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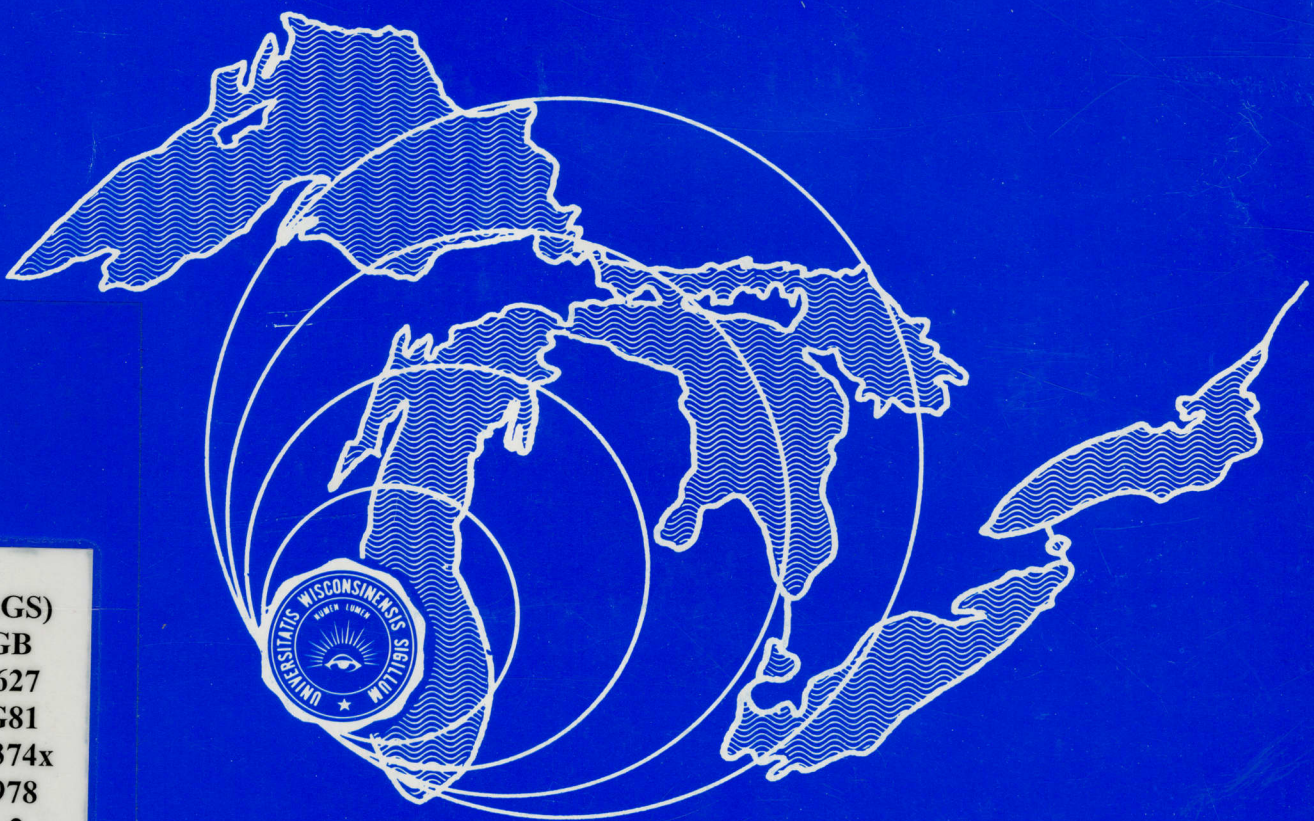

MILWAUKEE, WISCONSIN 53201 U.S.A.

SPECIAL REPORT NO. 36

Time-series plots of Lake Ontario currents, temperatures, and winds

(IFYGL, Winter 1972-73)

by

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June, 1978

ABSTRACT

Vector time-series plots of currents and wind stress and scalar plots of water temperature are presented at 10-day intervals using hourly data from Lake Ontario, December 1972 - March 1973. The data were collected as part of the International Field Year for the Great Lakes (IFYGL). The currents and temperatures were measured at about 15 and 75 m at nine stations: one near mid-lake, about 40 km from shore, and in about 140 m of water; the other eight spaced around the lake, about 50 km apart, 15 km from shore, and in 100 m of water.

An examination of the records shows that inertial currents occurred only intermittently, having speeds less than 15 cm s^{-1}; however, they did appear at nearly all stations during a period of stable, vertical stratification. Most of the current variance is accounted for by low-frequency fluctuations of the alongshore flow; fluctuations with periods on the order of 10 days appear to propagate counterclockwise around the lake.

ACKNOWLEDGEMENTS

My study of the winter circulation of Lake Ontario was made possible by the support of Prof. Clifford H. Mortimer (Center for Great Lakes Studies) and with the help of Dr. Robert L. Pickett (Great Lakes Environmental Research Laboratory, NOAA).

CONTENTS

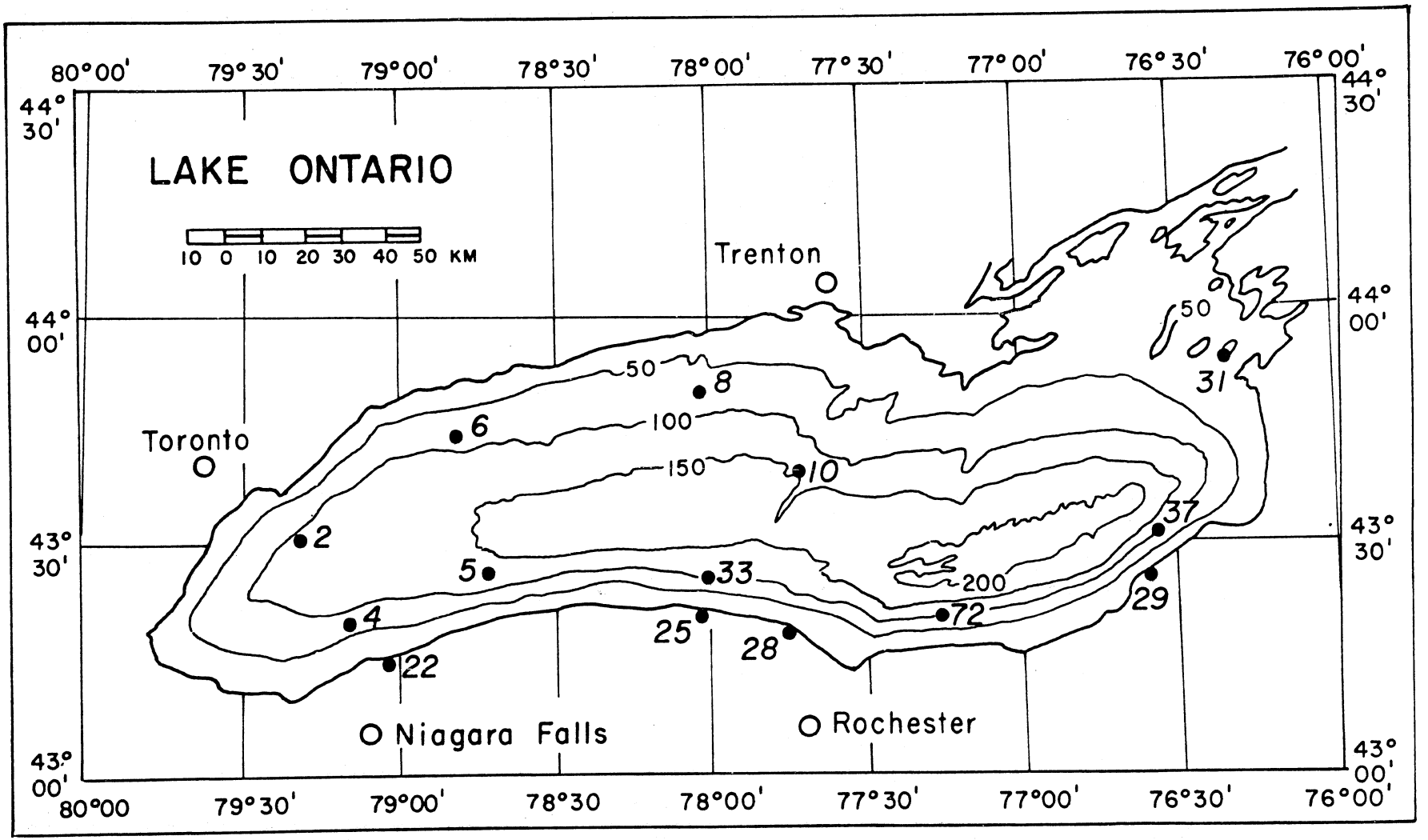

Fig. 1. Topographic map of Lake Ontario showing locations of the winter moorings and land stations (Sta. 22,25,28,29, and 31). Isobath depths are in meters.

Introduction

As part of the IFYGL program to measure the climatology of Lake Ontario, currents and water temperatures were sampled every 30 minutes at nine stations (Fig. 1) with Plessey and Geodyne current meters, from 1 December 1972 through late March 1973, by E.B. Bennett's group at the Canada Center for Inland Waters. Details can be found in Byron (1976), Anonymous (1972), and in the volumes of the IFYGL Technical Plan (IFYGL Project Office, 1972 a,b, and c).

A computer tape containing hourly values of the winter data was kindly provided by Dr. Robert L. Pickett of NOAA's Great Lakes Environmental Research Laboratory. A listing of the tape showed that Stations 2,5,10,33, and 37 had complete records at a shallow depth, either 15 or 16 m, and 75 m; but that complete records from only a shallow depth were available for Sta. 4,5, and 8, and from only 75 m for Sta. 72. Now, in general, the shallow currents had been measured with a Plessey meter at 15 m and a Geodyne instrument at 16 m, but usually only one shallow record extended uninterrupted over the 4-month period. (Shallow records from Sta. 2 for December, when both current meters were working at that station, are shown on p. 13-15, and the agreement

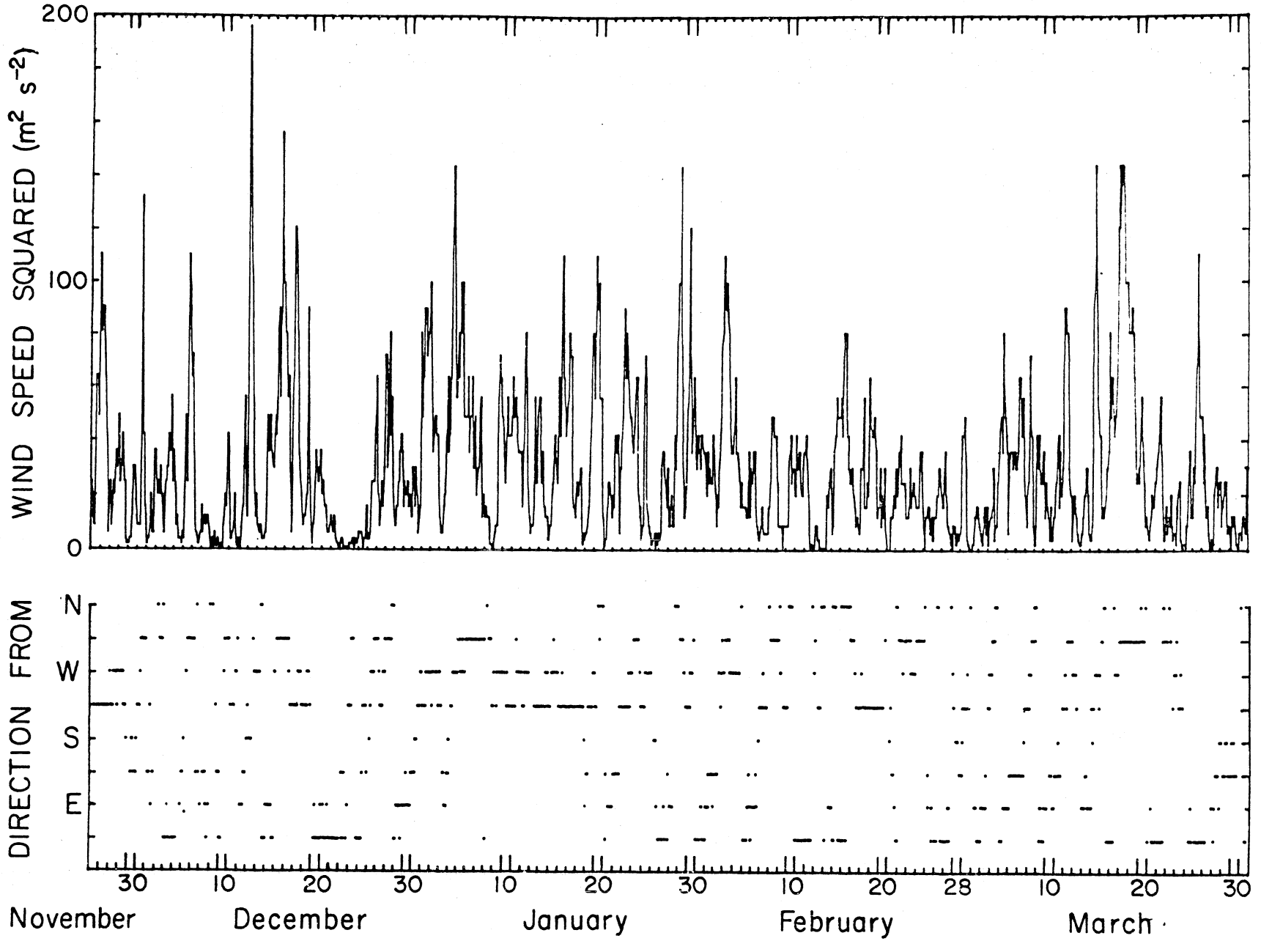

Fig. 2. Values of the square of the wind speed and the direction from which the wind is blowing for 26 November, 1972 through 31 March, 1973. The 3-h data are from Irbe and Mills (1976) who used reports from three airport stations and weather maps to estimate conditions over Lake Ontario. Wind direction is given with reference to eight compass directions; variable winds are plotted using a speed of zero. Eastern Standard Time is used.

between meters is fairly good.) In this report then, only the longer shallow record and 75-m records will be presented (in 10-day long plots).

To allow comparisons to be made between currents and wind forcing, time-series plots of wind will also be presented. An overview of the winter winds is given in Fig. 2 which shows values of the square of the wind speed (which are proportional to wind stress) and wind direction for the Lake Ontario region as calculated from 3-h meteorological data of Irbe and Mills (1976). Hourly winds, measured at 10-m height, are also available from U.S. land stations (Fig. 1). [See Foreman (1976) for station details.] An intercomparison for a 28-day period (Fig. 3) shows good agreement among stations and between land stations and Irbe and Mill's regional winds. Vector plots of winds from Sta. 25 (centrally located on the southern shore) have been plotted using the 10-day format and follow the plots of the currents.

In addition to the temperature time-series presented later, information on the lake's thermal structure was provided by Airborne Radiation Thermometer (ART) flight surveys (Irbe and Mills, 1976) and by ship surveys (Boyce, 1972).

It is hoped that an examination of the detailed time-series plots presented in this report may

Text continues on page 8.

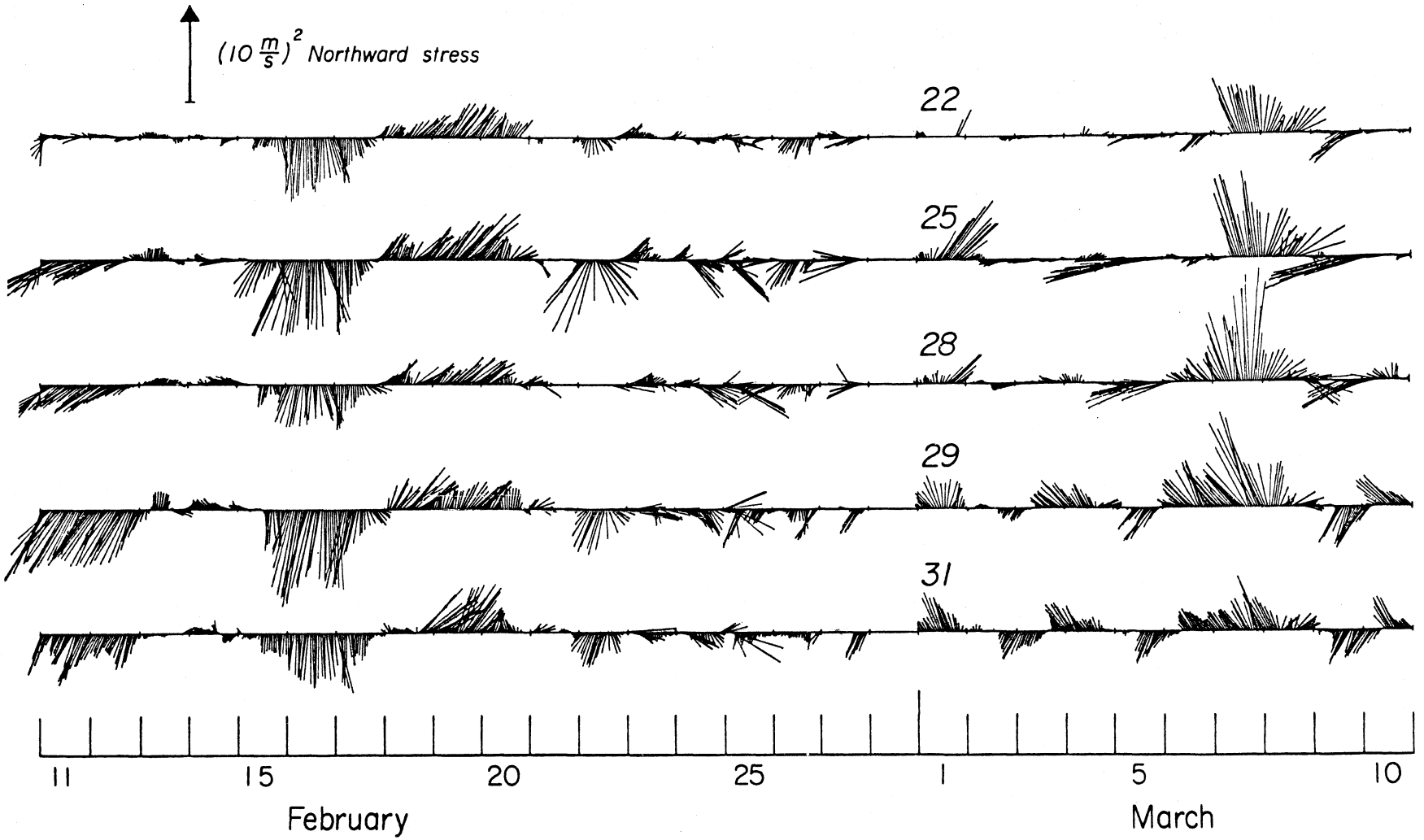

Fig. 3. Winds observed on land stations 22-31 for the period 11 February through 10 March 1973. The quantity plotted is $\underset{\sim}{V}\,|\underset{\sim}{V}|$, where $\underset{\sim}{V}$ is the wind vector with speed in m s-1 and pointing in the direction the wind is going. There are gaps in the data; for instance, there is no data for 28 February.

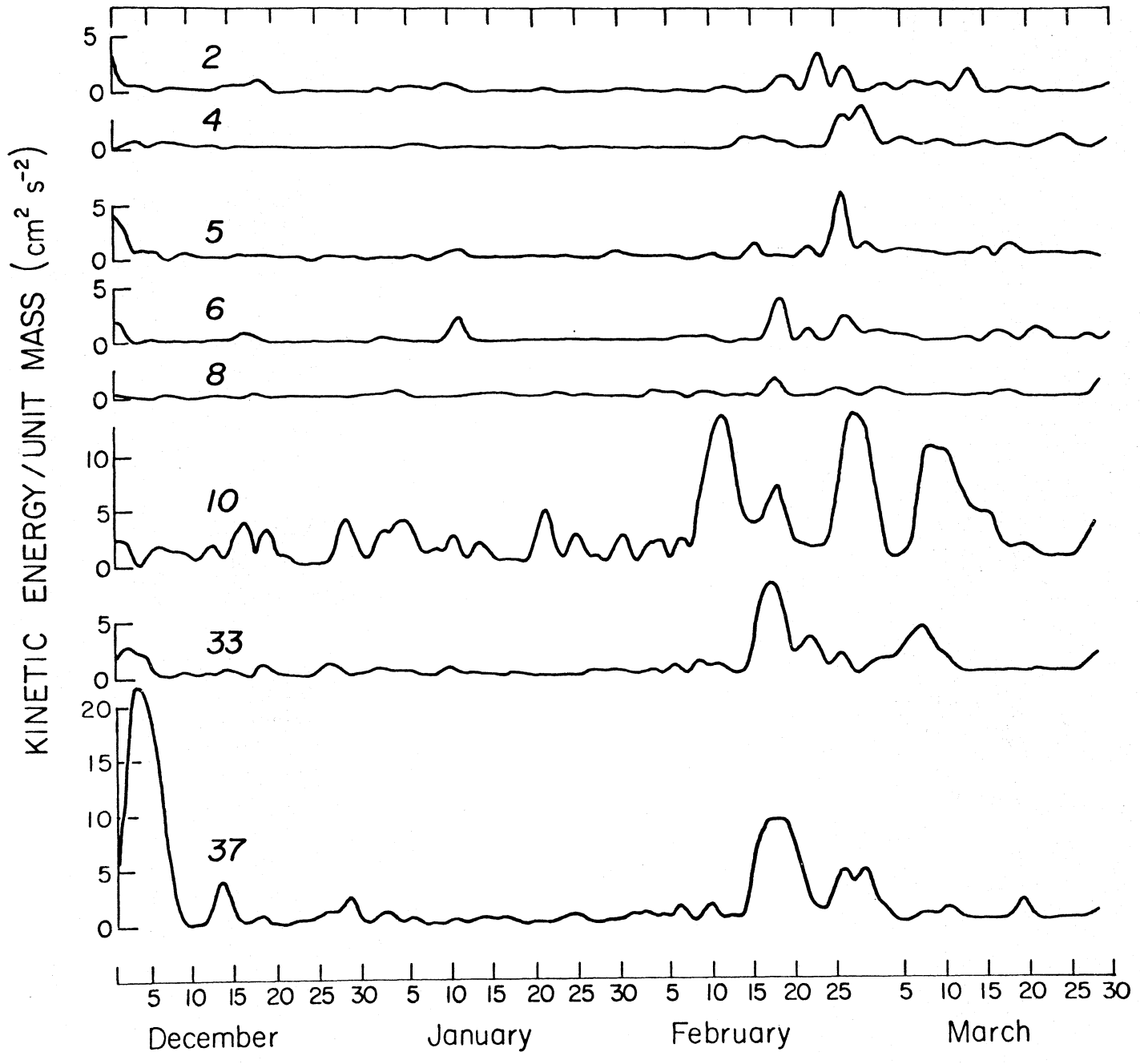

Fig. 4. Kinetic energy per unit mass calculated from numerically-bandpassed shallow currents for 1 December through the last full day of data (28-30 March). Each plotted point is an 8-h average of $(u^2 + v^2)/2$.

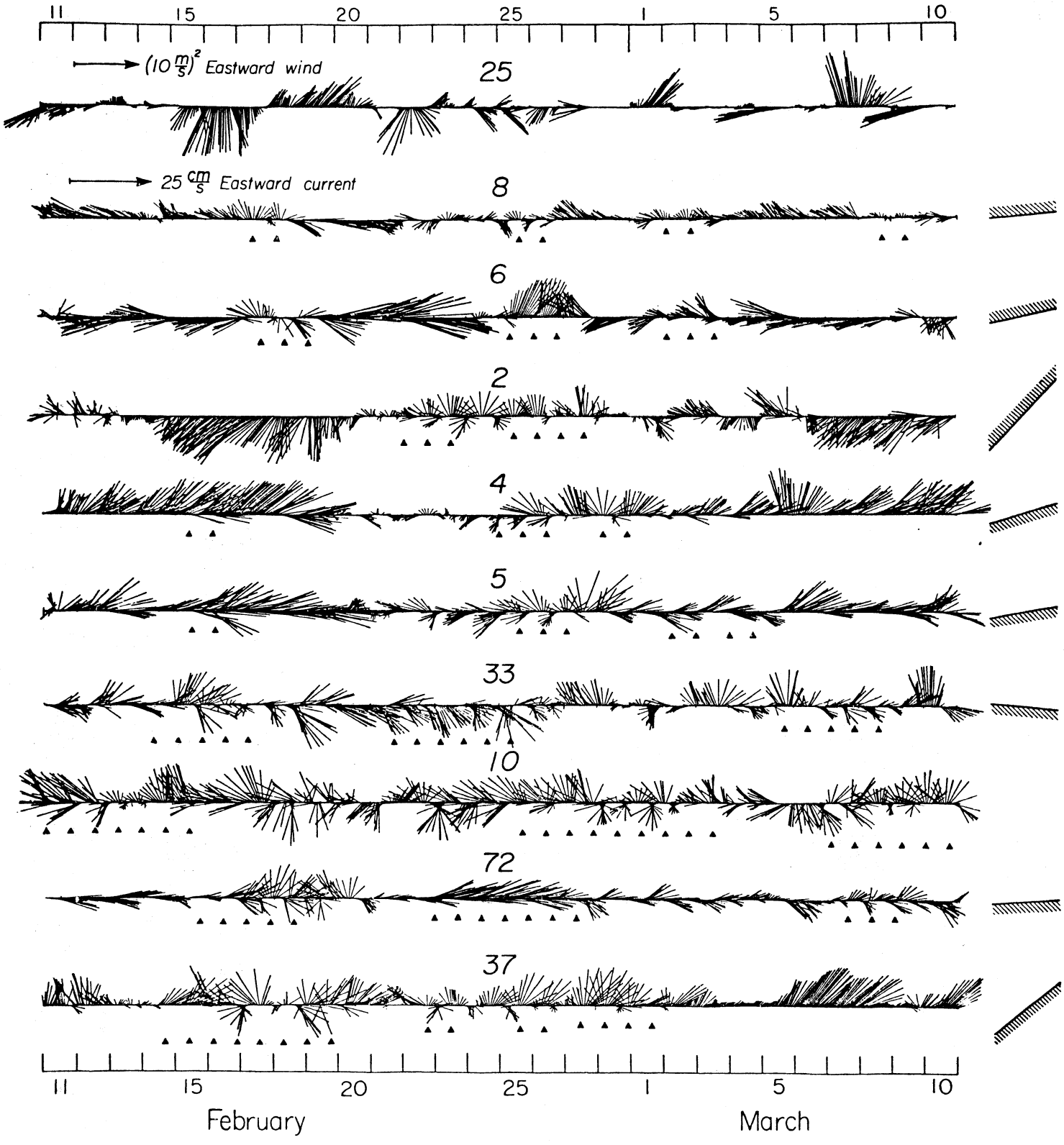

Fig. 5. Vector time series arranged top-to-bottom according to station position following a counterclockwise circuit beginning with Sta. 8, for the period 11 February through 10 March, 1973. The 15-m or 16-m currents are shown except for Sta. 72, in which case the 75-m current had to be used. Also shown are Sta. 25 winds, plotted as $\underset{\sim}{V}\,|\underset{\sim}{V}|$ where $\underset{\sim}{V}$ is the wind vector, direction towards. Triangles, spaced an inertial period (17.3 h) apart, lie below northward-pointing vectors during conspicuous inertial episodes. On the right is indicated, where appropriate, the orientation of the local bathymetry. North is at the top of the figure.

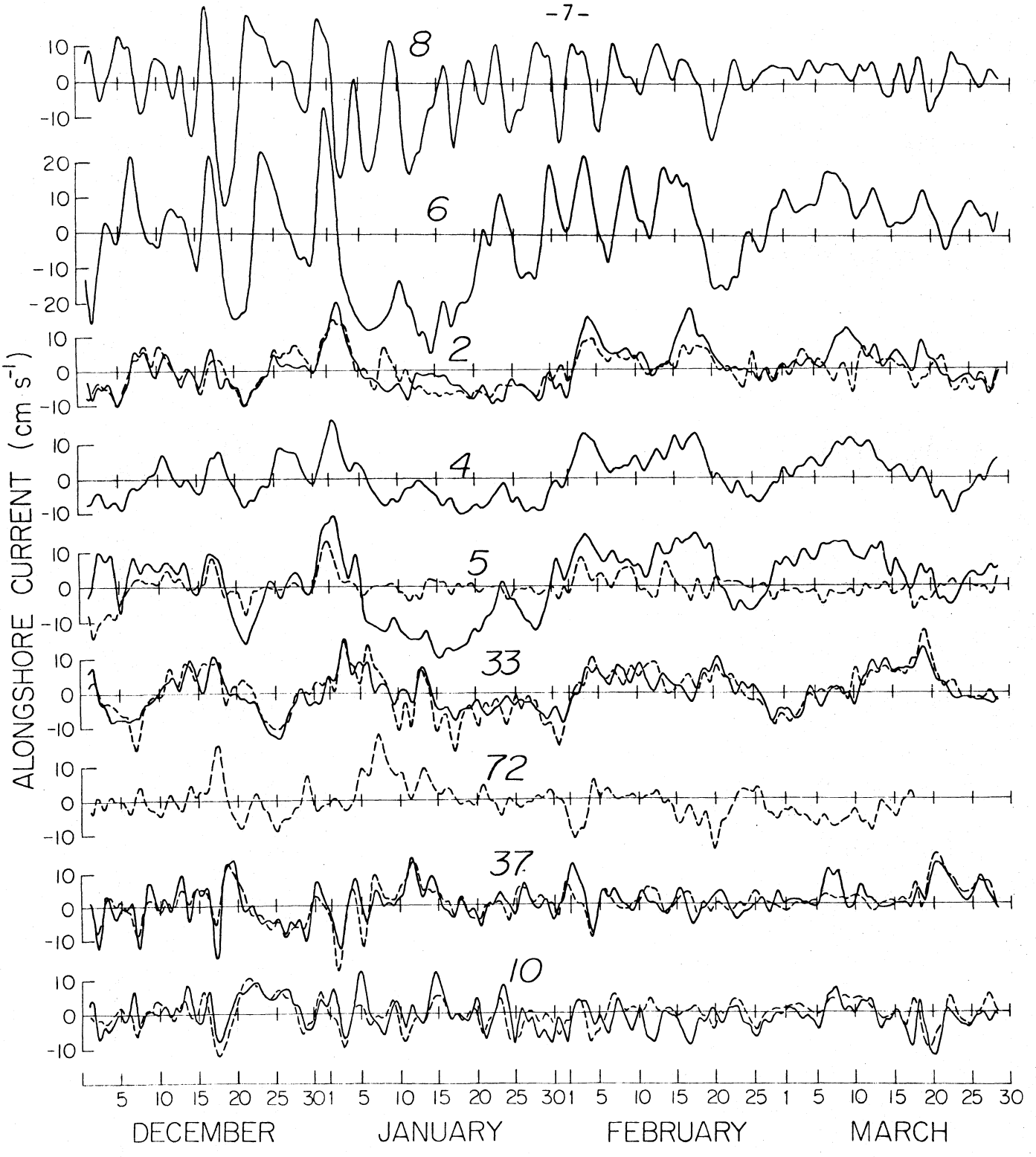

Fig. 6. The alongshore flow, reckoned positive when the flow is to the right while looking offshore, at 15 m (solid curves) and 75 m (dashed). The time series are arranged top-to-bottom according to station position following a counterclockwise circuit beginning at Station 8. The mid-lake station, Station 10, is plotted at the bottom.

be of some use to other investigators. The monthly-mean circulation of Lake Ontario has already been documented by Pickett in a series of papers (Pickett, 1976; Pickett, 1977; Pickett and Bermick, 1977) but perhaps episode-by-episode analyses, using this report as a guide, may prove enlightening.

Discussion

My examination of the winter data has led to the investigation of the near-inertial energy band (Marmorino, 1978a) and of the very low frequency flow (Marmorino, 1978b). The time history of energy in near-inertial currents, determined by numerical filtering, is reproduced here as Fig. 4 where it can be seen that inertial "events" occurred intermittently and accounted for little kinetic energy on the average. The inertial events can be seen in the time-series plots as well of course, and Fig. 5 shows records from each station during the one period (mid-February through early March) which had inertial currents at nearly all the stations. By examining the temperature series for those stations with instruments at 15 and 75 m, one finds that these "lake-wide" inertial events coincided with a period of lake-wide, stable, vertical stratification. Temperature fluctuations can also be observed in the plots; some may have been induced by an interaction of the inertial flow with (observed) horizontal temperature gradients.

On the other hand, the lowpassed (periods greater than about 2 days) alongshore flow (Fig. 6) is always energetic. Close examination of the fluctuations shows a general counterclockwise propagation of signal around the lake, at a rate consistent with first mode topographic Rossby waves.

The possibility of measurement errors should be mentioned. For instance, the 75-m flow at Sta. 5 is often times strongly onshore or offshore which is at variance with conditions at the other stations. It is possible that the direction sensor for this meter was faulty; if so, the 75-m vectors need to be rotated about 90° counterclockwise from their plotted positions.

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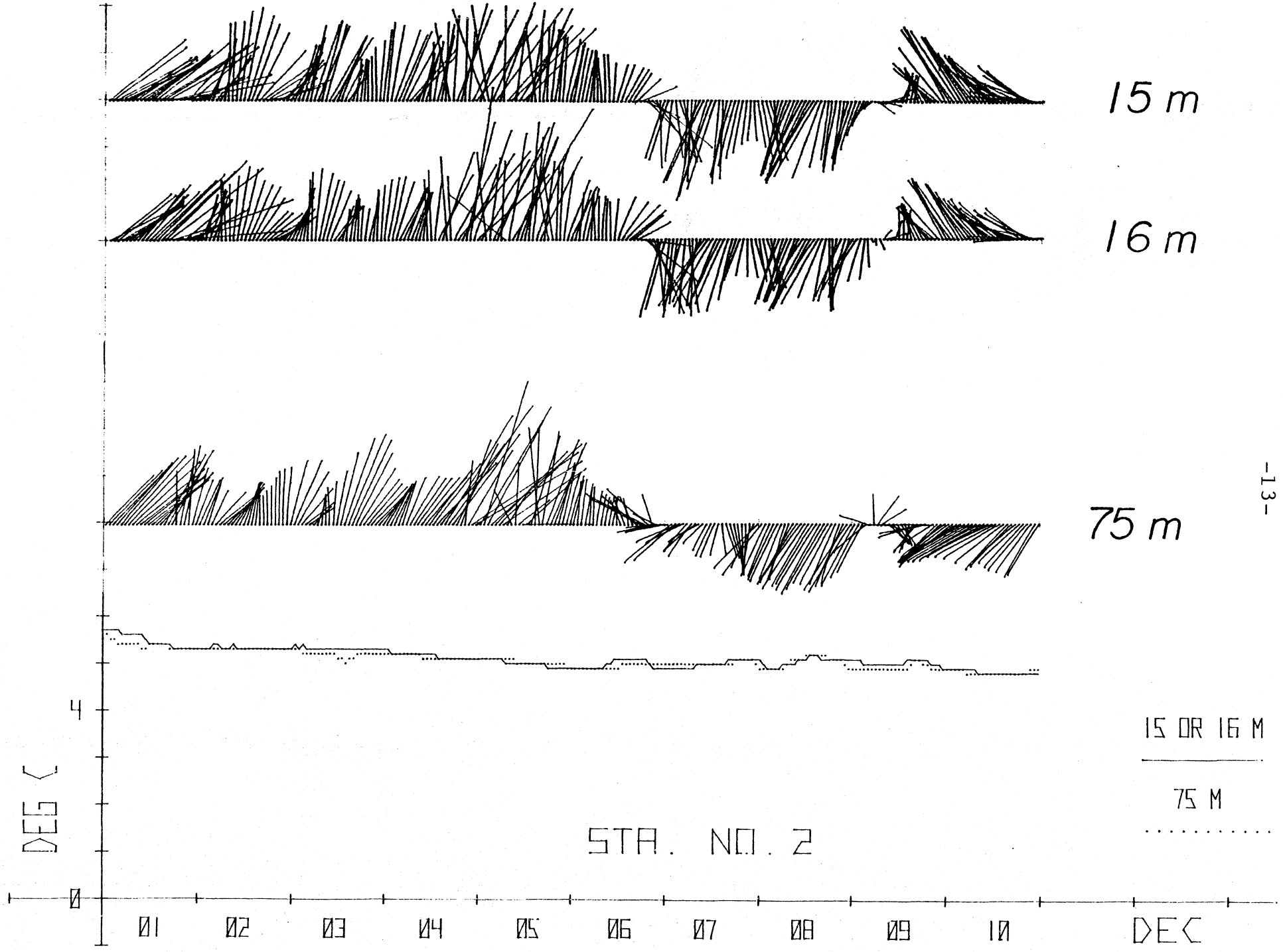
Time-series plots of currents and temperatures

