

COMPUTER GRAPHICS FOR METEOROLOGICAL  
DATA

by: Ronald Lusen  
DCS-TR-#58

Dept. of Computer Science  
Rutgers, The State University of N.J.  
New Brunswick, New Jersey

Geophysical Fluid Dynamics Laboratory/NOAA at  
Princeton University  
Princeton, N.J. 08540

## Abstract

Algorithms for the automated plotting of meteorological observations of the atmosphere are presented. The computer graphics hardware and software, utilizing a Stromberg Datagraphics 4020 microfilm recorder, is first described. The manual methods for plotting these data, which have in use around the world for many years, are then described, followed by a description of the algorithms for automating the plotting. Results of both manual and automated methods are shown and comparisons are made between the two methods. The computer graphics approach clearly has significant advantages.

## 1. Introduction

This paper describes an algorithm that has been developed to automate the function of plotting meteorological data. These data consist of thousands of measurements of atmospheric temperature, pressure, wind speed and direction, plus additional parameters, which are made every day at many levels in the atmosphere, at points all over the earth.

In order to study or analyze the data, it is generally necessary to plot the data on maps. Plotting thousands of measurements each day requires a considerable amount of manual labor. Automation of this procedure, using computer graphics, is obviously advantageous in reducing the labor required, and in increasing the quantity of maps that can be produced in a given time.

Section 2 of this paper contains a description of the graphics facility being used for this work, while Section 3 describes the conventional, manual techniques for plotting meteorological data. Section 4 describes the computer algorithms for automating these techniques, and Section 5 presents the results obtained.

## 2. Graphics Facility

### A. Hardware

The graphics facility consists of a Stromberg-Datagraphics (formerly Stromberg-Carlson) 4020 Computer Recorder, which is off-line from the large, high speed computer on which the plotting program is run. The 4020 contains a special electron beam tube, two cameras (one 35mm, one 16mm), a tape drive, and associated hardware and electronics.

The plotting surface is a four inch square area on the flat face of the electron beam tube. The electron beam can be aimed at any of 1024 by 1024 raster positions on the face of the tube. By passing the beam through a special stencil contained inside the tube, the beam can be shaped into the form of any of 64 alphabetic, numeric and special characters, and then plotted at any raster position on the face of the tube. In addition, the beam can be swept in a straight line from one raster position to another on the tube face. Curved lines are approximated by drawing a series of straight line segments. With these relatively simple steps and a significant amount of software, complex images can be drawn on the plotting area, ranging from pages of text to two-dimensional projections of three (and higher) dimensional images.

The tube phosphors have a rapid decay time. Thus, the first part of an image being plotted has usually died out before later parts of the image are drawn. However, since the tube is mounted in a light-proof cabinet, facing directly into the camera lens, and the camera shutter remains open until the entire image has been drawn, the complete image is captured on film even though it appears only in short-lived pieces on the face of the tube. Beam intensity and thus image brightness are under program control, as is the camera shutter and frame advance.

Also under program control are two filter wheels and a form flash. The gray scale filter wheel is used to further control the image brightness on the film by positioning the desired filter in front of the camera lens. The color filter wheel is used to produce color images, as the tube is monochromatic. Finally, the form flash is used to flash any of a number of specially prepared slides of commonly used partial images, into the camera lens, thus avoiding the repetitious drawing of that part of the desired set of pictures.

#### B. Software

Programs run on the central computer have access to a library of subroutines which are used to generate basic commands for the 4020. These commands are written to a display file on a tape which is physically transferred to the 4020 for processing. The library contains routines for plotting points, characters, digits, or symbols; drawing straight lines; printing labels, titles and text; approximating curved lines by series of straight lines; plotting linear, semi-log, and log-log scales; and control of the cameras, filters and form flash. There are also routines for scaling of data and conversion of numerical values to characters, including plus and minus signs and decimal points, for printing of numeric values. All of the plotting commands for the 4020 are in terms of the 1024 by 1024 discrete raster positions on the face of the tube.

In addition to these basic routines, the library also contains routines that permit the programmer to handle and plot the data in any real, continuous space for which a transformation can be defined into the discrete raster coordinate system. The programmer defines this transformation with a call to a special routine, giving the scale and range of the

data relative to the raster coordinate system. Once this is done, the programmer can call plot routines using the real values of his data. Lower level plot routines then automatically convert the data to raster coordinates before issuing the commands for the 4020. This capability greatly facilitates the plotting of technical data.

