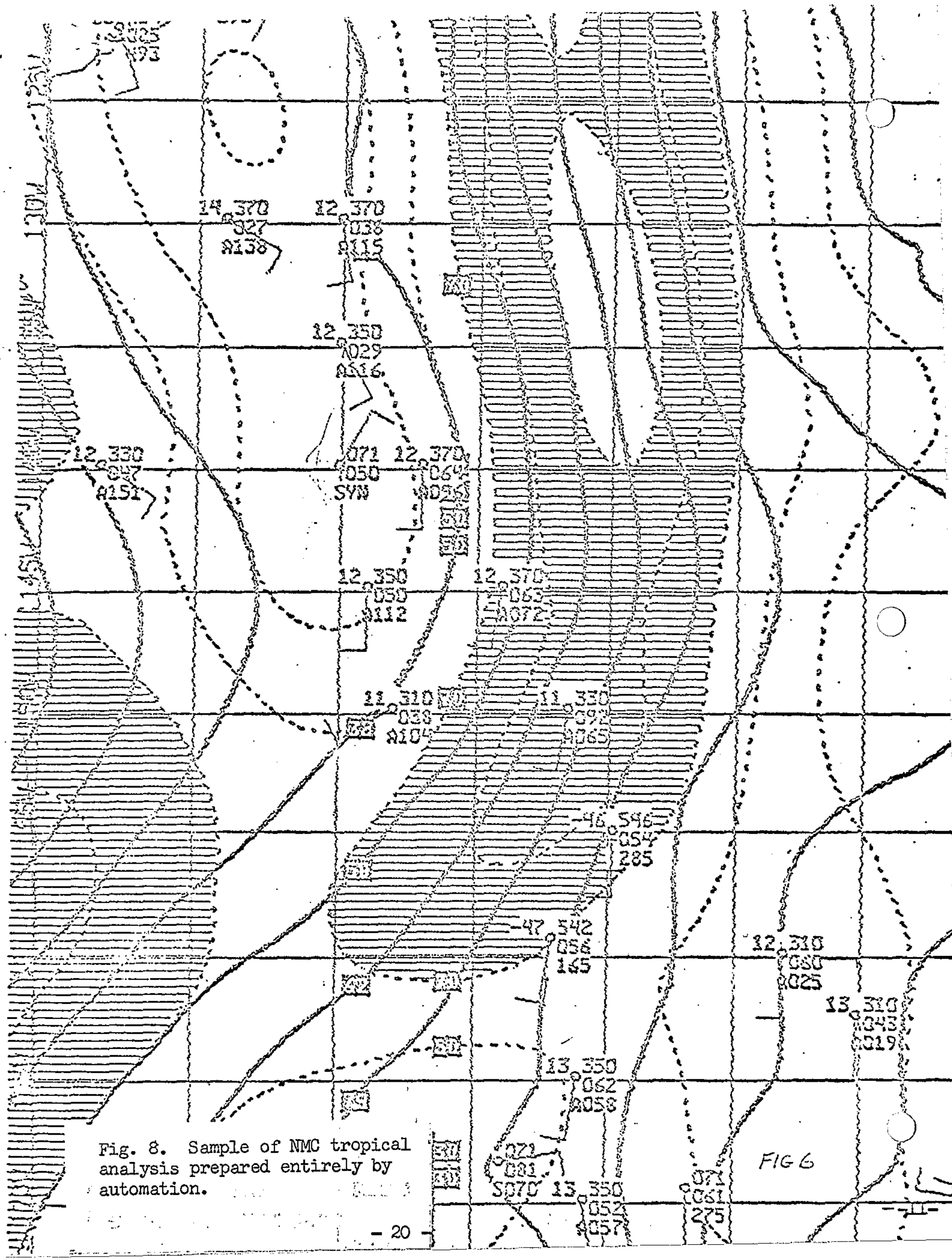

Fig. 8. Sample of NMC tropical analysis prepared entirely by automation.