On the following pages are shown 10-day plots of hourly-averaged currents and temperatures for Sta. 2,4,5,6,8,10,33,37, and 72 from 1 December 1972 through the last available day in March 1973. The currents are plotted as vector time-series with the vectors pointing in the direction toward which the water is flowing (this kind of presentation is sometimes called a "stick" plot), the shallow current (if any) being shown near the top of the page, and the 75-m current (if any) shown near the middle of the page. (Only for Sta. 2 in December are both shallow currents--15 and 16 m--shown; otherwise, only the depth providing the longer time series is plotted.) Each tic mark for the current plots represents an increment of 5 cm s^{-1}. North is at the top of the plots. The shallow and 75-m temperatures (solid and dotted curves, respectively) are shown in the lower panel of each page where each tic mark on the vertical axis represents an increment of 1°C.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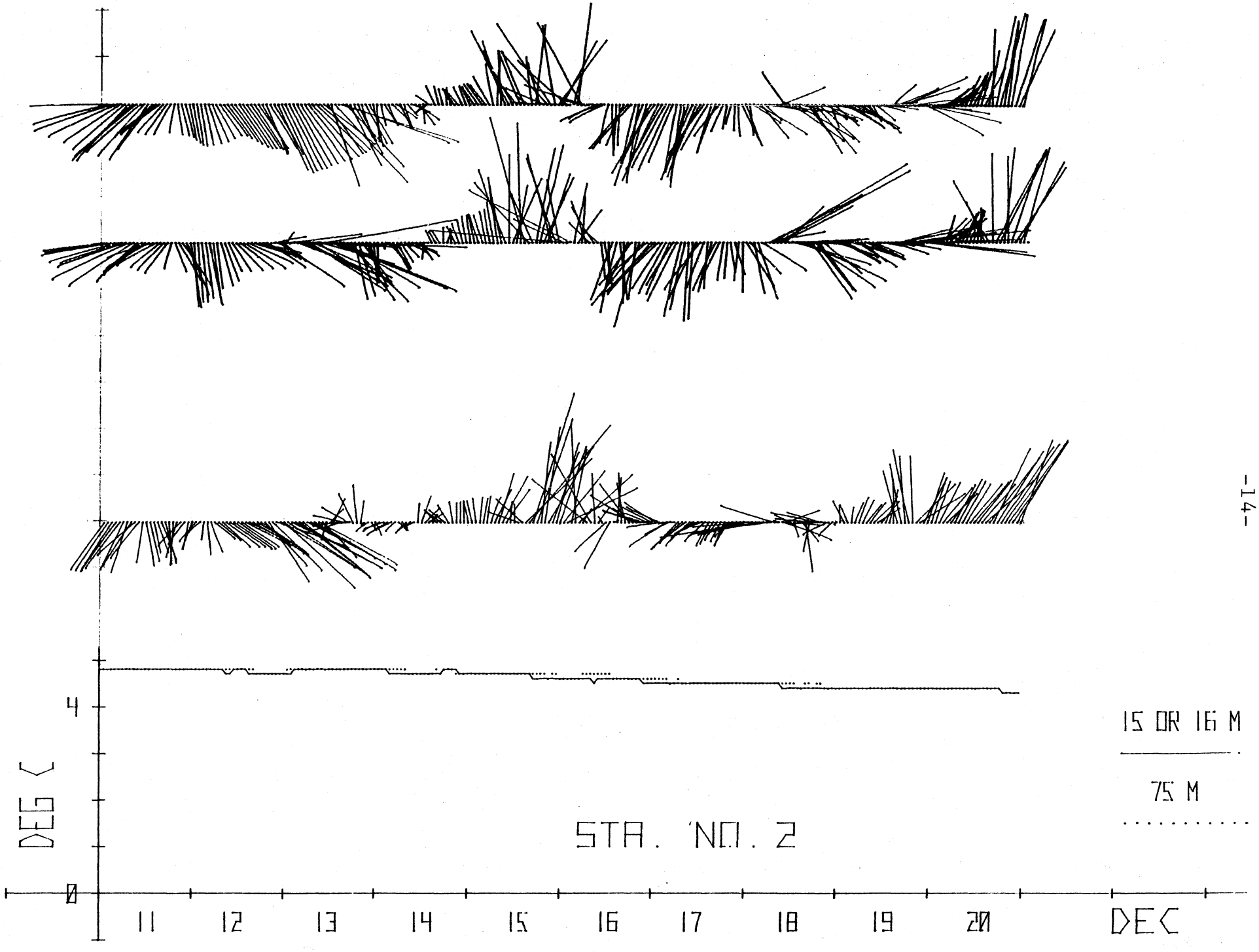
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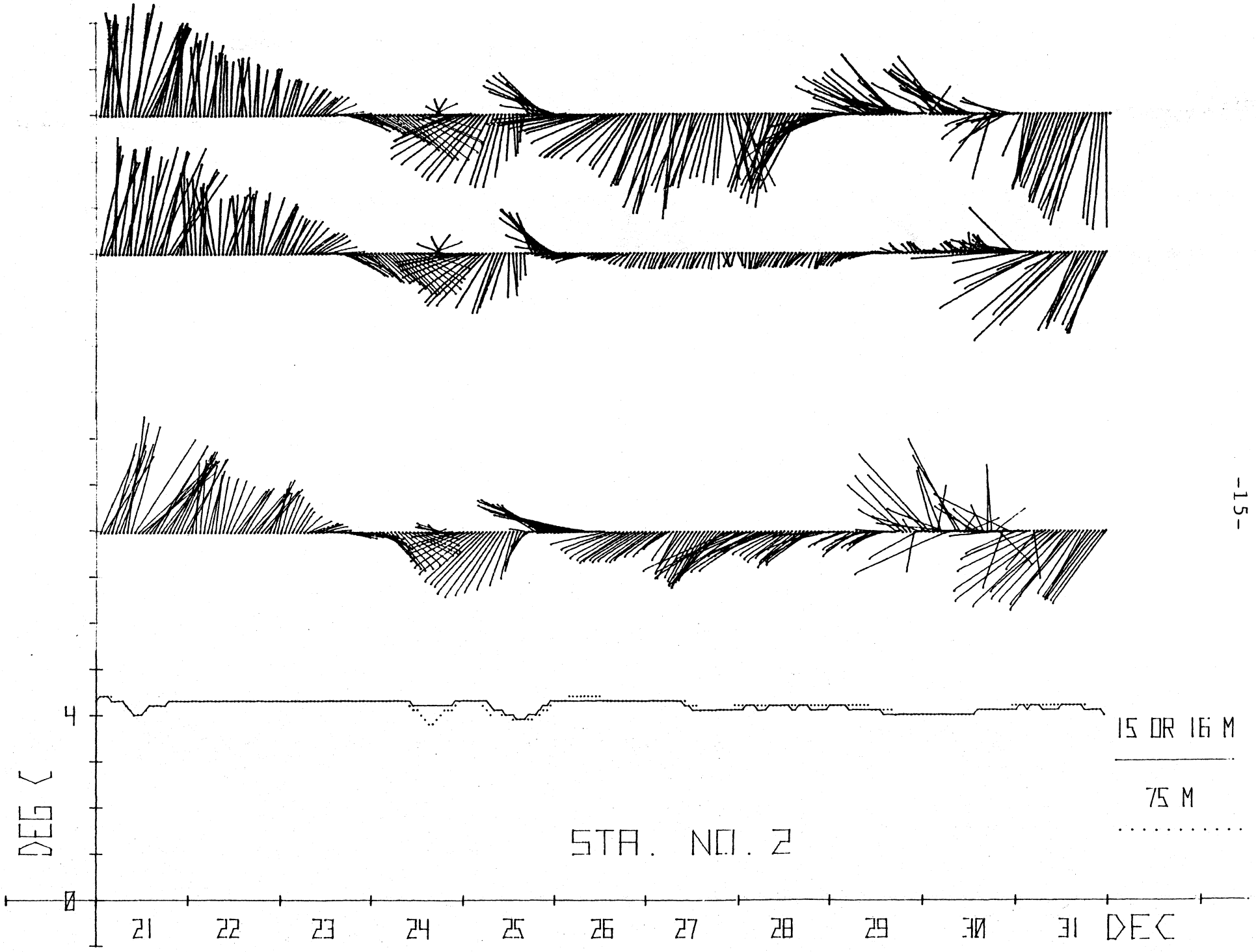
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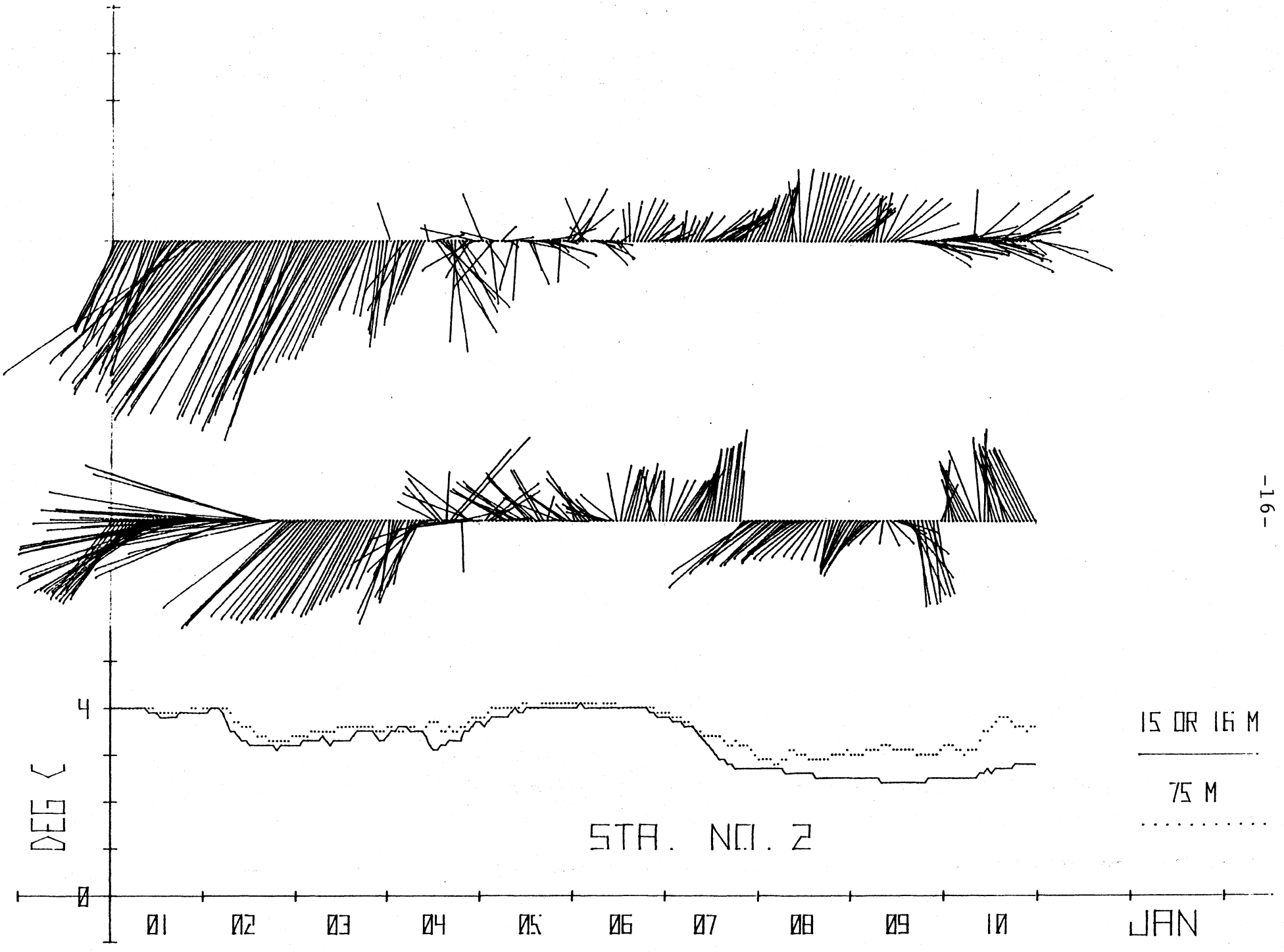
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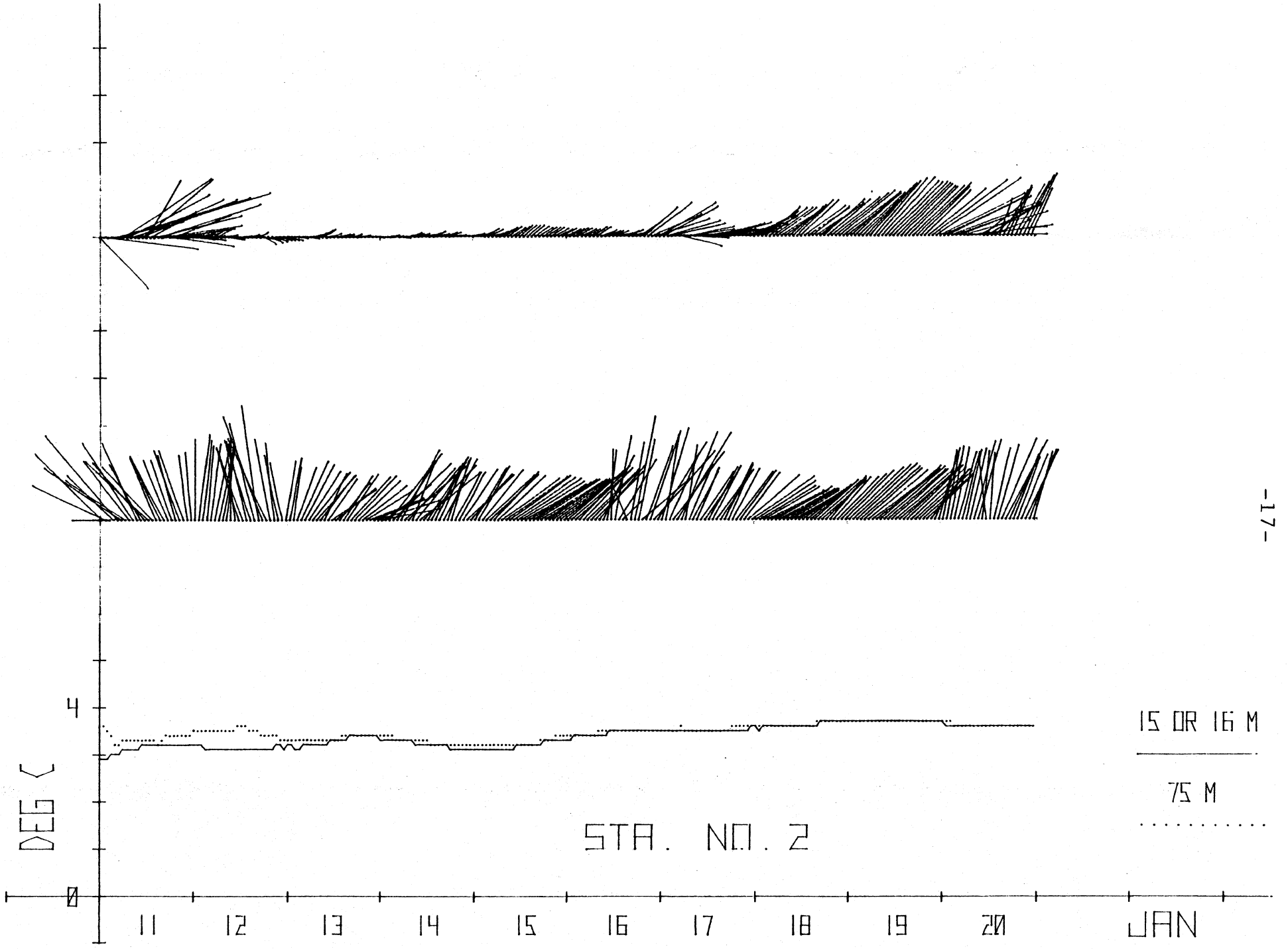
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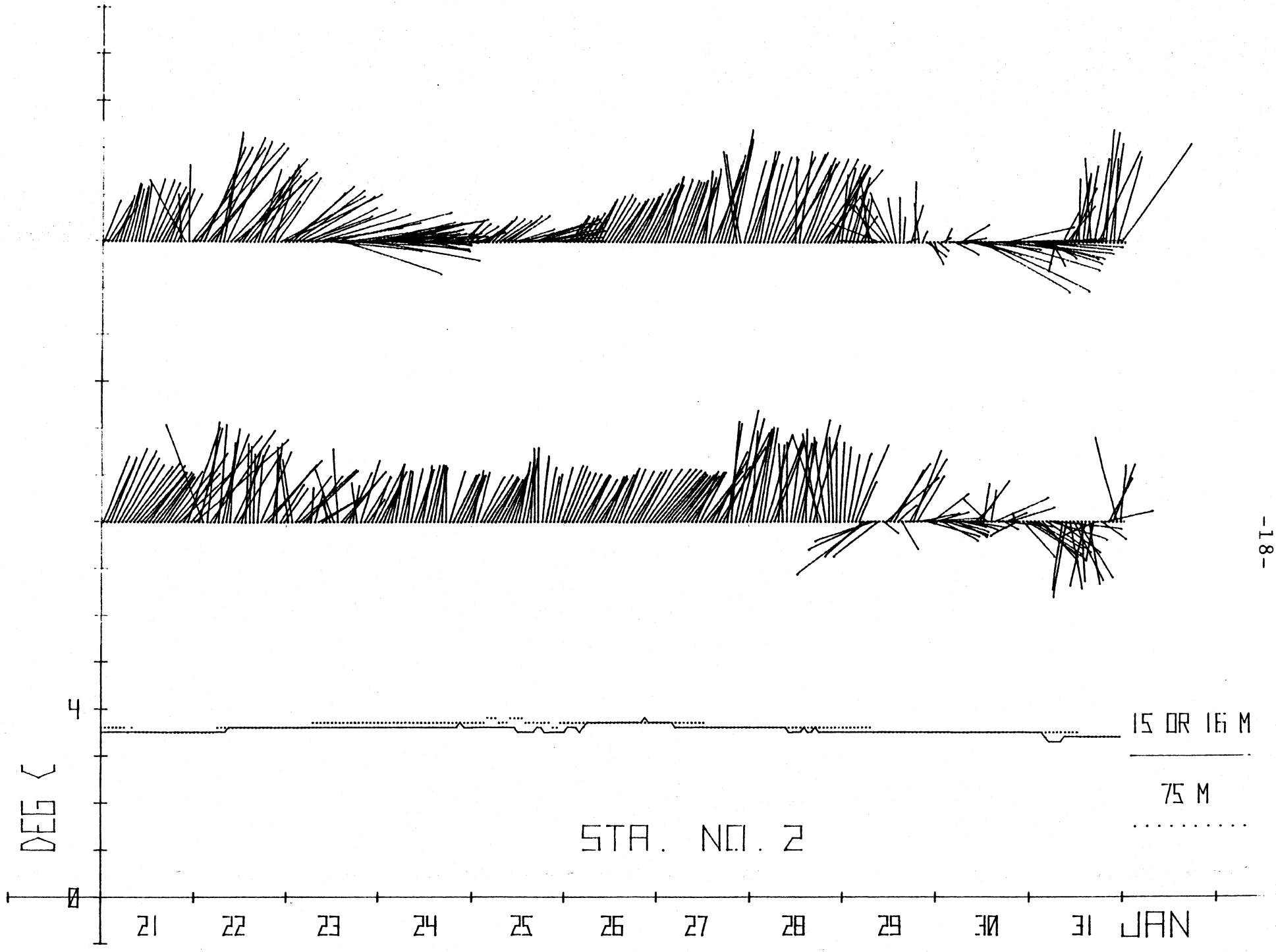
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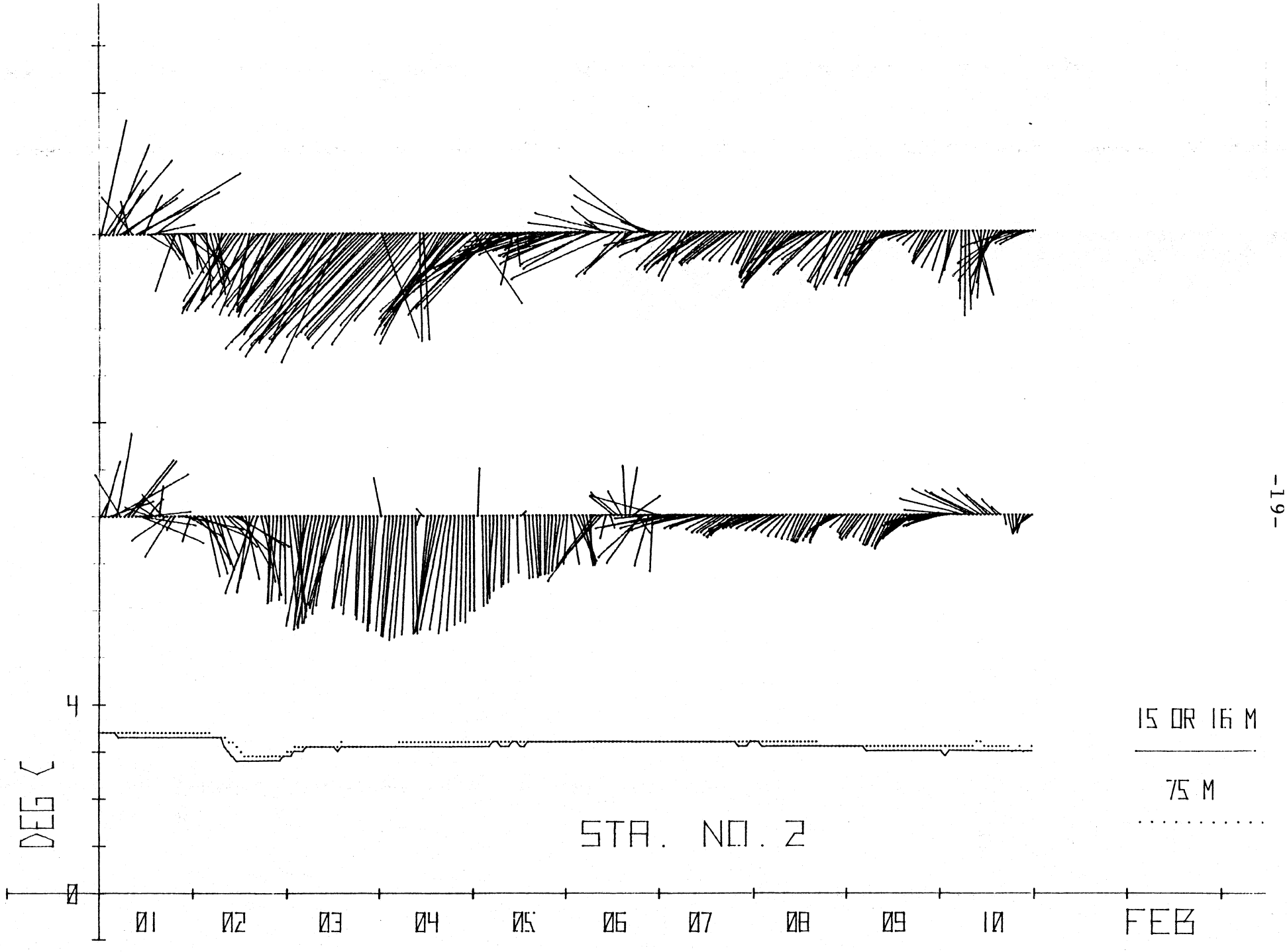
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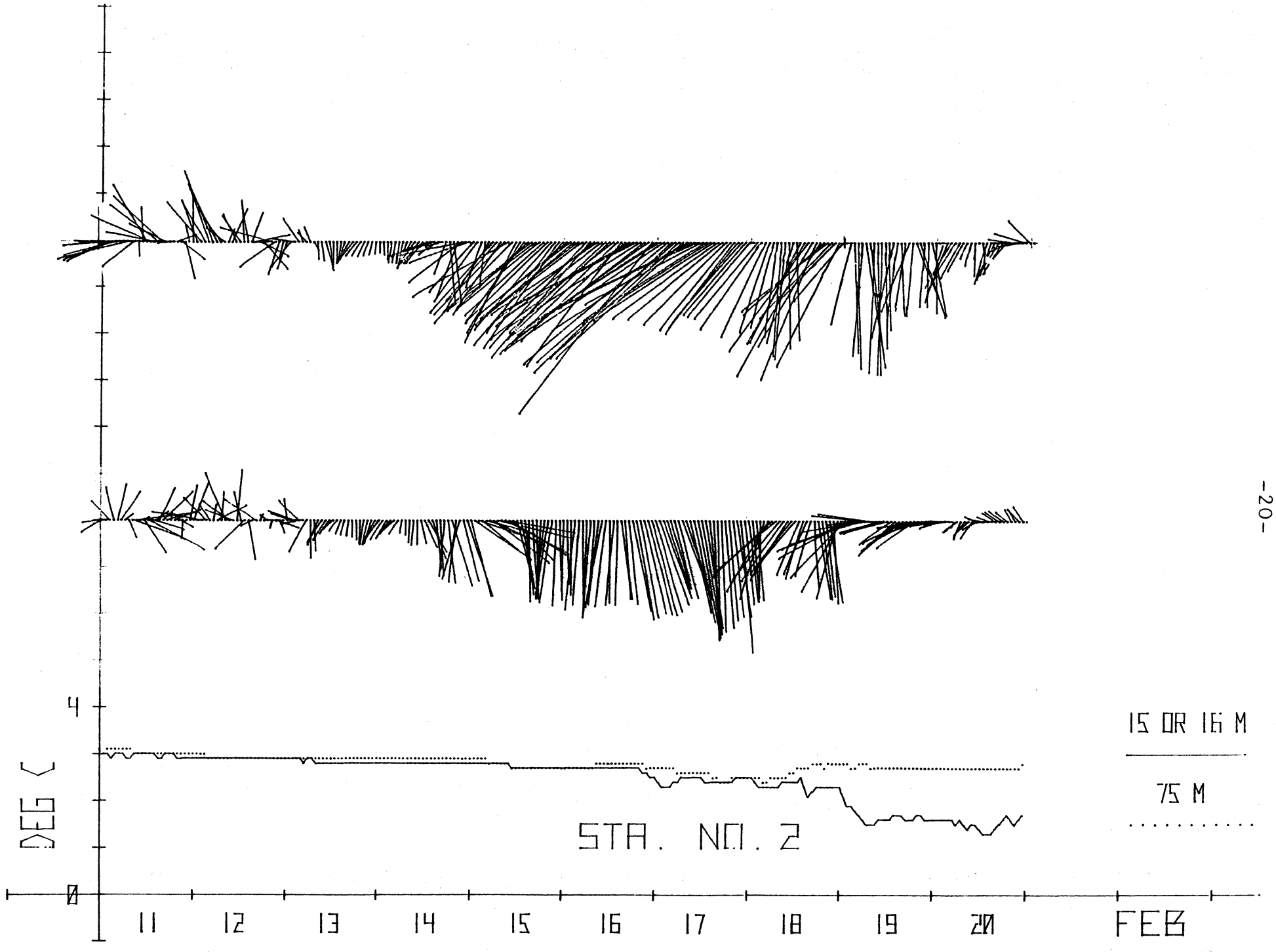