### 3. Conventional Plotting of Meteorological Data

Various activities in meteorology and related fields, particularly in weather analysis and forecasting, require knowledge of the physical state of the earth's atmosphere. For this purpose, measurements of temperature, wind speed and direction, atmospheric pressure, and other parameters are made at many levels in the atmosphere, at points all over the globe, at regular intervals called synoptic times. Many of these measurements are made by balloon borne instrument packages, called sondes, which are launched from ground stations or ships at sea. Some of these sondes transmit their measurements to the ground station (radiosondes). Some are tracked by radar to obtain wind information (rawinsondes). Additional measurements are made by reconnaissance and commercial aircraft (aireps). Satellites are also used now to measure atmospheric parameters by remote sensing. Many of these measurements are sporadic, either in space or time, or both.

Within hours from the time the measurements are made, they are collected and transmitted to local, national and global weather centers, one of which is the National Meteorological Center of the U. S. National Weather Service, near Washington, D. C. Here, some of the data are normally plotted by hand according to standard conventions, many of which were adopted long before the advent of computers.

A typical RAOB (radiosonde or rawinsonde observation) would be plotted as shown in Figure 1. An arrow or wind barb is drawn, representing the wind speed and direction. The head of the arrow is a small circle that is plotted on a map at the location from which the balloon was launched, or the place where the observation was made. The arrow points in the

direction (to the nearest 10 degrees) toward which the wind is blowing. The shape and number of feathers on the arrow shaft indicate the wind speed, usually to the nearest 5 knots. In this paper, however, all wind speeds are in meters per second. A triangular feather represents 50 meters per second (mps), a long feather 10 mps, and a short feather 5 mps. Thus, the wind barb in Figure 1 shows a wind of 65 mps at 30° from due north. Other data, such as temperature in degrees Celcius and geopotential height in meters, are annotated near the head of the arrow, with temperature generally to the left and height to the right. Only the 3 least significant digits of height are shown, since all meteorologists know that the average height of the 850 mb pressure level is 1500 meters. Thus, 570 means 1570 meters. Note also, that the temperature and height are annotated in such a way as to not overlay the arrow itself. Obviously, the exact orientation of the figures representing the temperature and height data depend on the direction of the wind.

Another complicating factor is that the side of the arrow shaft to which the feathers are drawn represents the Coriolis force. This is the force that, due to the earth's rotation, causes an air mass, which is trying to move in a straight line, to curve one way in the Northern Hemisphere and the other way in the Southern Hemisphere. Thus the feathers are drawn to one side of the arrow shaft in the Northern Hemisphere and to the other side in the Southern Hemisphere. Other complications include drawing the wind barb through the circle for aircraft reports and satellite data, and drawing the circle but no arrow shaft if the wind speed is less than 2.5 mps.

Figures 2a-2d show most of a global map plotted manually, using data for November 4, 1969, 12:00 noon Greenwich Mean Time (GMT) at the 850



millibar (mb) pressure level in the atmosphere (approximately one mile above sea level). Figure 2e shows part of the map for the 200 mb level (near the stratosphere). Note that a temperature obtained from an orbiting satellite also has the time of the measurements annotated. For example, "18.14Z" means 18 degrees Celcius measured at 1400 hours GMT, or 2:00 P.M.

#### 4. Design of the Display Frame

The display of a single frame is built up in stages. Both real latitude and longitude coordinates and discrete raster coordinates are used to create the display. Early in the program the desired transformation (e.g. mercator) from real space (latitude and longitude) into raster space (1024 by 1024 discrete values) is defined. Thereafter, plotting can be done either in raster coordinates or in real space coordinates.

Raster coordinates are first used to outline the plotting area with a rectangular boundary, allowing top, side and bottom margins for labels and titles. Tic marks are drawn every five degrees in latitude and longitude around the border, and labels for latitude and longitude are printed. The equator is drawn and a title is printed at the top. The title usually consists of a starting and ending time and date covering the period during which the data was obtained. For example, "NOV 4, 1969 7 Z THRU NOV 4, 1969 18 Z AT 850 MB LEVEL" means the 12 hour period from 7:01 a.m. Greenwich Mean Time (GMT or sometimes Z), November 4, through 6:00 p.m., November 4, 1969. The pressure level in the atmosphere in millibars (mb) at which the measurements were made is also given in the title. These parts of the display are plotted directly in raster coordinates.