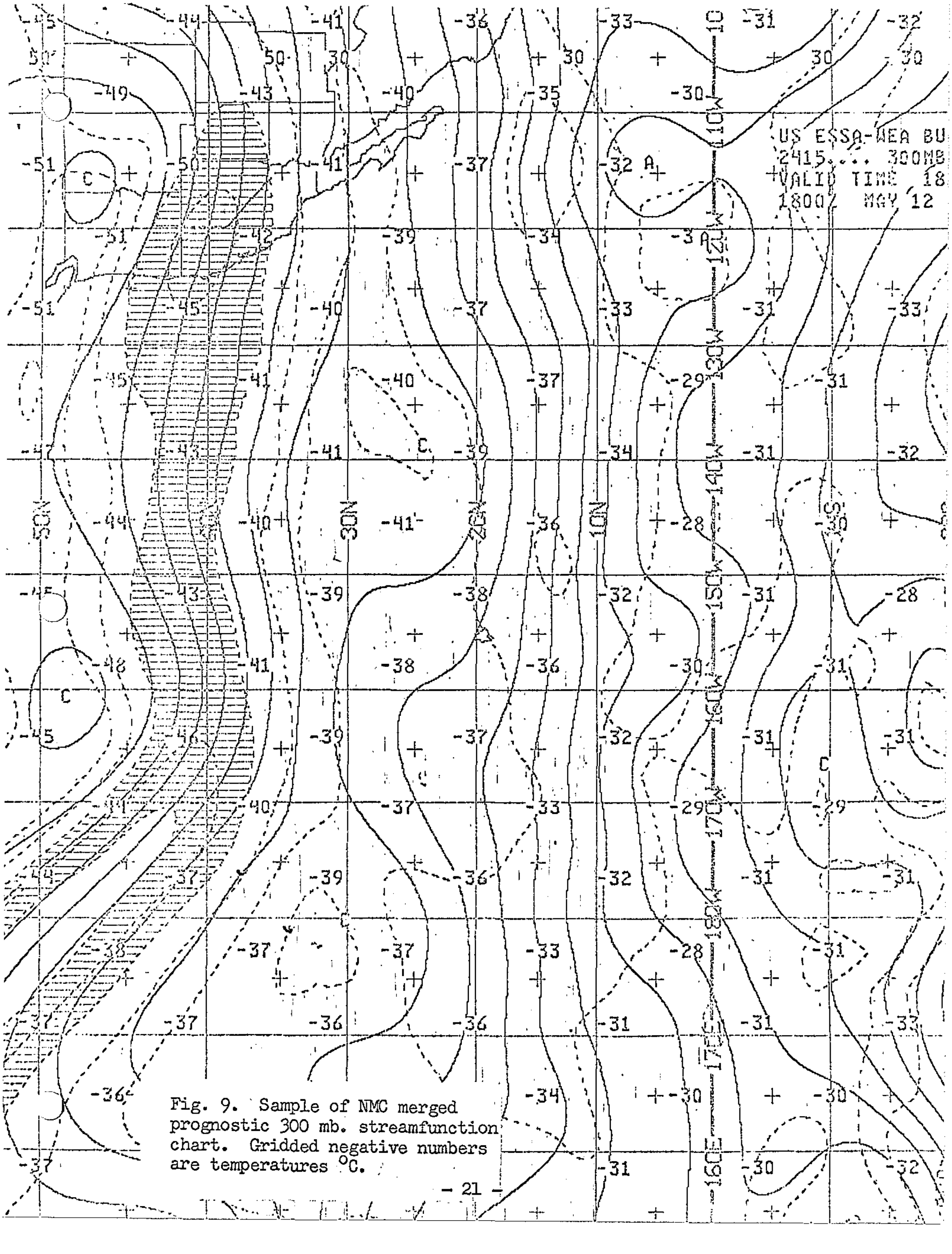

Fig. 9. Sample of NMC merged prognostic 300 mb. streamfunction chart. Gridded negative numbers are temperatures °C.

b. Tropical Prognoses. As described by Bedient and Irwin (3) the state of the art has not reached the point where operationally produced dynamic prognoses can show skill over simple persistence in the band between about 20°S to 20°N. It is well known that considerable skill over persistence is shown by the NMC 6-level primitive equation (PE) model in higher latitudes. NMC is taking both of these facts into account by producing a "merged" prognoses package on a special 116x44 point cylindrical grid. Here, the tropical analyses are merged in the band 26°N to 37°N with suitable prognostic streamfunction fields resulting from a PE model computation. Thus, we "forecast" persistence in the tropics and use the prognostic results for higher latitudes from the PE model. The result is a "merged" prognosis on a global band from 40°S to 60°N. A section of this output is shown in fig. 9.

Digital wind values from this merged model are supplied major airline flight planning activities on the Mainland.

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