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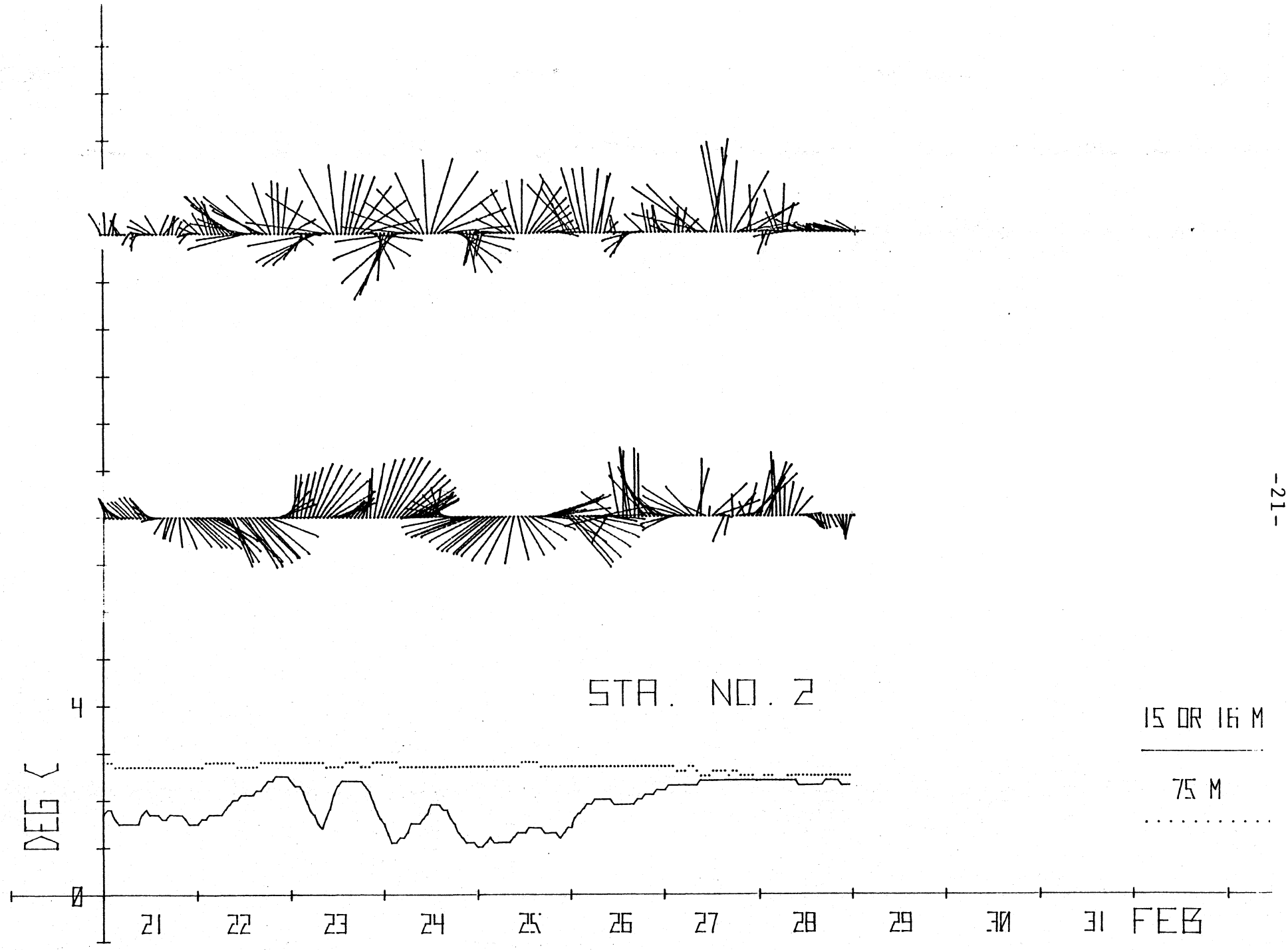
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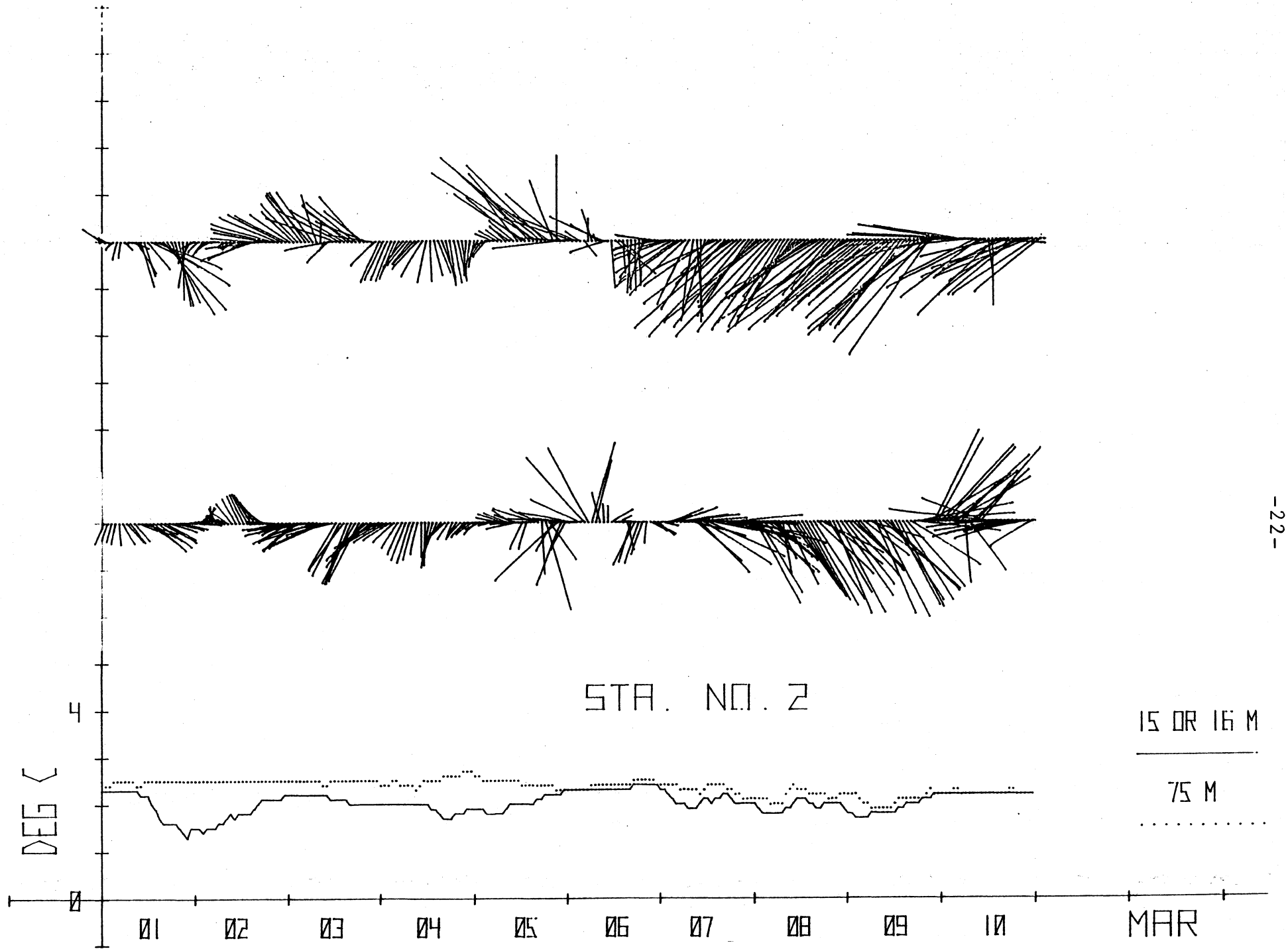
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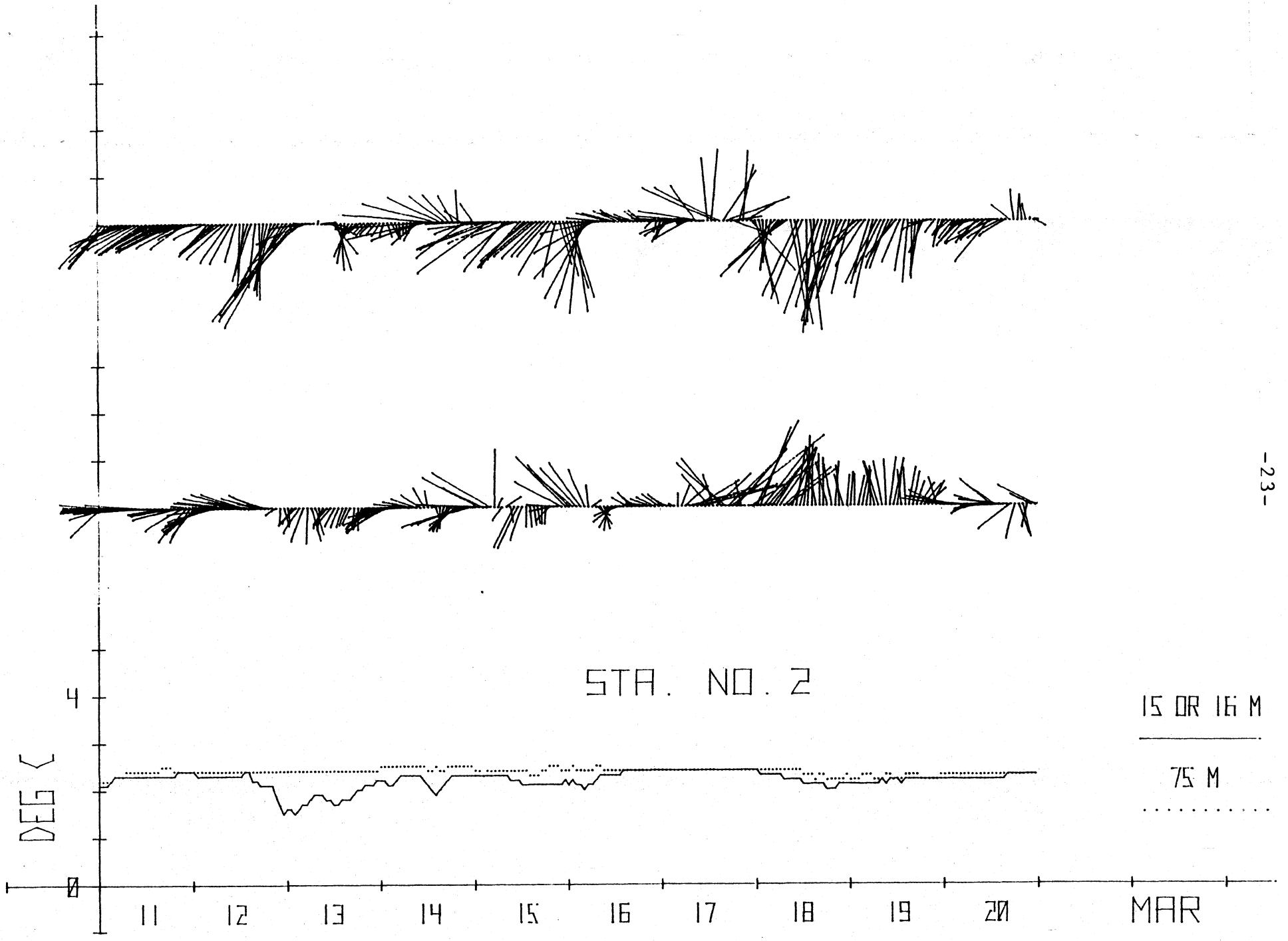
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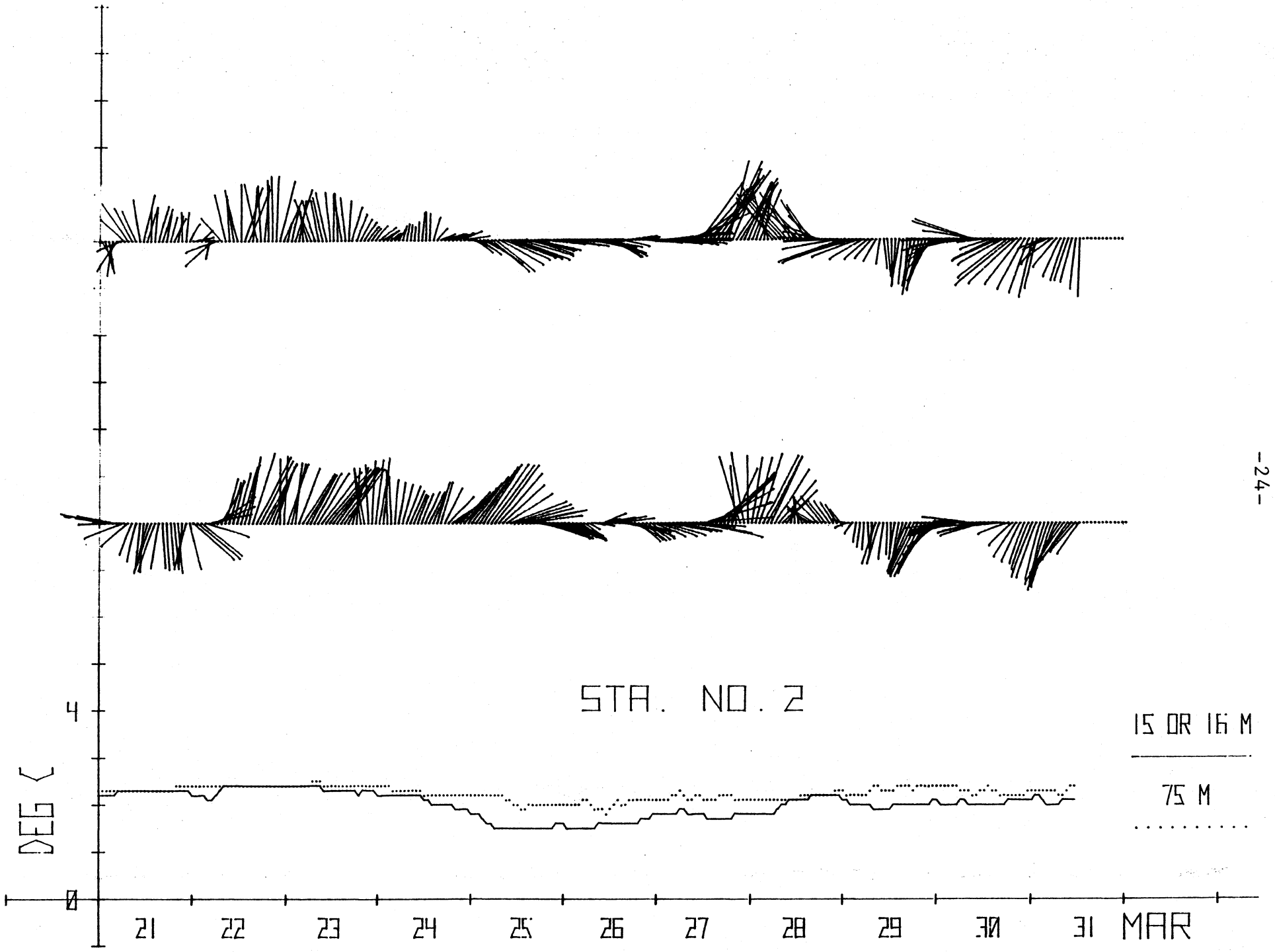
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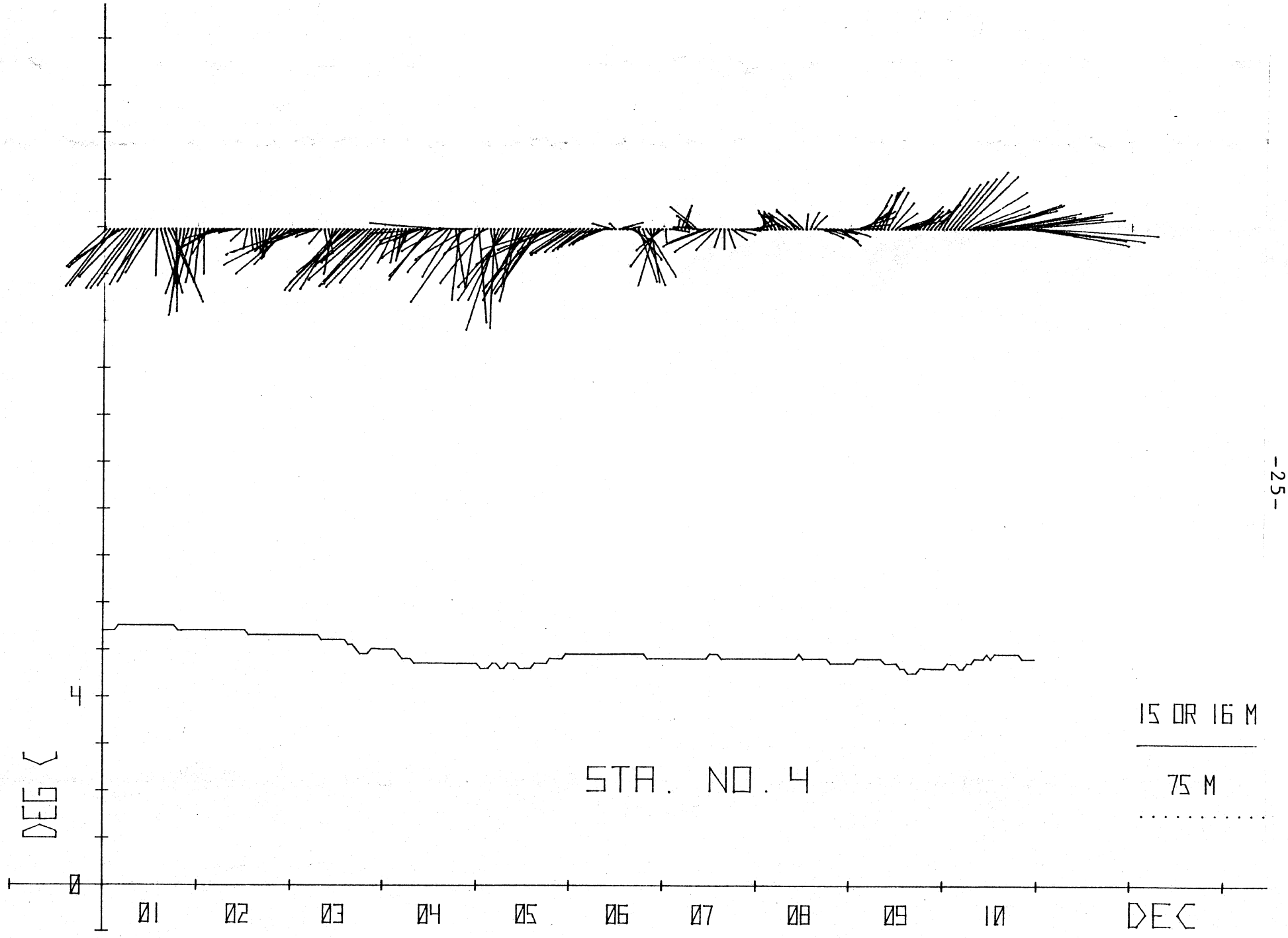
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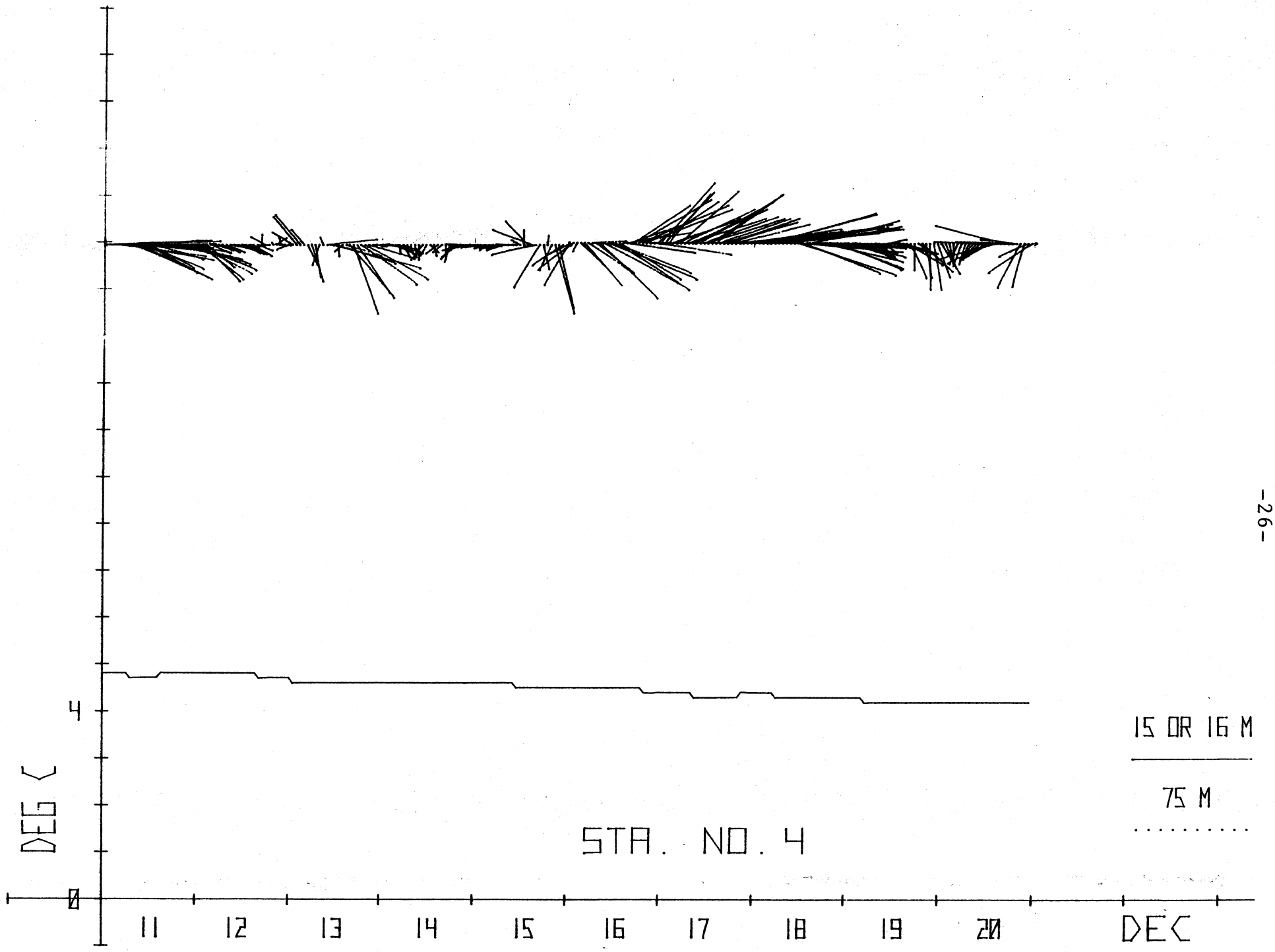
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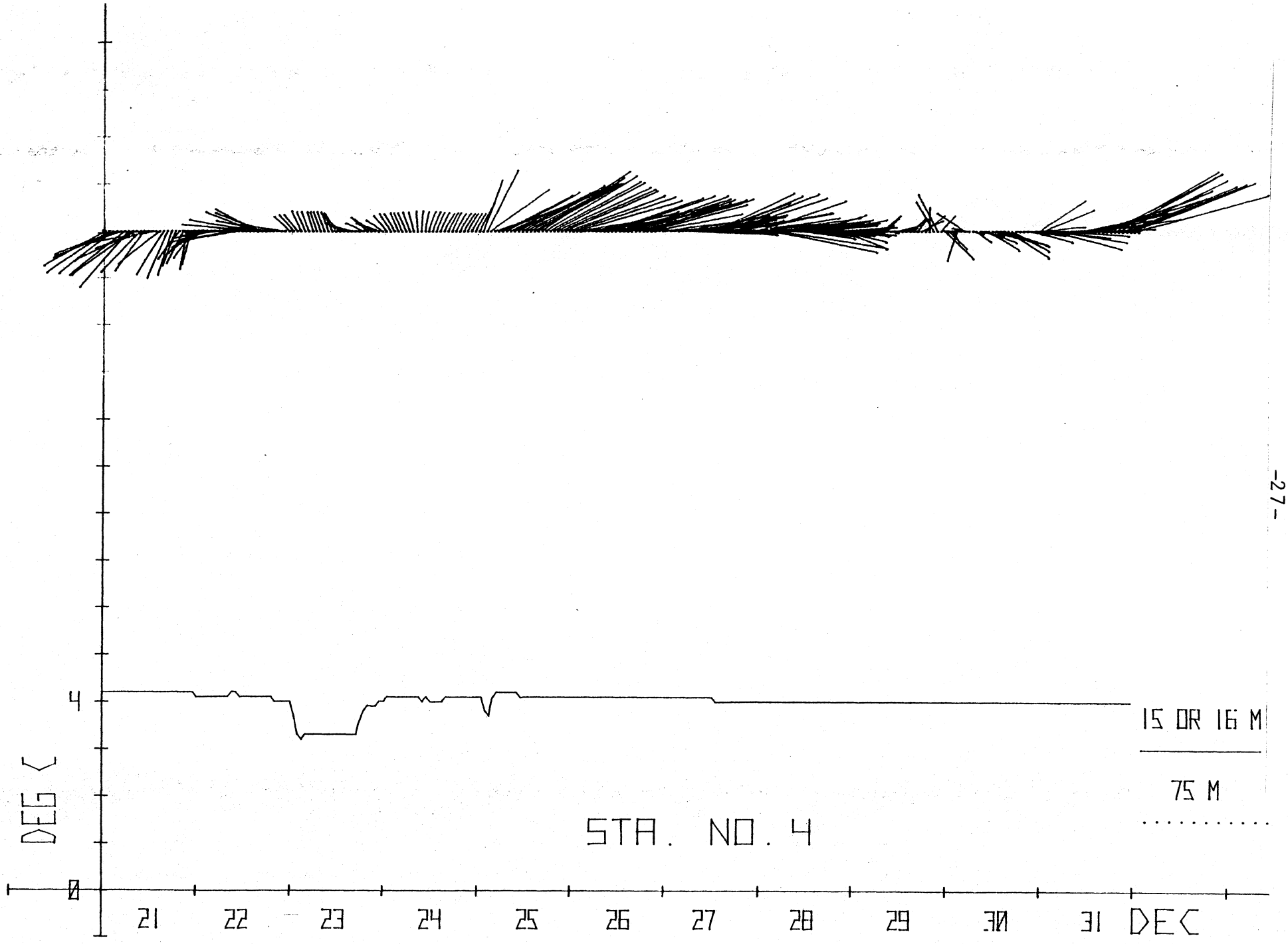
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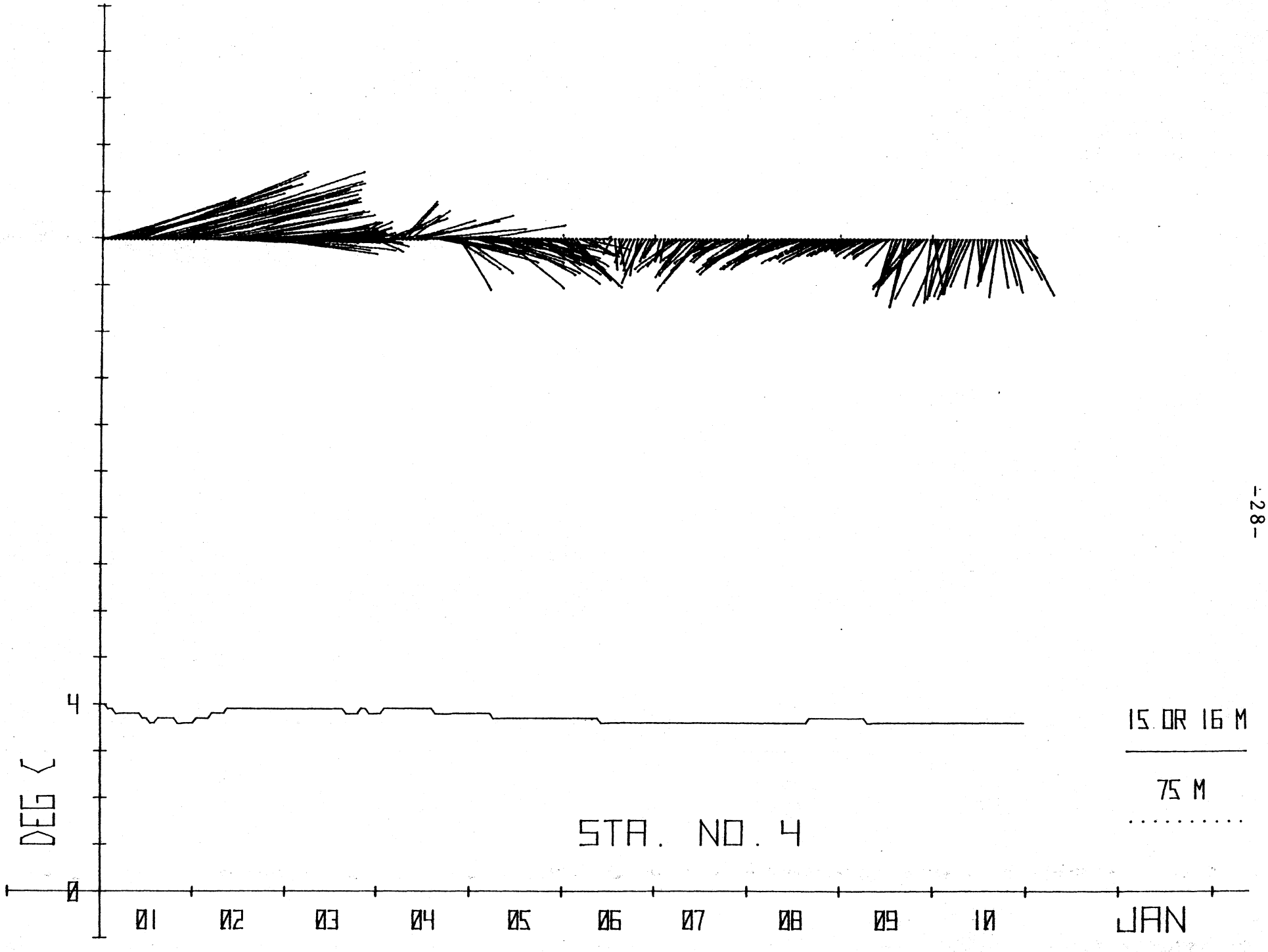
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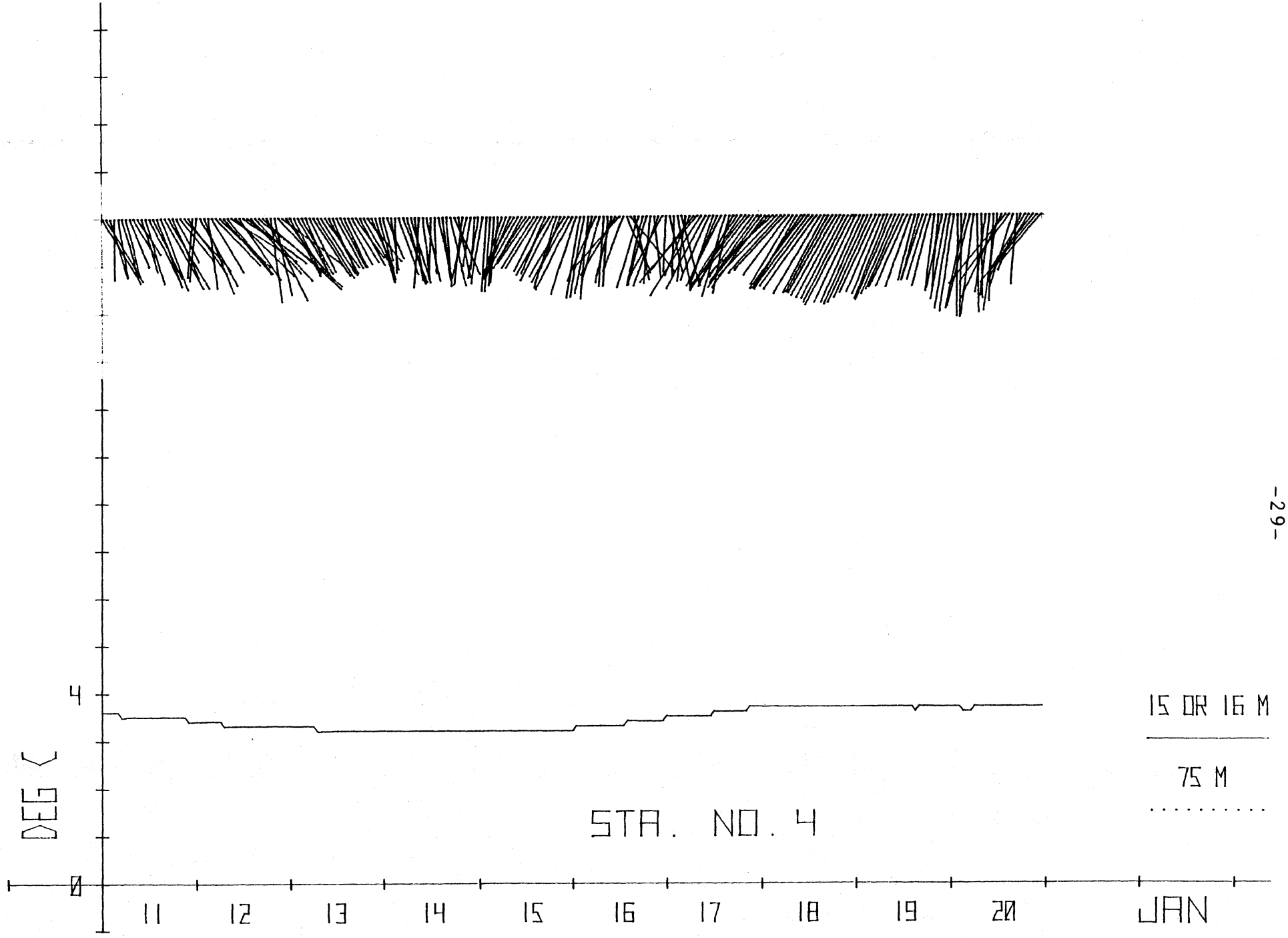
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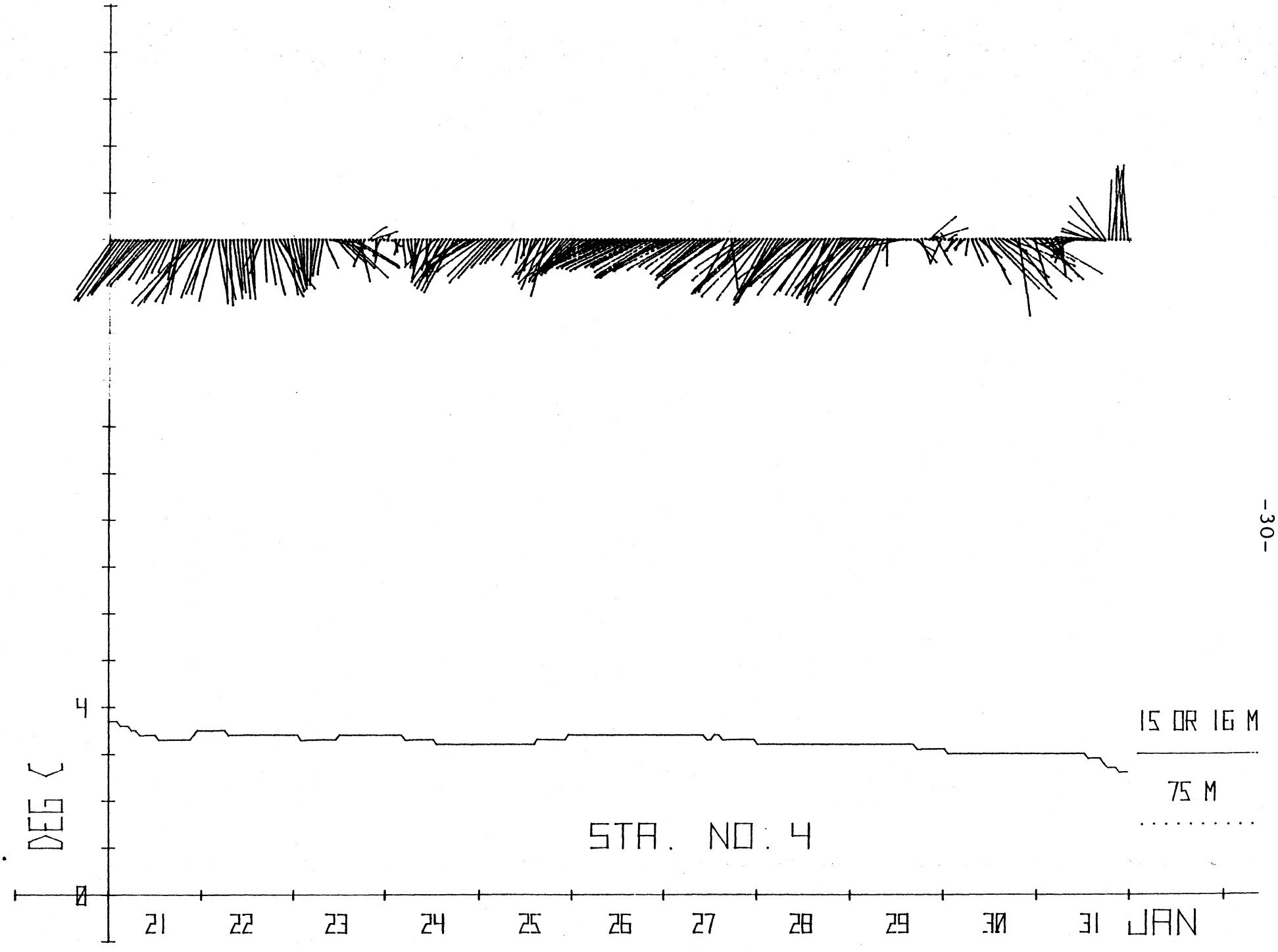
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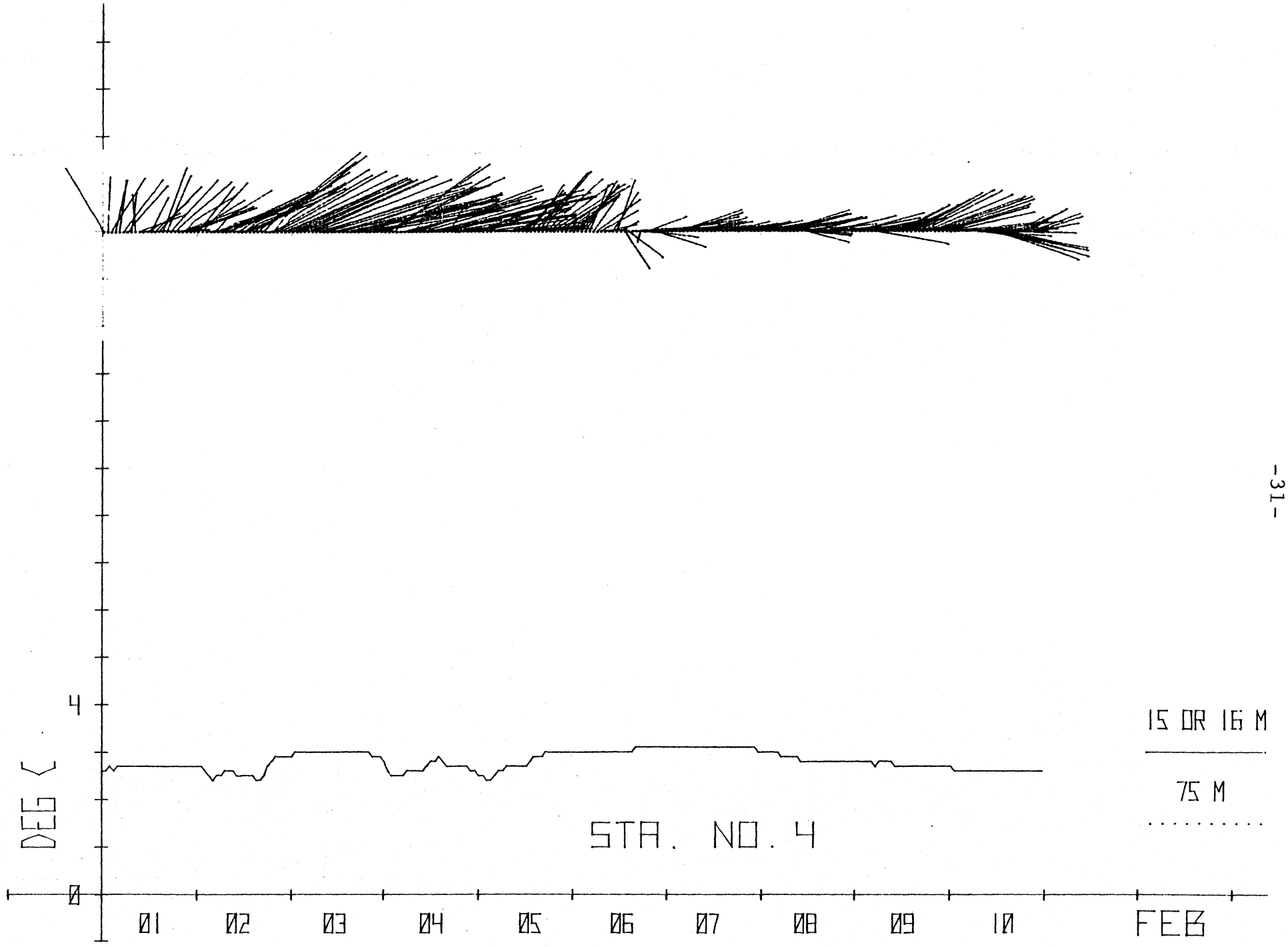
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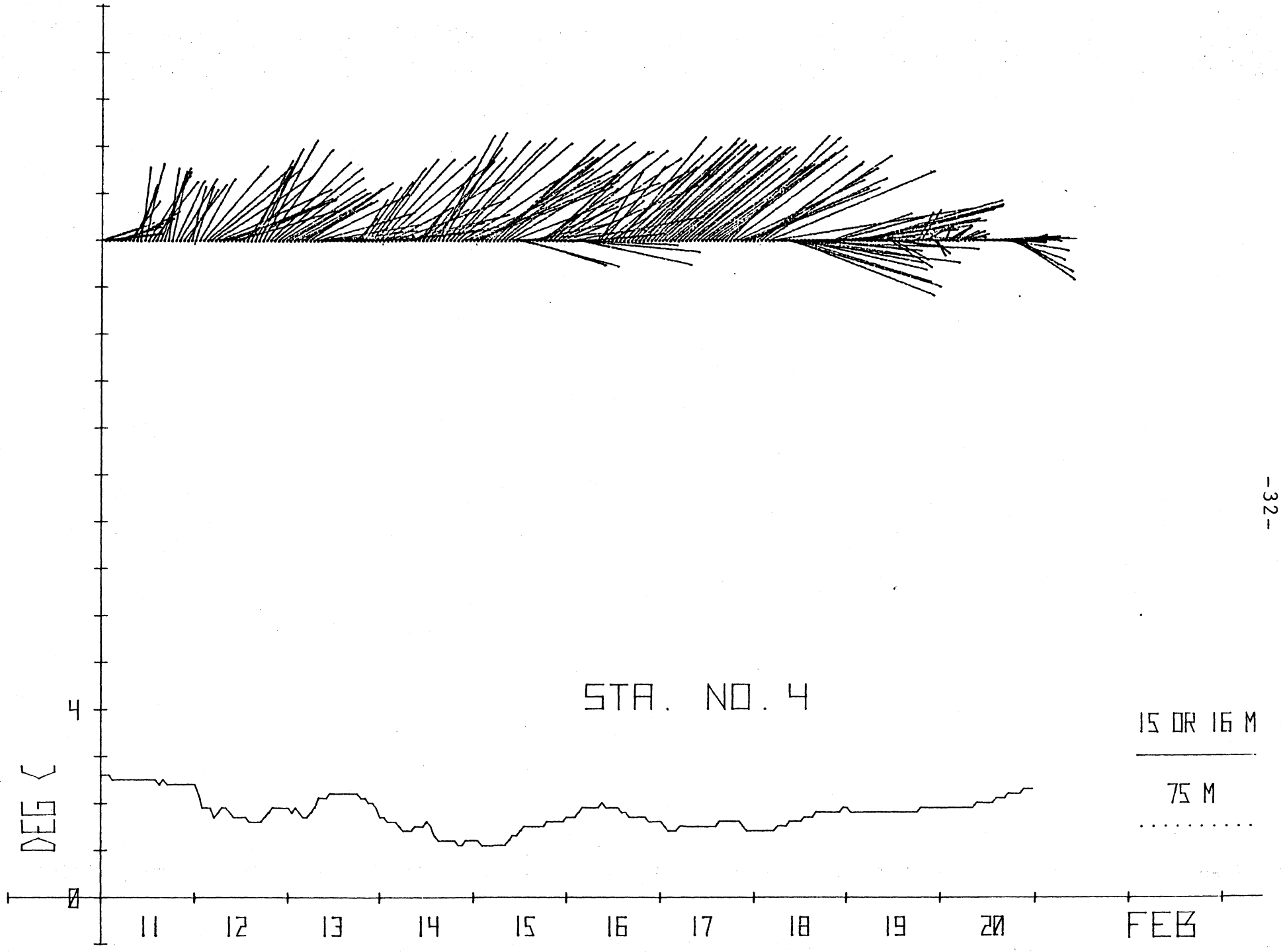
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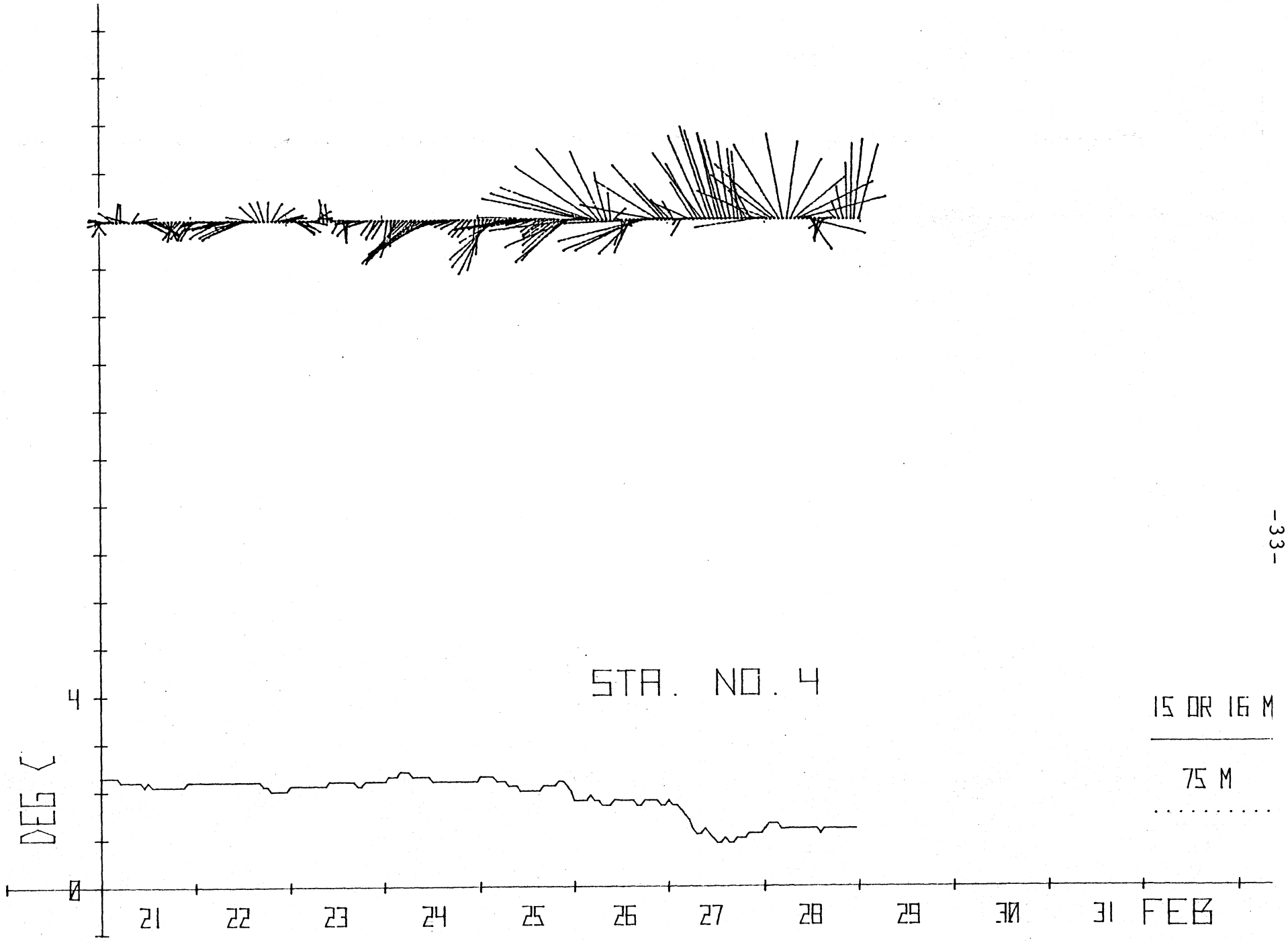
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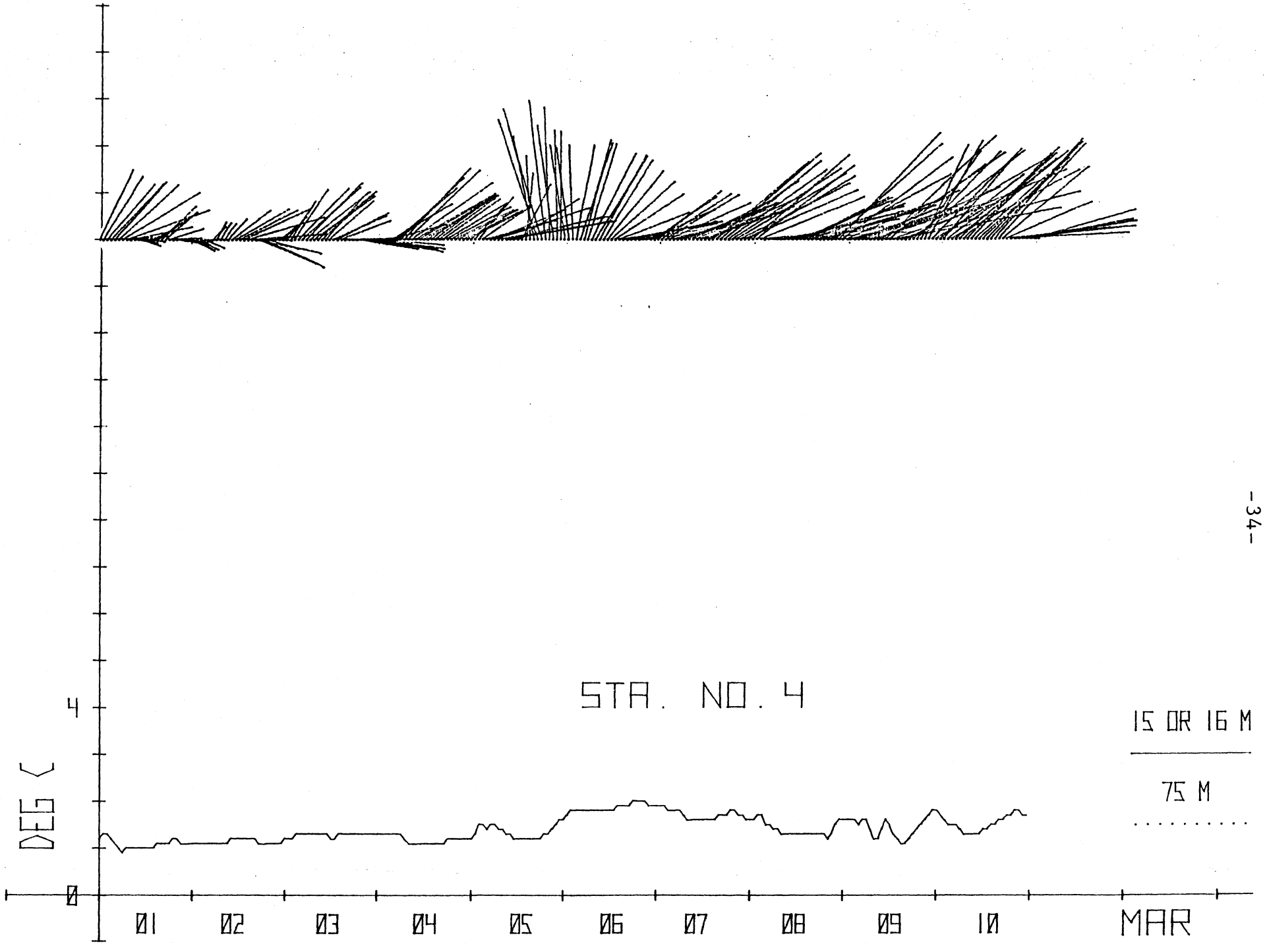
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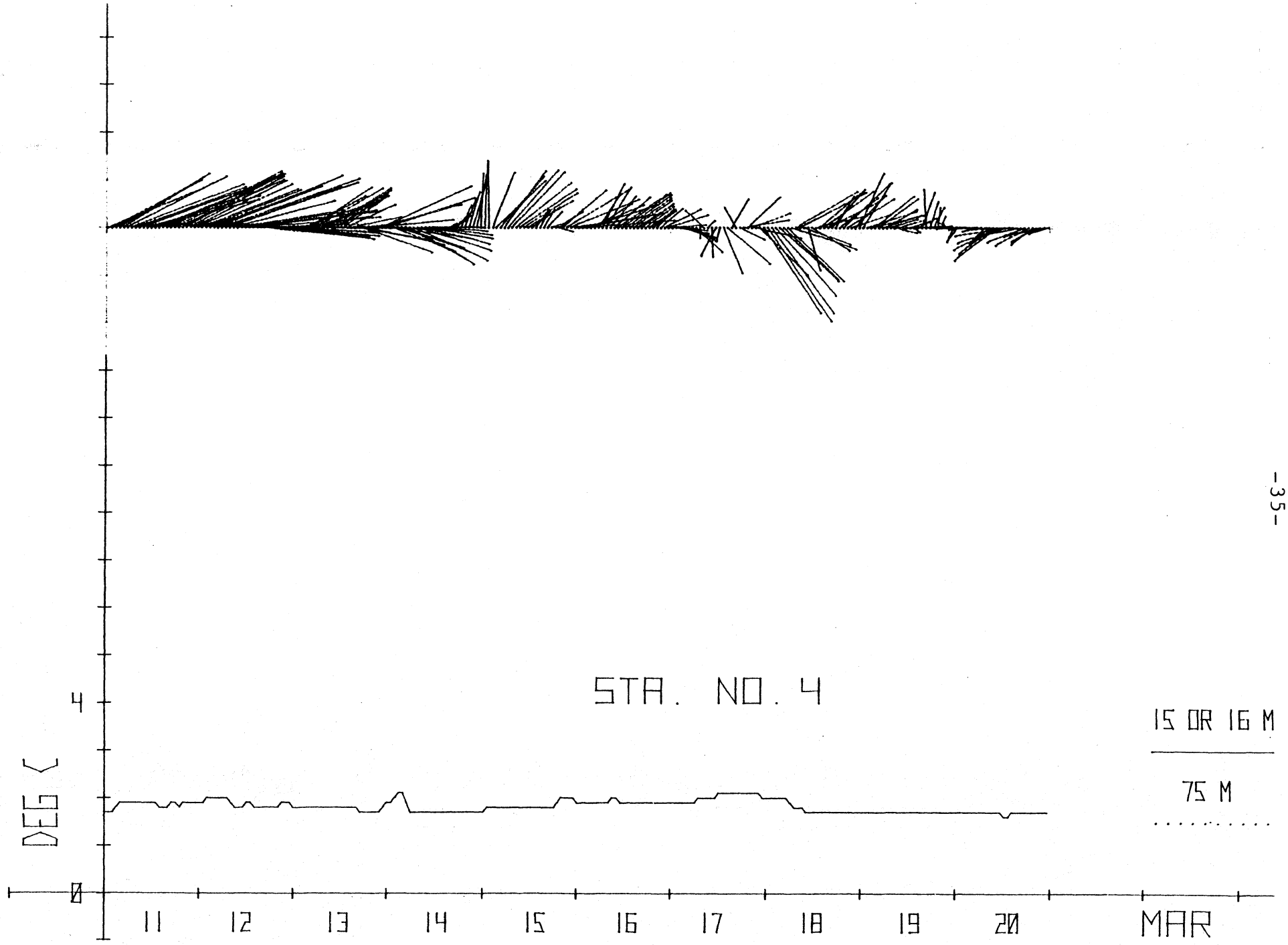
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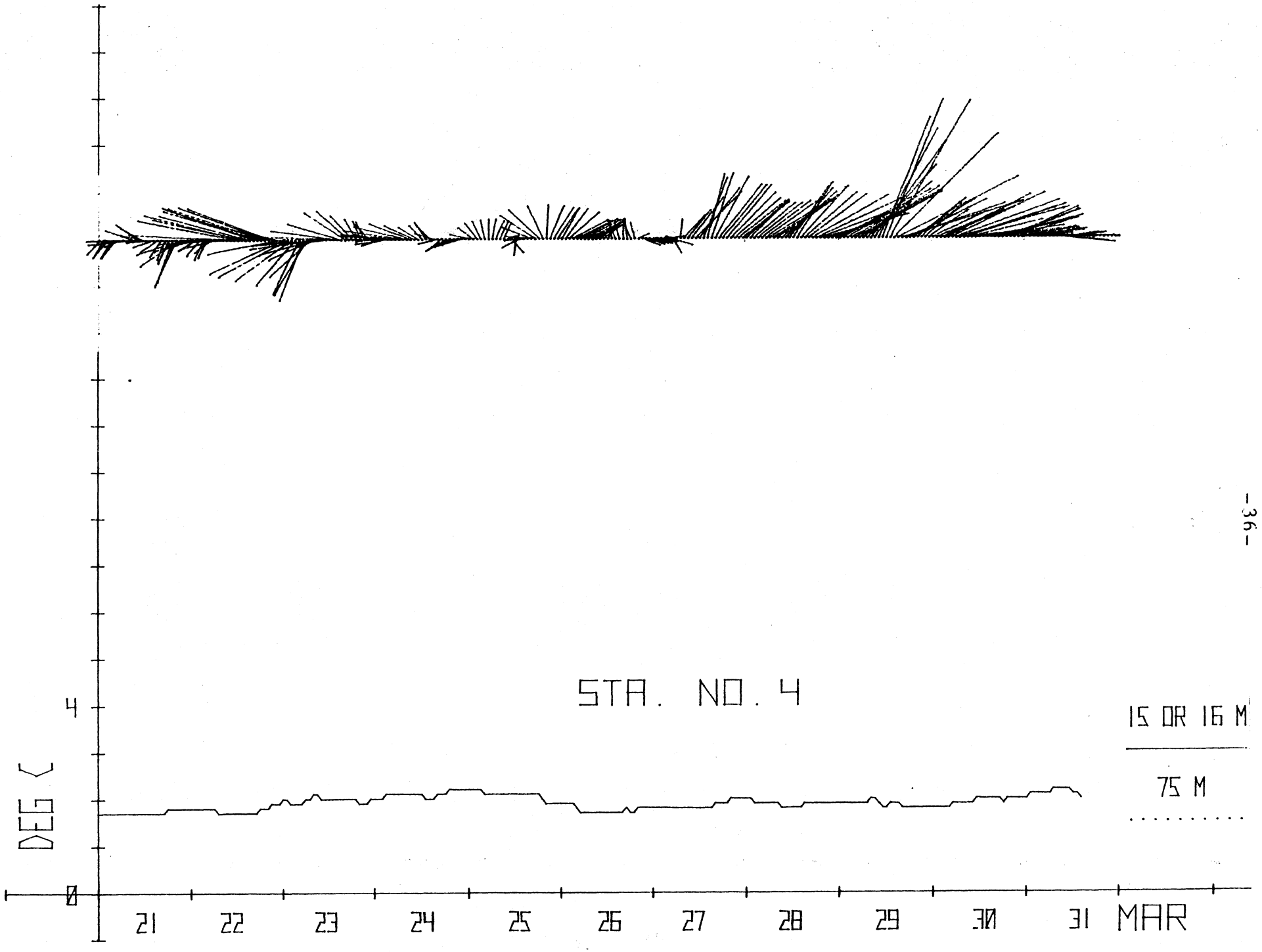
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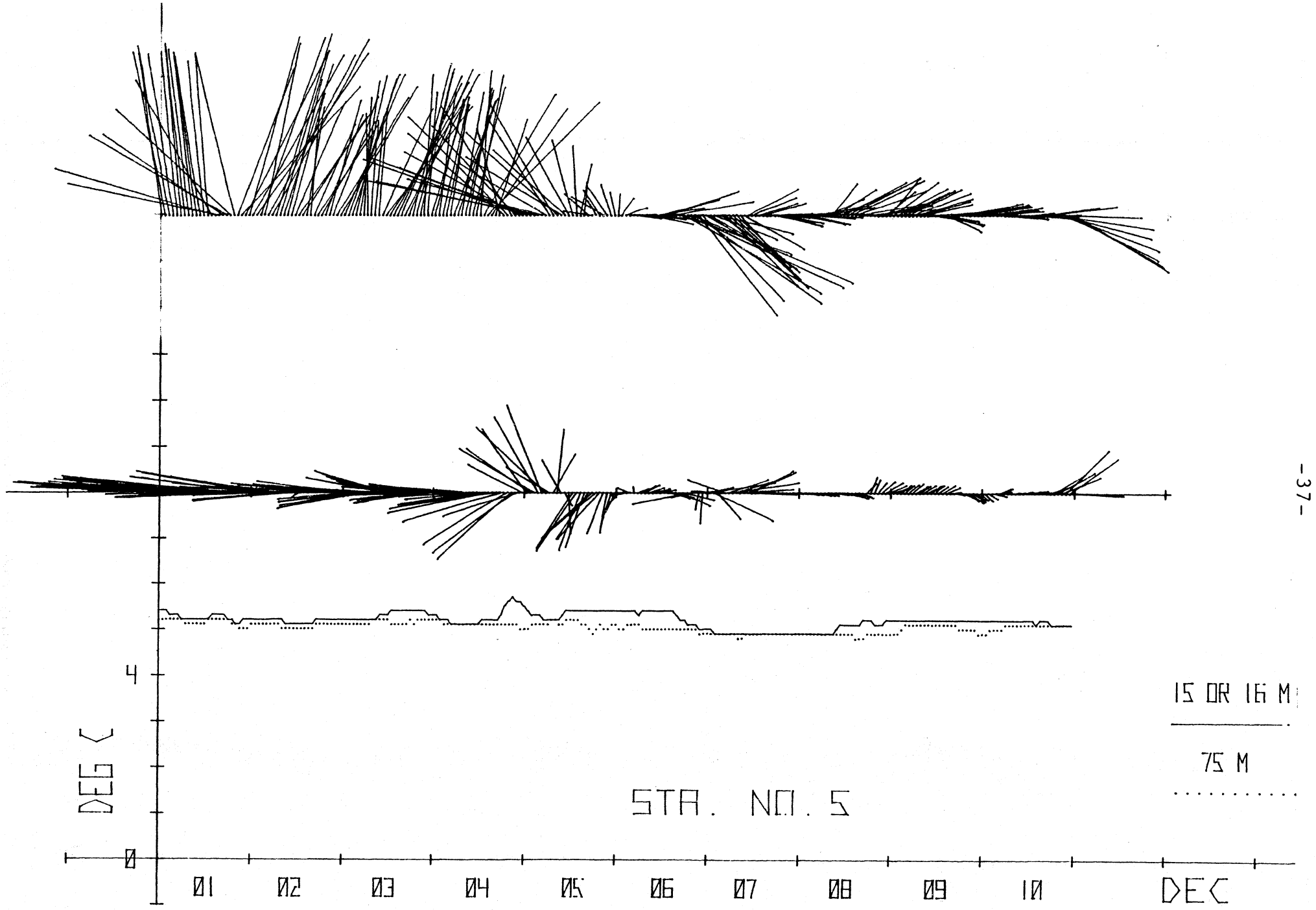