The geography, which is plotted in real (latitude-longitude) coordinates, is obtained by plotting a special file of data points which represent the coastal boundaries of continents and islands. With this data file, any geographical map for any part of, or all of, the world can be plotted using any map projection desired. Common examples of map projections are mercator, stereographic and latitude-longitude projections.

The final steps in plotting the display involve plotting the observed measurements. Since meteorological observations are usually plotted to

the nearest 5 or 10 degrees in wind direction, to the nearest 5 knots in wind speed (5 meters per second in our examples), to the nearest whole or tenth of a degree in temperature, and to the nearest meter in height, it is necessary only to plot discreet values of these parameters as opposed to a continuum of real values.

Each complete observation, consisting of temperature, height and wind speed and direction is plotted using a combination of real space and discrete raster coordinates. First, a special character is plotted at the location of the head of the arrow shaft, using the real latitude and longitude from which the observation was made. Different characters are used to represent different types of observations. A degree symbol is used for land RAOBS (radiosonde or rawinsonde), the letter S for ship RAOBS, A for AIREPS (aircraft reports), C for winds derived from satellite cloud pictures, and an asterisk for temperatures derived from satellite measurements.

The remainder of the plotted observation, which consists of arrow shaft, feathers and the annotated temperature and height, are then built up using tables of incremental raster positions relative to the last point plotted. (All lines are plotted on the SD4020 using the incremental change in horizontal (I) and vertical (J) raster positions relative to the last position of the electron beam.) These tables were constructed by manually plotting numerous cases on ruled graph paper and choosing what appeared to be optimal values for the raster increments. Nine tables are needed, as follows: one for the arrow shaft (which was chosen to be 30 rasters in length), two for the sides of the triangular feathers (each representing 50 meters per second), two for the spacing between feathers along the arrow shaft, one for the long feathers (each

representing 10 meters per second), one for the short feathers (each representing 5 meters per second), and one each, for anoting the characters representing temperature and height, respectively. These last two are given relative to the arrow head. Each table contains 18 entries, representing the 18 possible wind directions to the nearest 5 degrees within a 90 degree quadrant. Four way symmetry is used to produce all 72 possible wind directions in 360 degrees. There are actually two sets of tables for the feathers, one set for the Northern Hemisphere and one for the Southern Hemisphere. This is due to the convention of drawing the feathers to one side of the arrow shaft in the Northern Hemisphere, and to the other side in the Southern Hemisphere.

Figure 3 shows the 10 steps used in the automatic plotting of the wind barb of Figure 1. Step 1 is the plotting of a small circle in real space at the location of the observation. The latitude-longitude position is first transformed into raster space by transformation routines, and the beam is then positioned, and the circle plotted on the face of the tube. The arrow shaft is drawn in step 2 by sweeping the beam to a new position defined by the changes in raster coordinates relative to the beams last position. The remaining lines of the figure are drawn in steps 3 through 8 by sweeping the beam, while it is either turned on (to draw a line) or turned off (to not draw a line). Steps 9 and 10 are drawn by character plotting routines by positioning the beam relative to the head of the arrow. Note that the feathers are not always attached exactly to the arrow shaft, but begin at the nearest raster point.

## 5. Results

Figures 4a through 4e show one frame each of the computer plotted data, and correspond to the manually plotted data of figures 2a through 2e. The data are plotted on a Mercator projection from 45° north latitude to 45° south latitude, and each frame covers 95° of longitude with a 5° overlap between frames. This overlap facilitates the cutting and pasting of 4 frames (4a through 4d) together to make a complete map of the earth from 45°N to 45°S. Such a map could, of course, be drawn in one frame, but it would be one fourth the size and have poorer resolution.

There are some differences between the computer drawn maps and the manually drawn maps. These are due primarily to differences in the processing of the data before the plotting was done. In particular, the winds derived from satellite cloud pictures were not used in the computer drawn maps. Also, a data observation will occasionally appear in the hand drawn map but not in the computer drawn map and vice-versa. Note that figures 4a through 4d annotate 4 digits for height instead of 3.

A comparison of figures <sup>4 a through 4d with figures</sup> 2a through 2e show very good agreement. Note in particular, that occasional human errors, such as the somewhat erratic location of some of the satellite data (see, for example, figure 2a) is obviously eliminated in the computer drawn maps. This improvement in accuracy, coupled with the convenience and speed with which the computer drawn maps can be produced, make this application of computer graphics a very valuable one indeed.

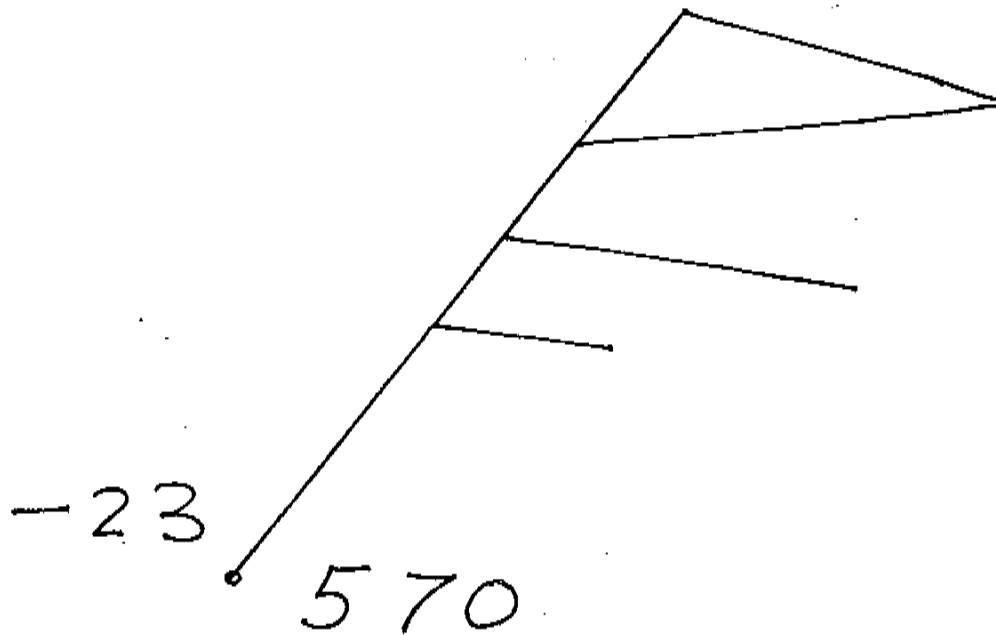


FIGURE 1

Typical hand drawn wind barb (much larger than real size) which shows a wind speed of 65 meters per second from 30°, with an annotated temperature of -23° celcius, and a geopotential height of 570, which means 1570 meters.