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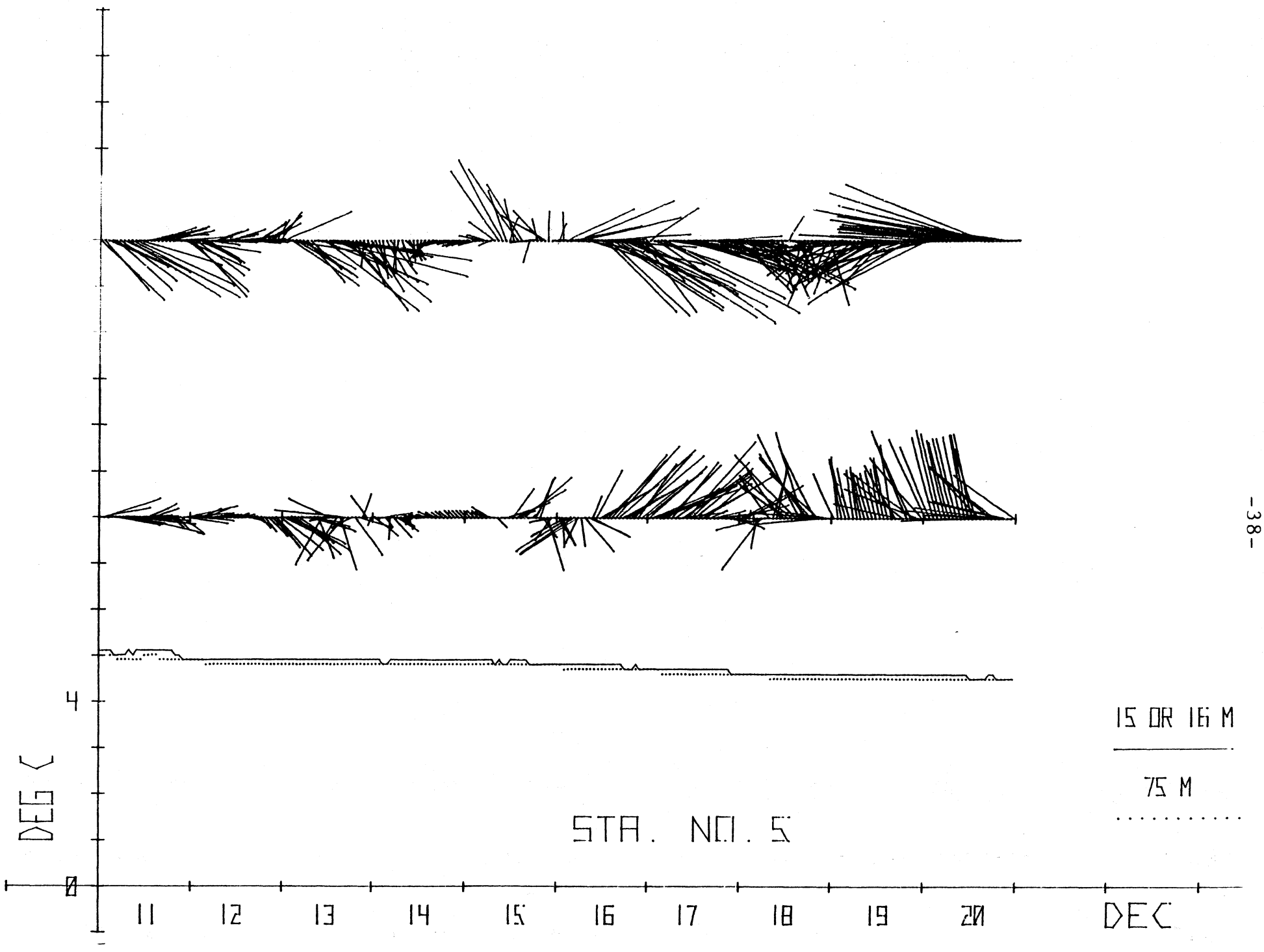
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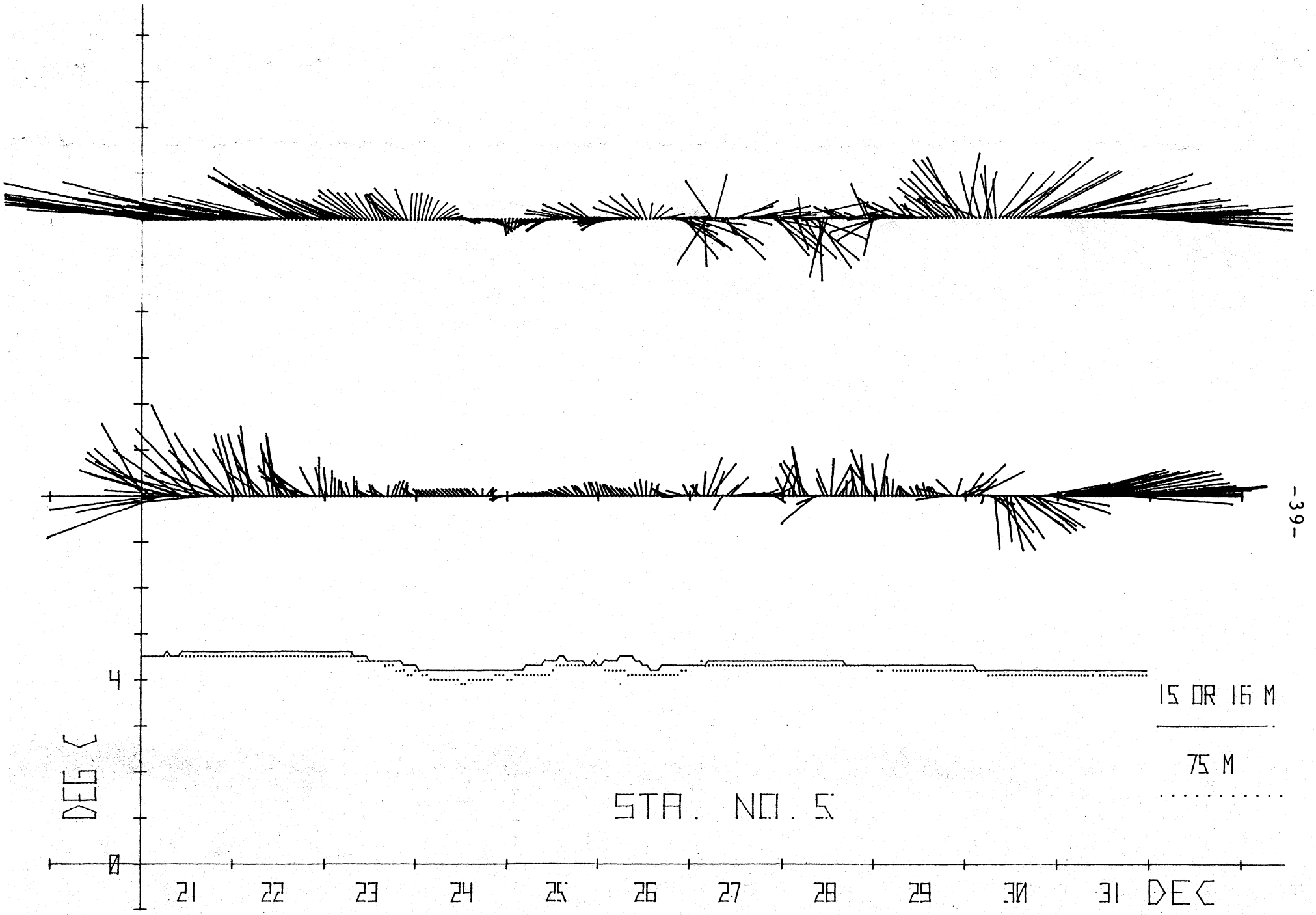
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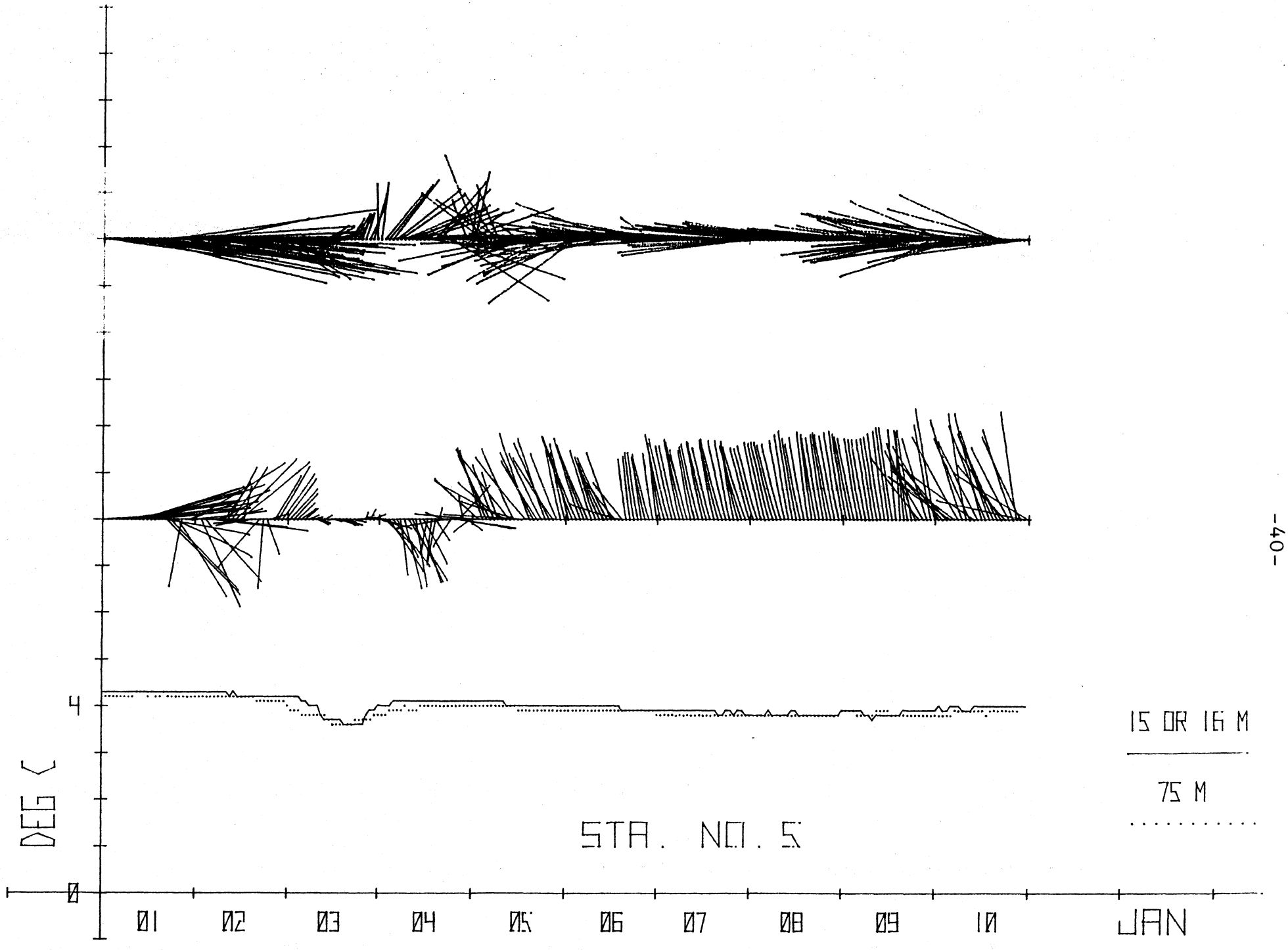
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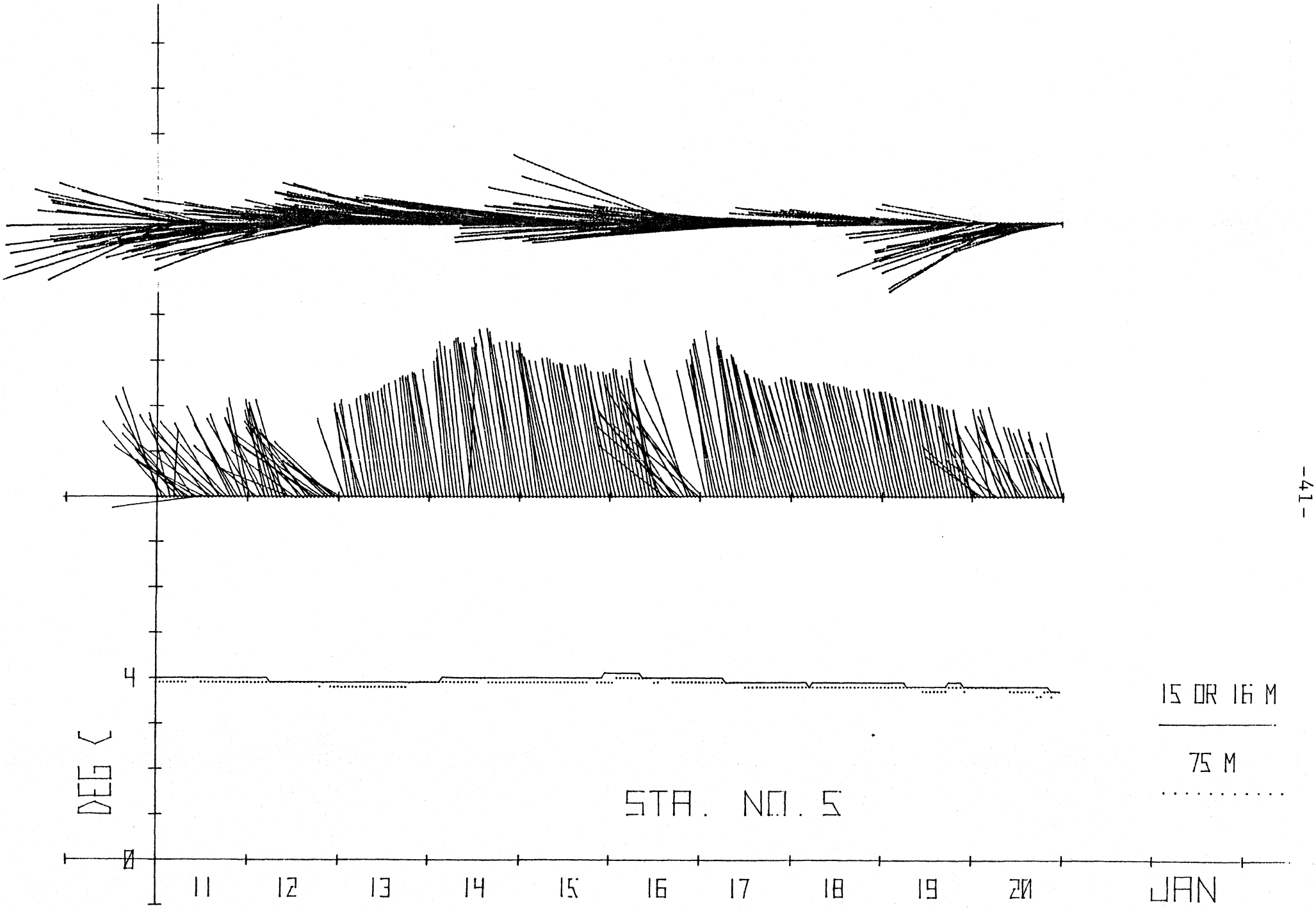
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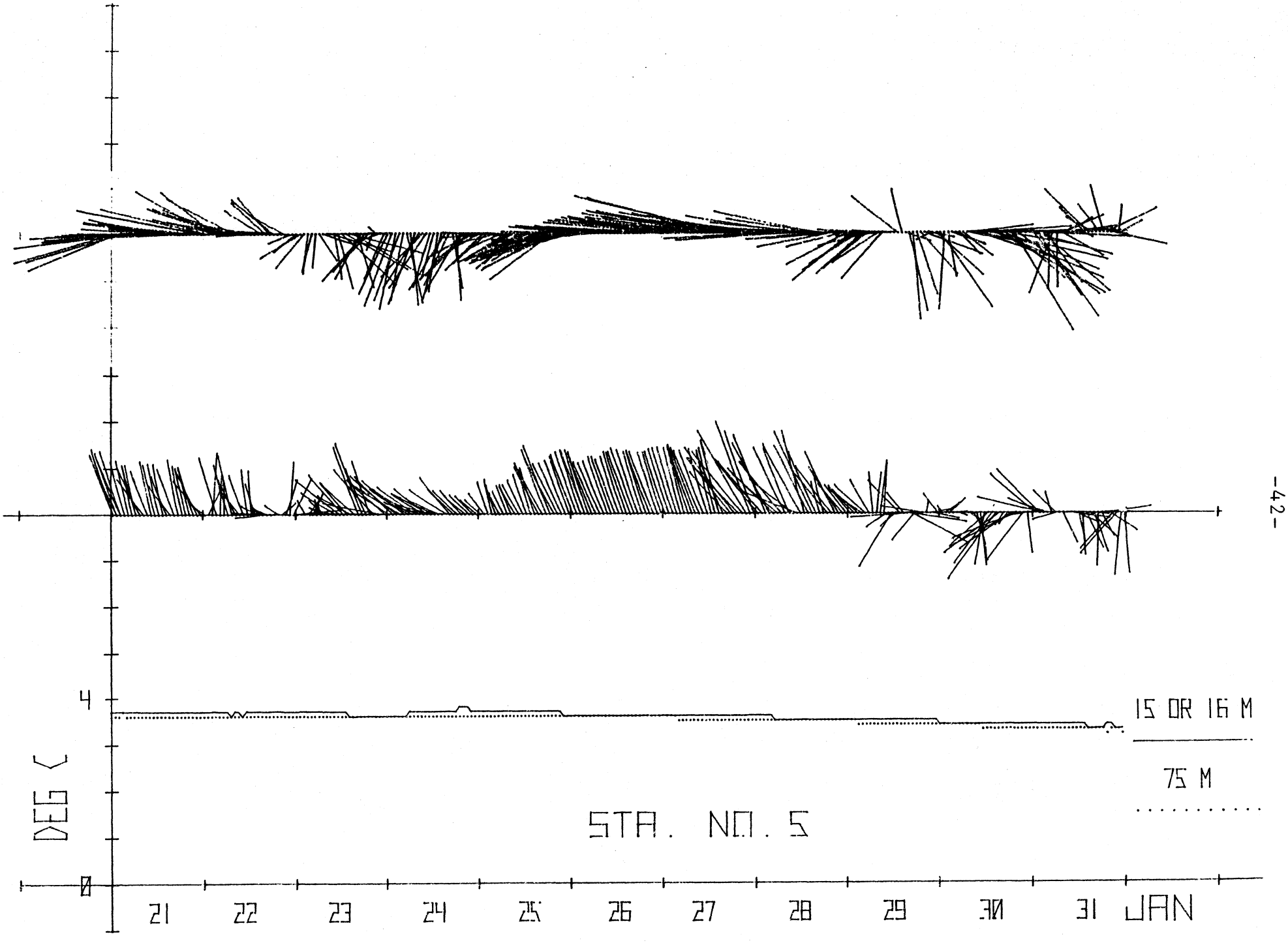
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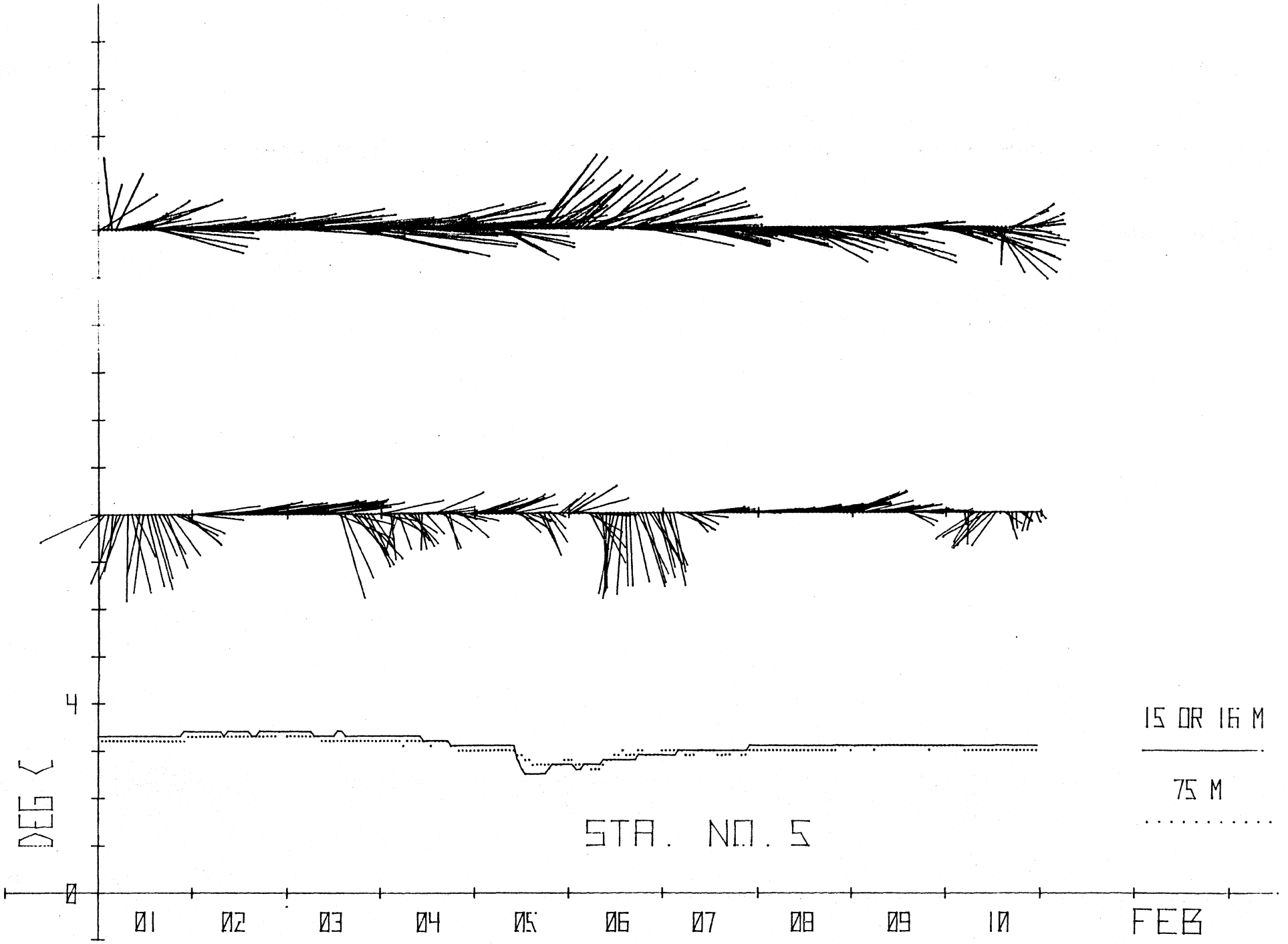
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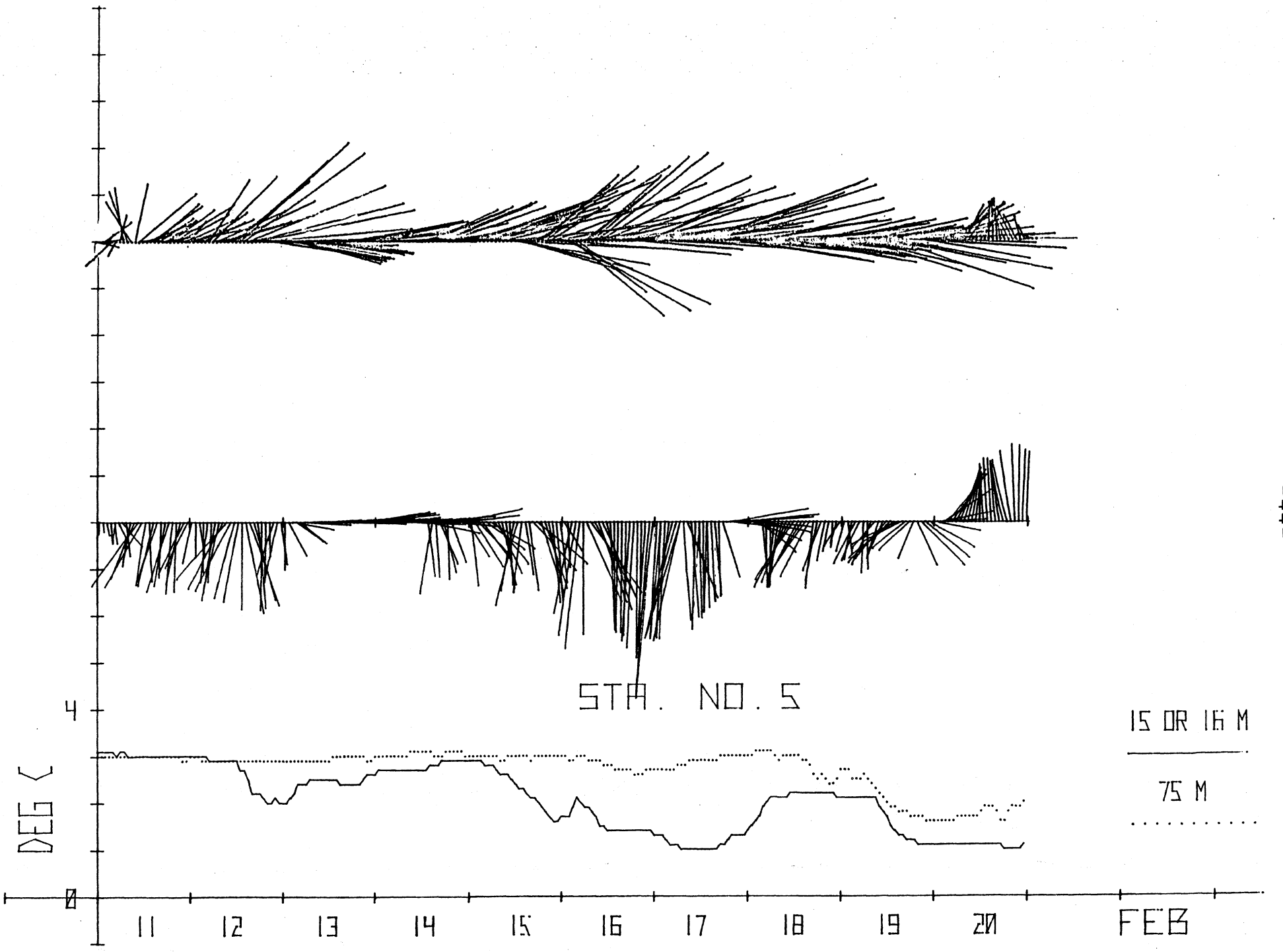
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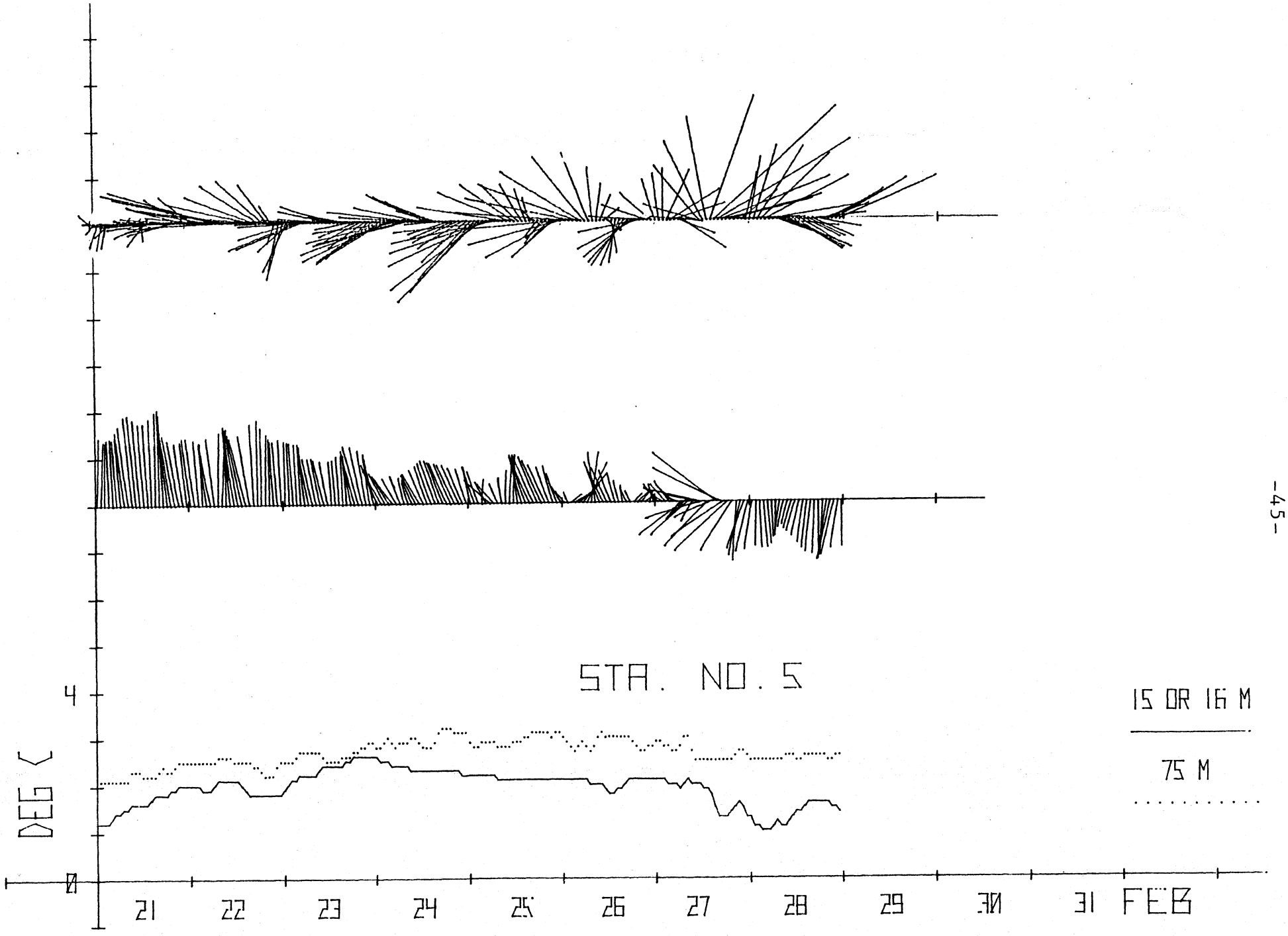
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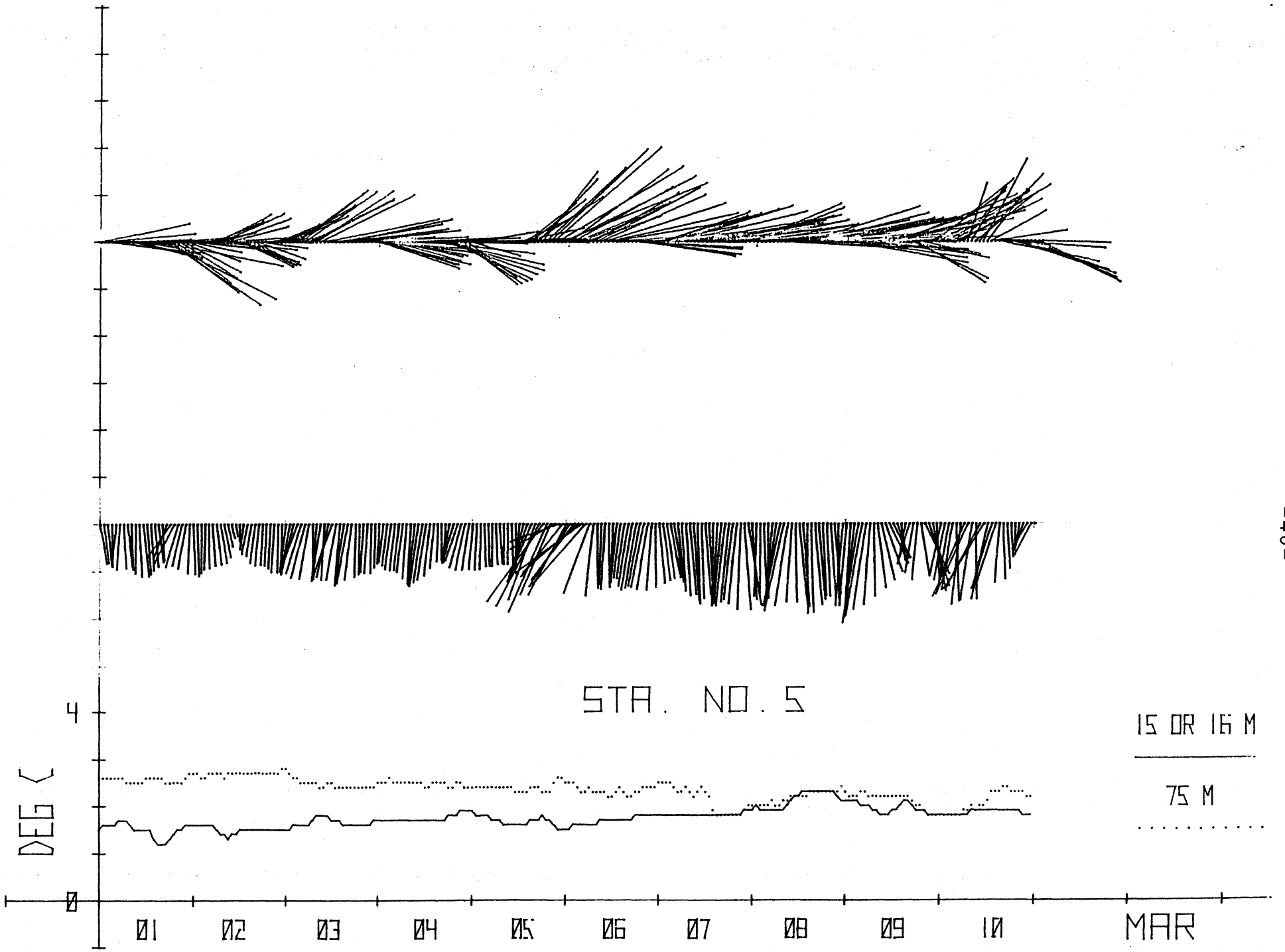
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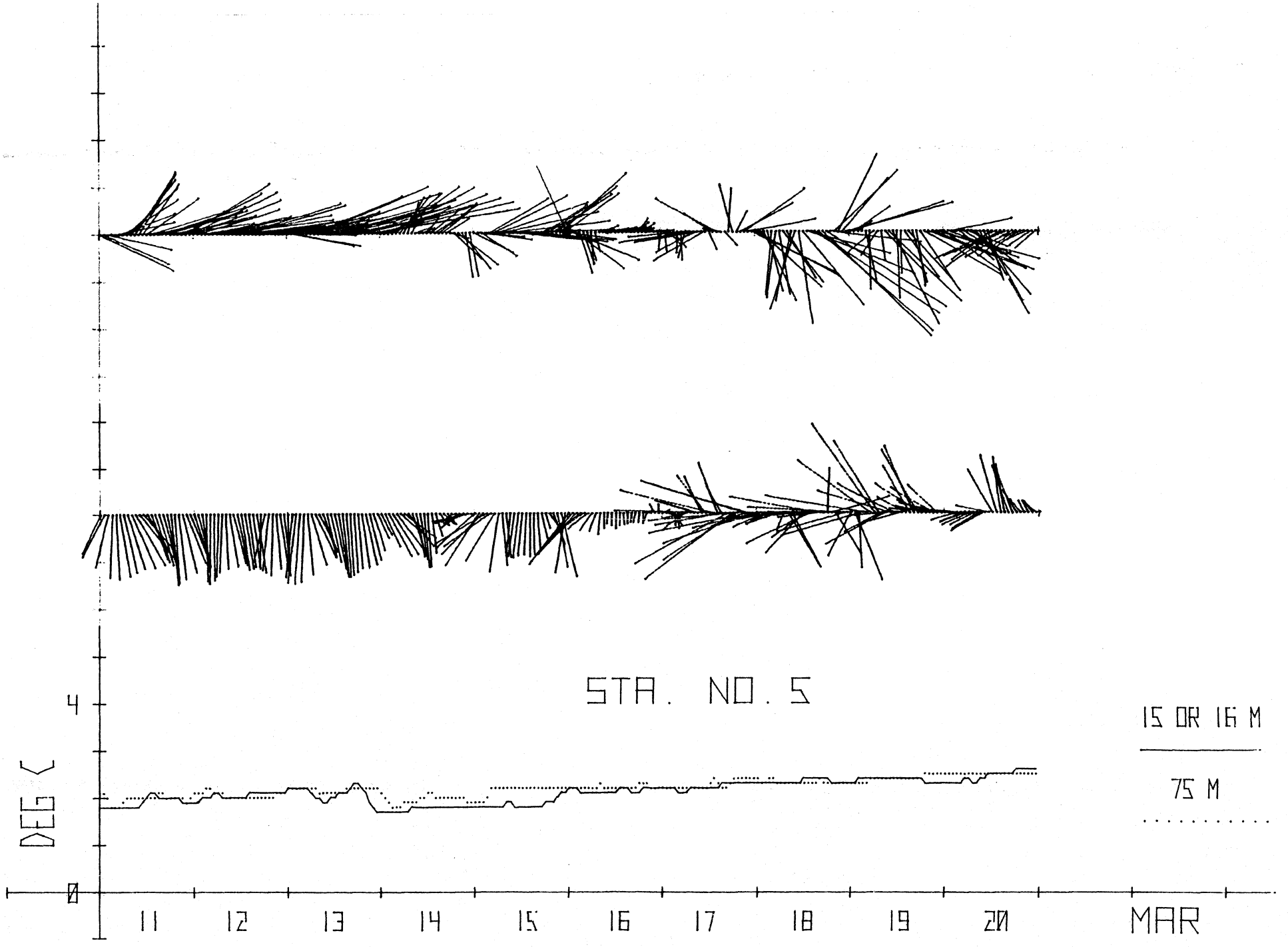
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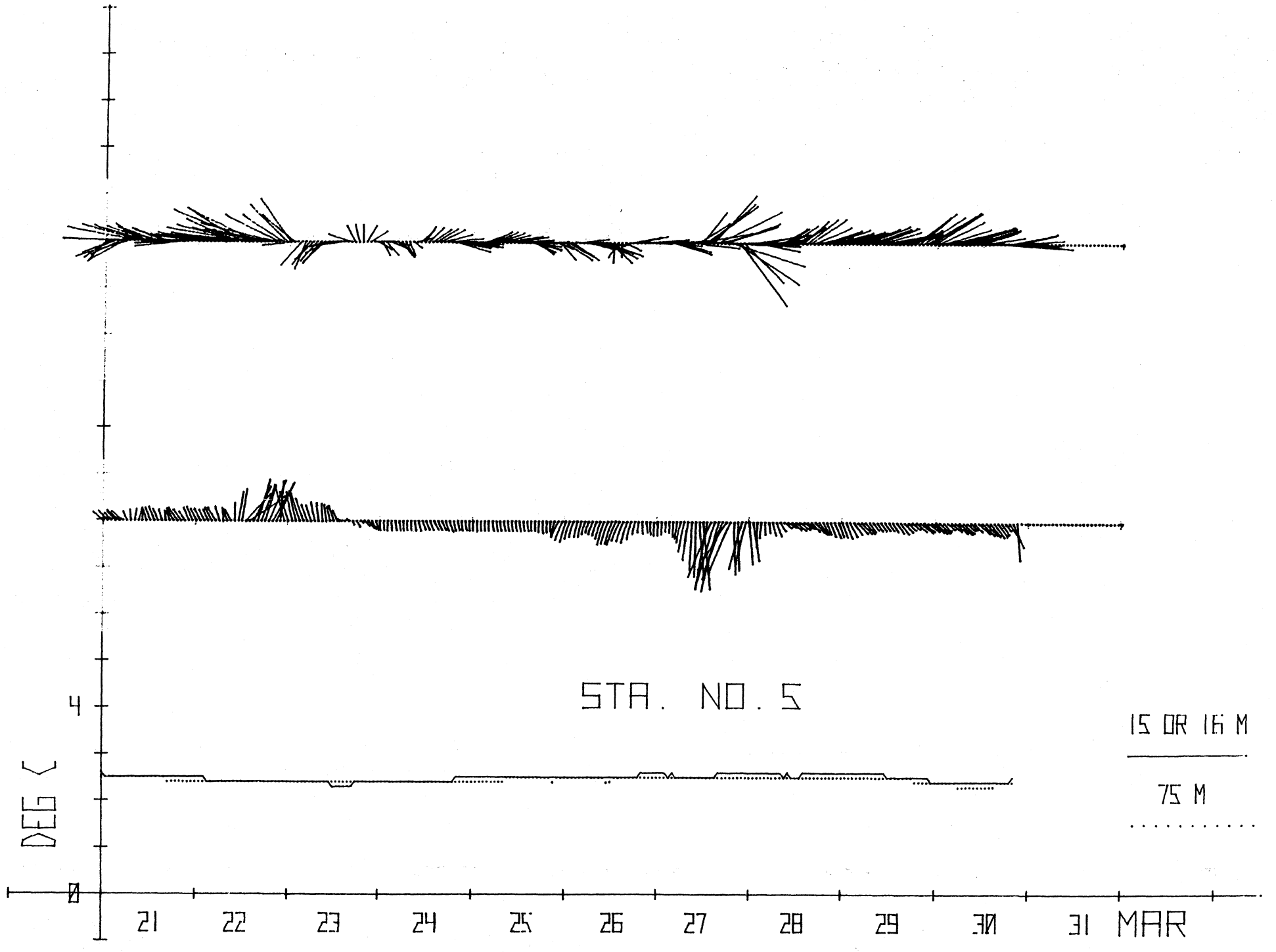
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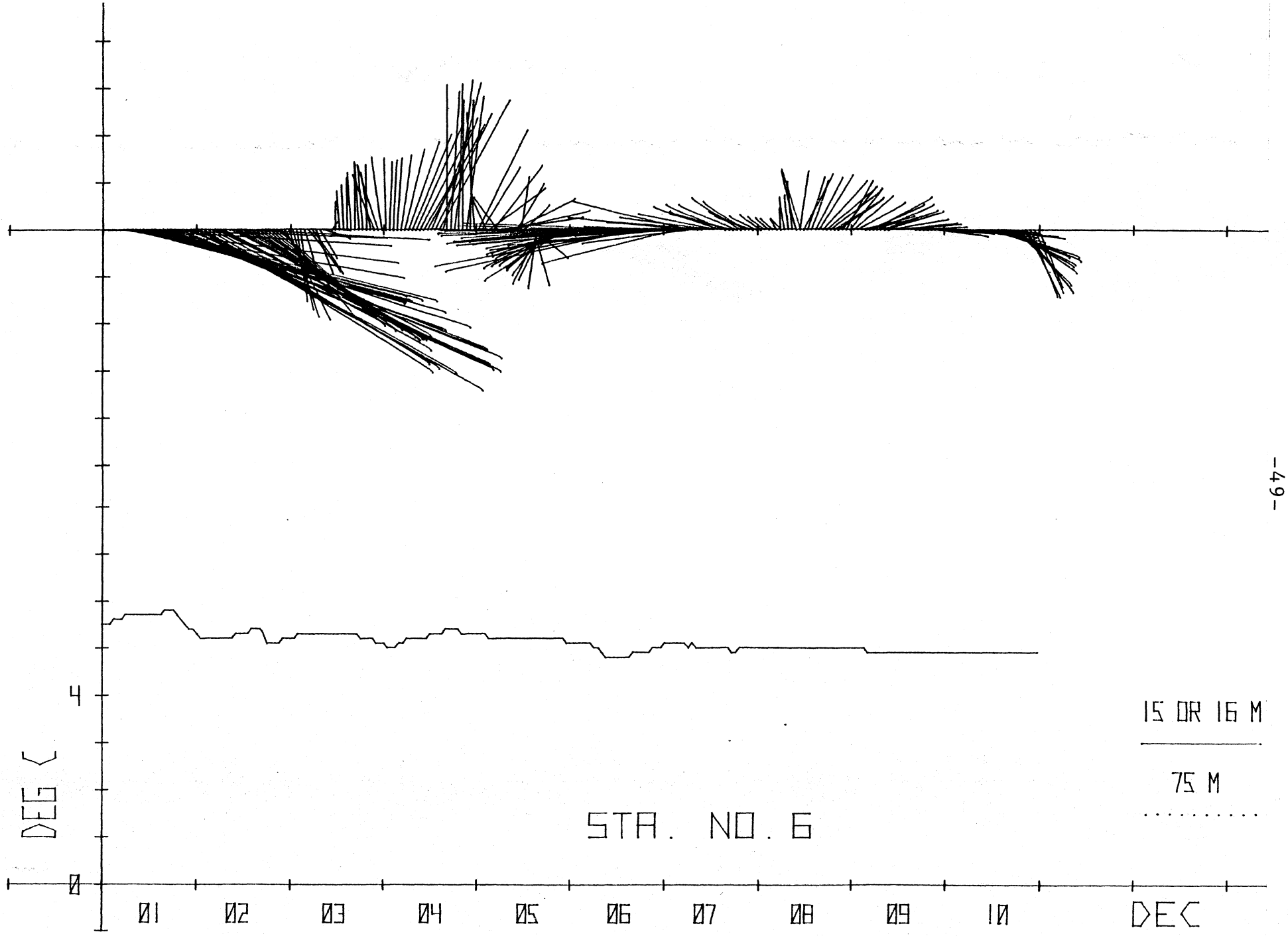
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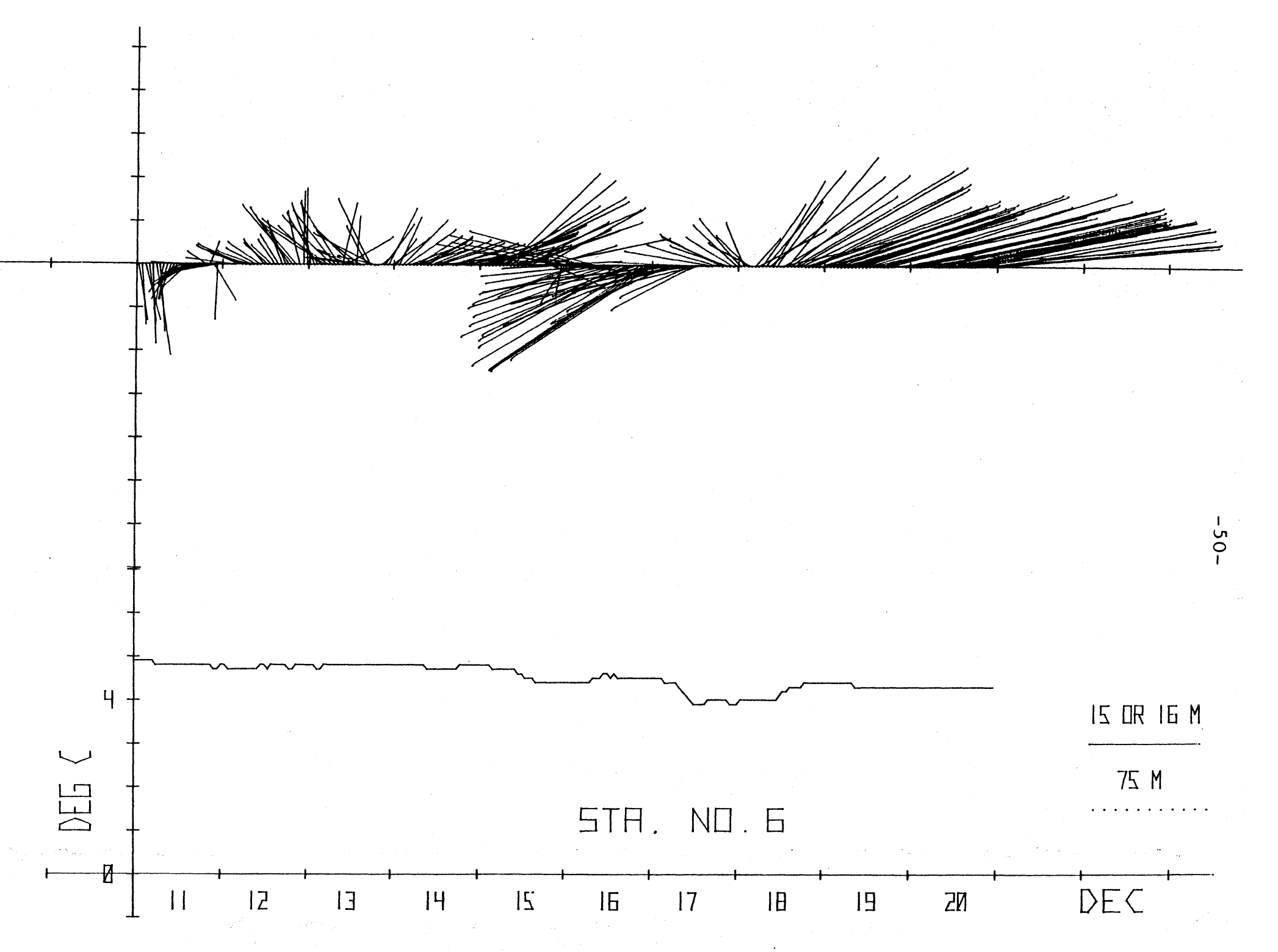
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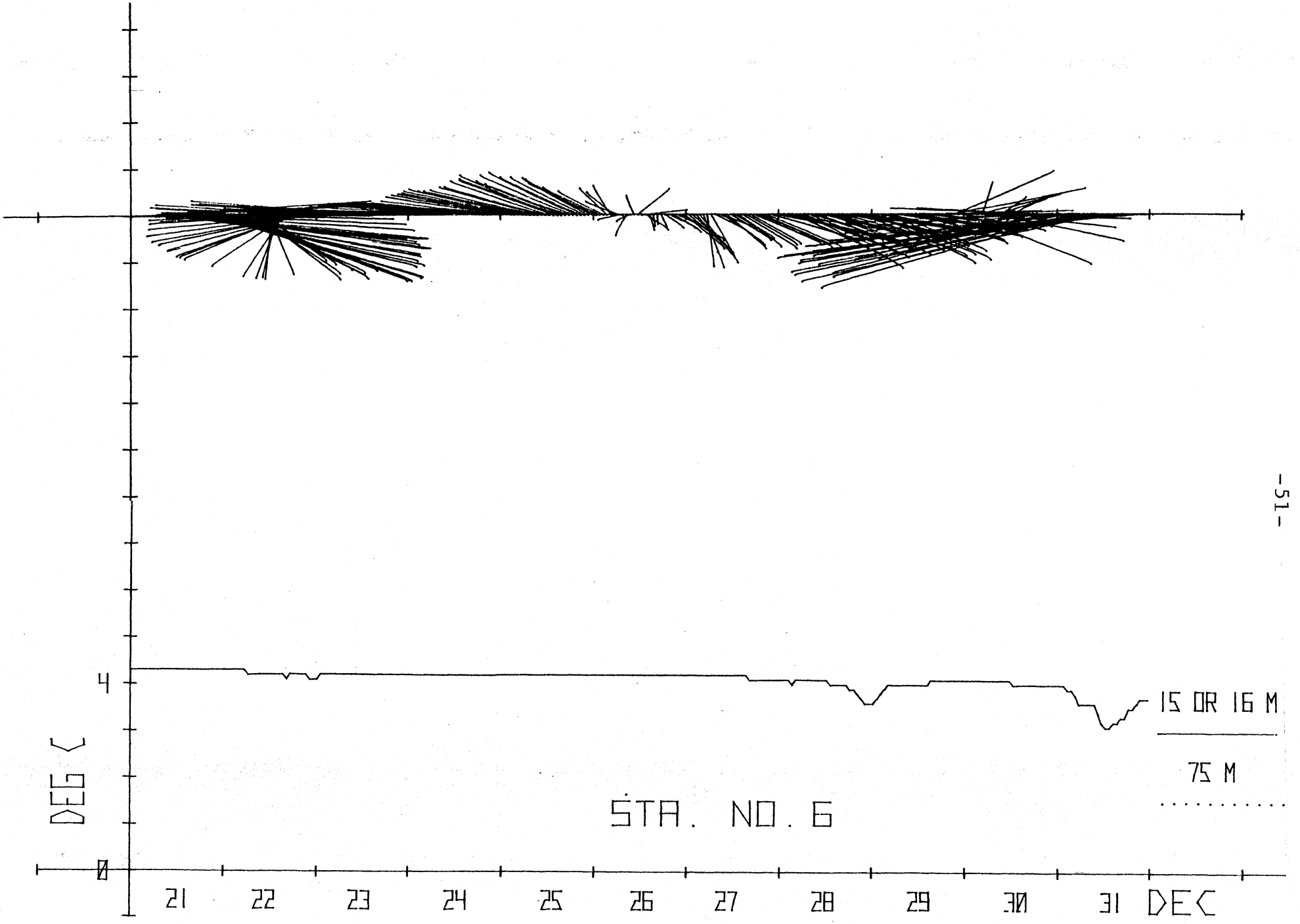
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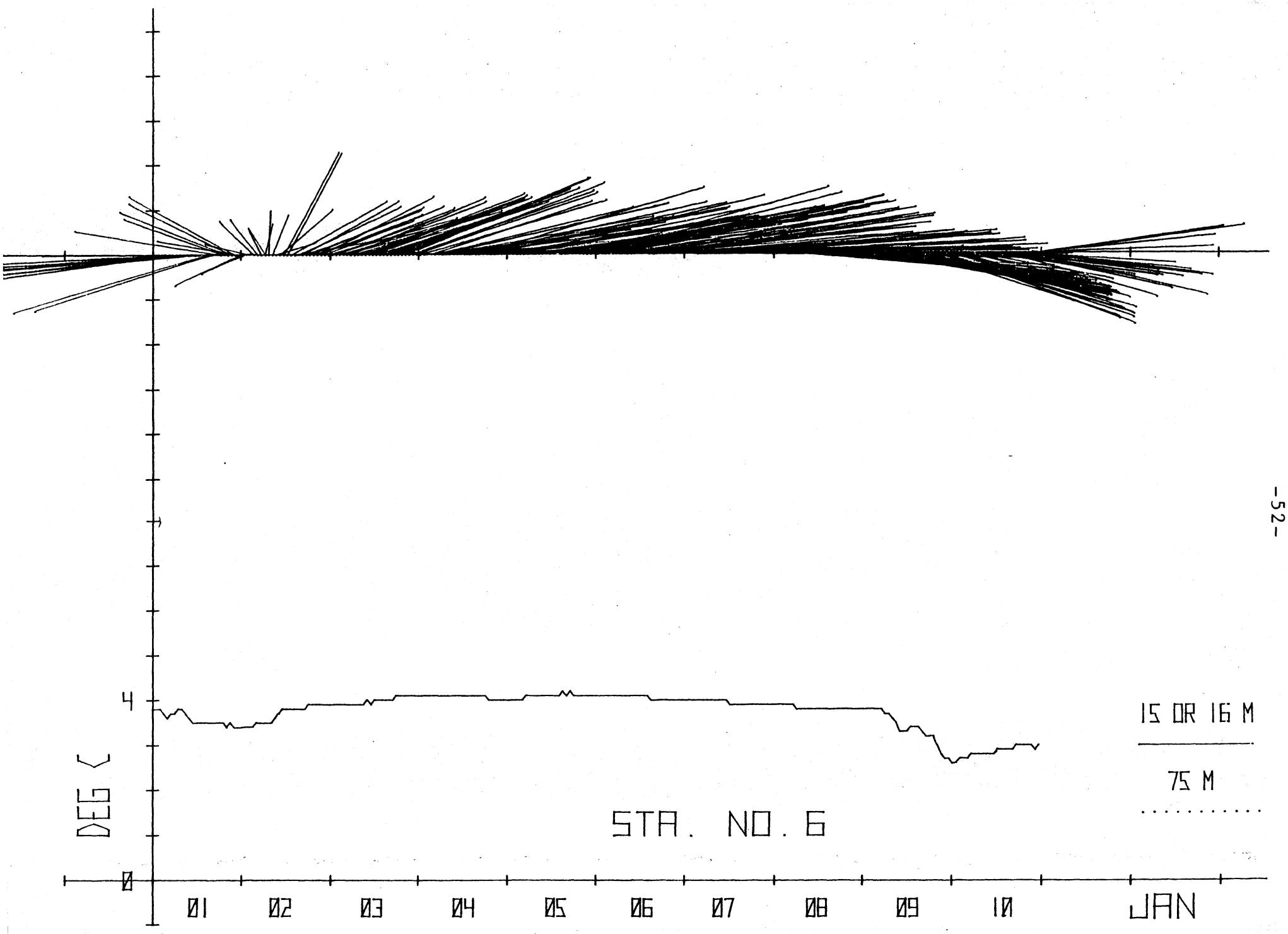
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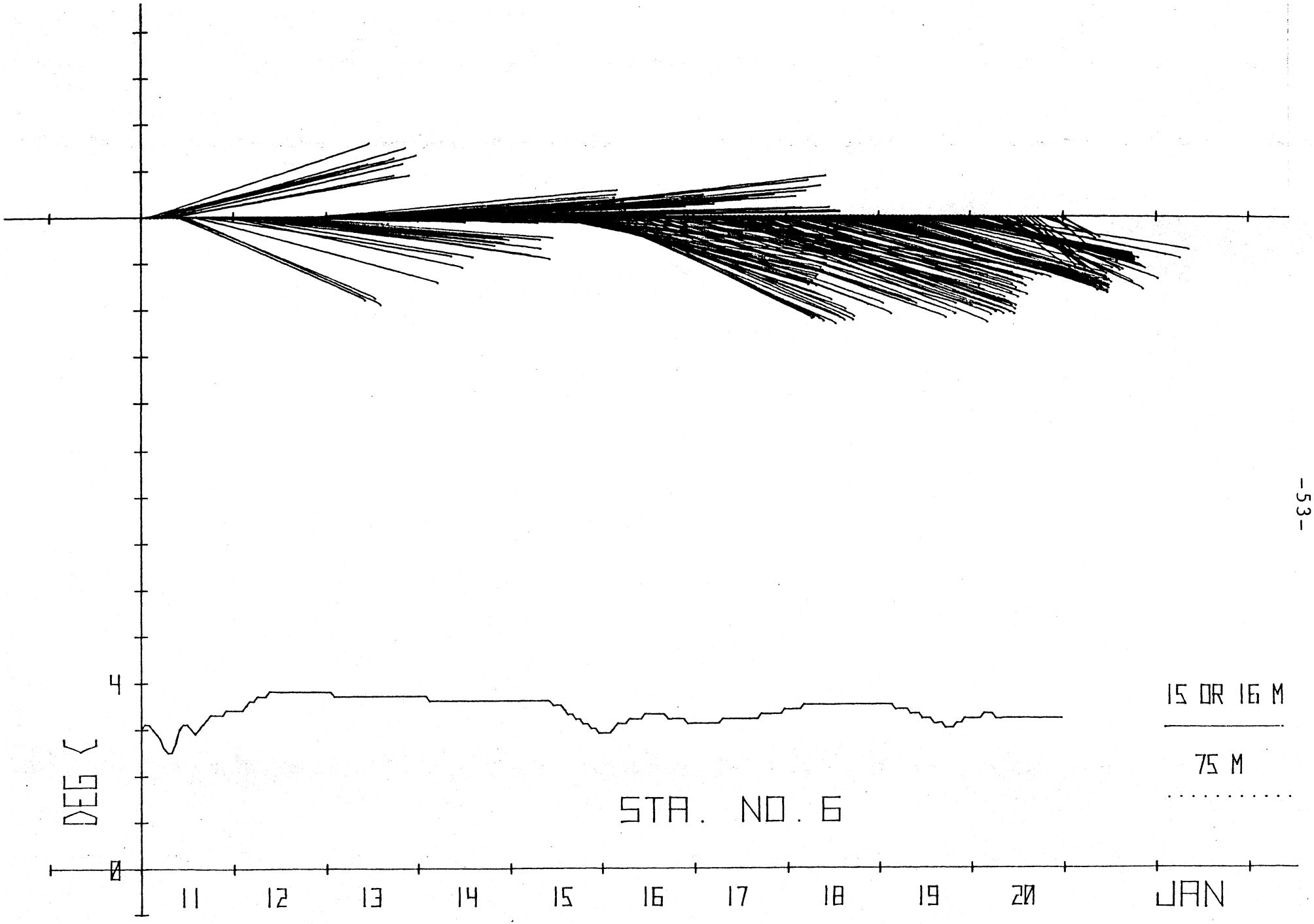
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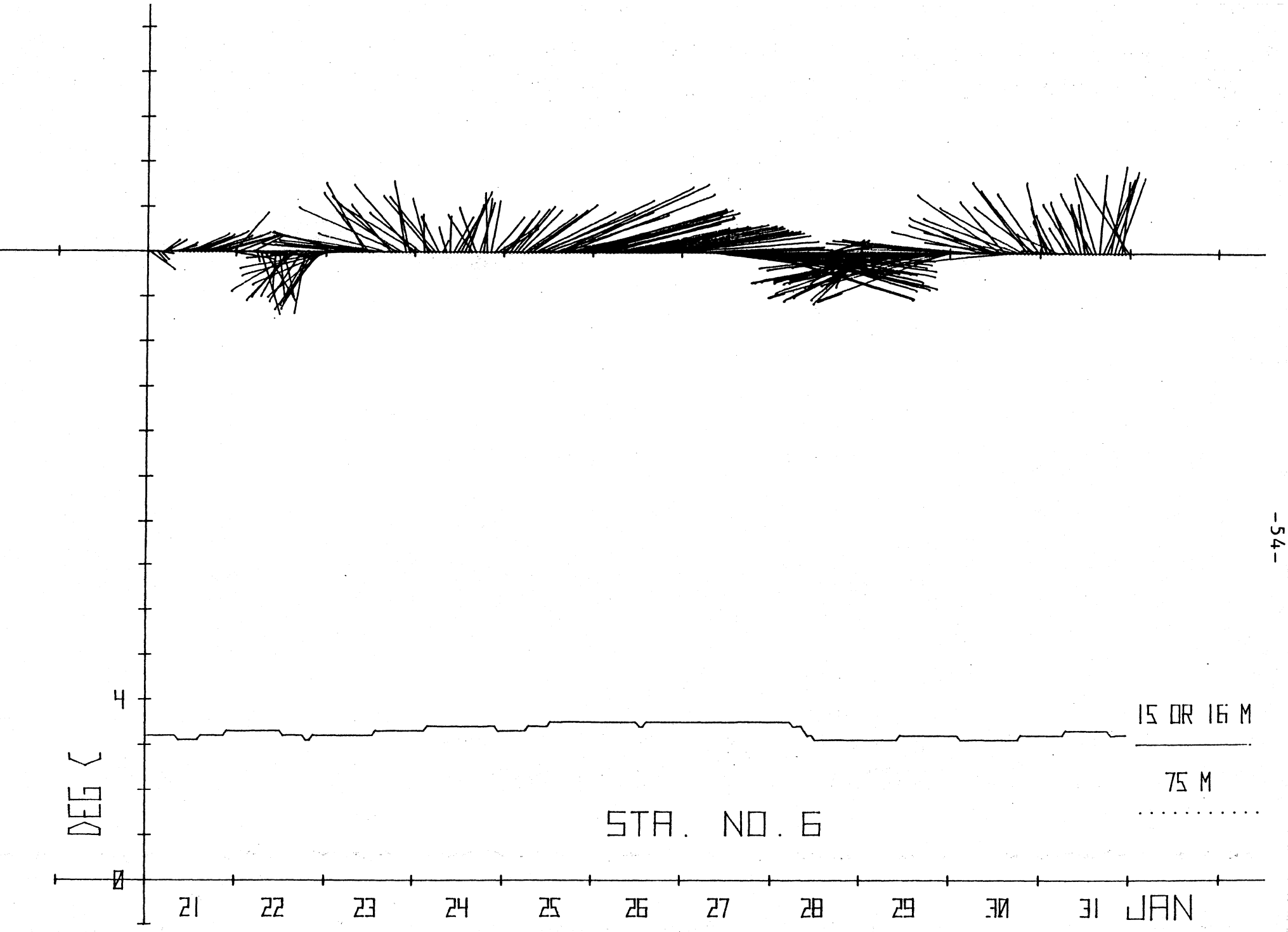