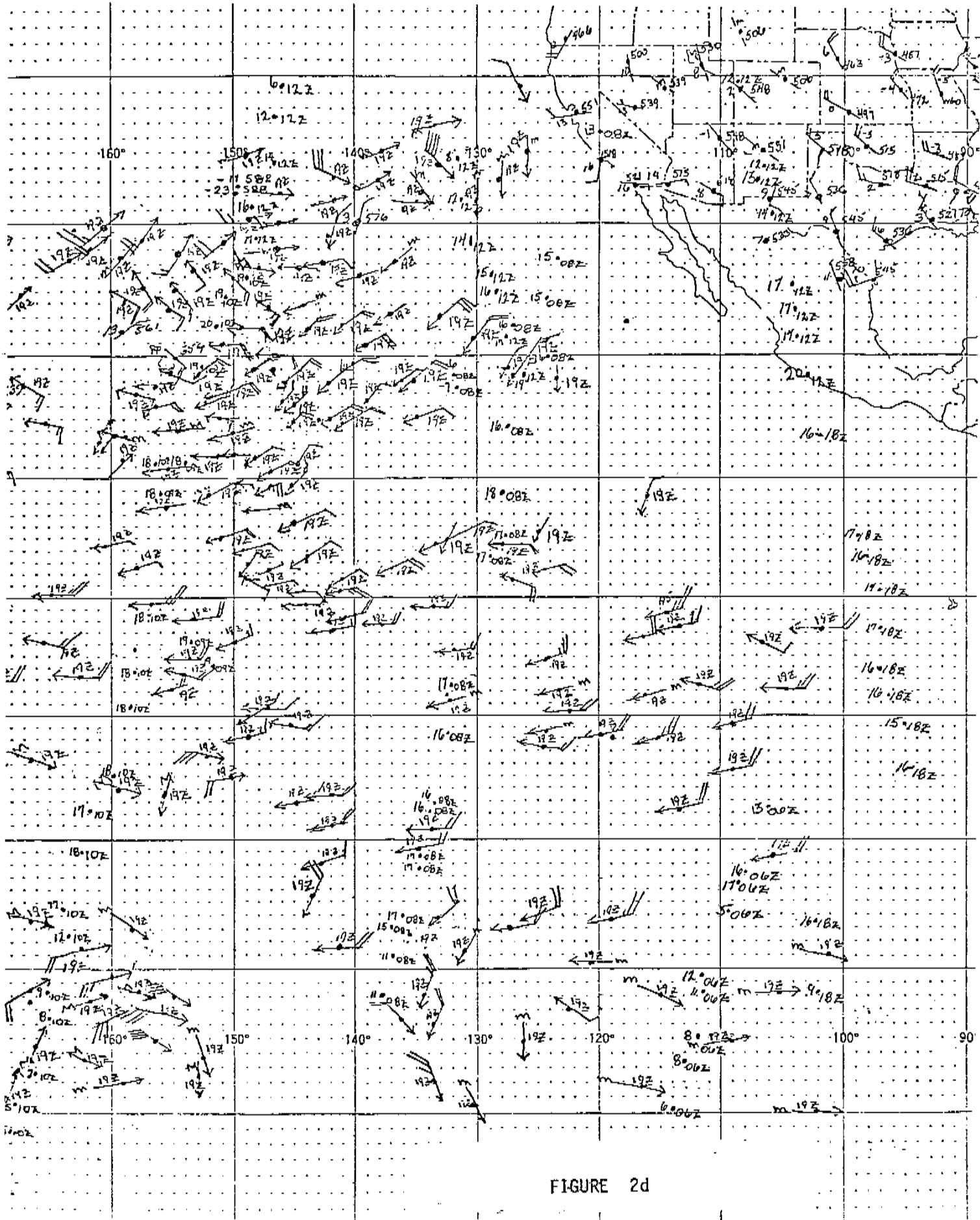


FIGURE 2d



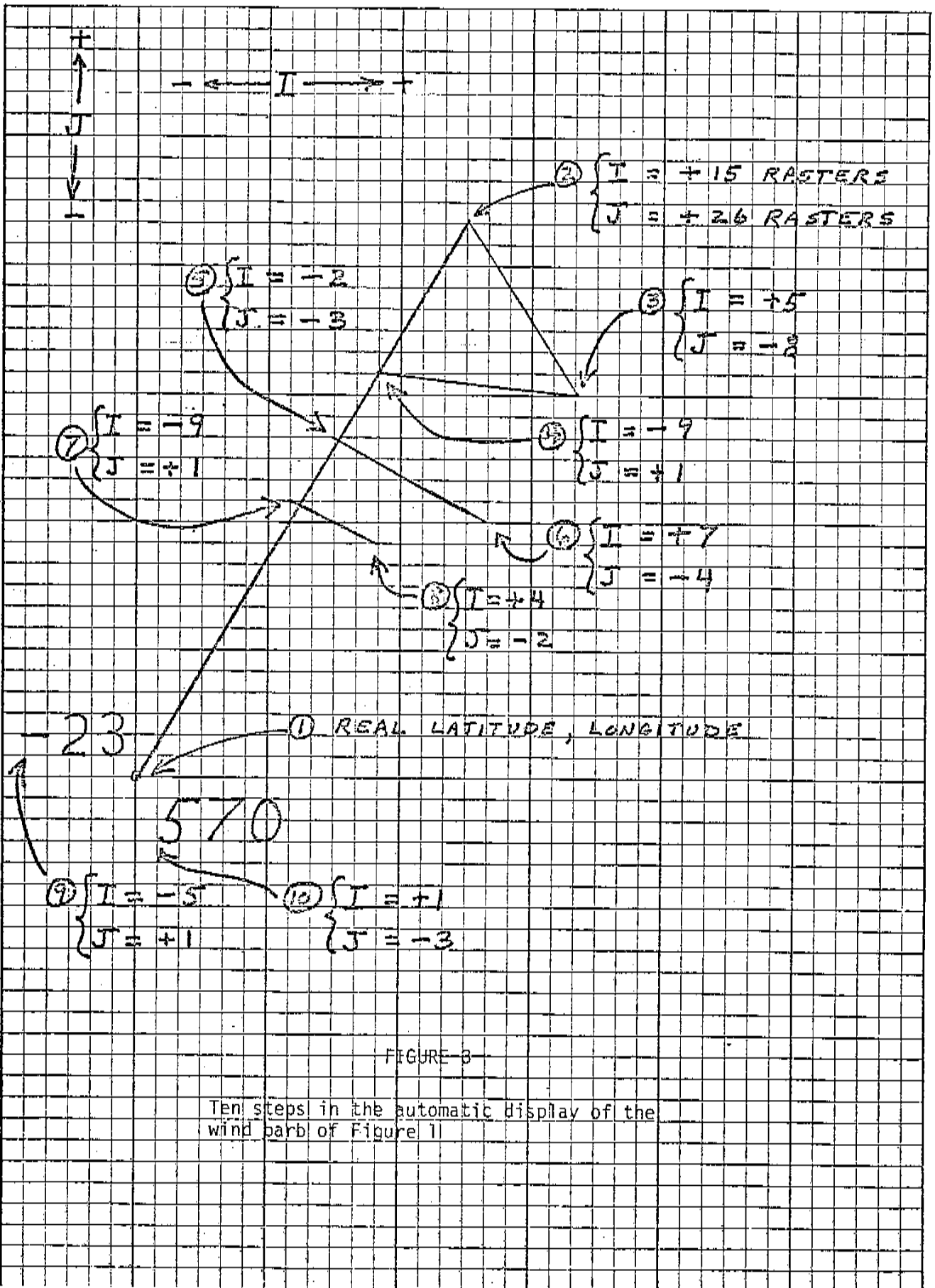


FIGURE 3

Ten steps in the automatic display of the  
wind barb of Figure 1)



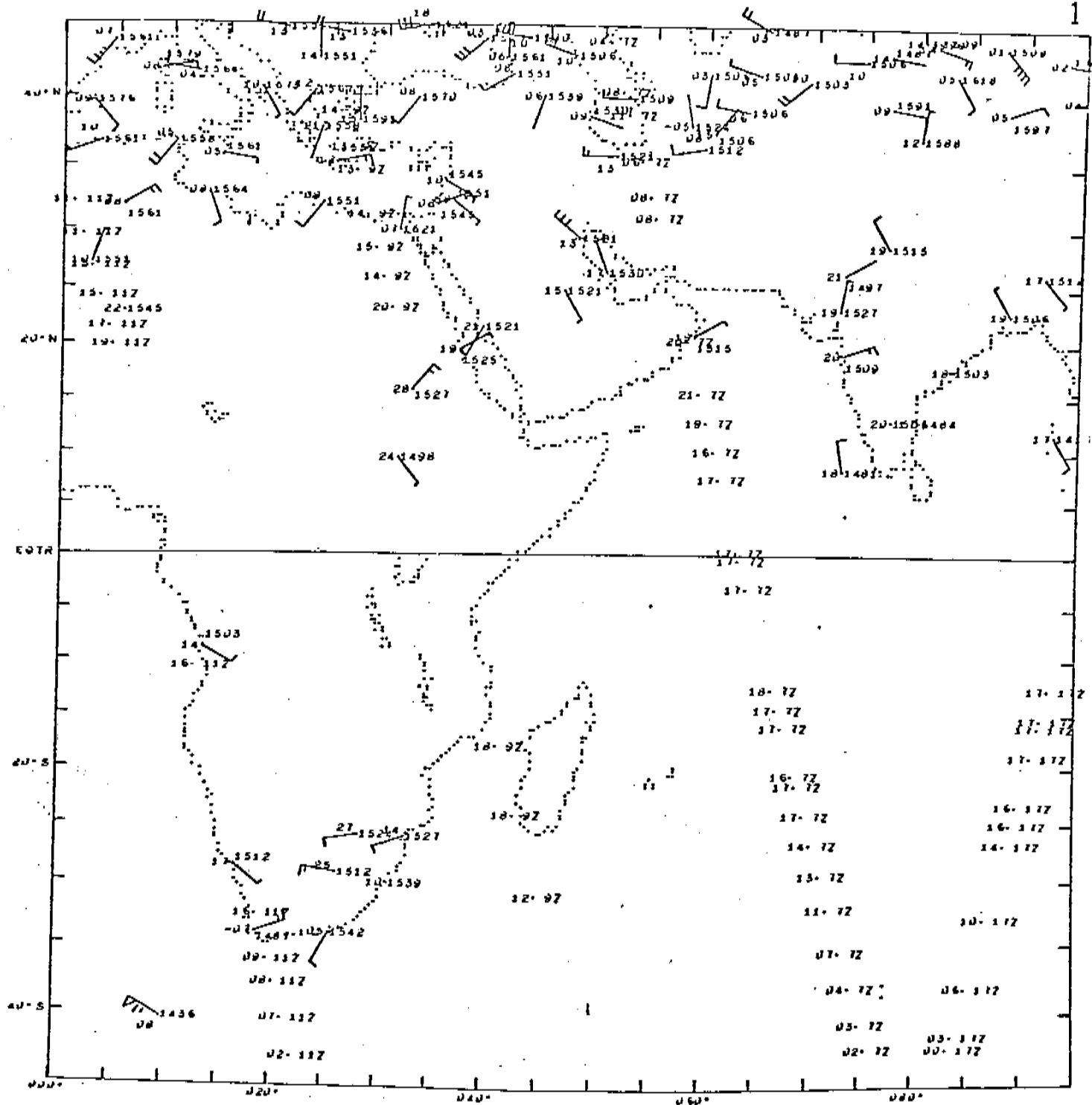


FIGURE 4b



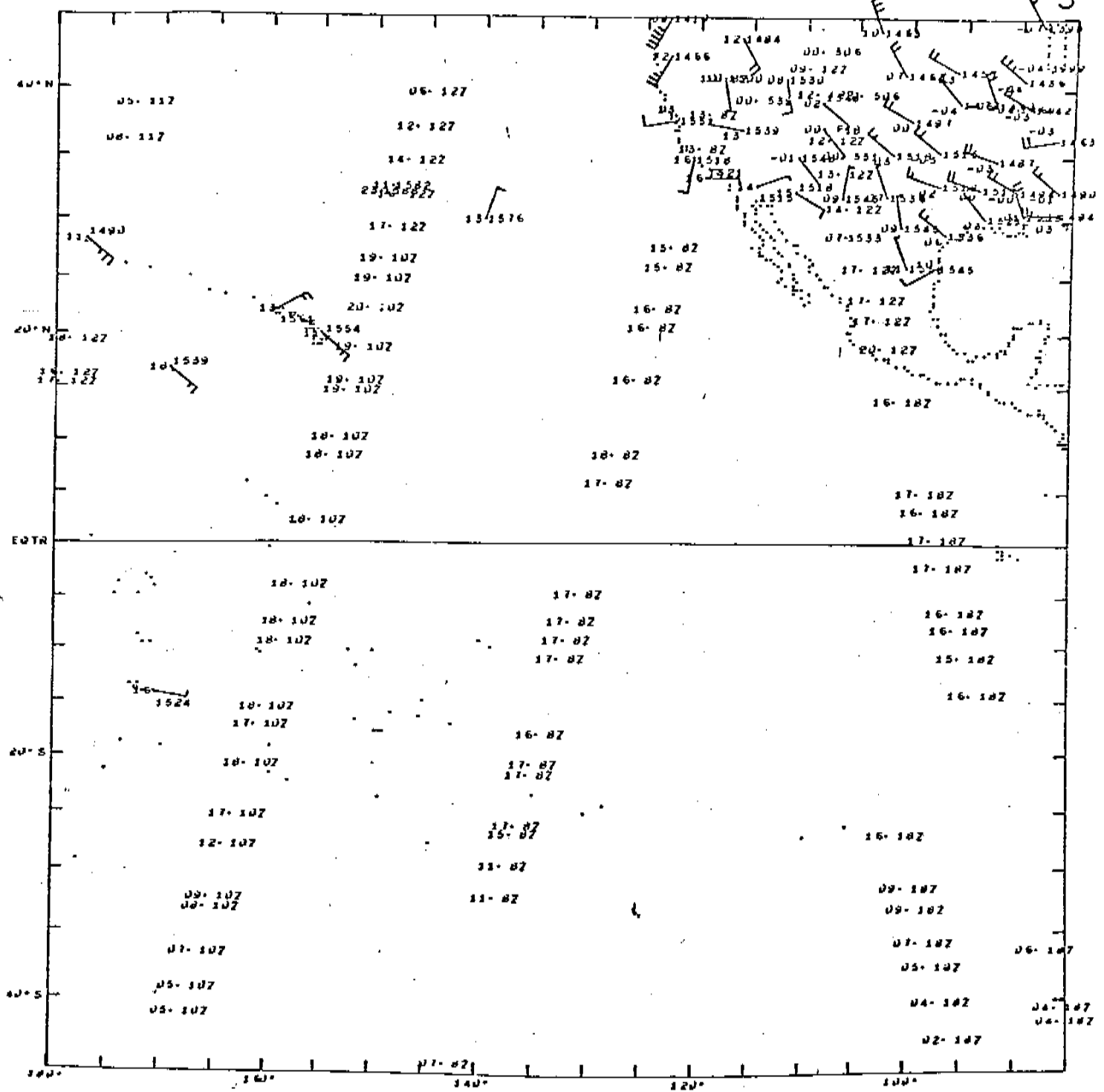