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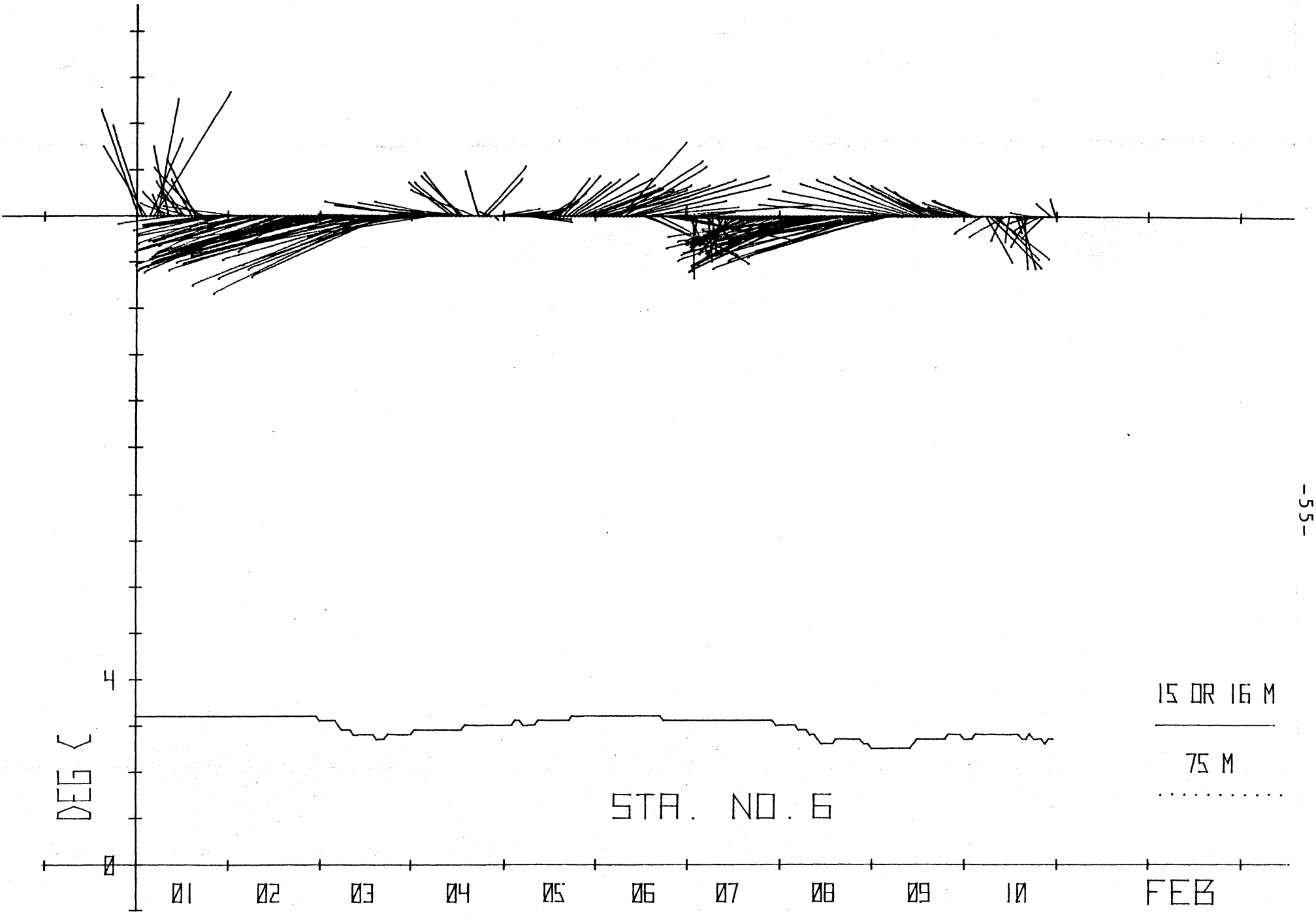
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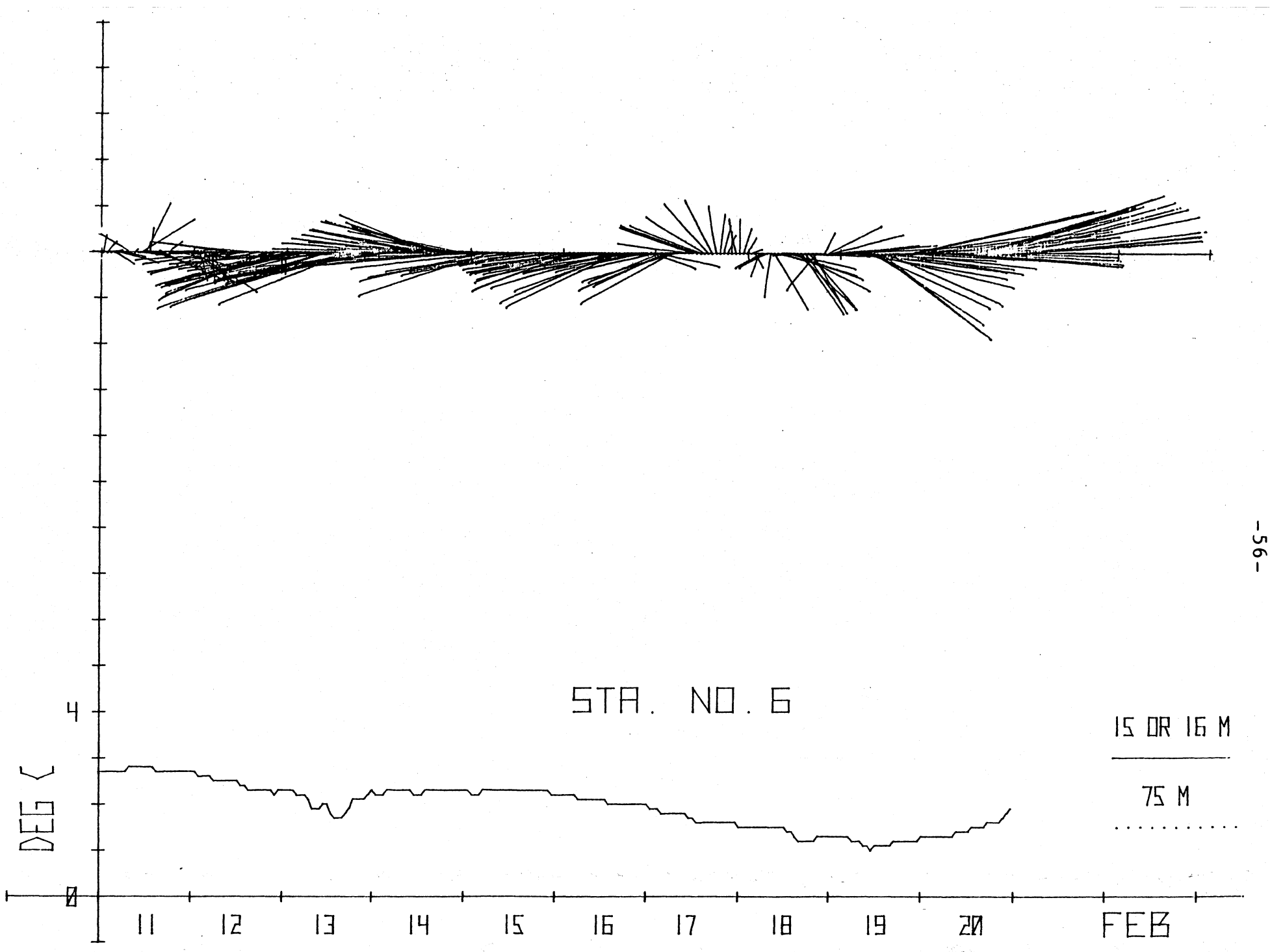
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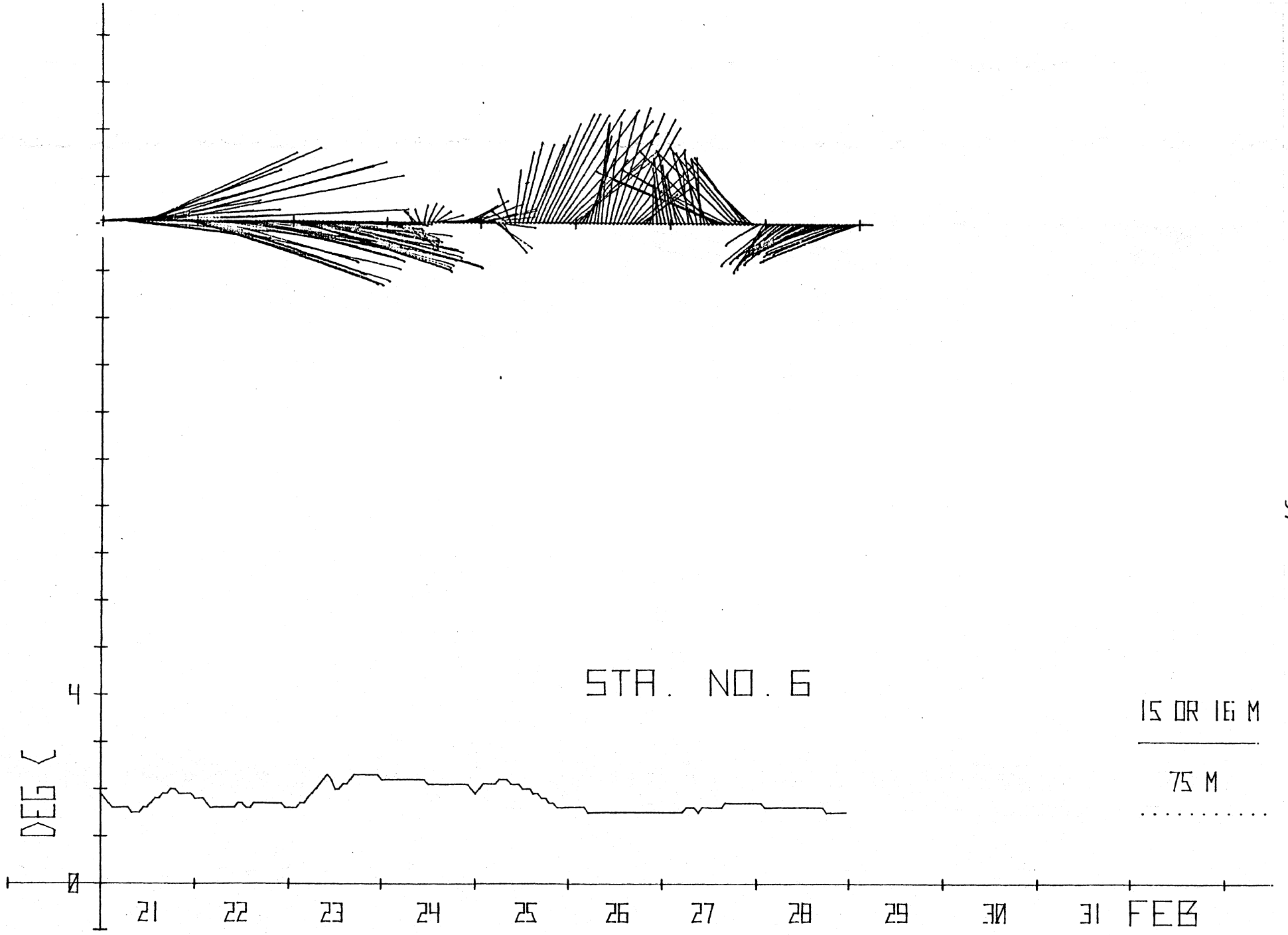
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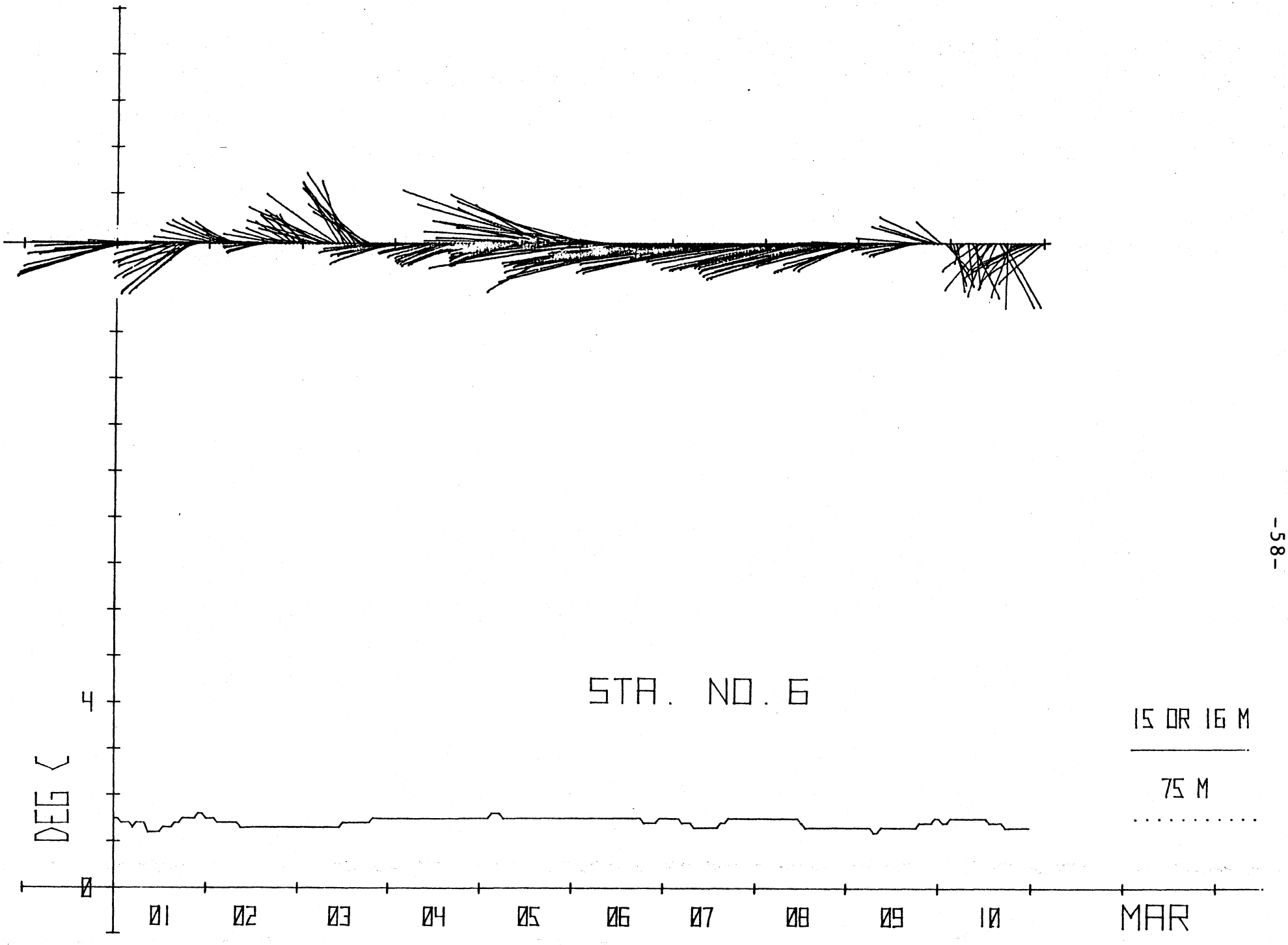
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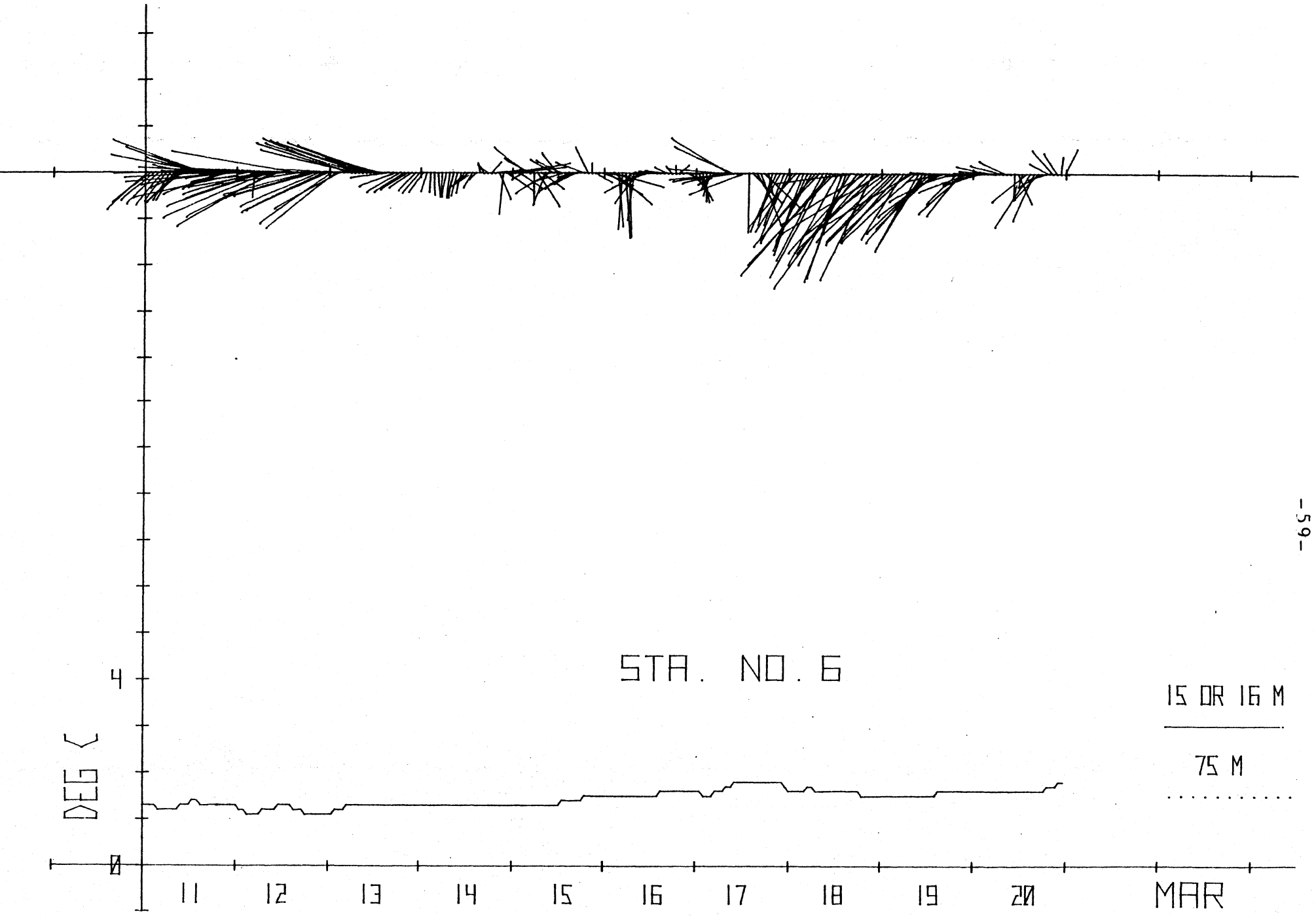
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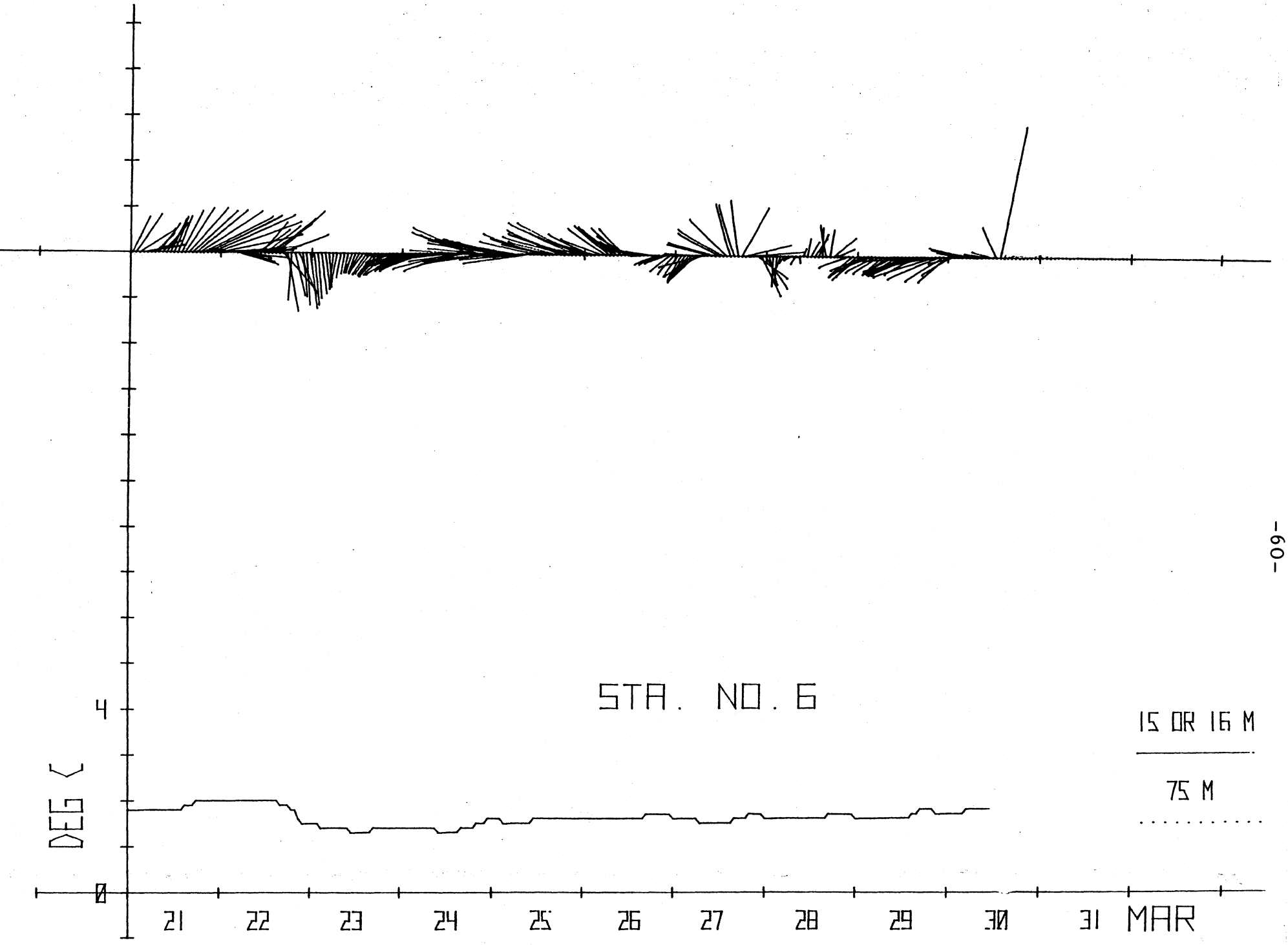
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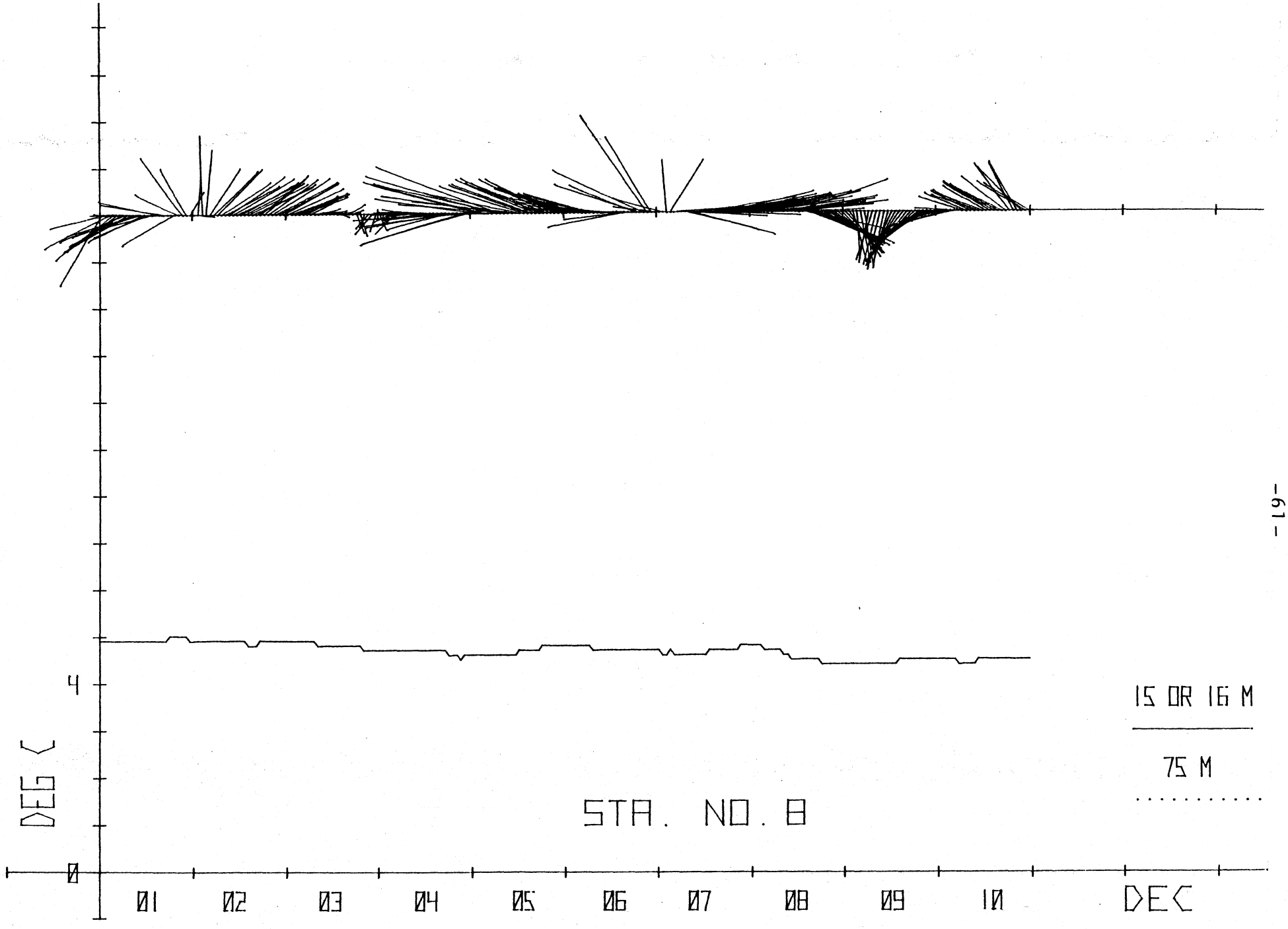
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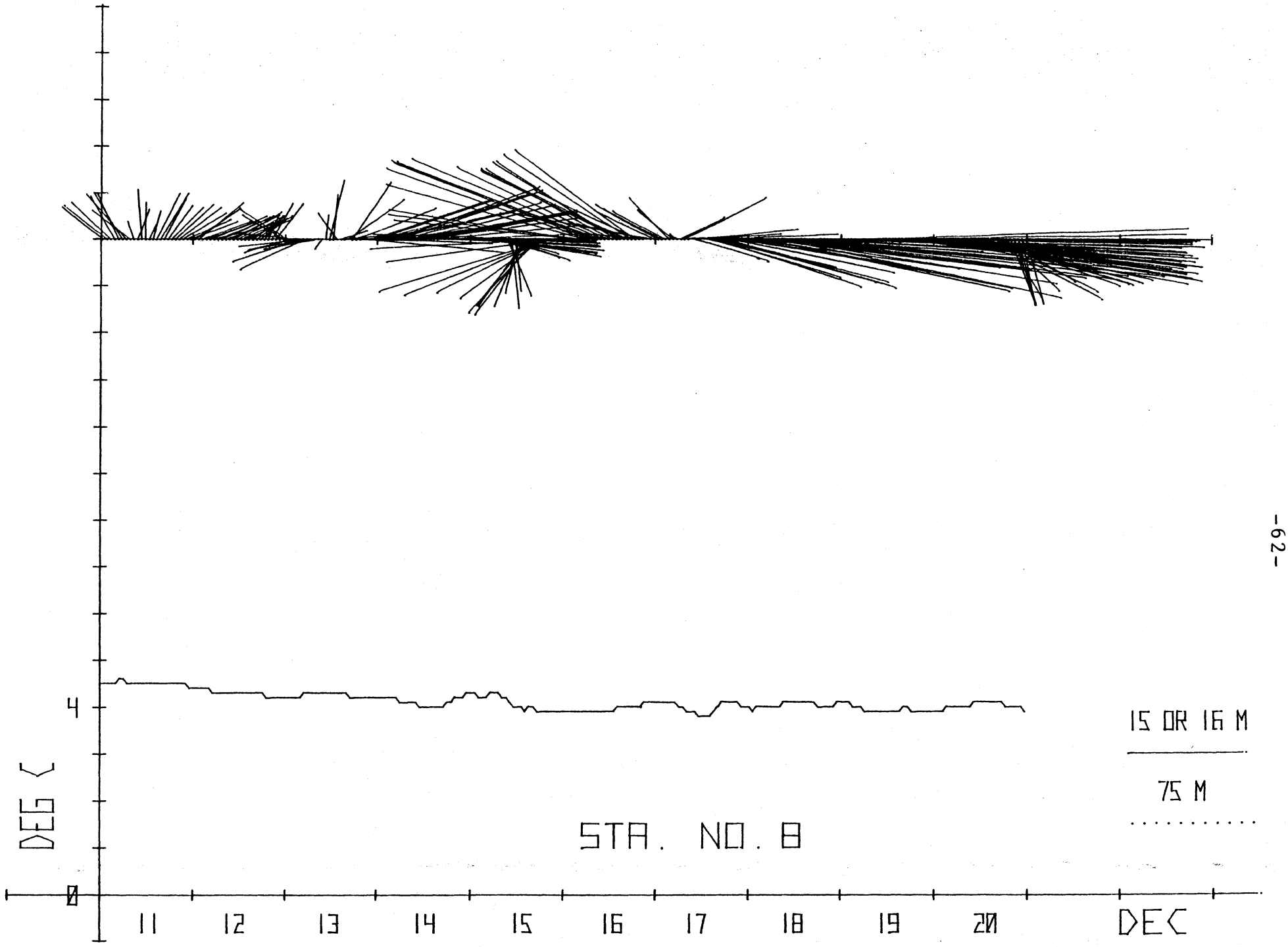
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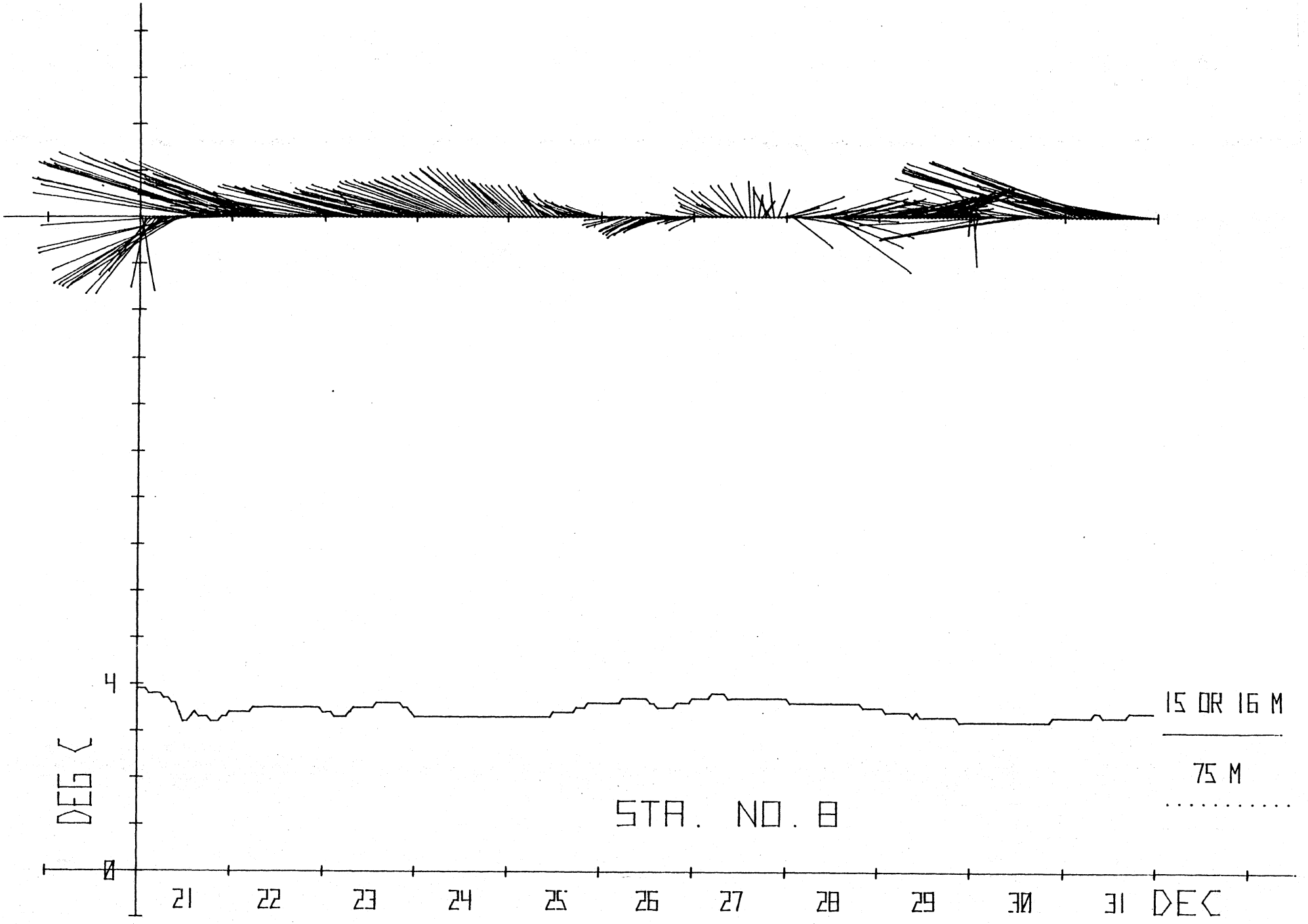
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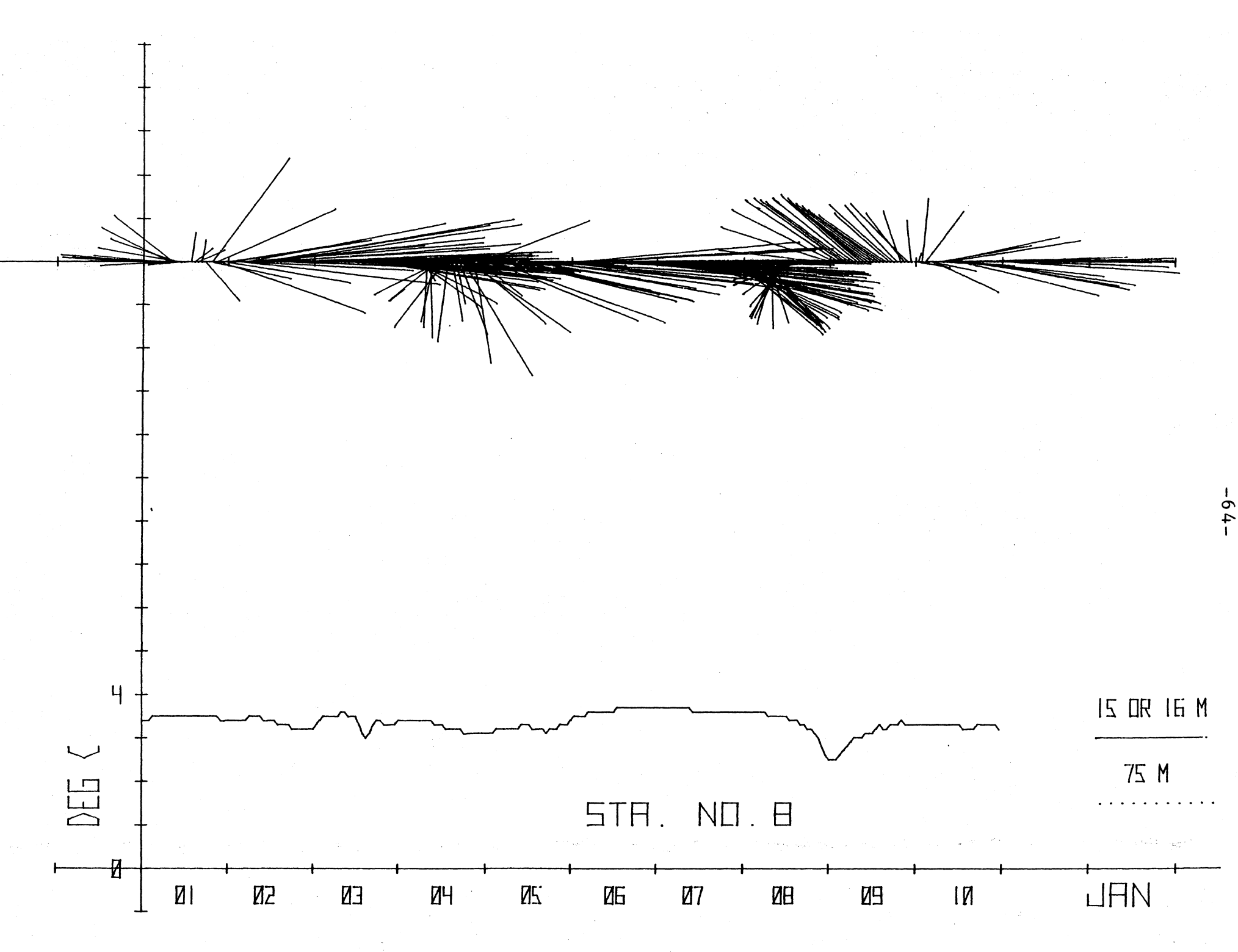
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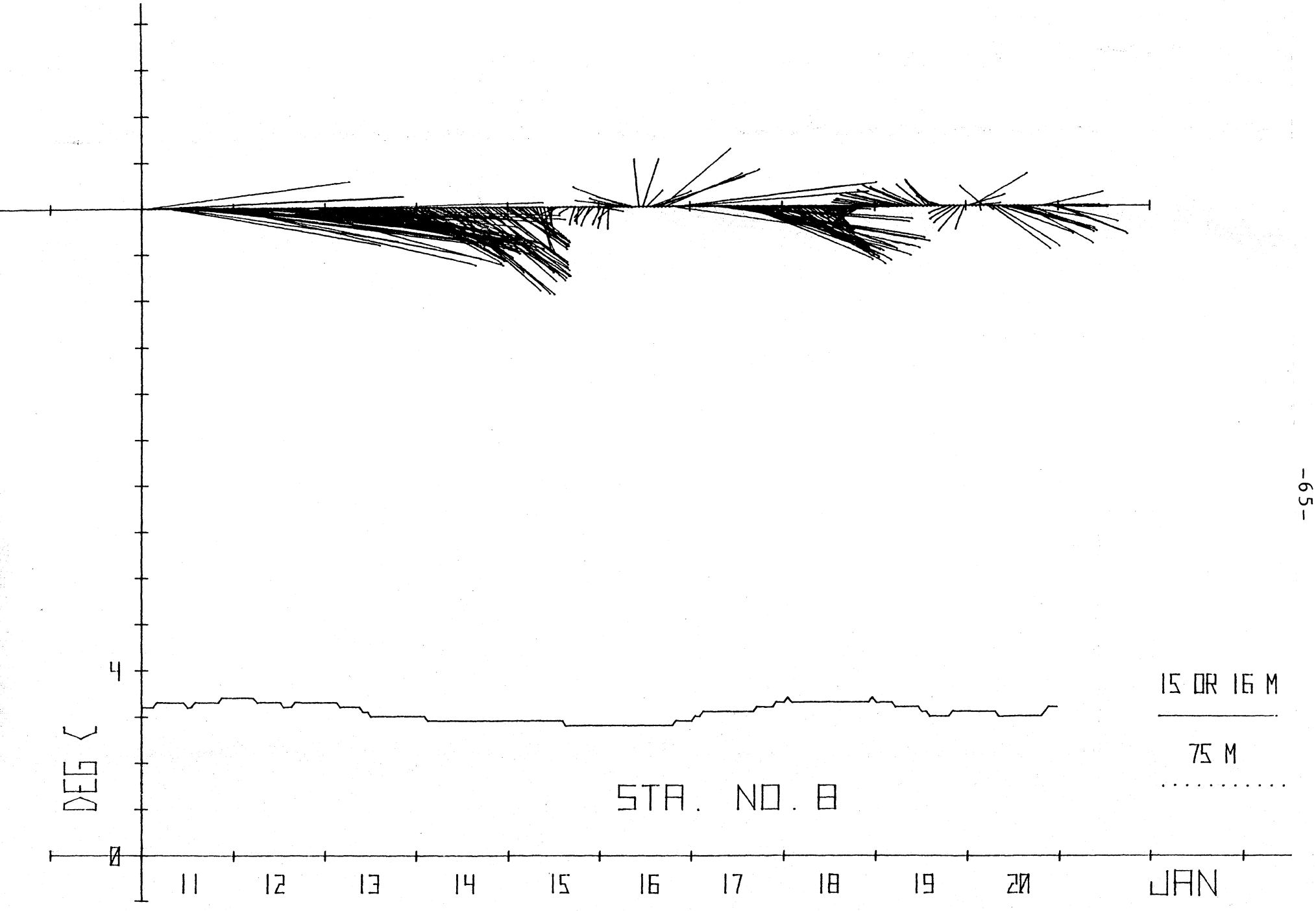
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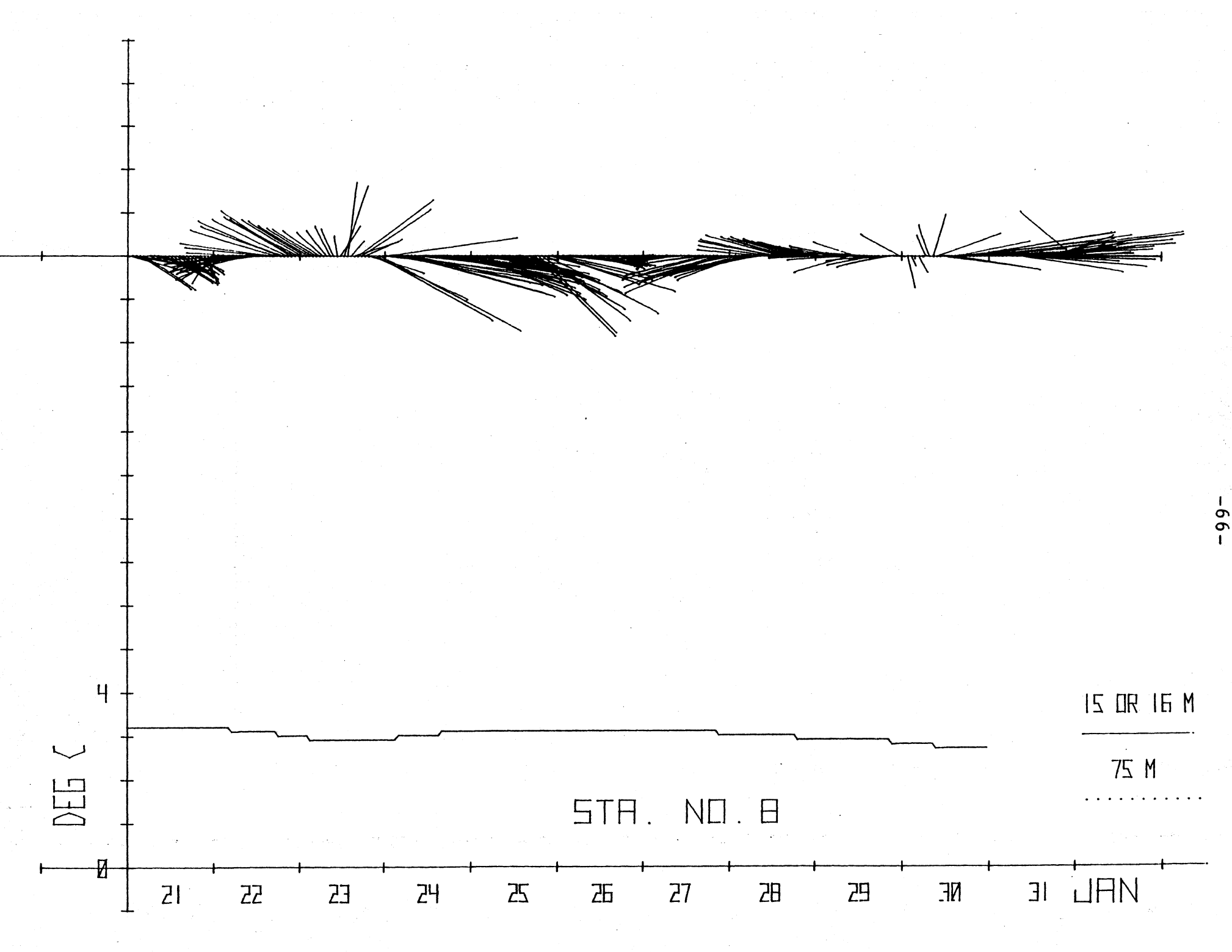
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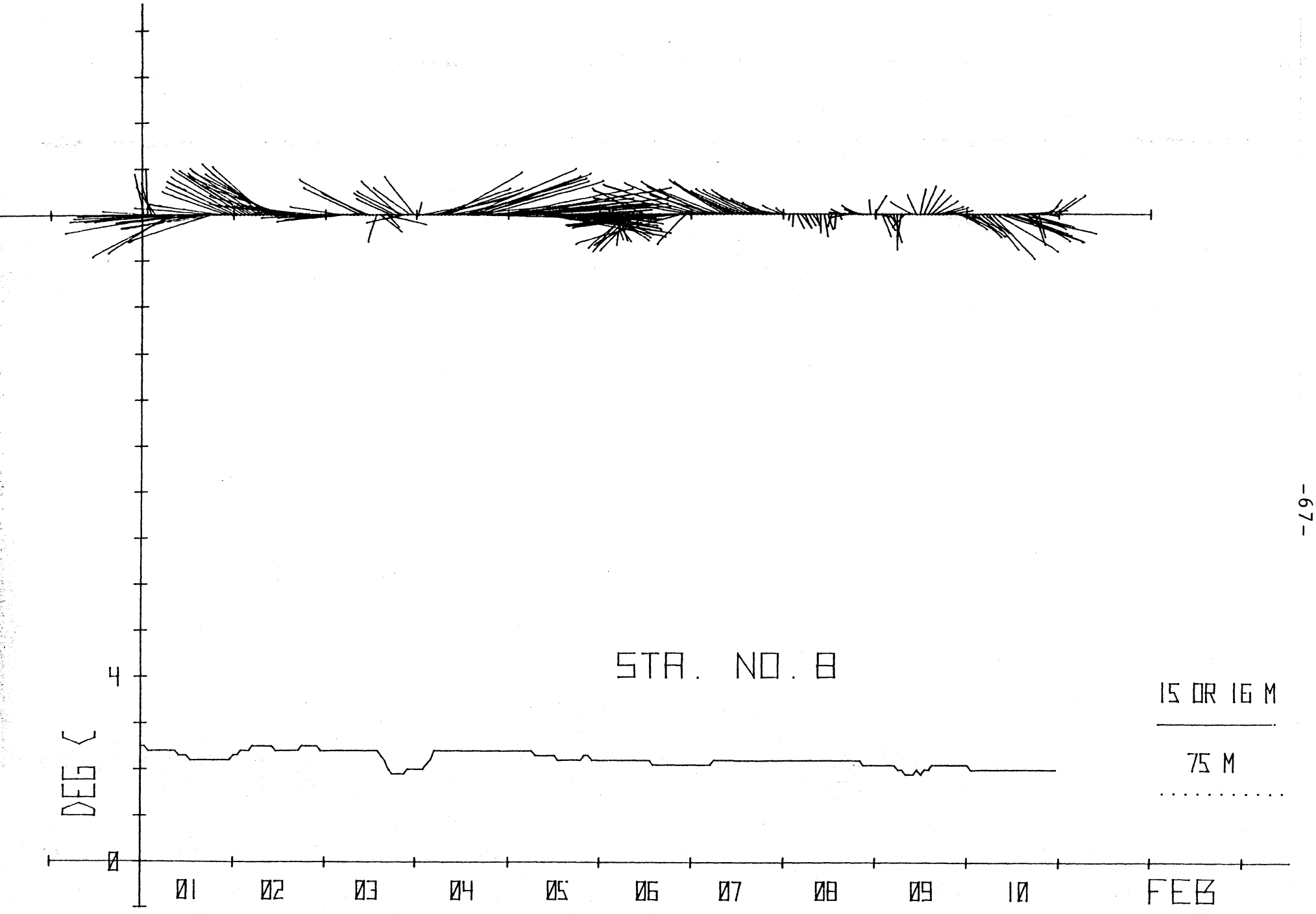
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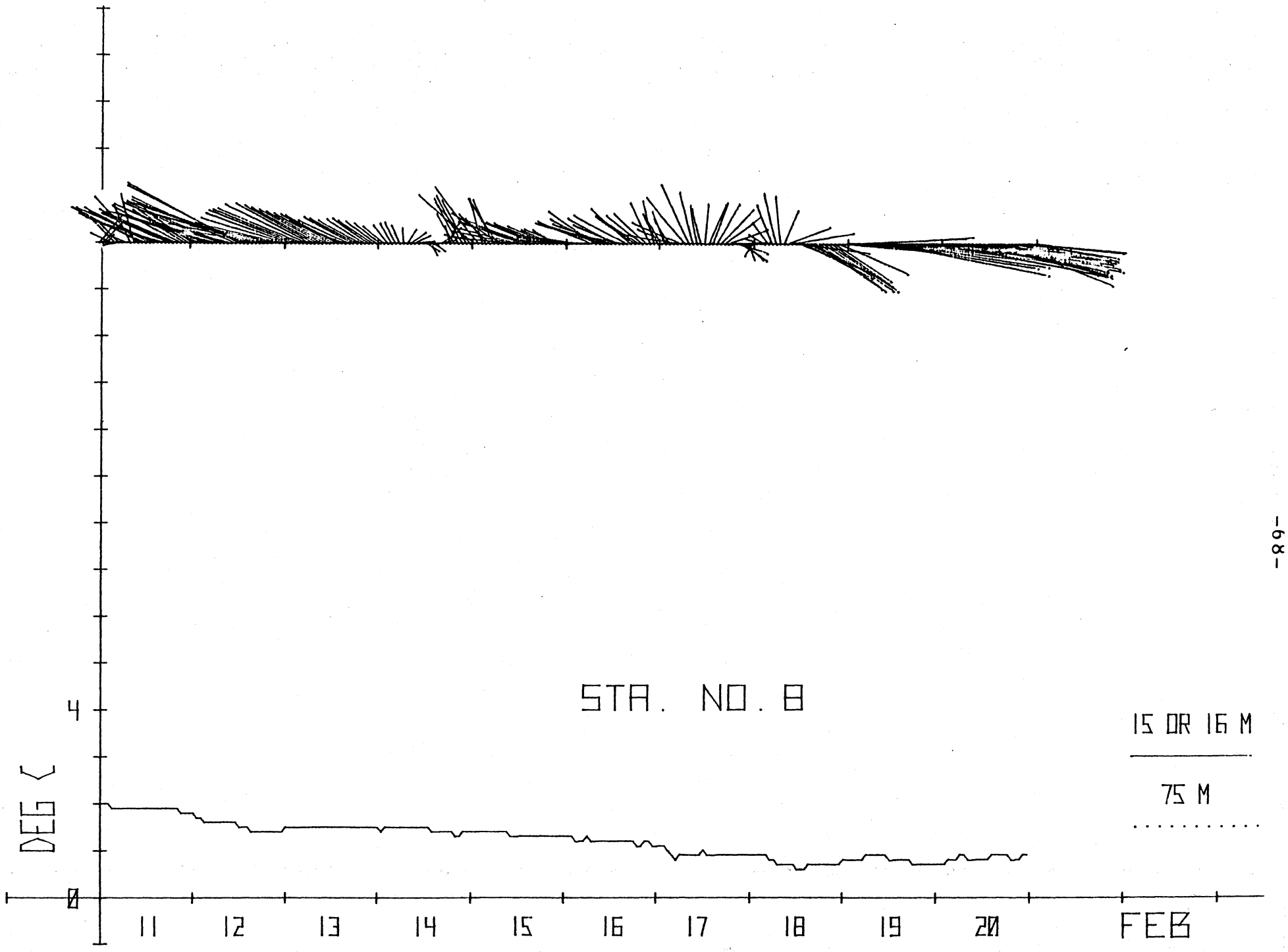
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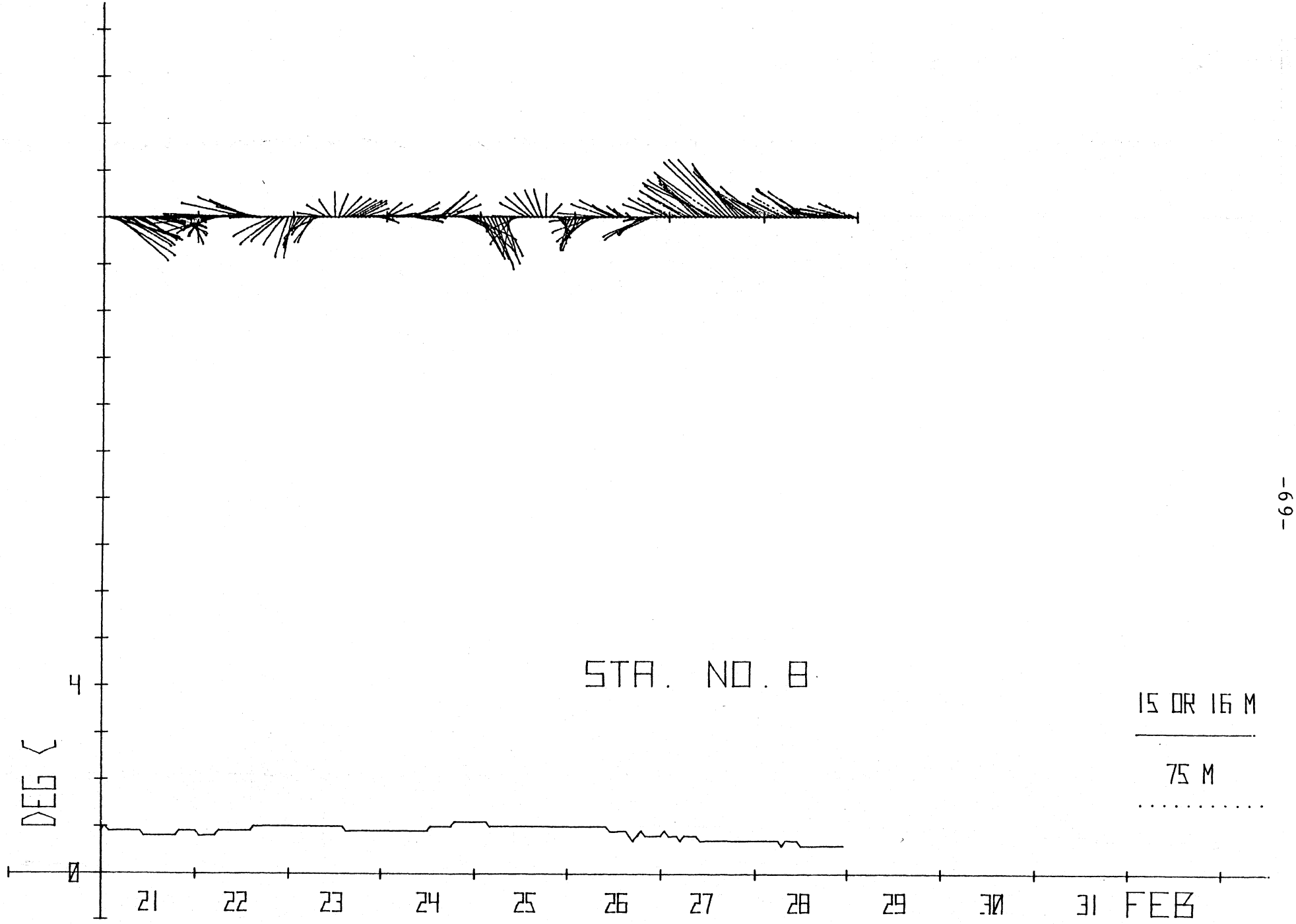
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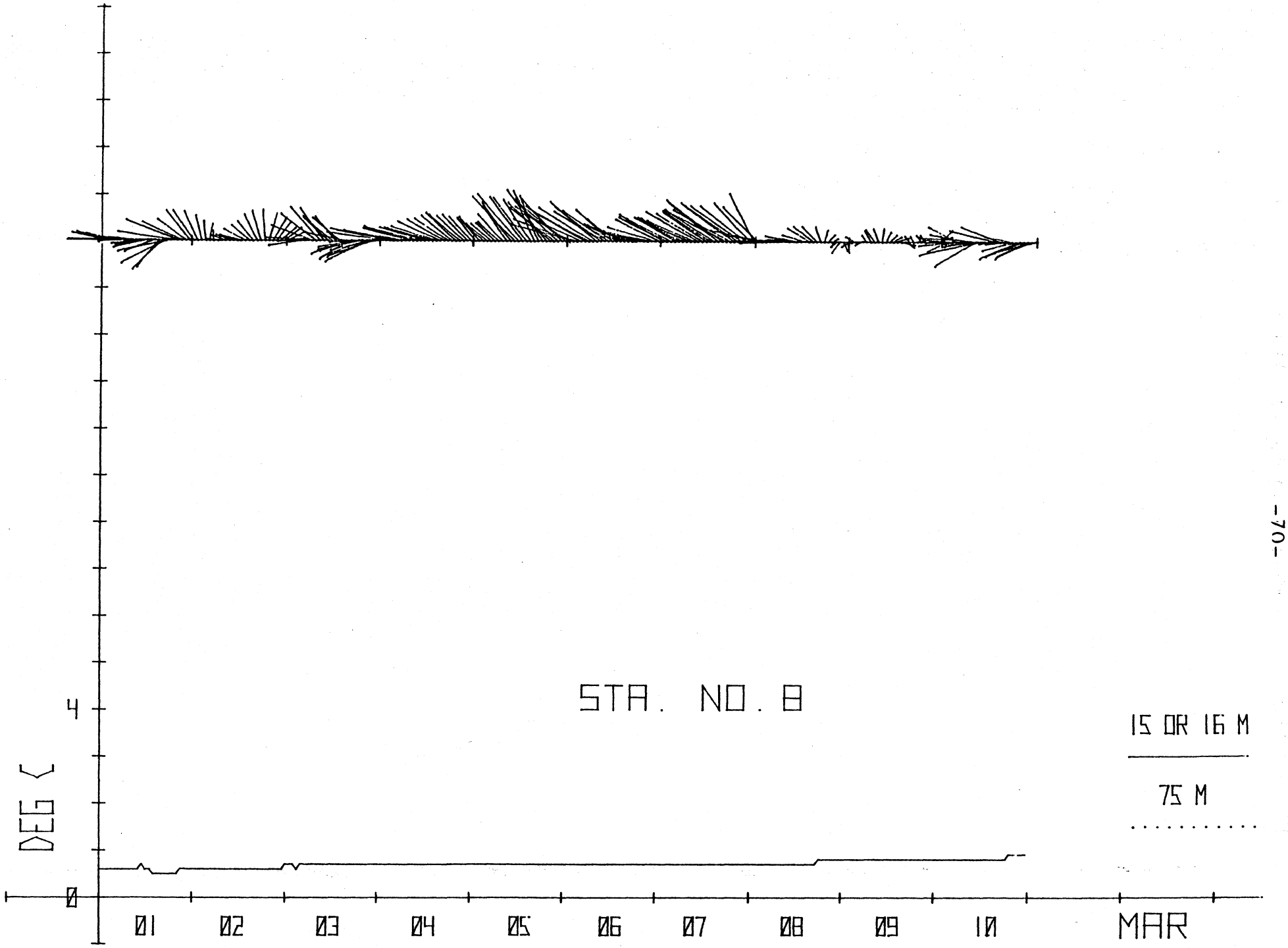
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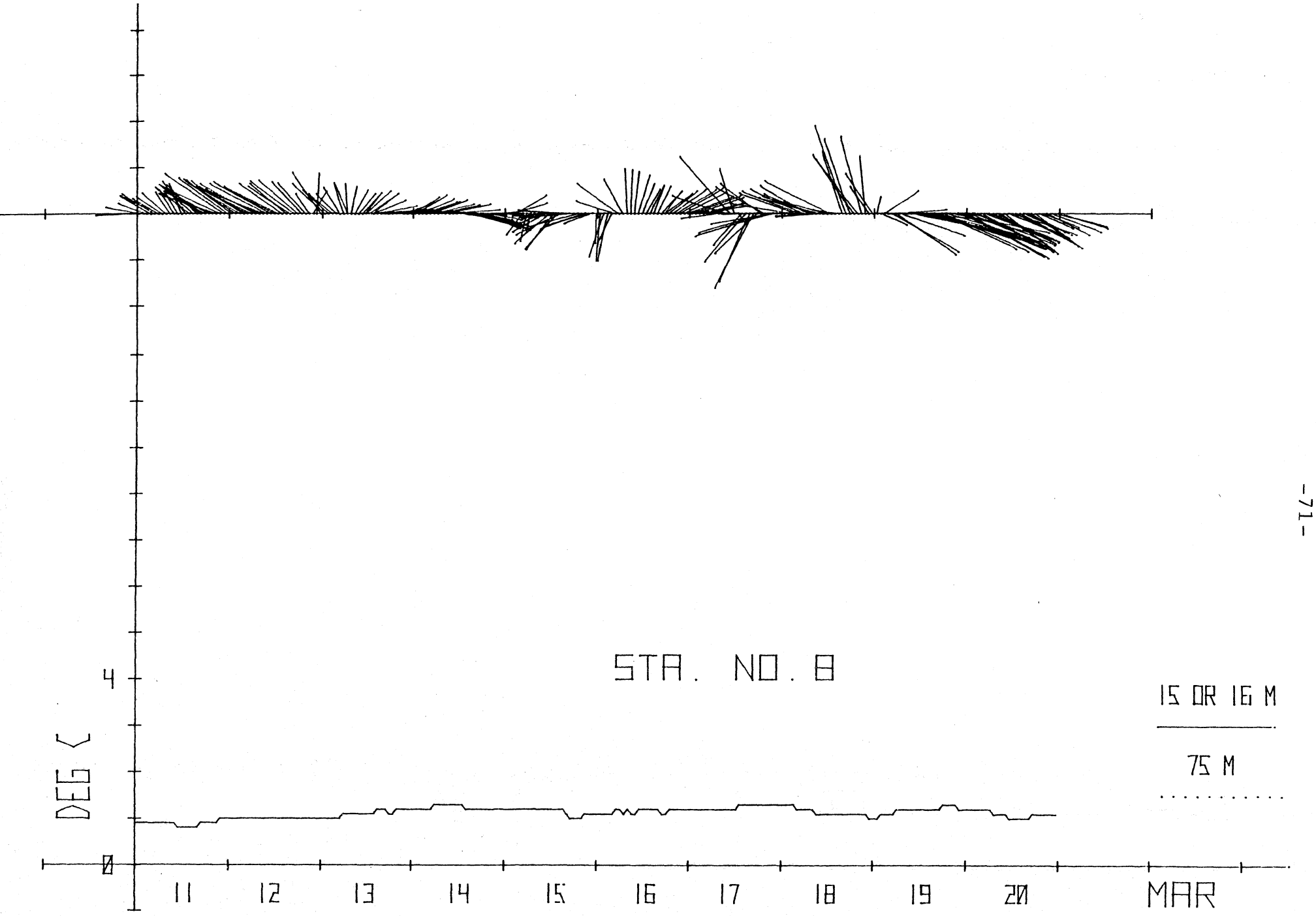
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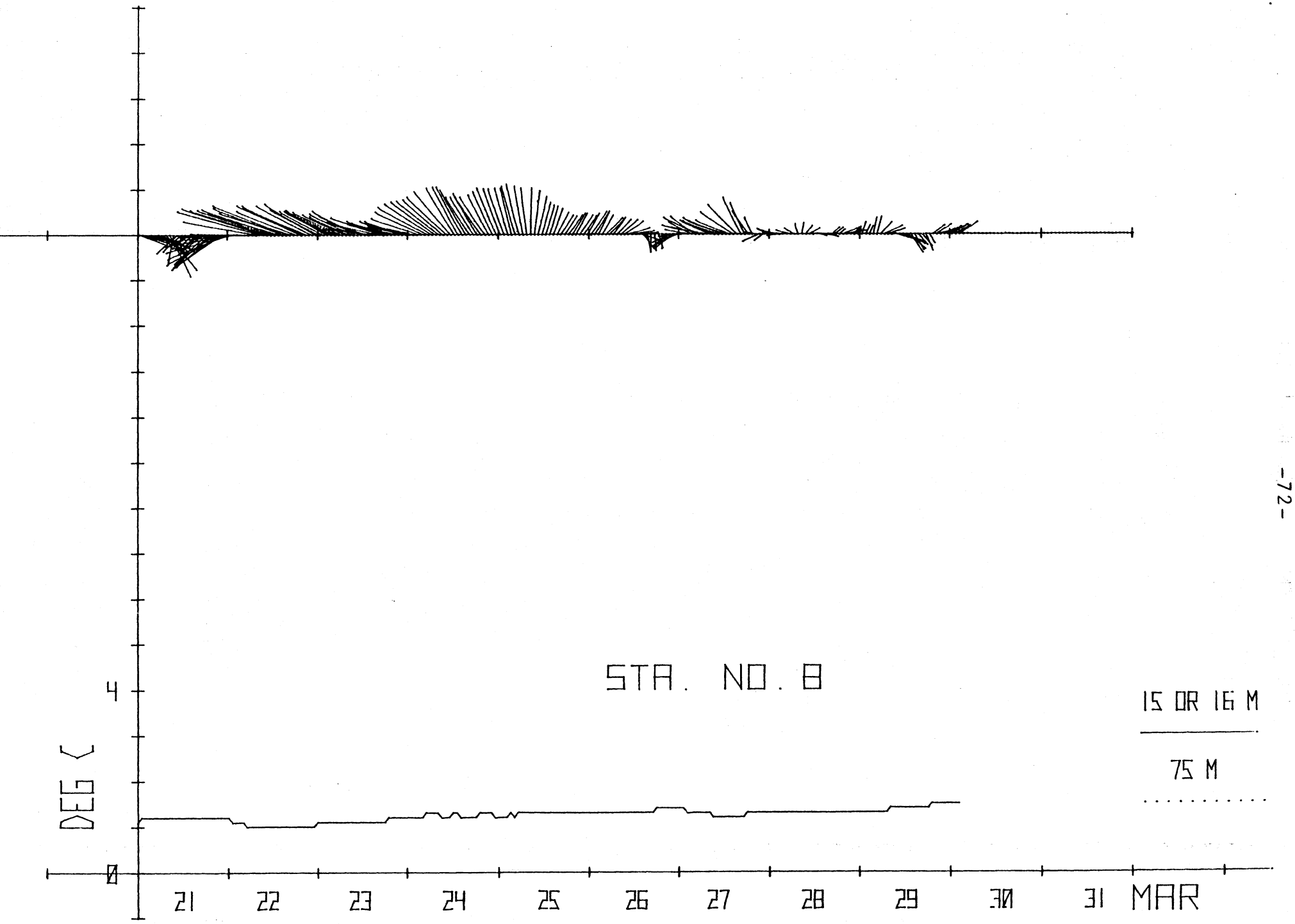
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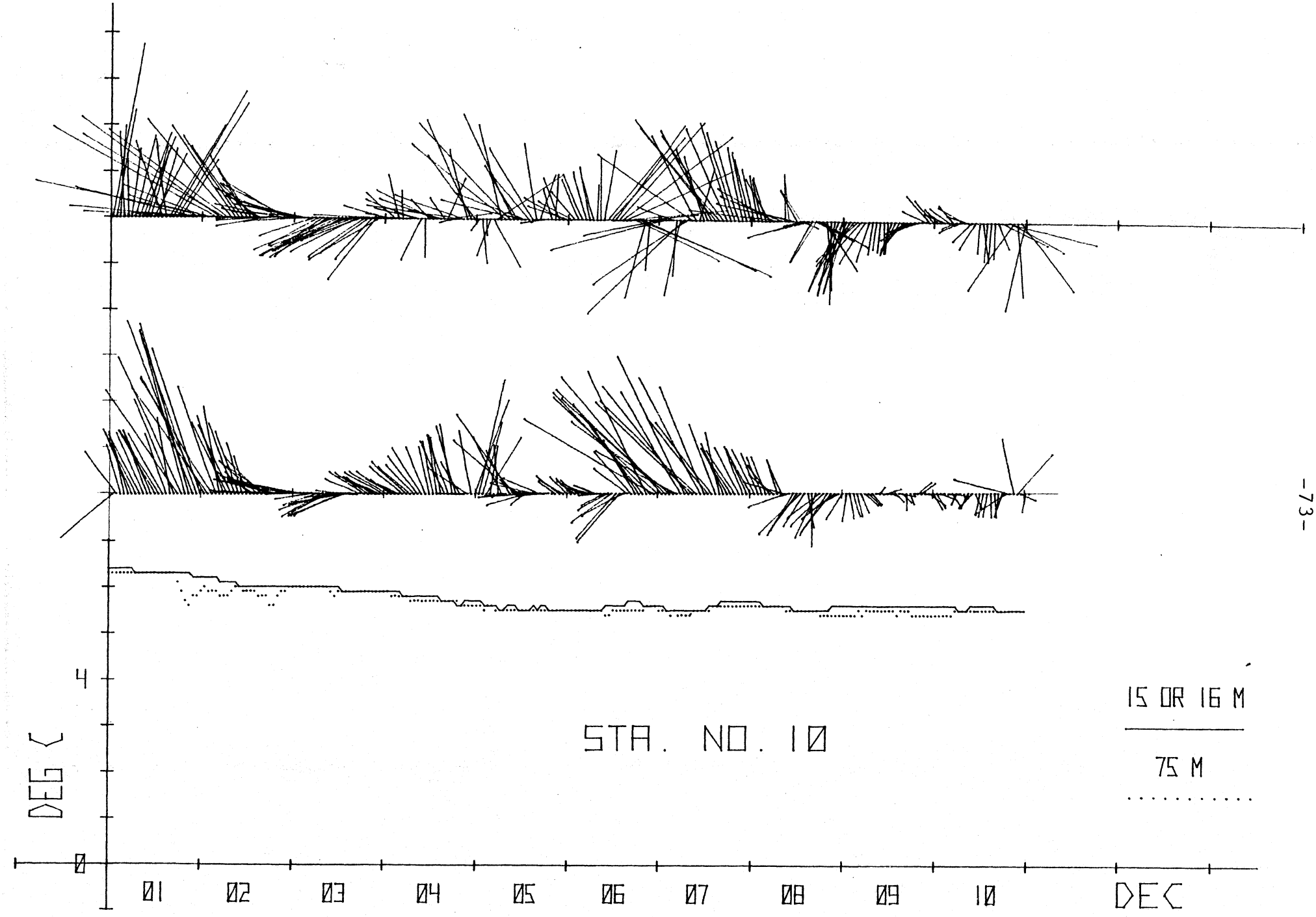
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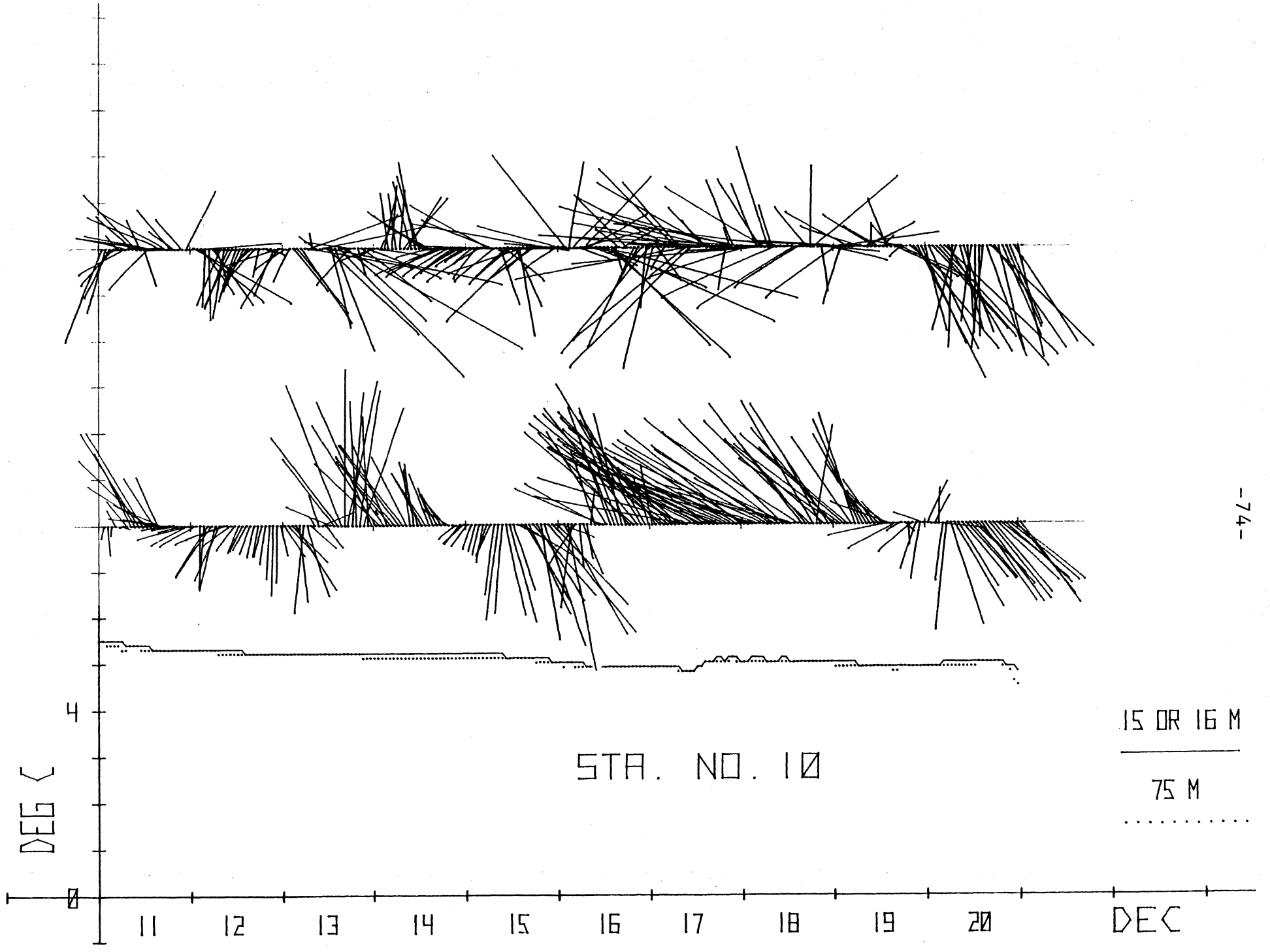
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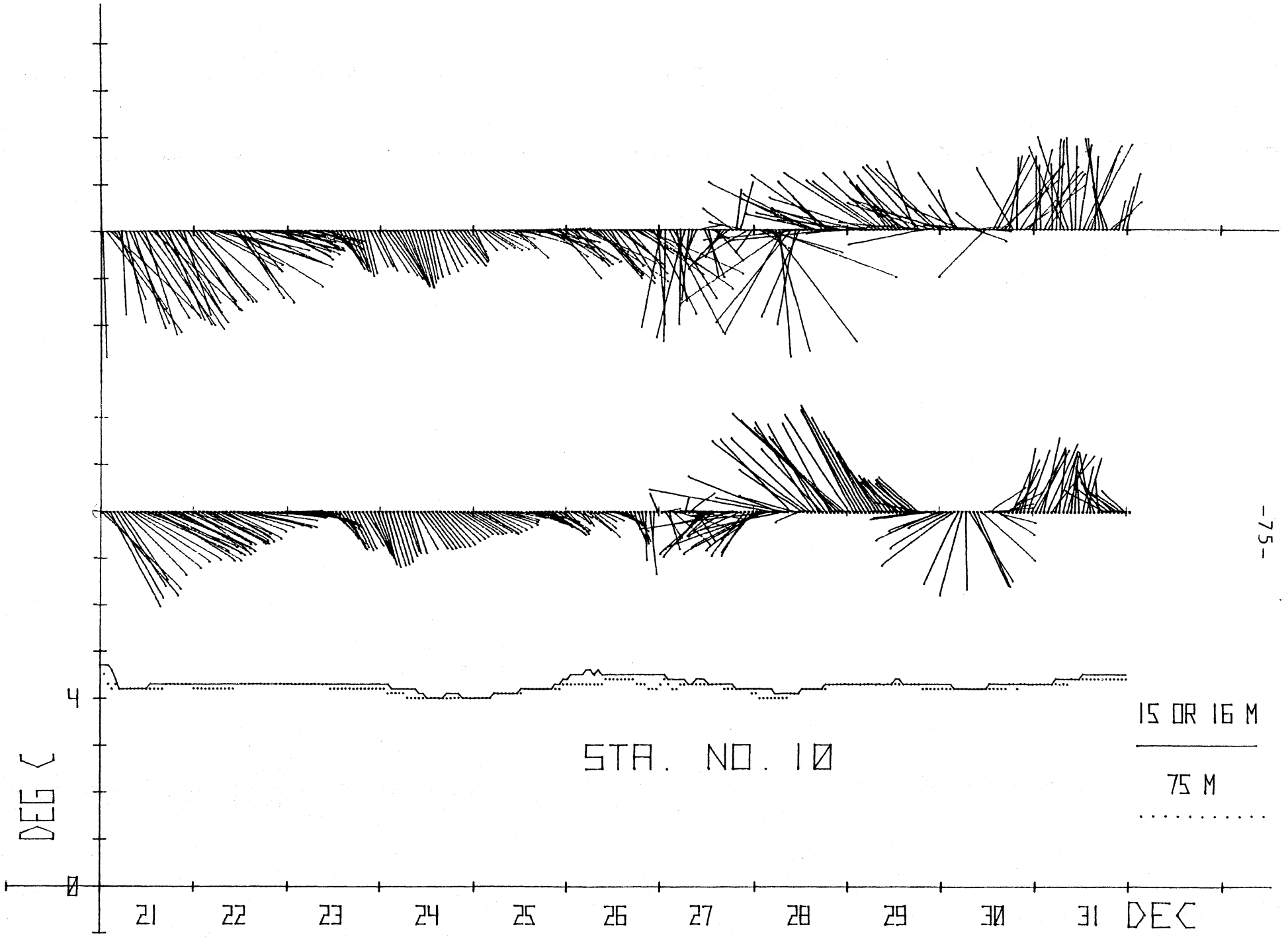
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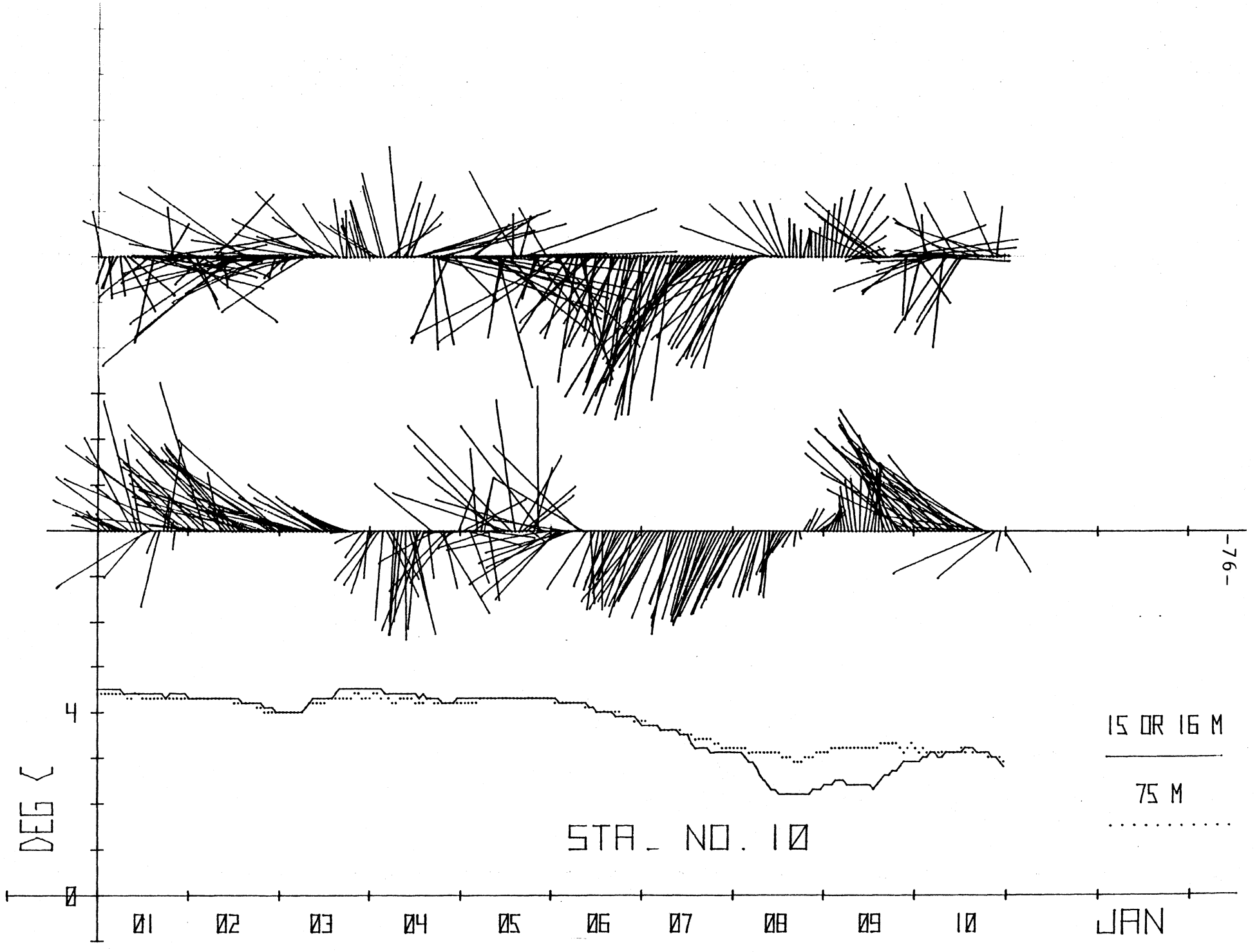
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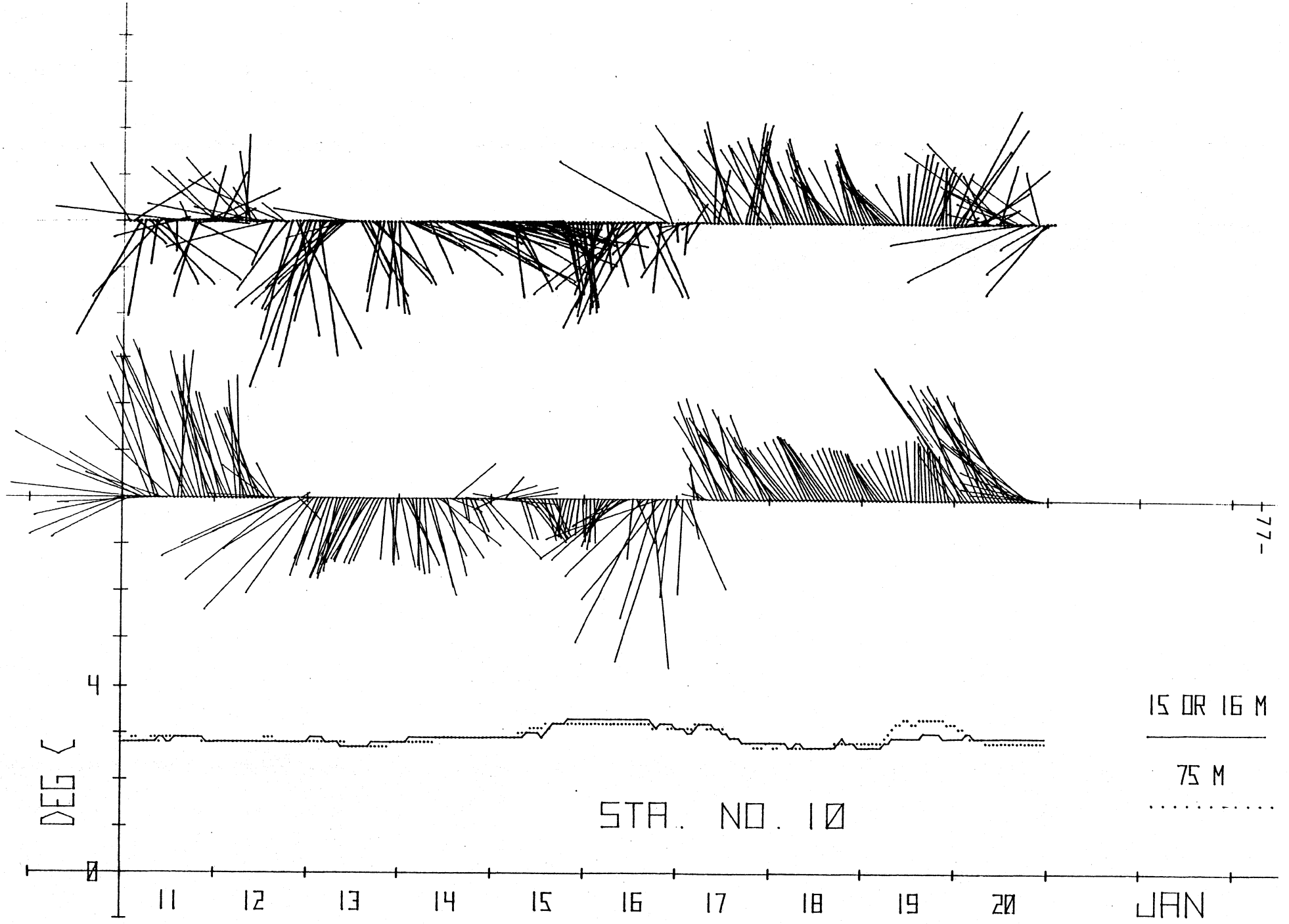
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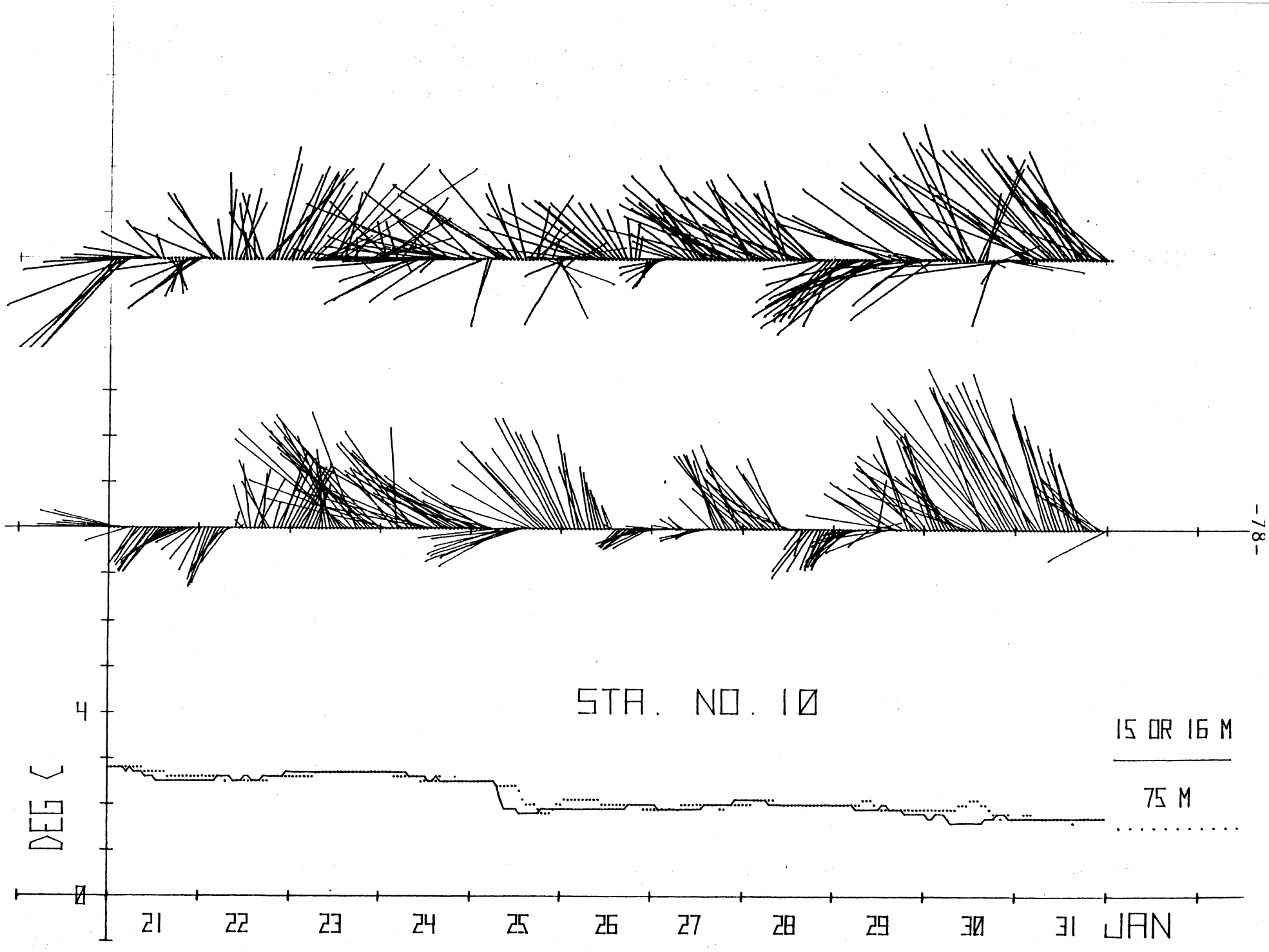
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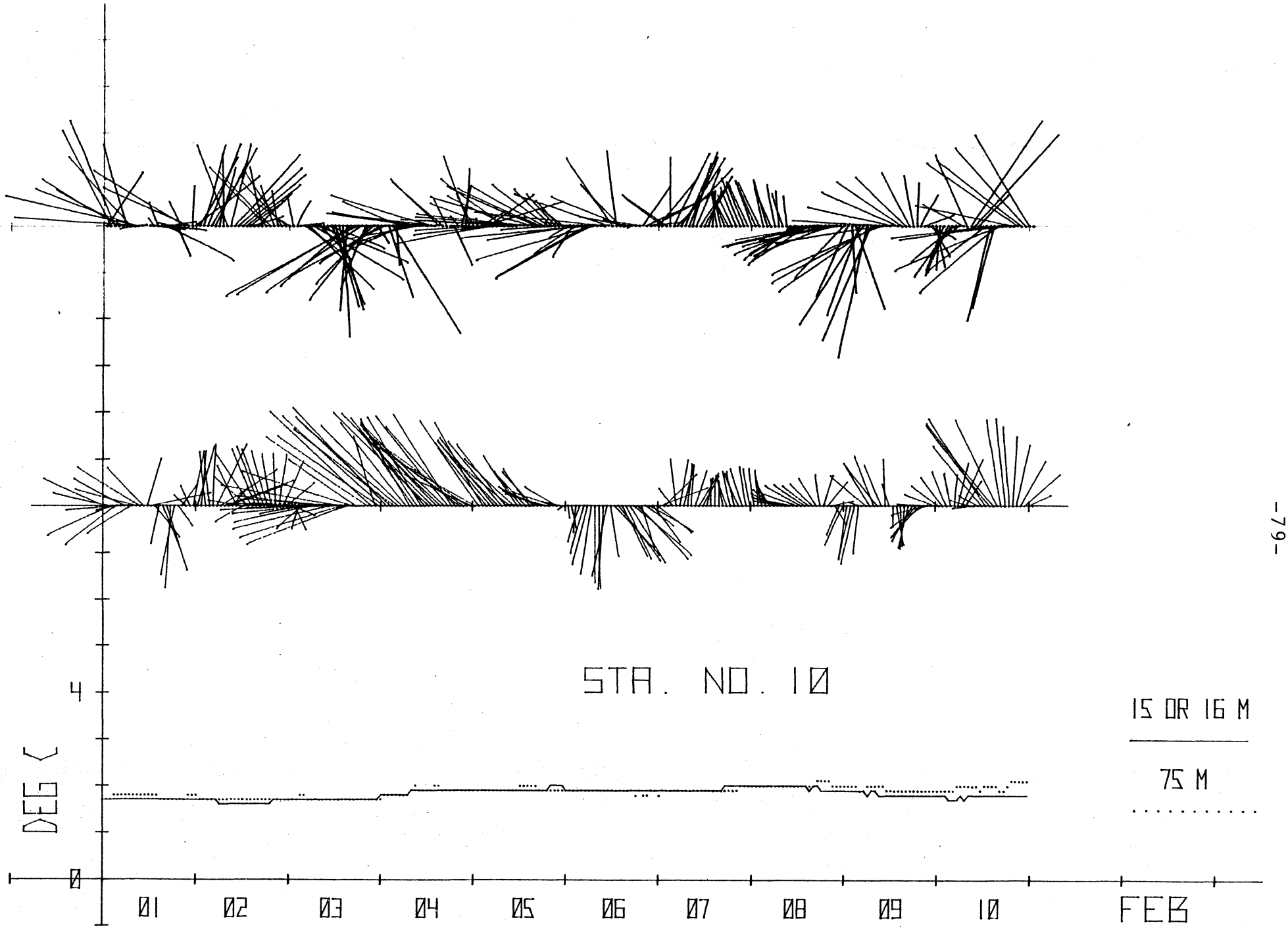
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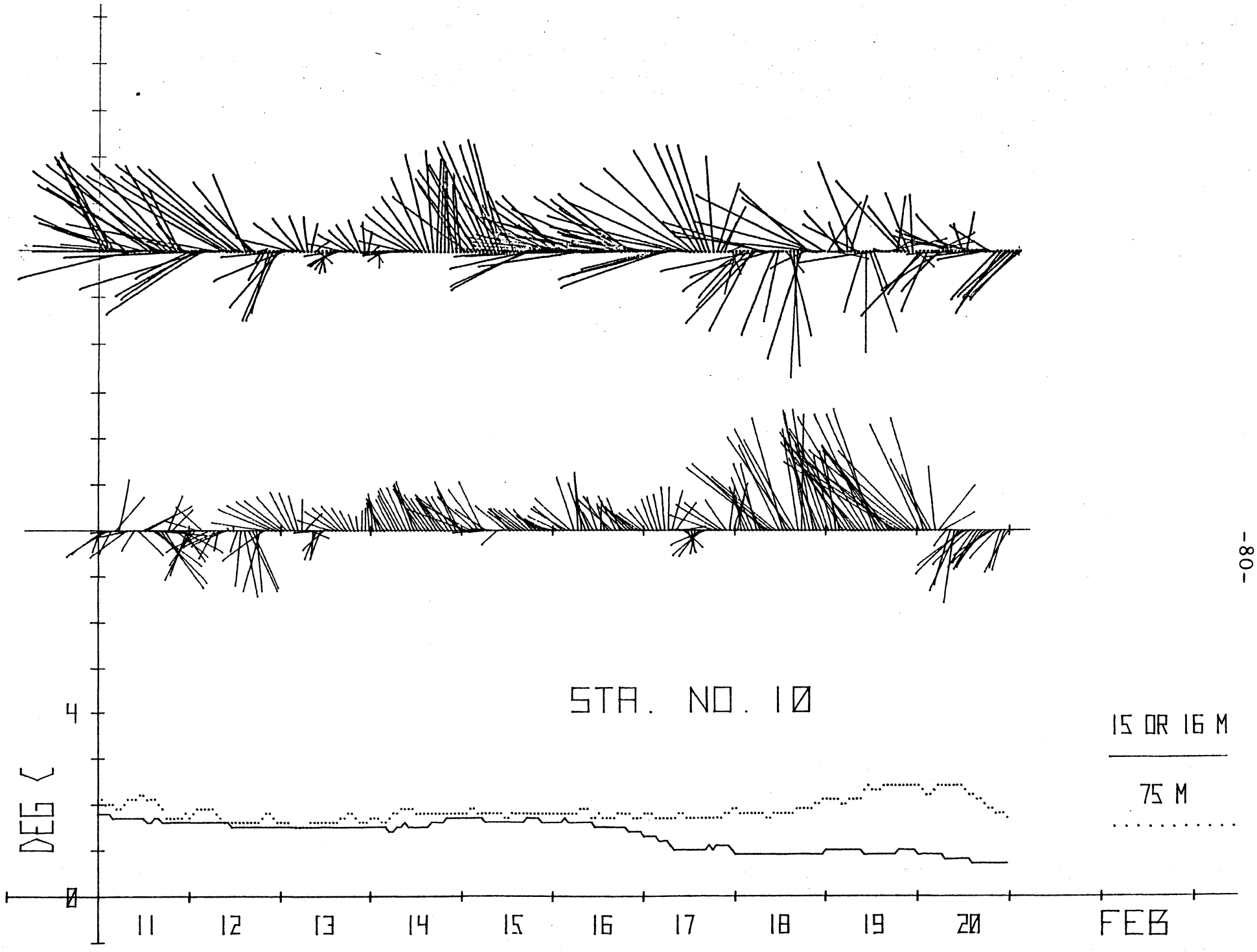
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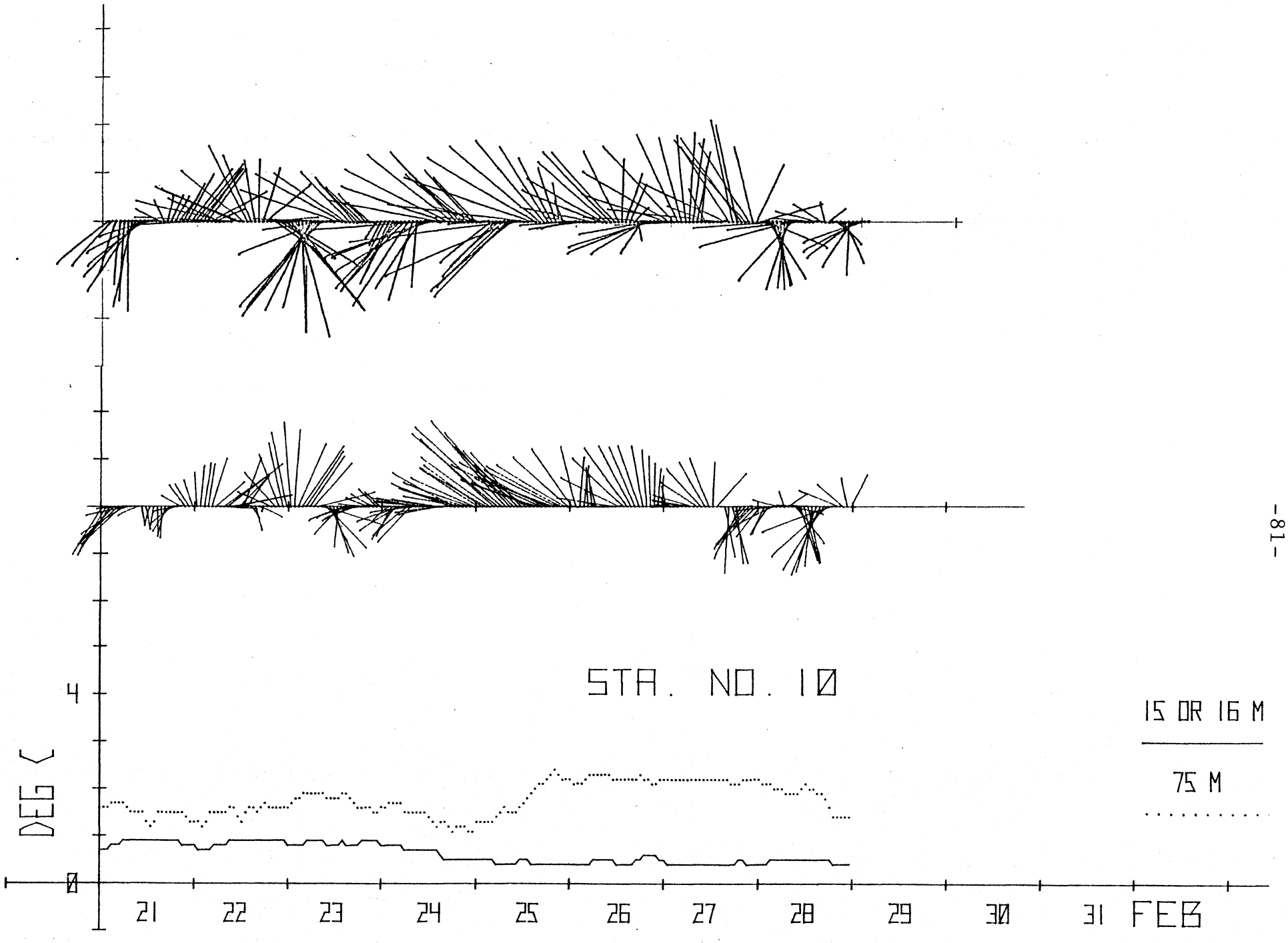
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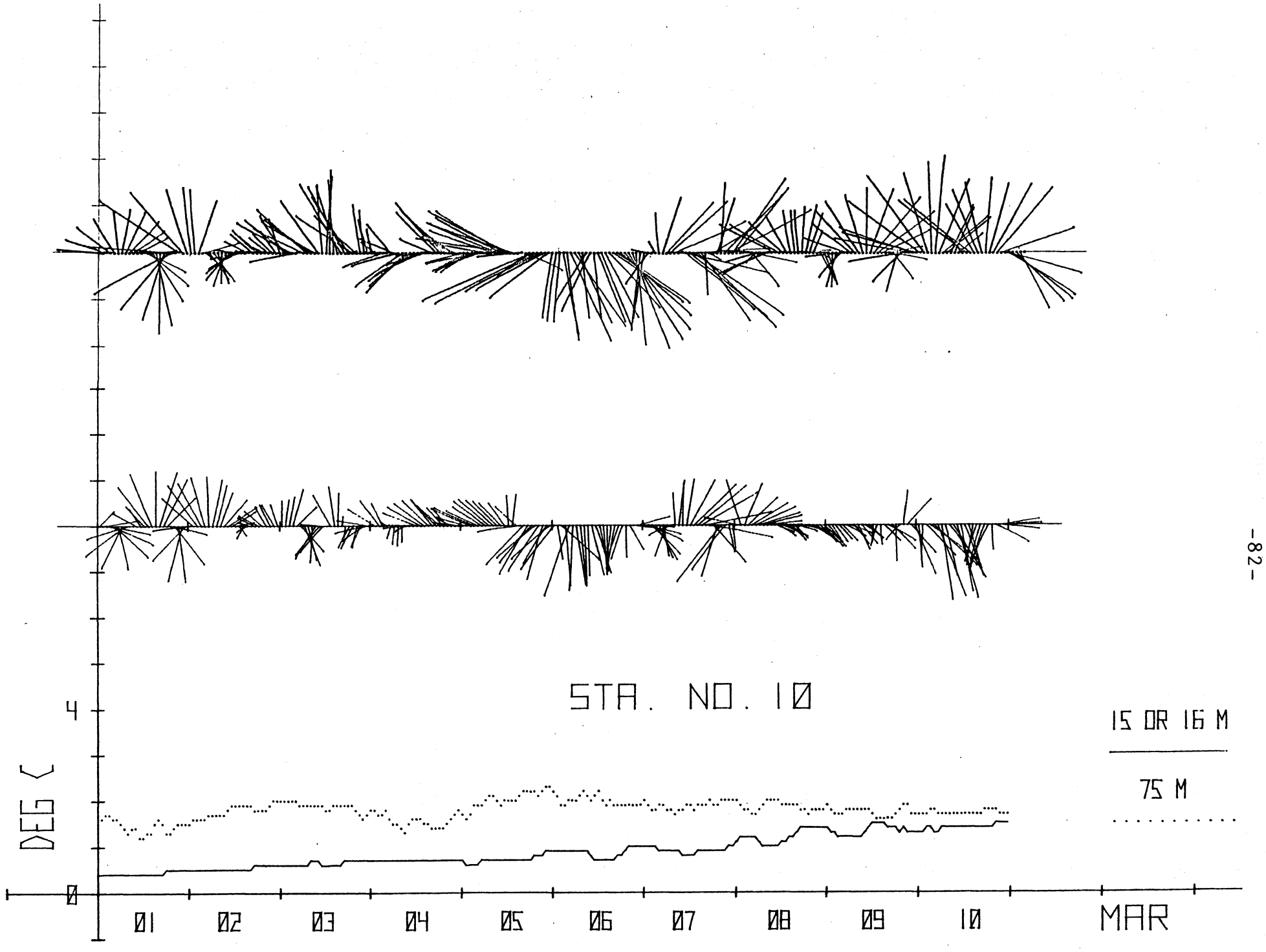
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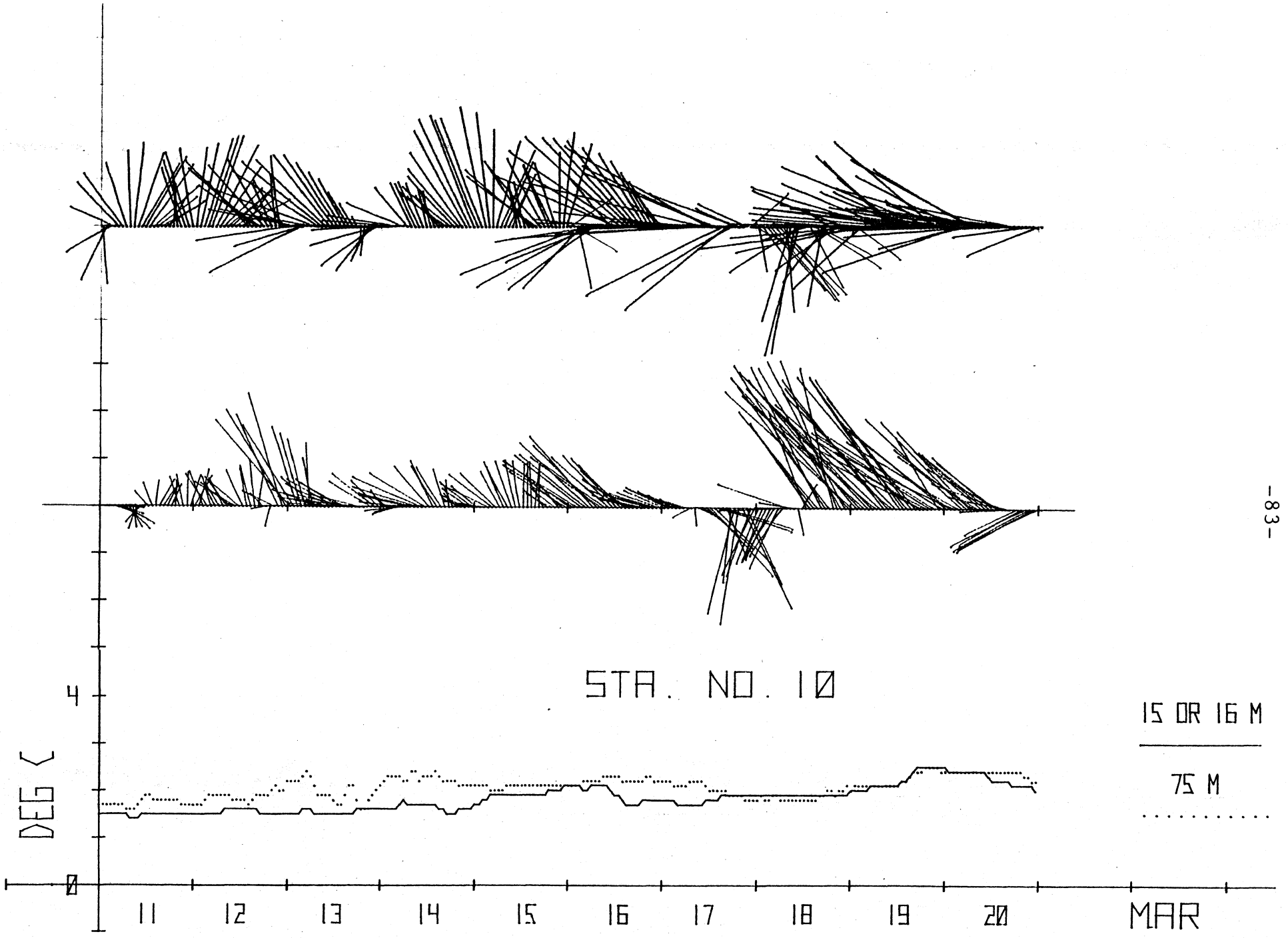
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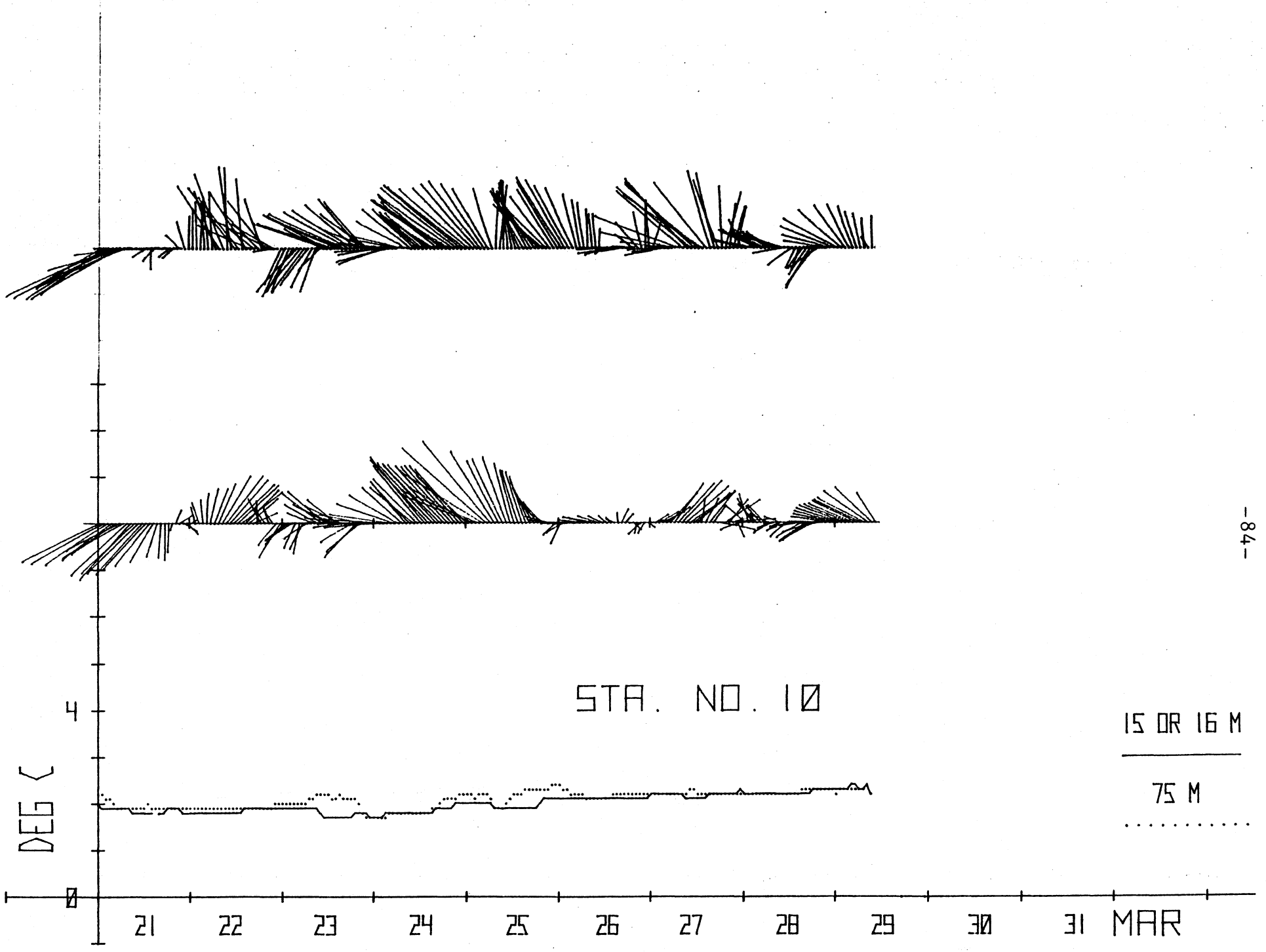
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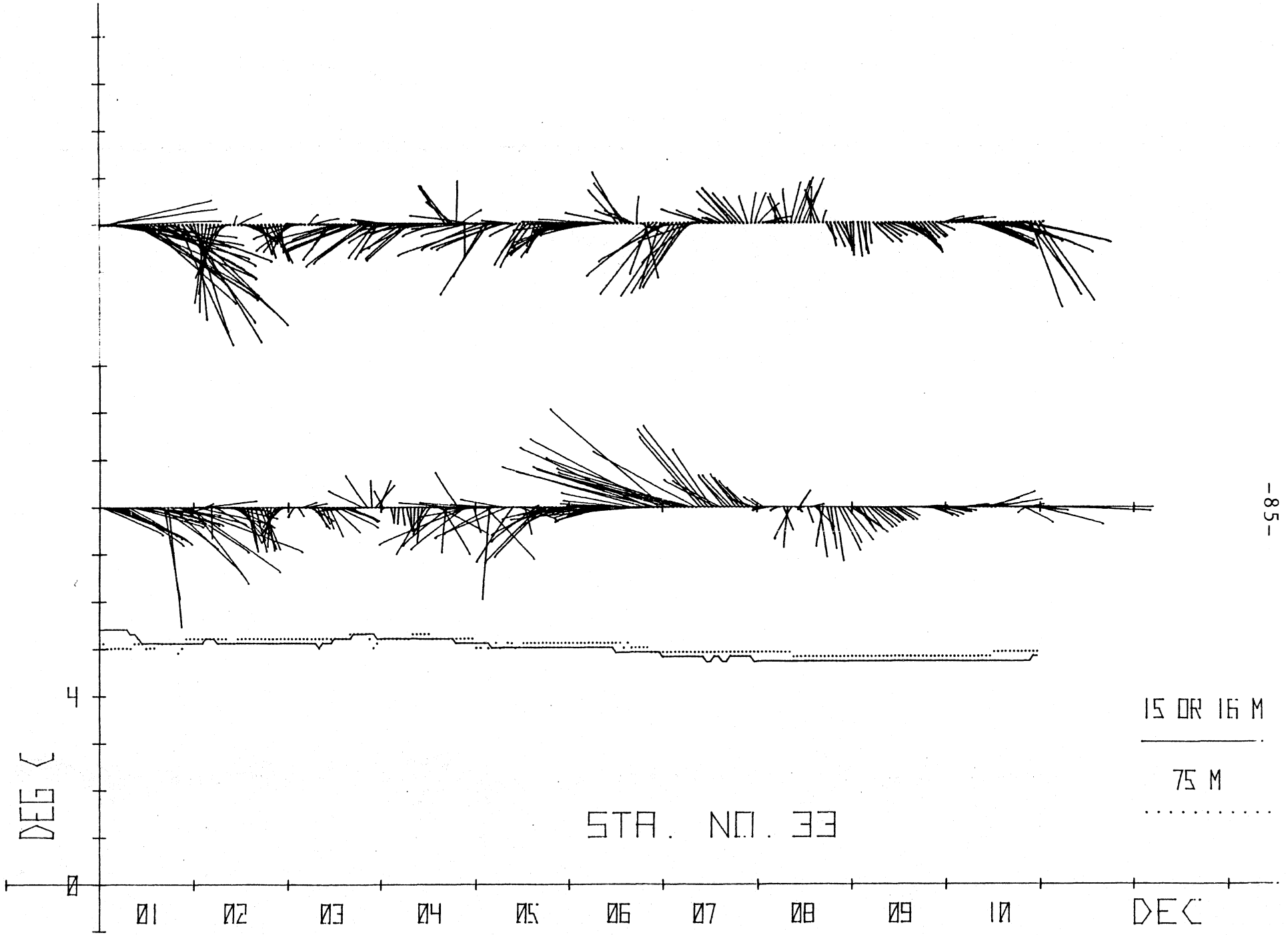
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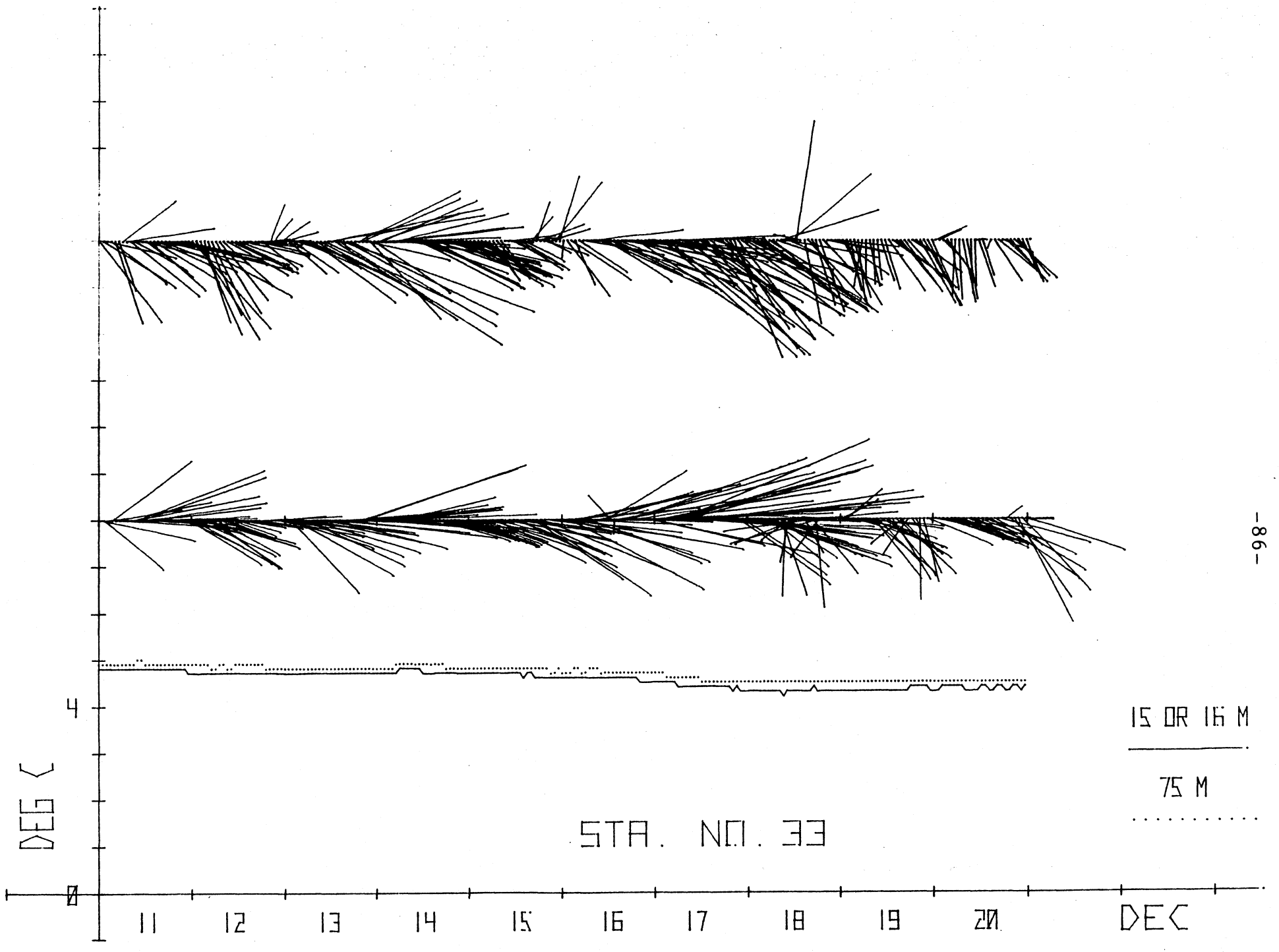
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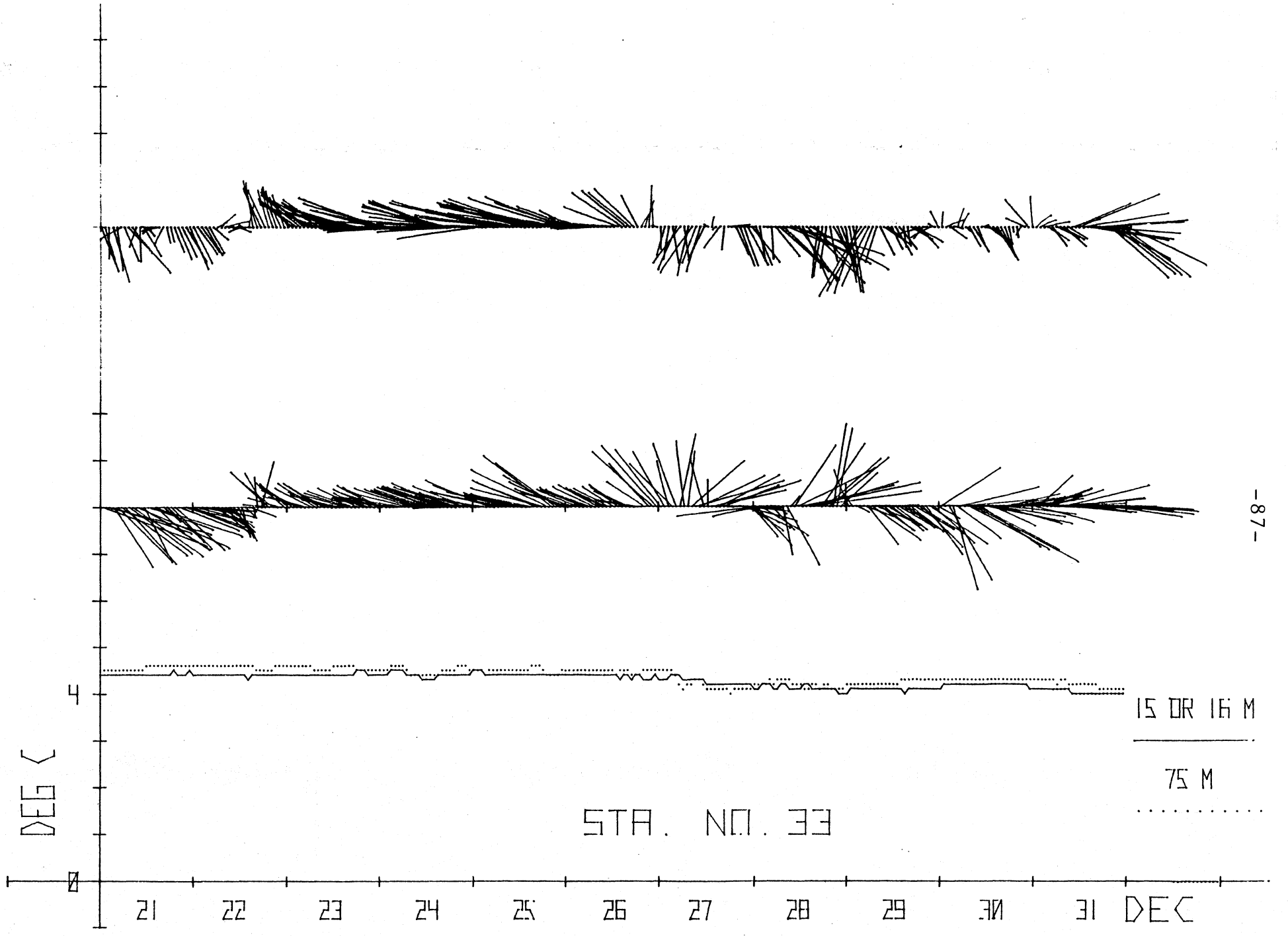
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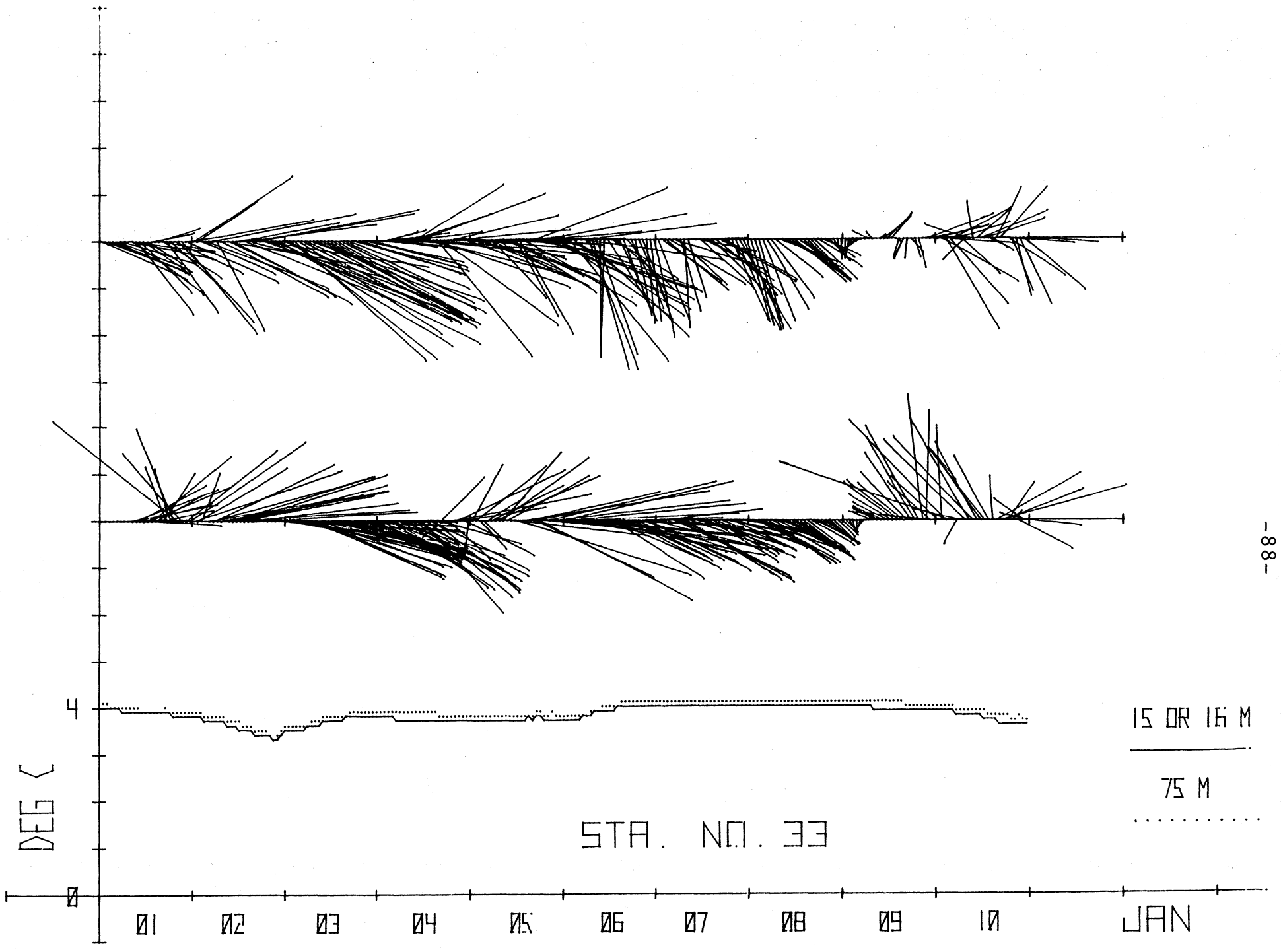