FIGURE 4d



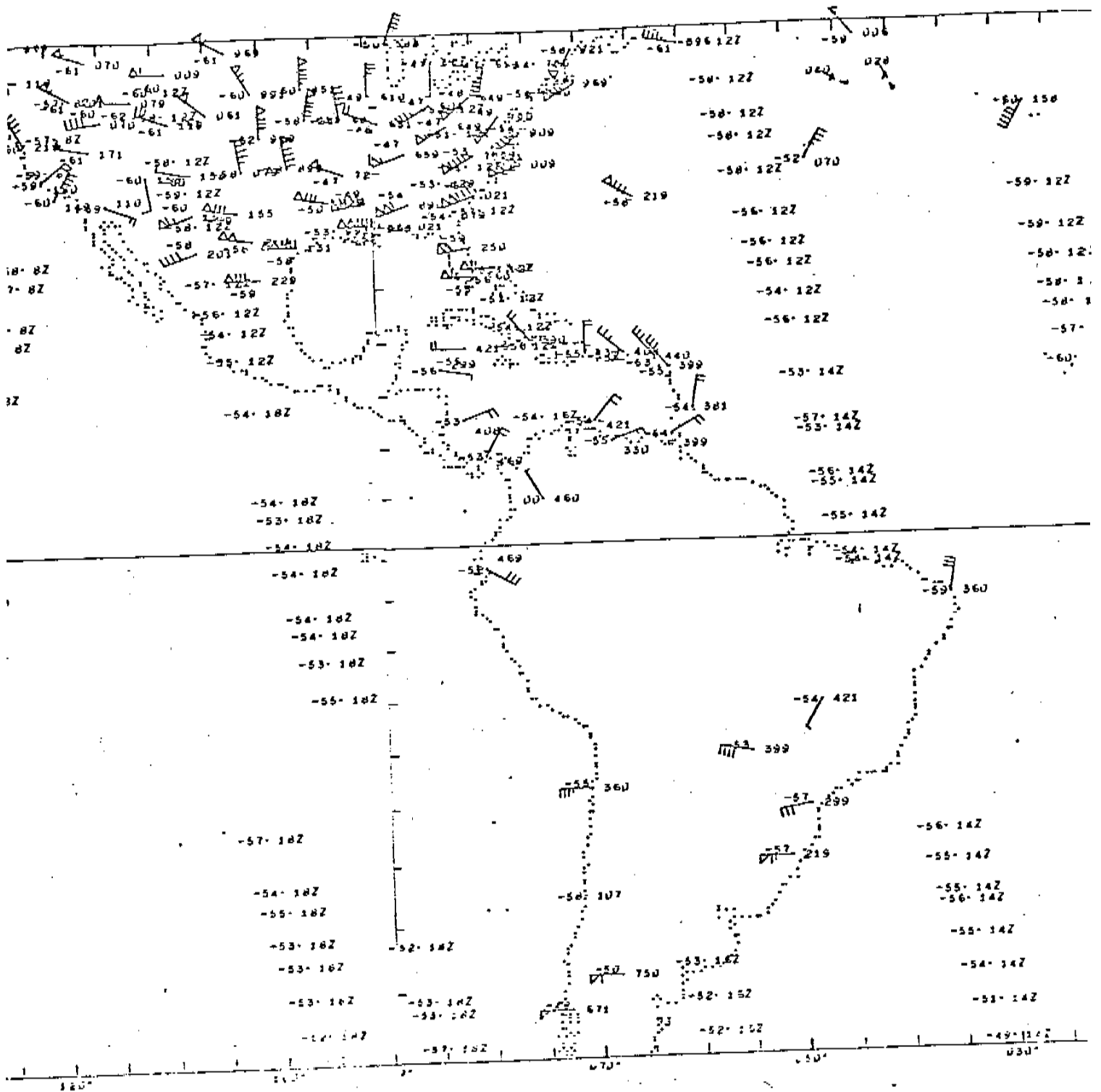


FIGURE 4e