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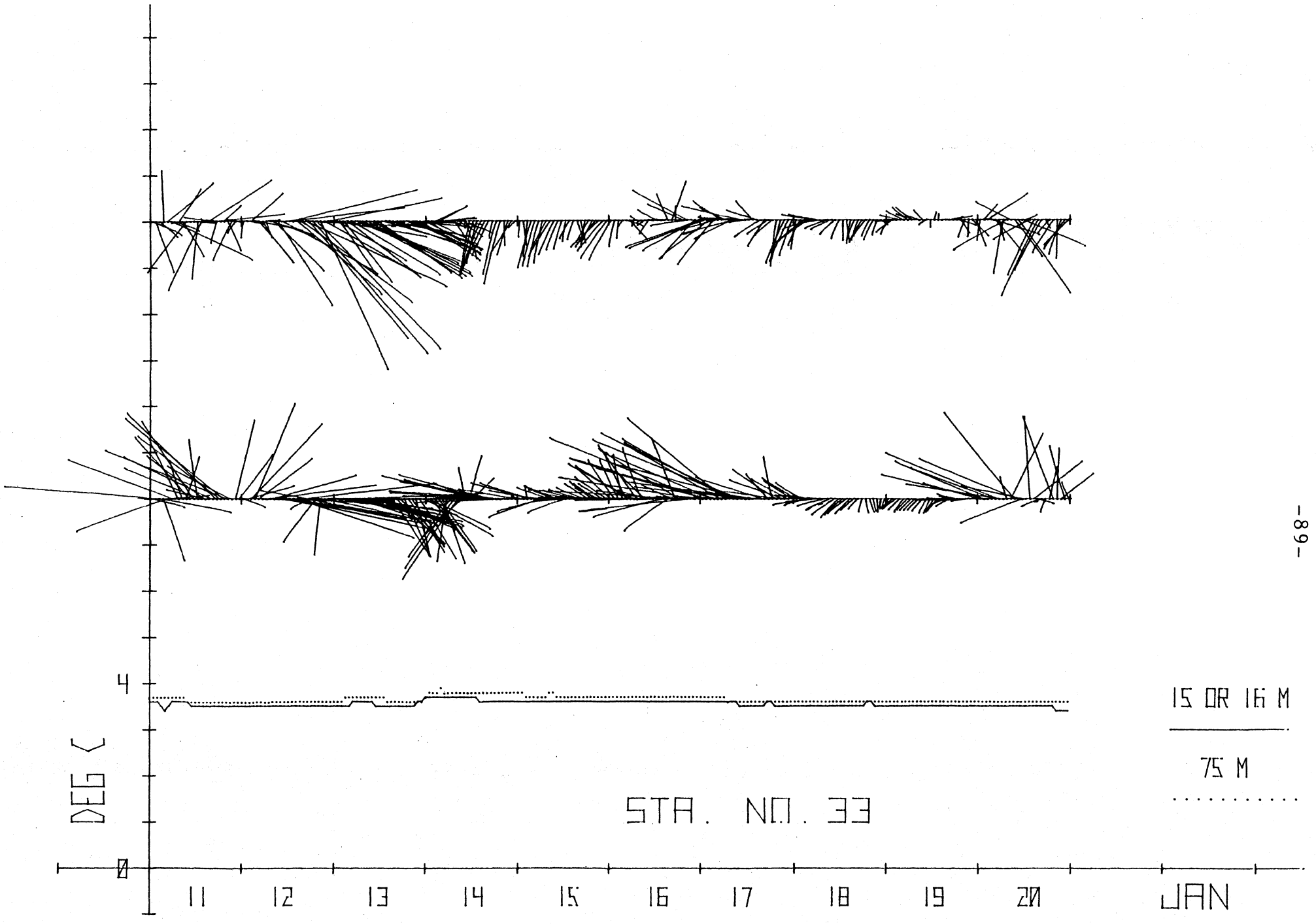
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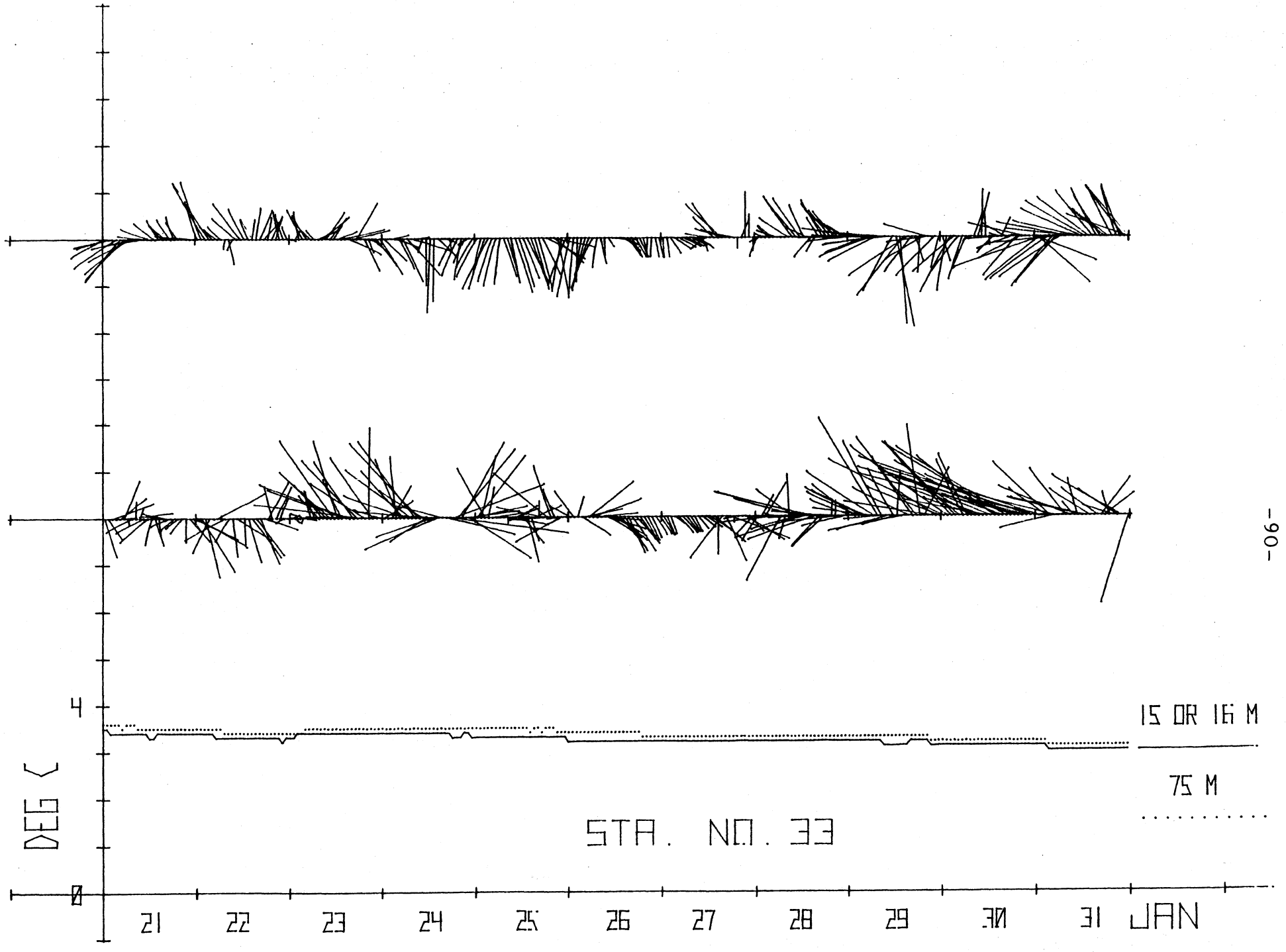
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75 M
STA. NO. 33
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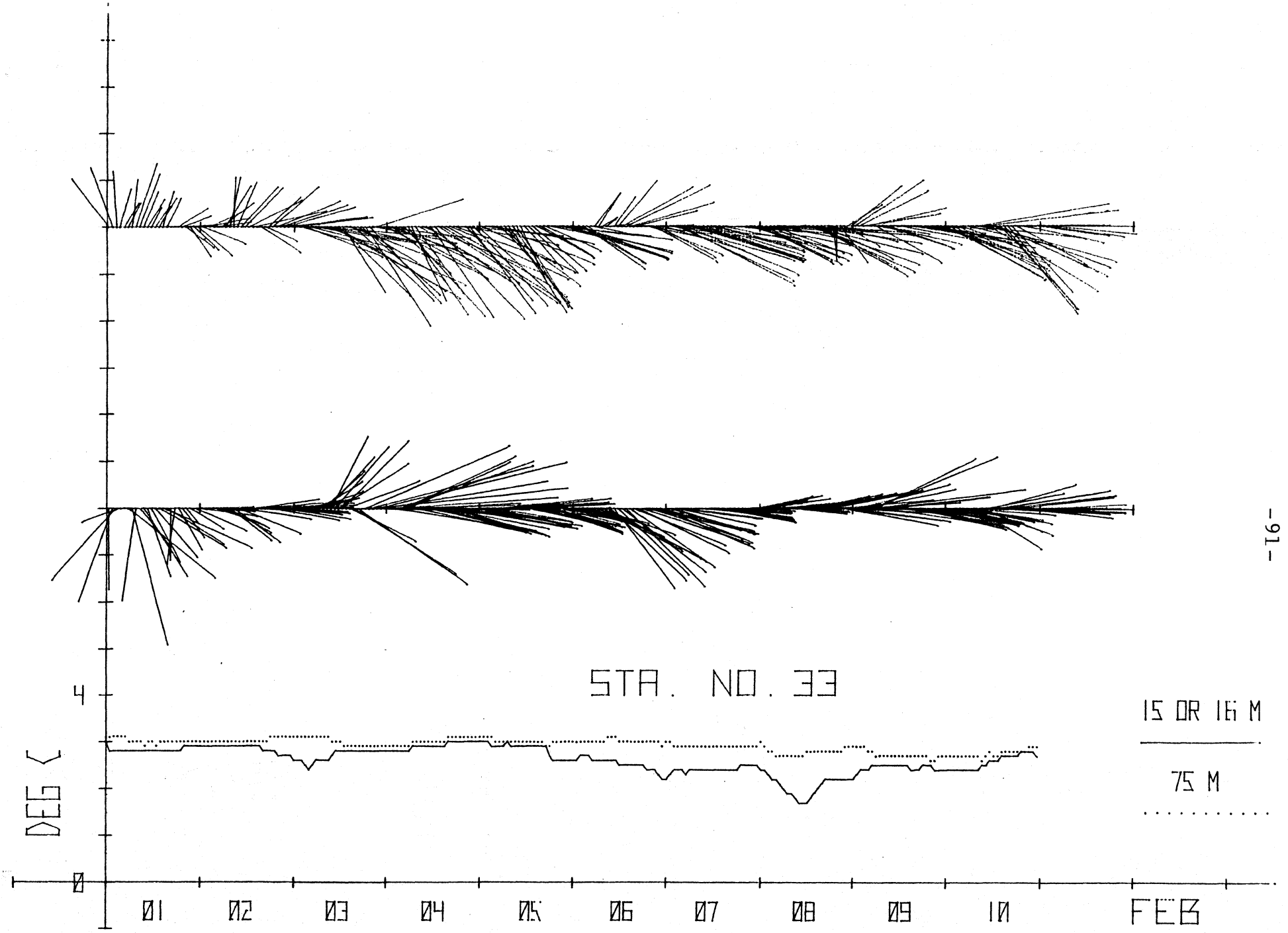
JAN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DEG C
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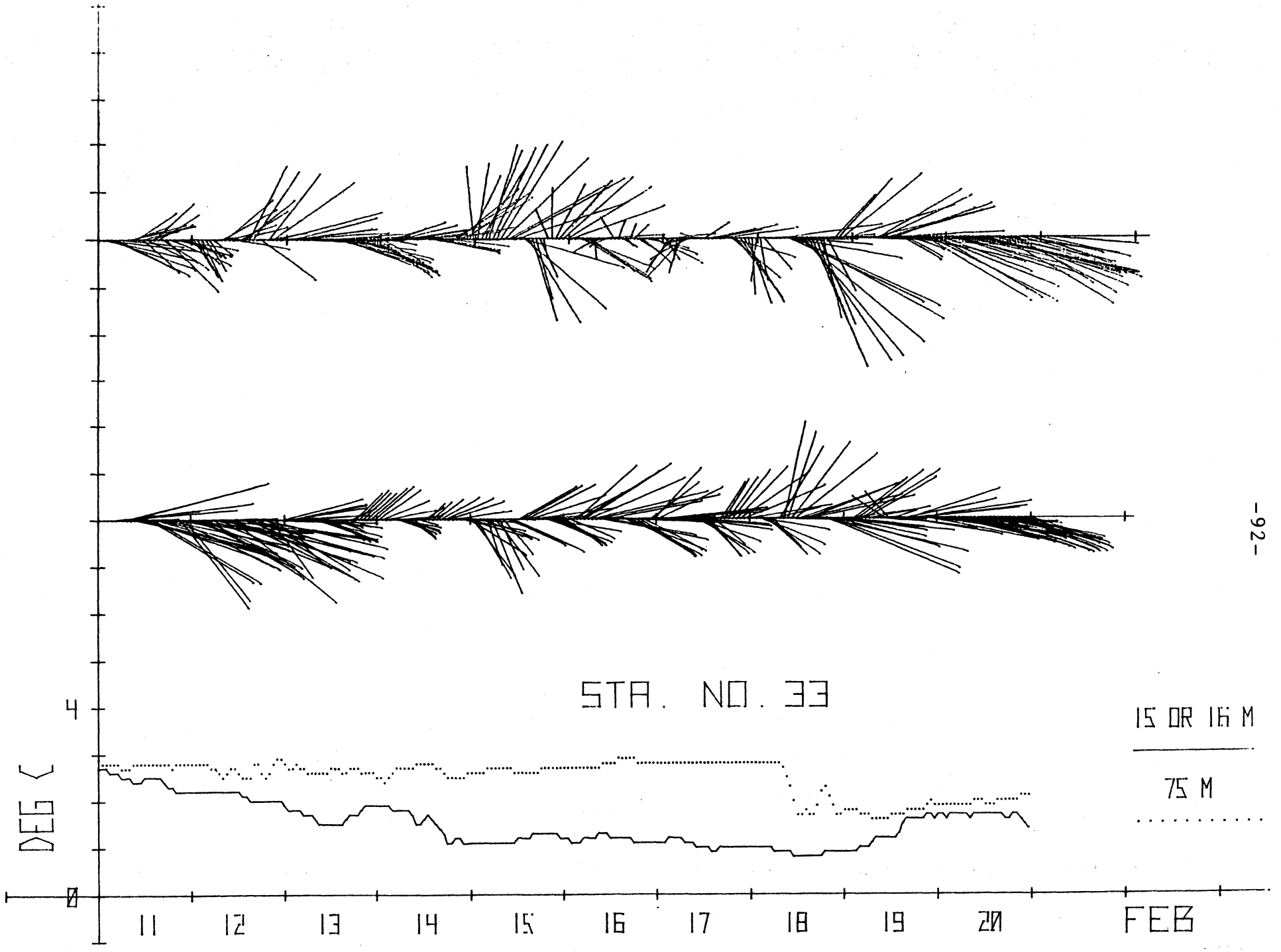
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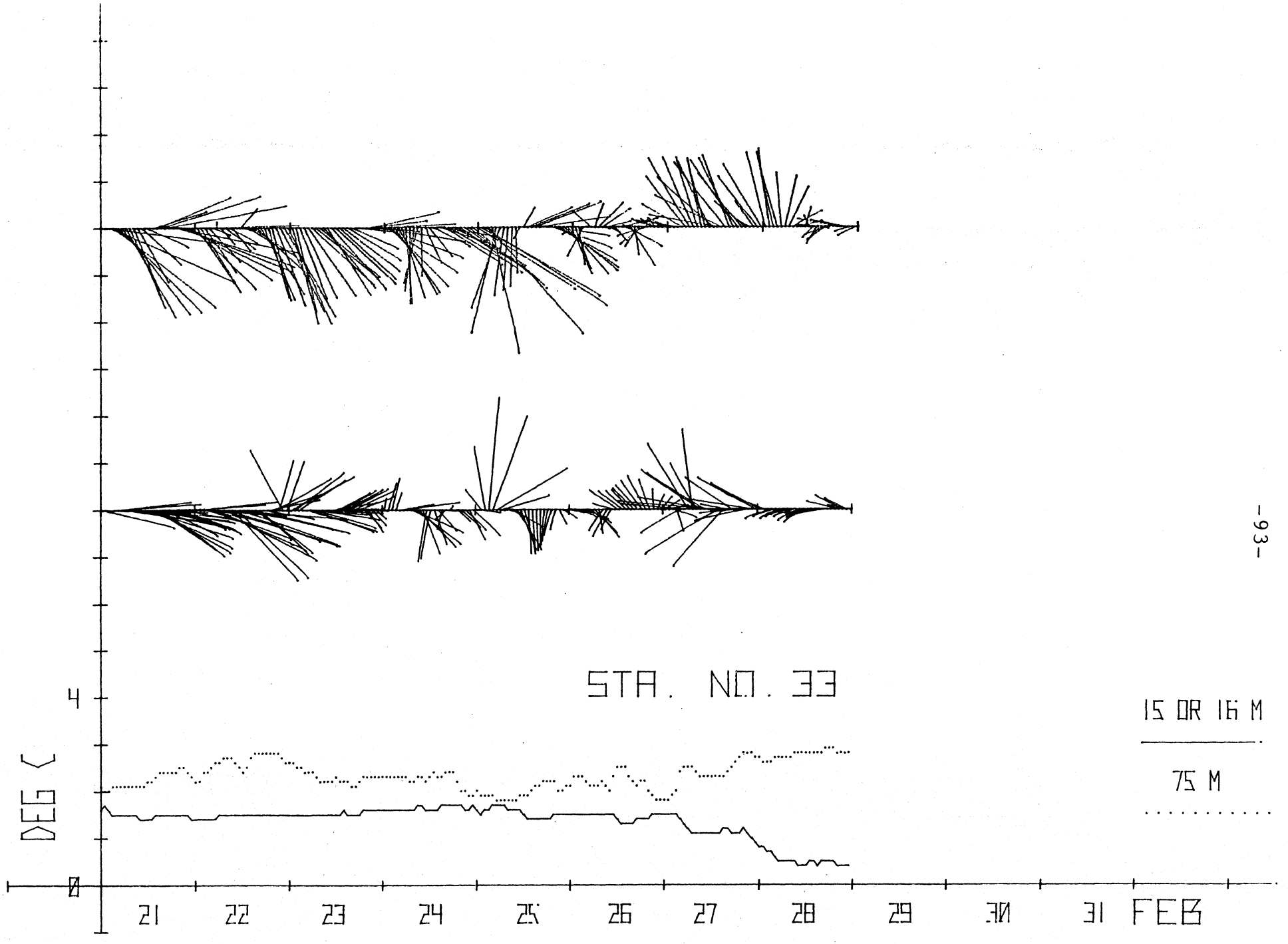
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75 M
DEG C
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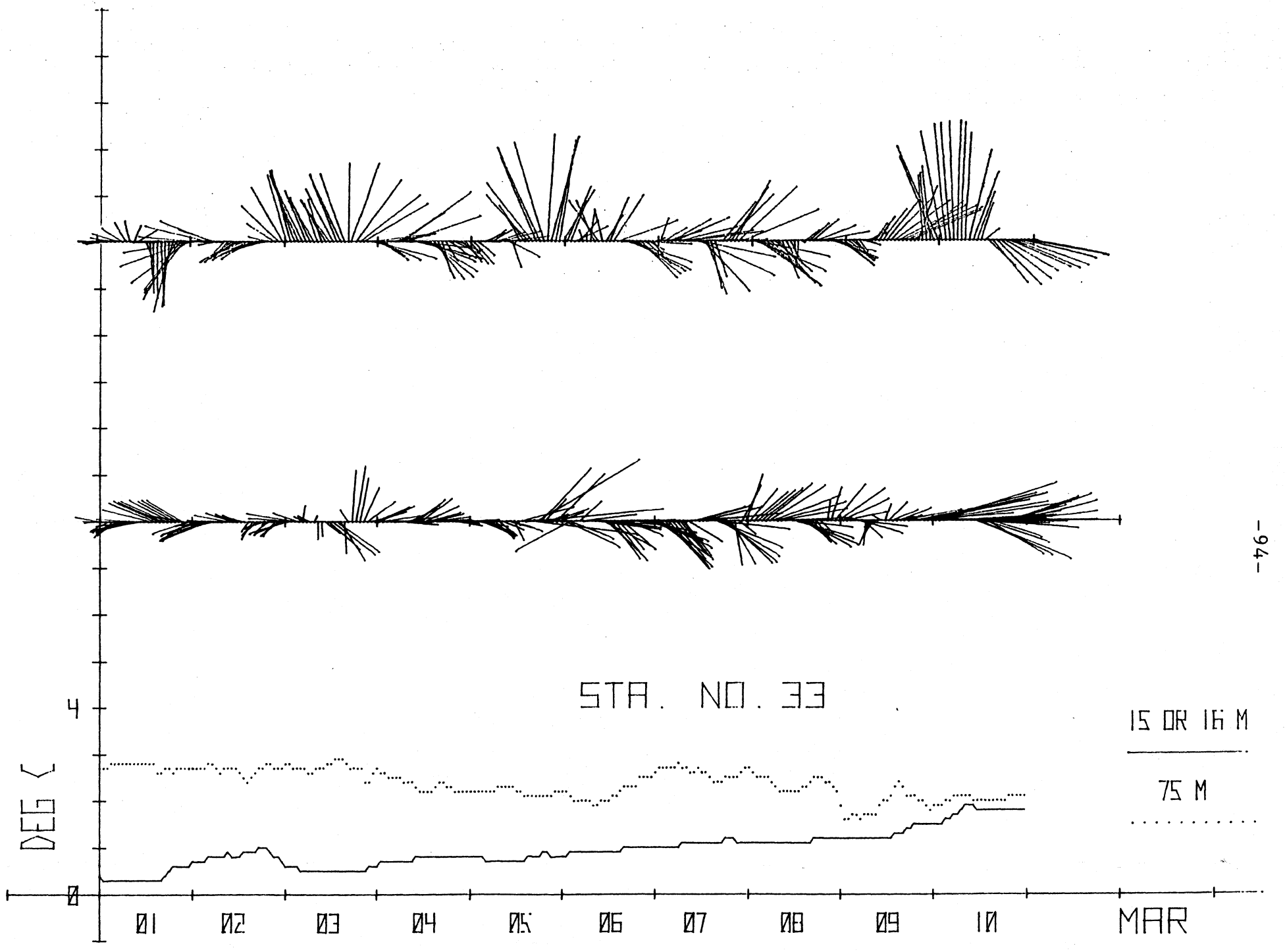
FEB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75 M
DEG C
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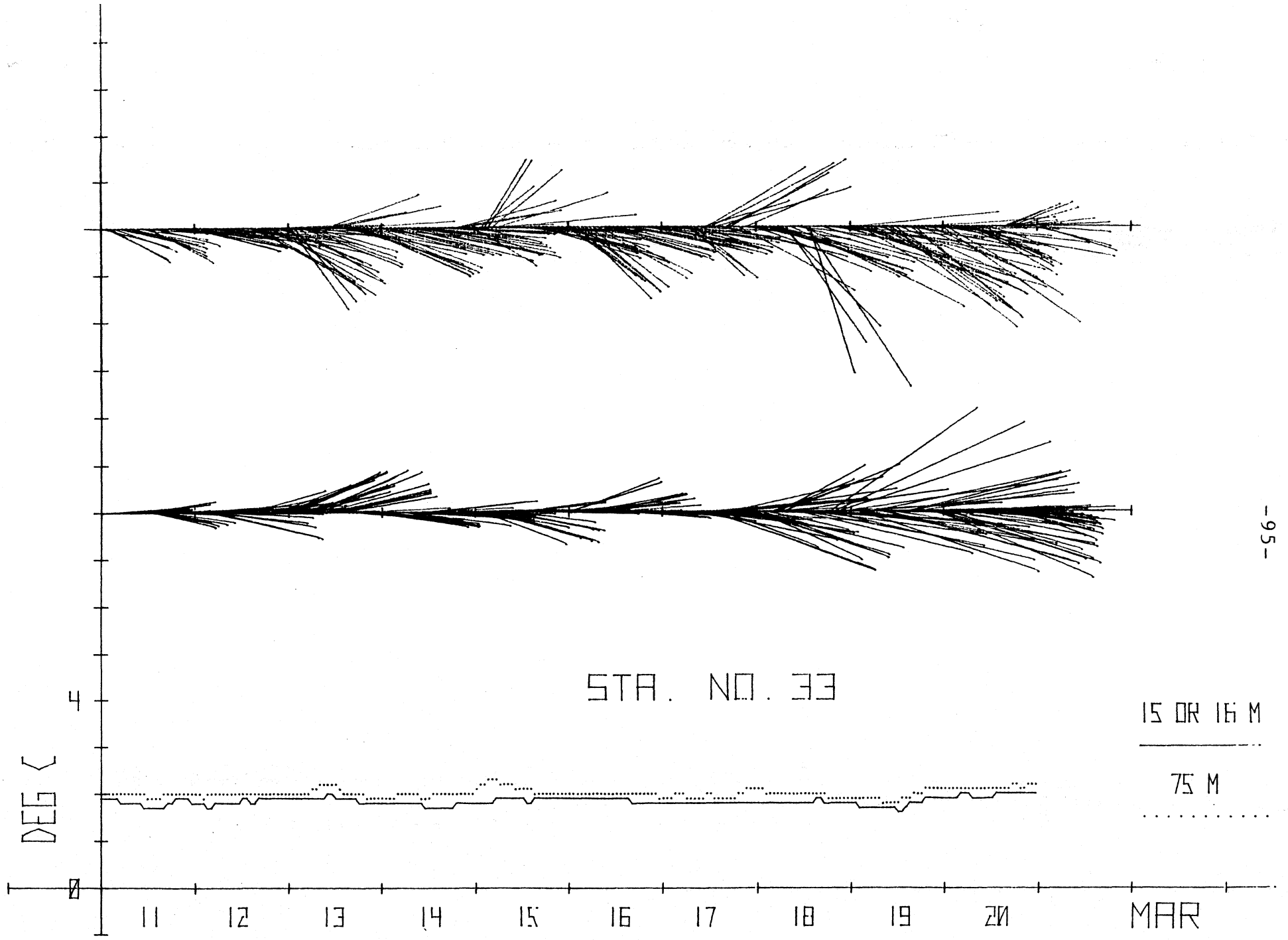
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15 OR 16 M
75 M
DEG C
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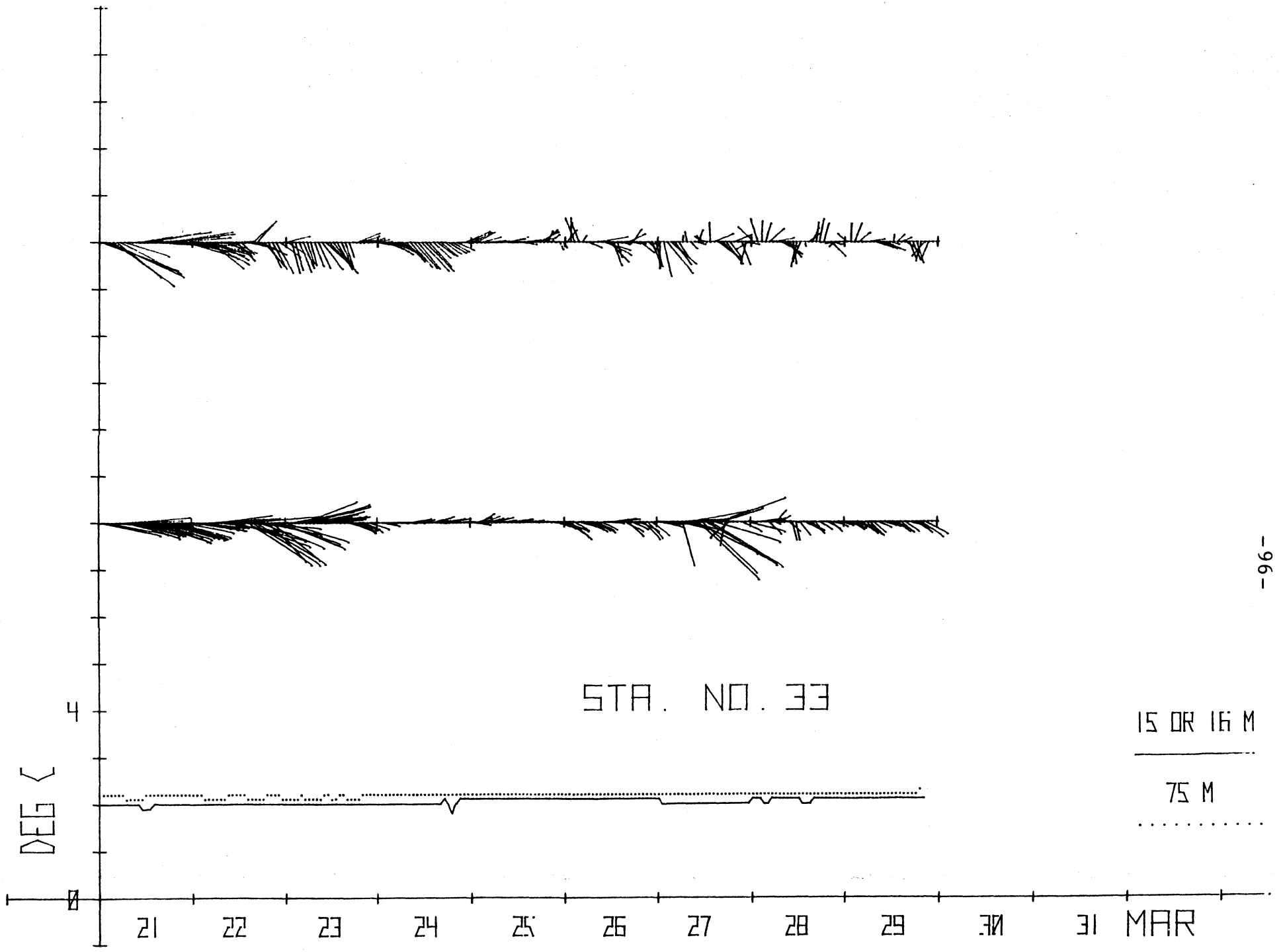
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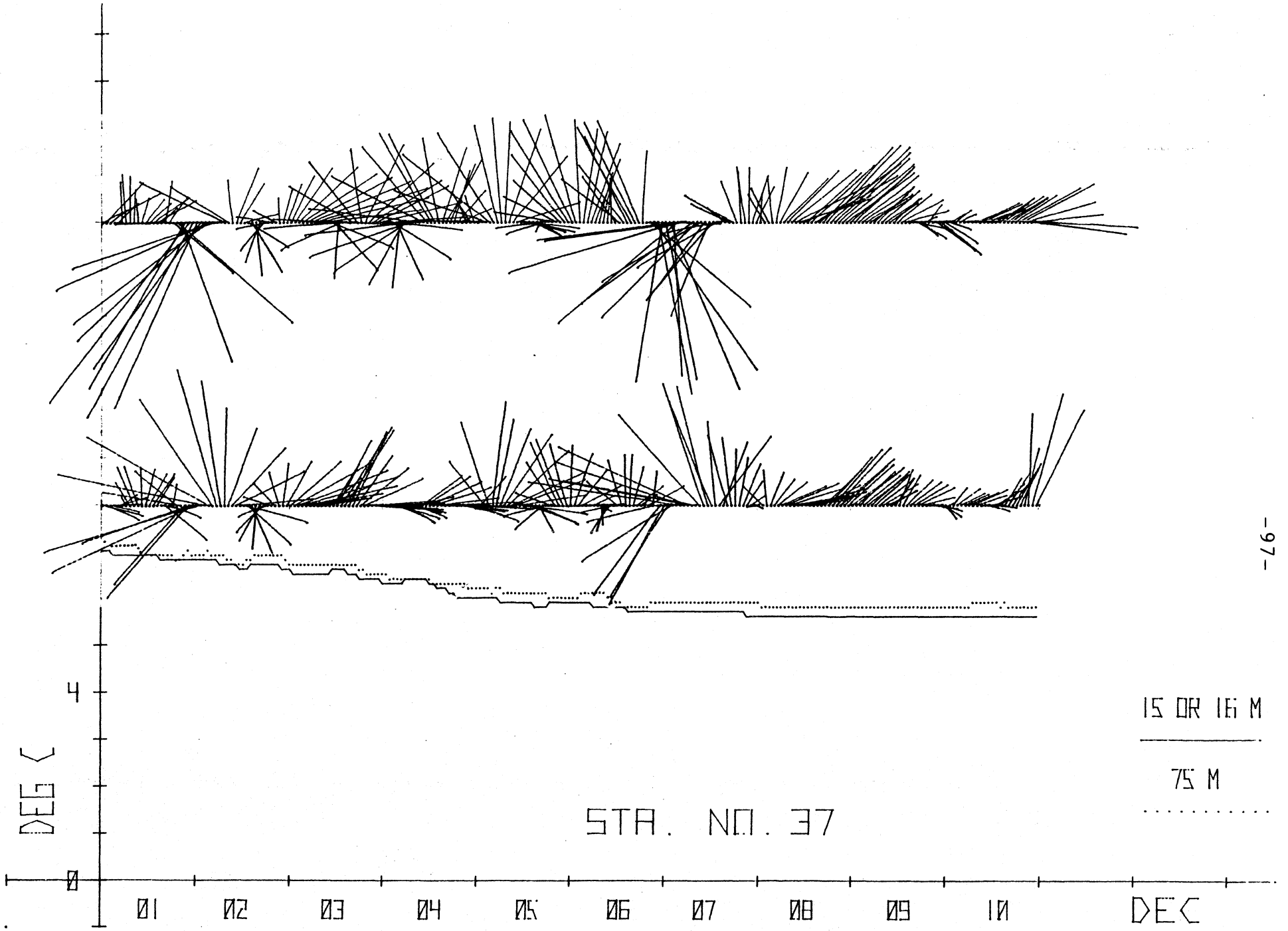
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DEC
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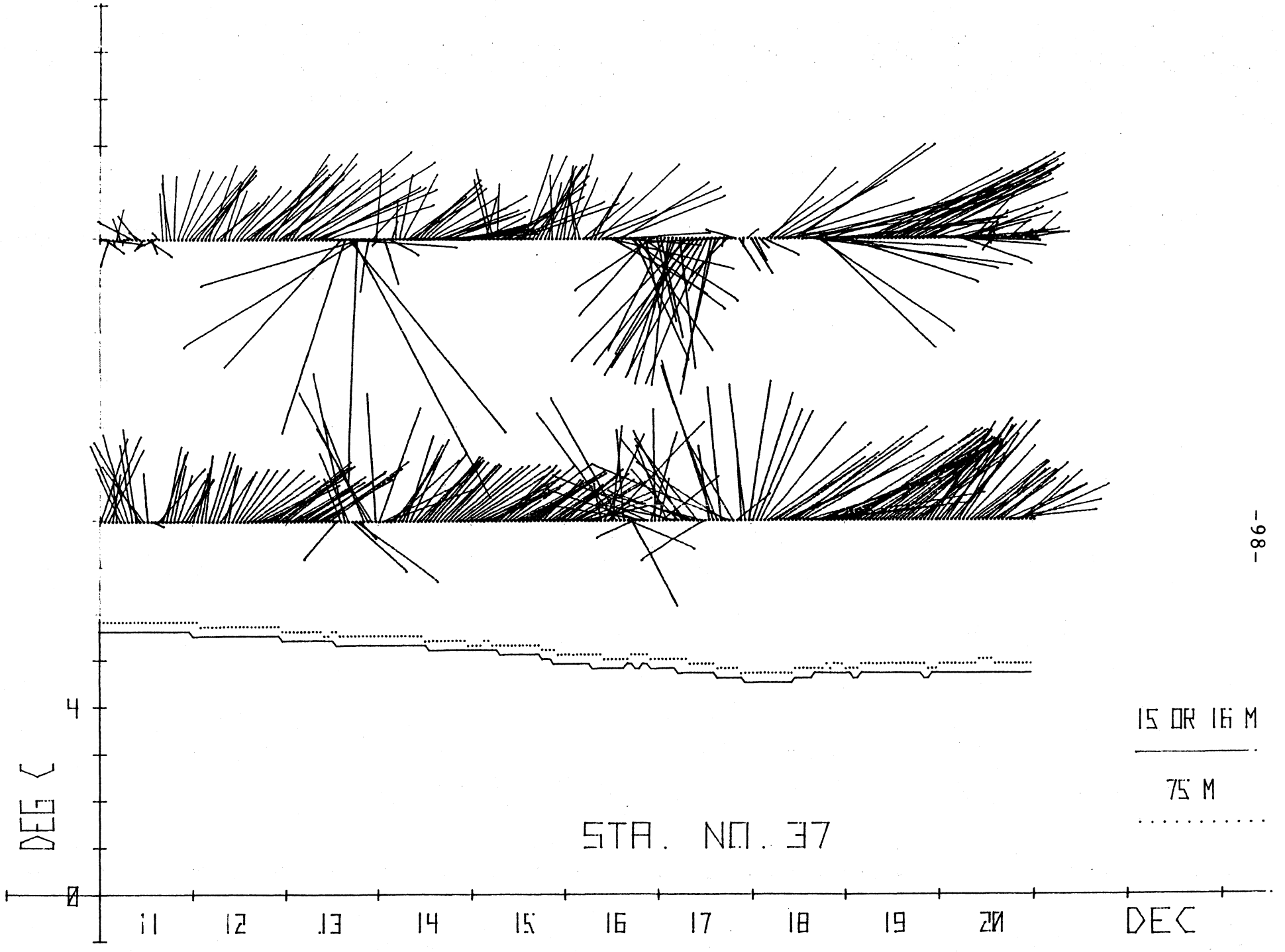
75 M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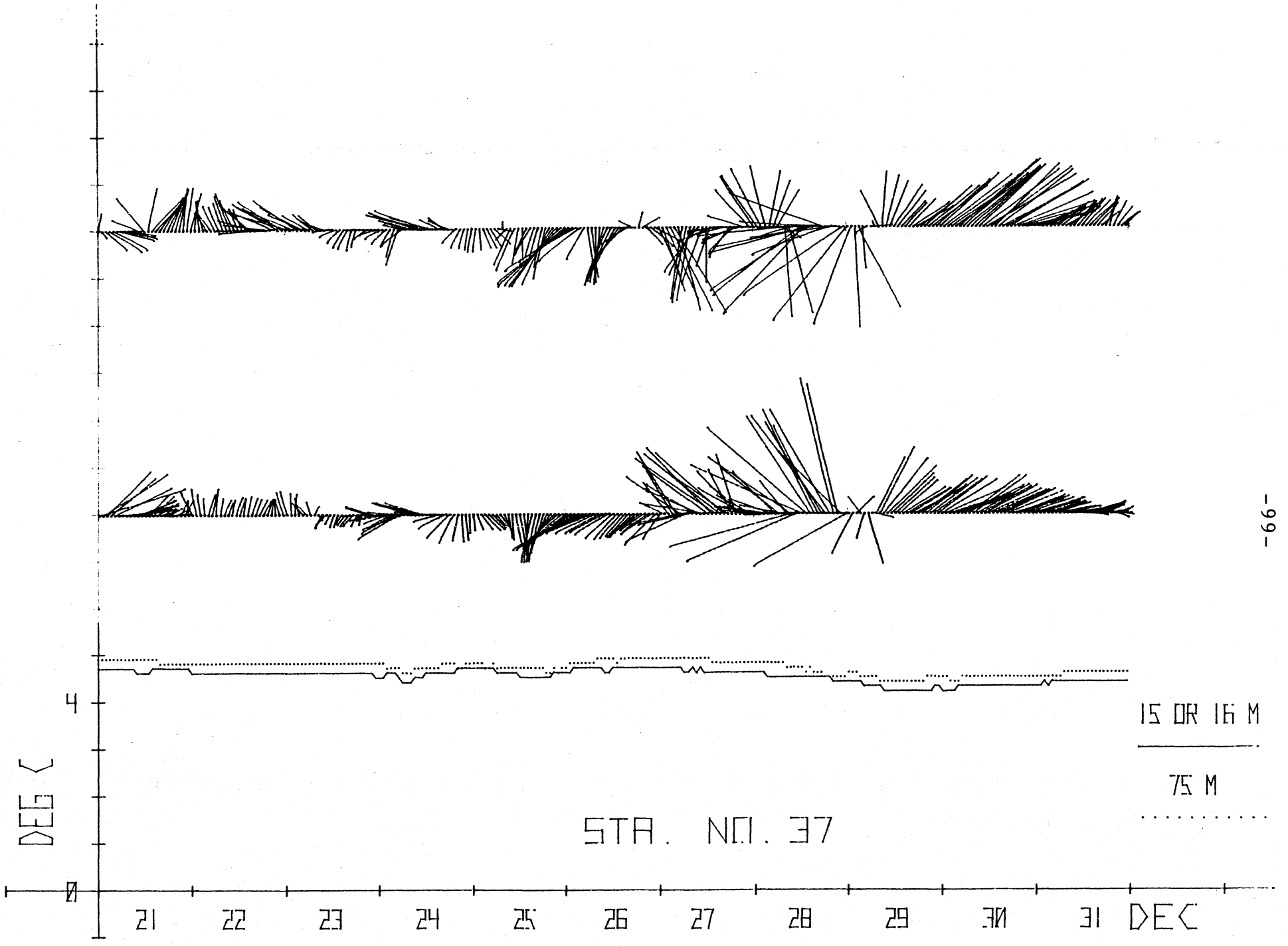
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75 M
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DEG C
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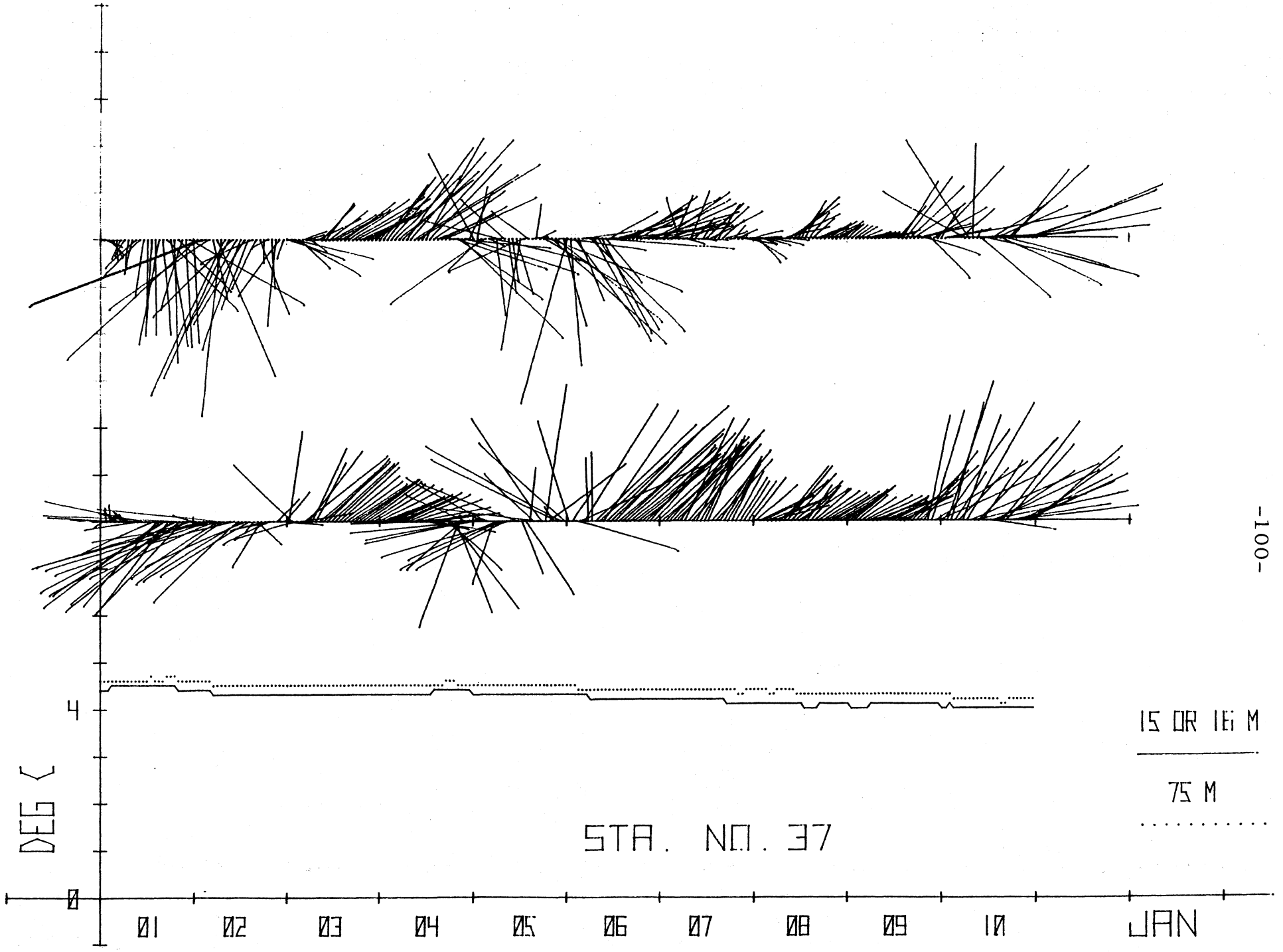
DEC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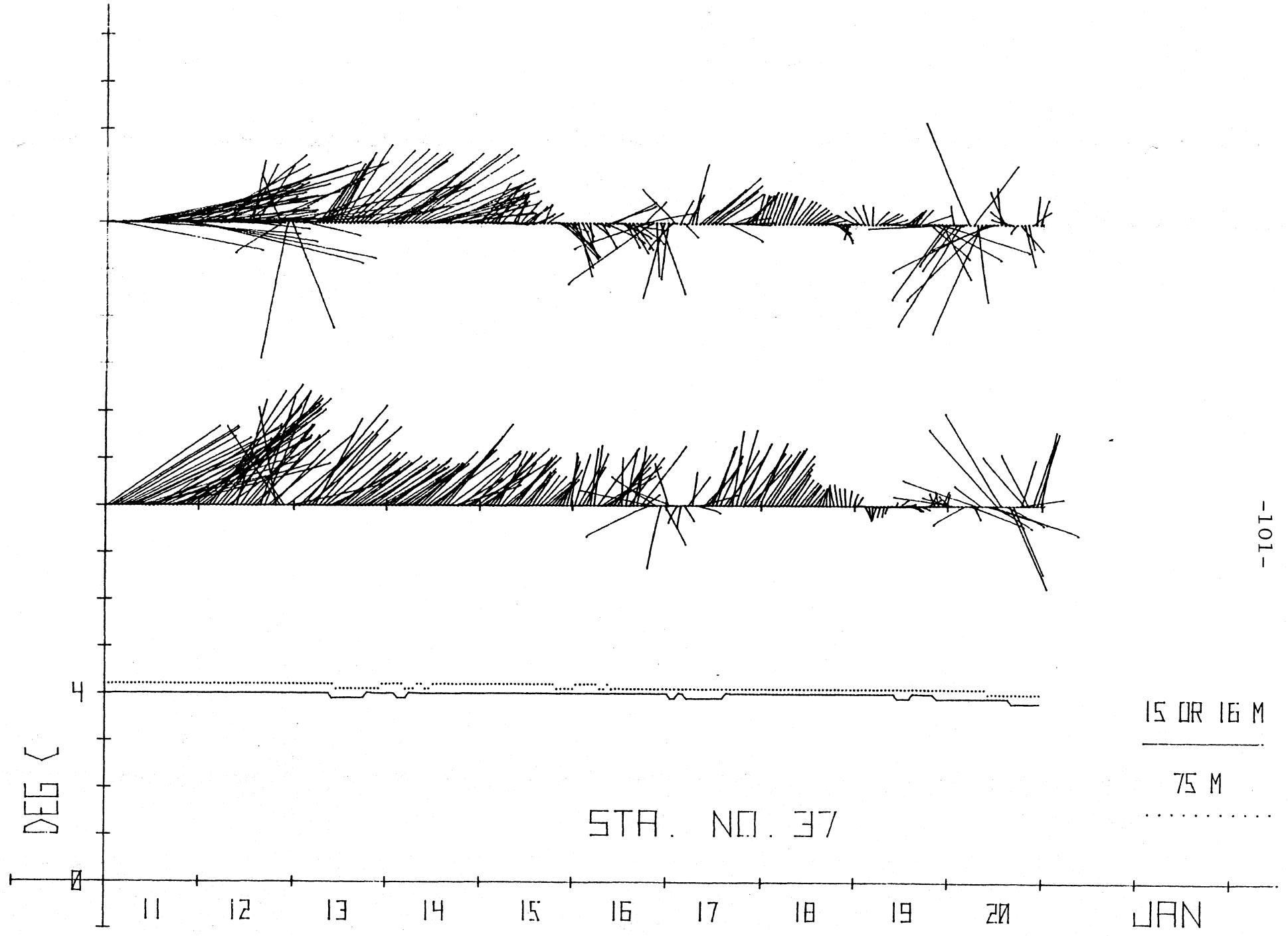
75 M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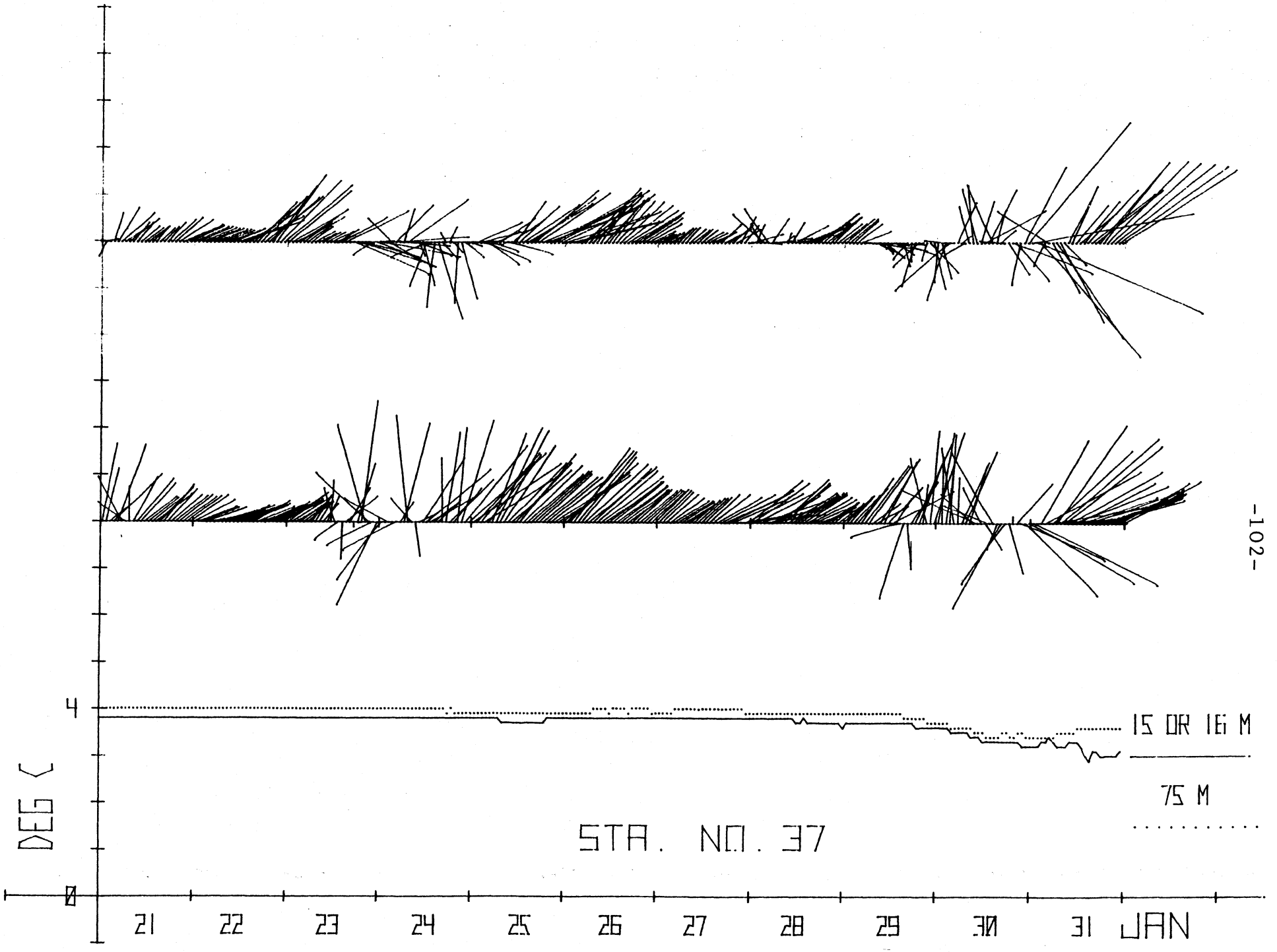
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75 M
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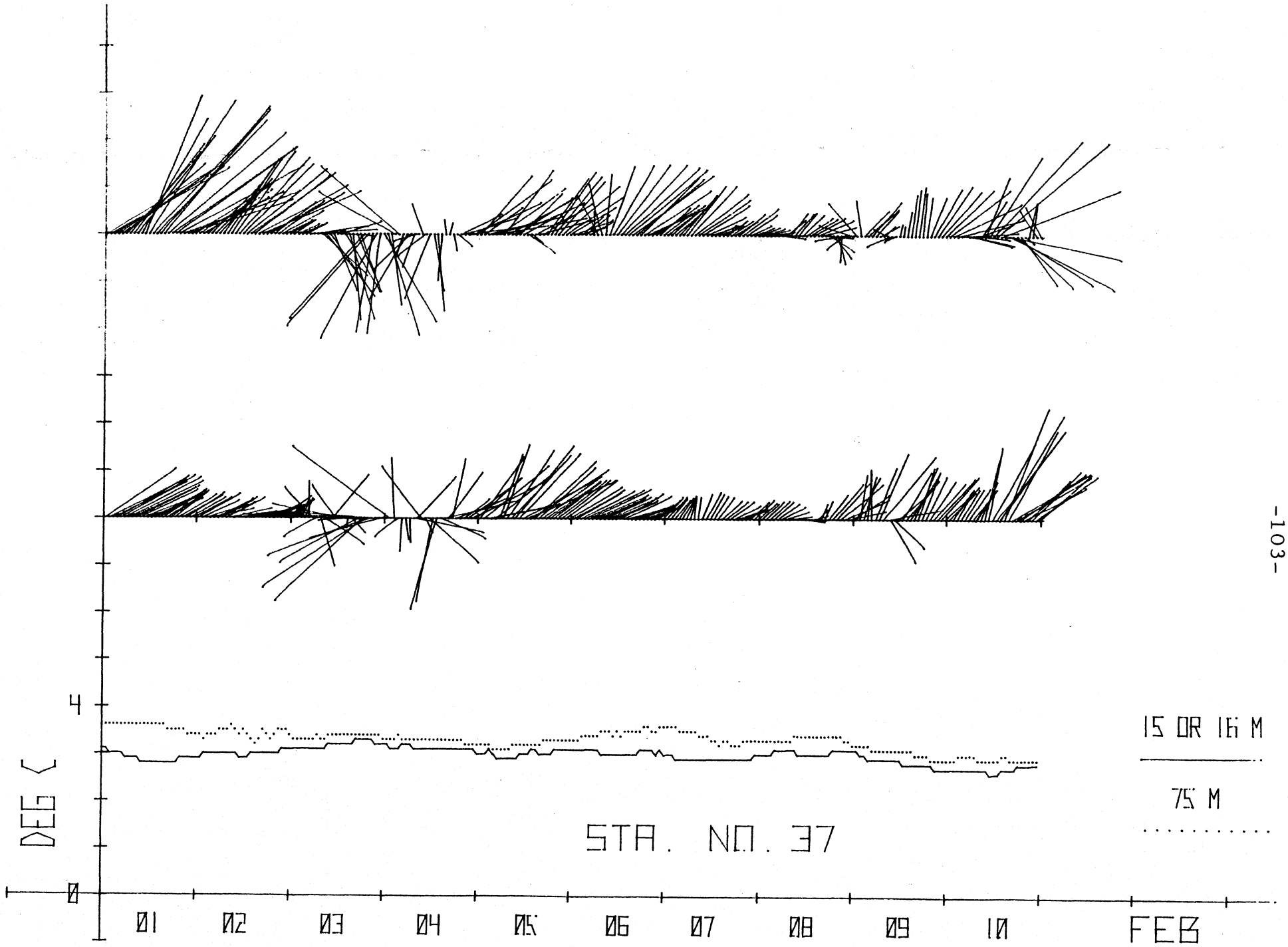
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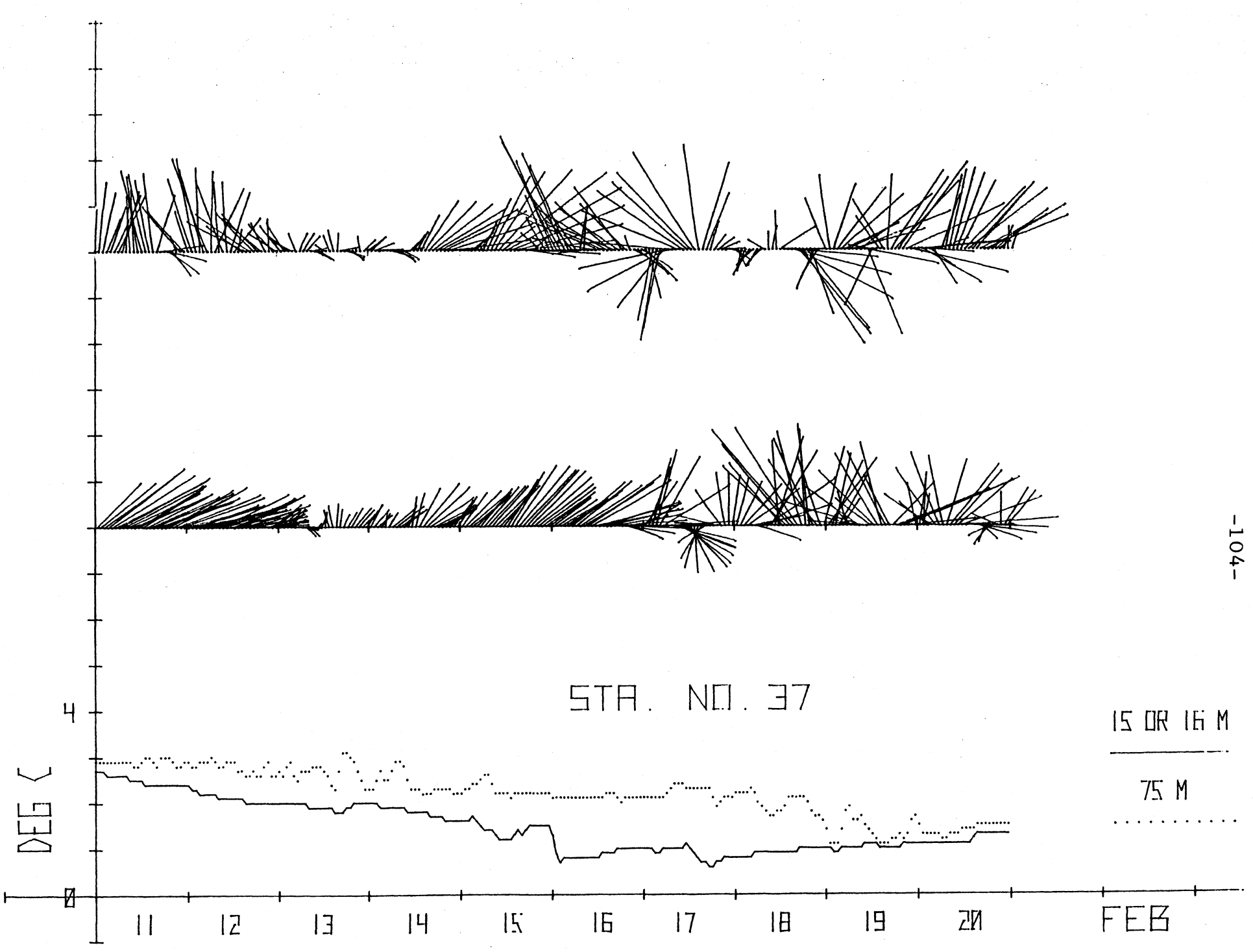
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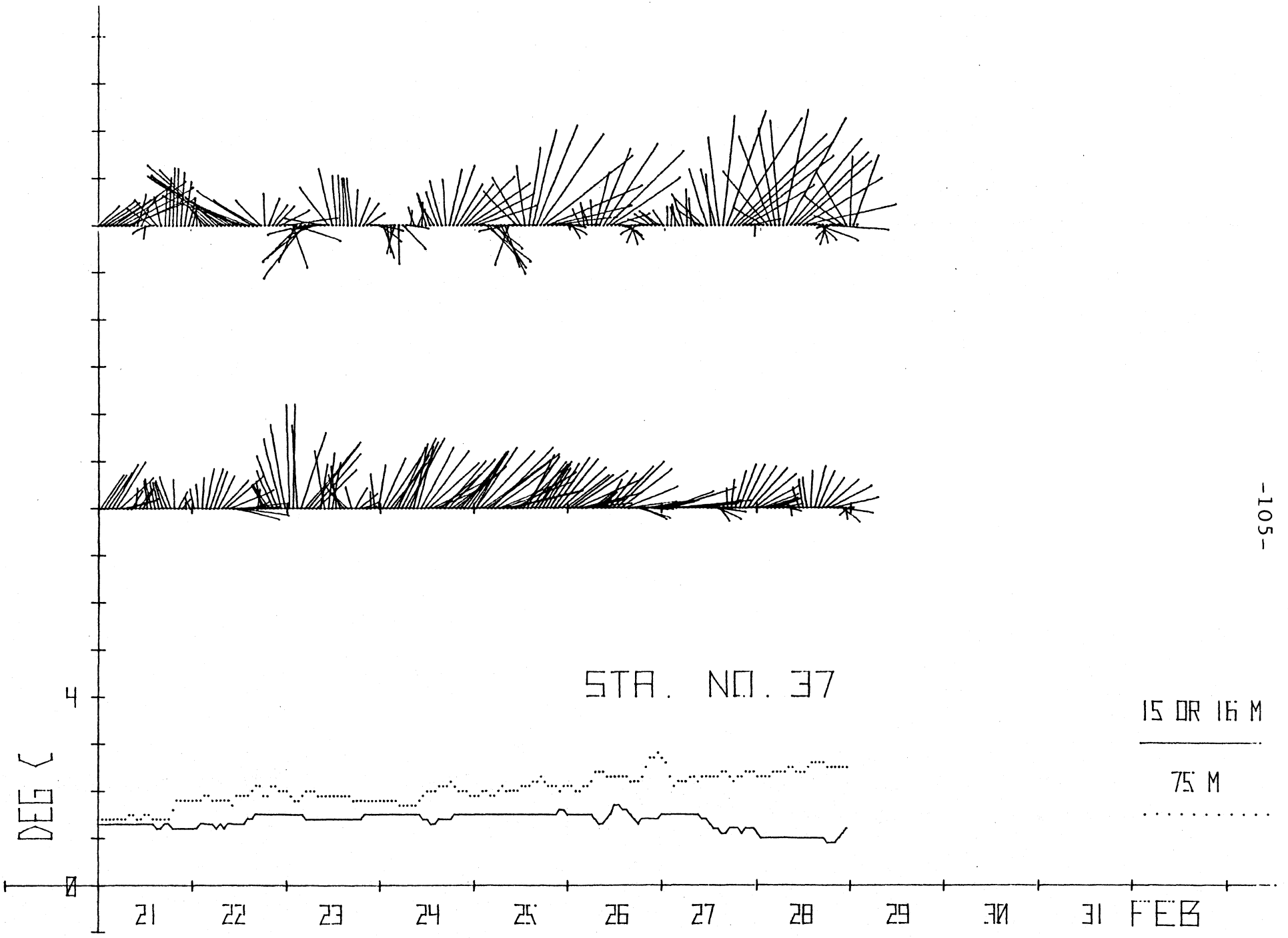
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DEG C
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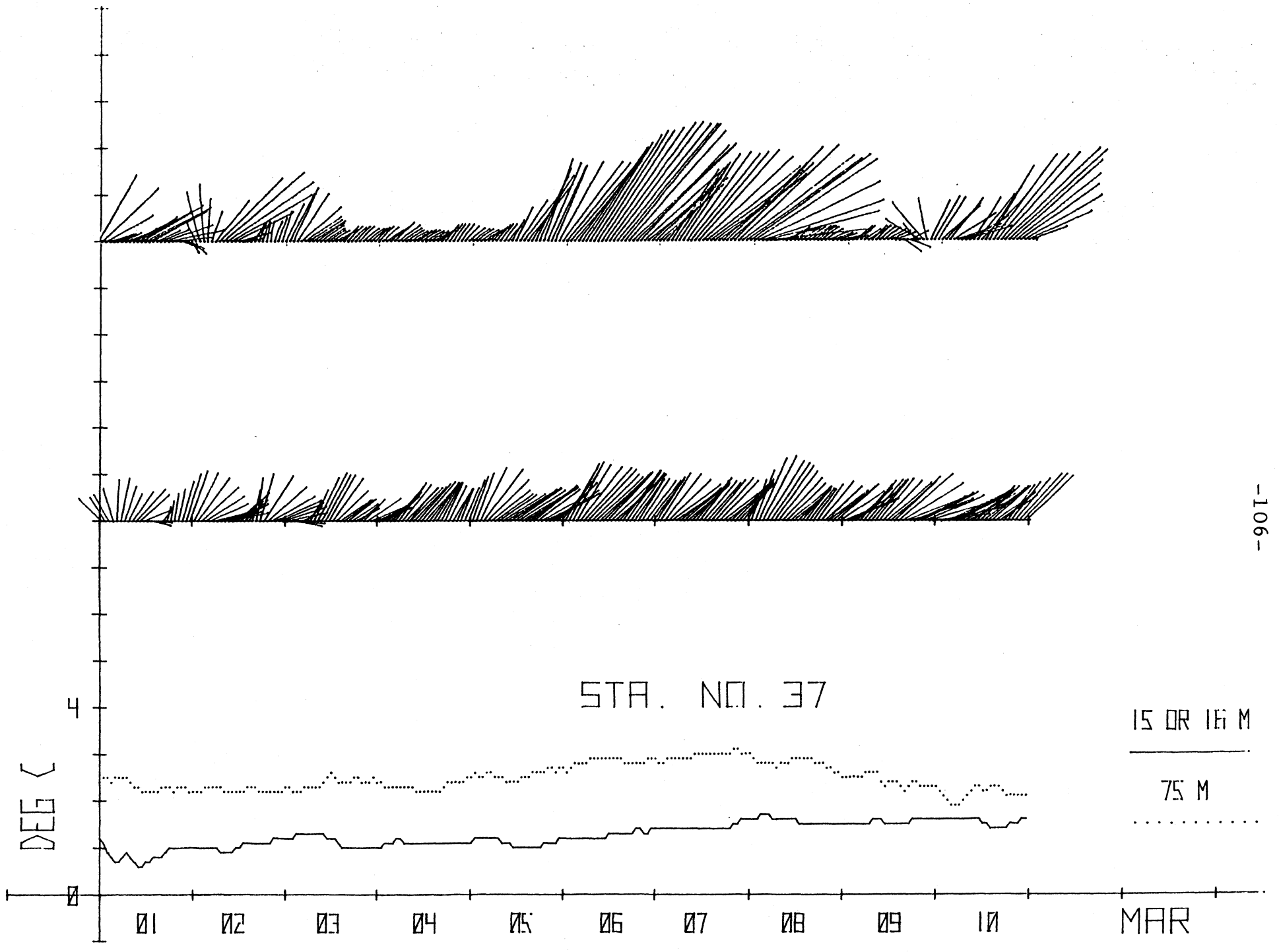
FEB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DEG C
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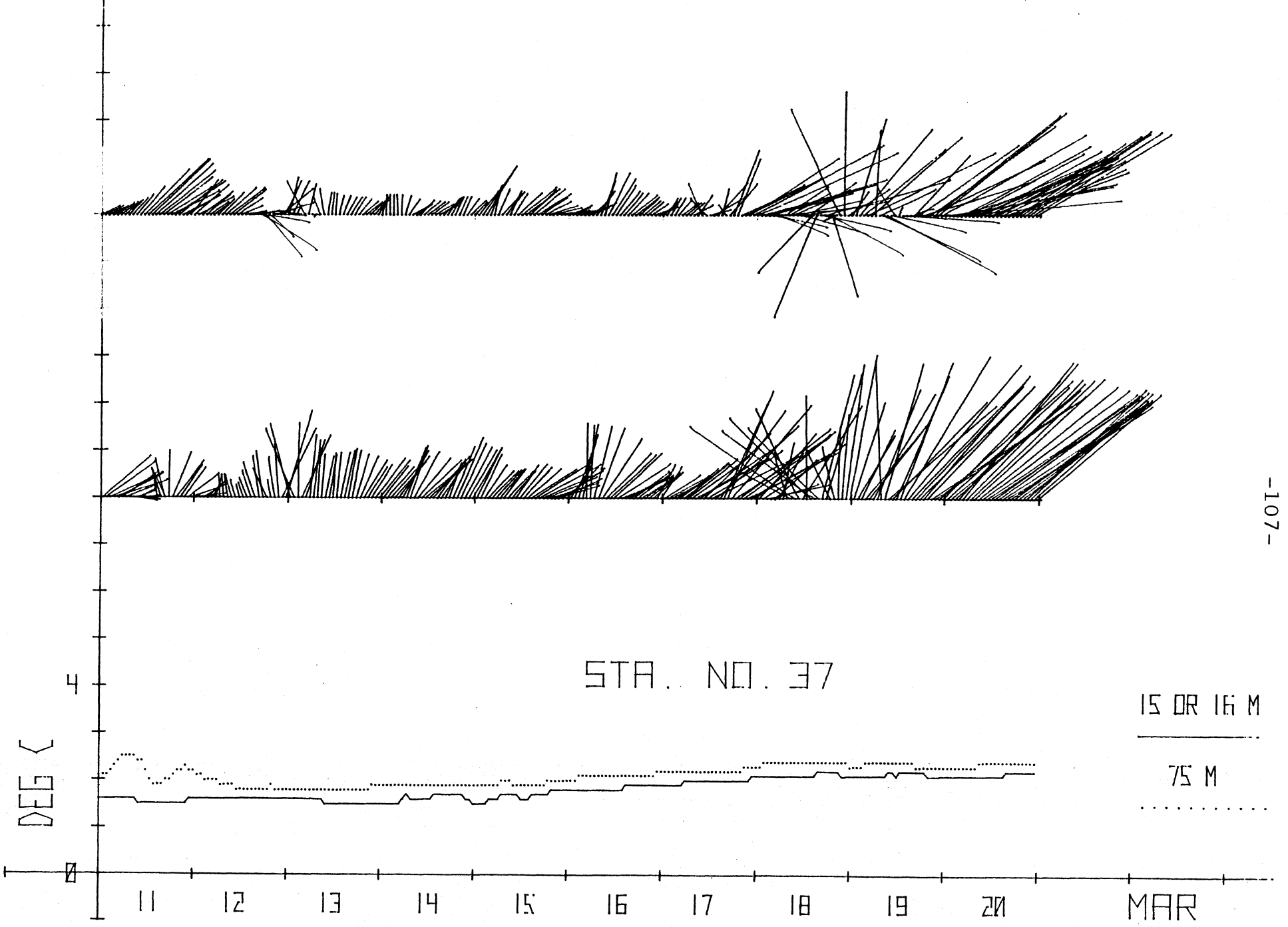
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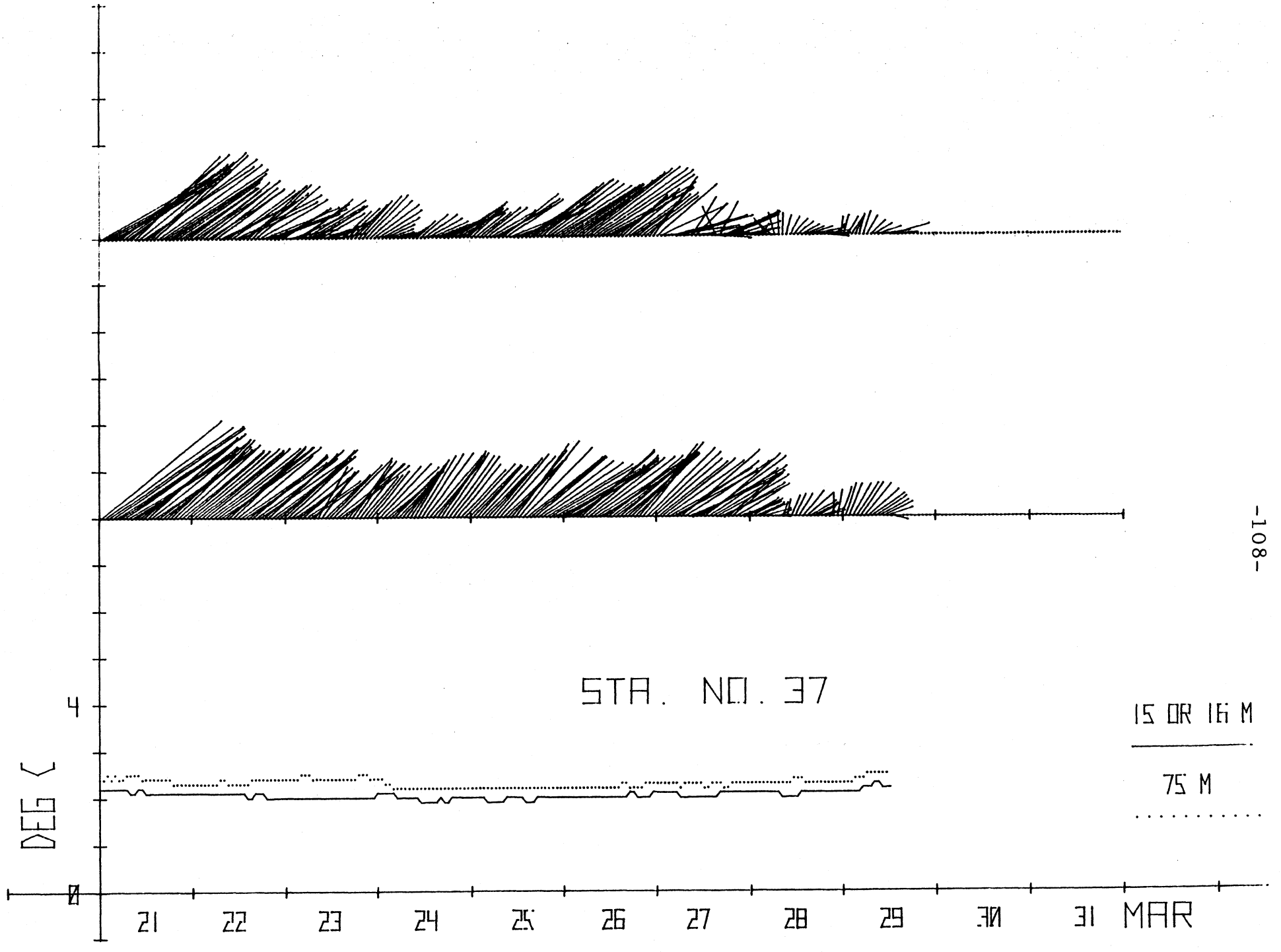
STA. NO. 37
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75 M
DEG C
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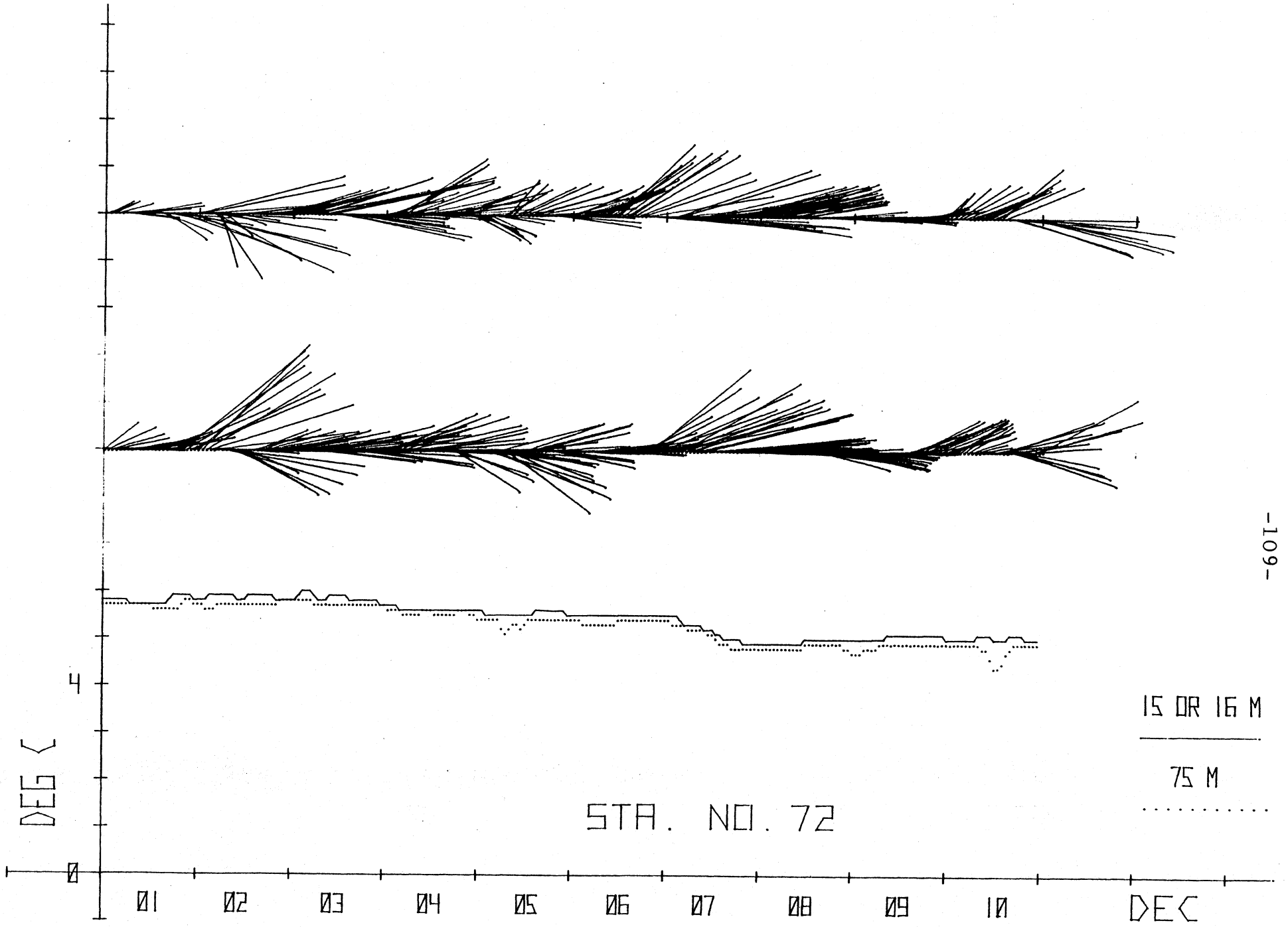
MAR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DEC
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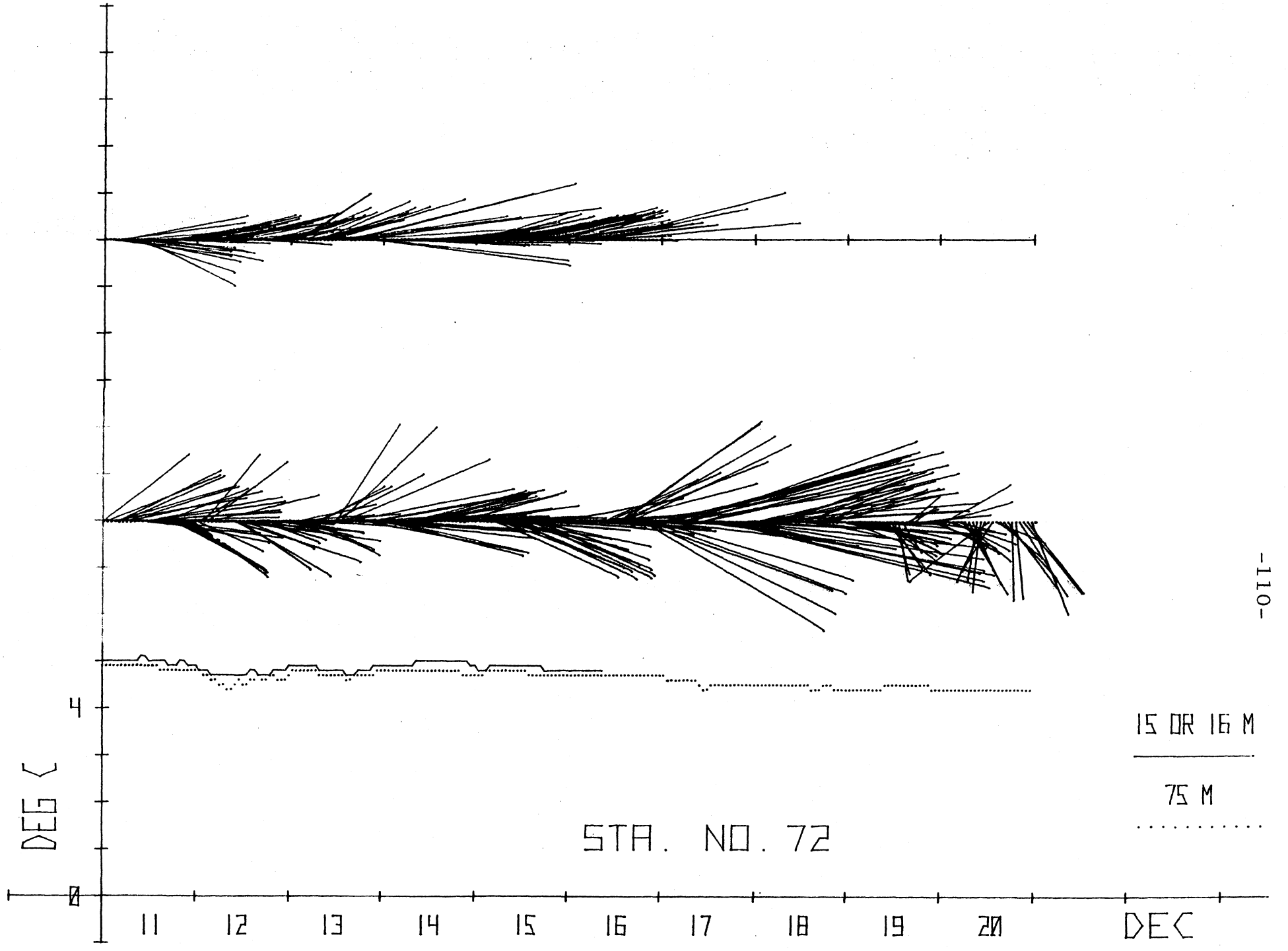
DEG C
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DEC
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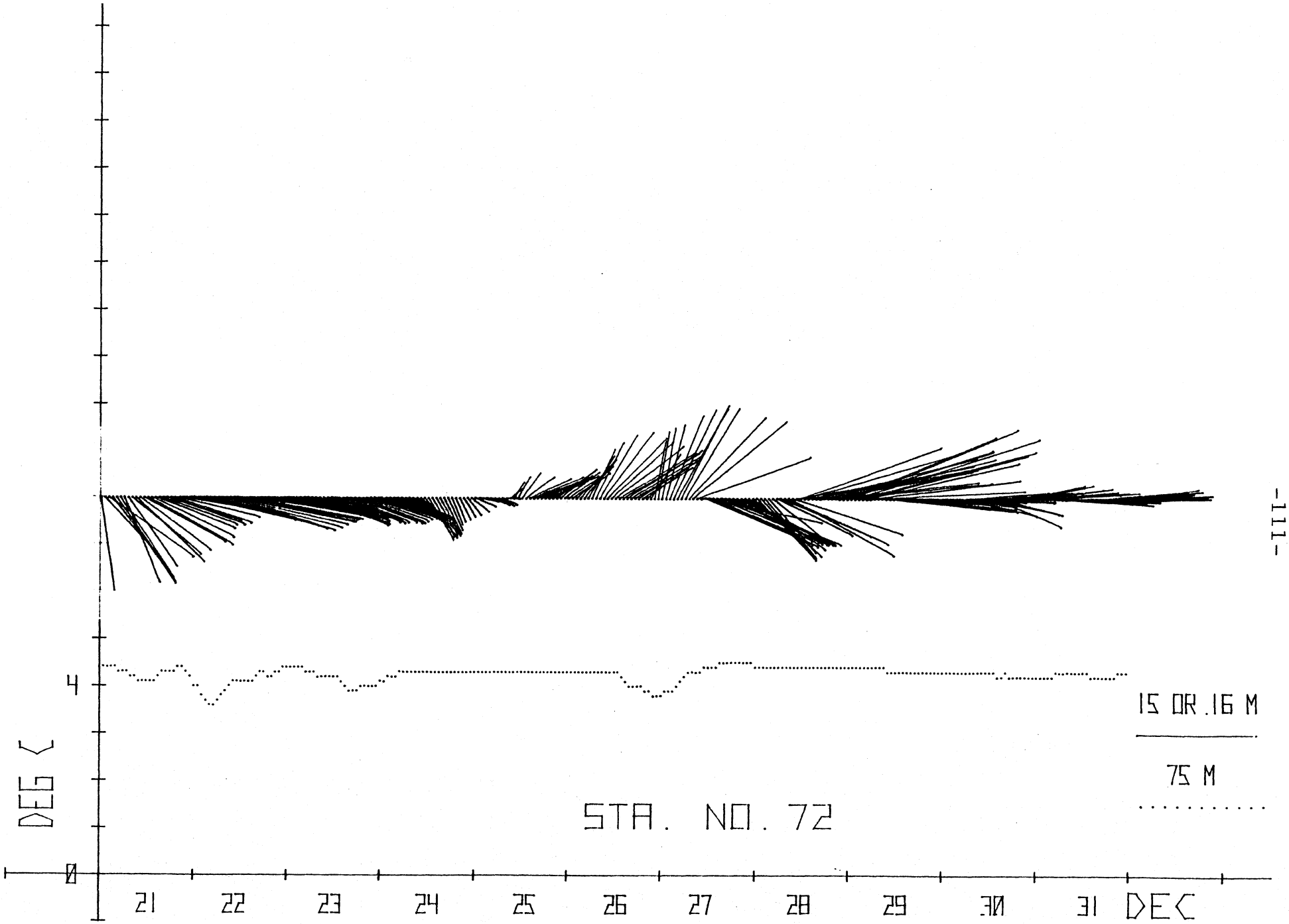
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75 M
STA. NO. 72
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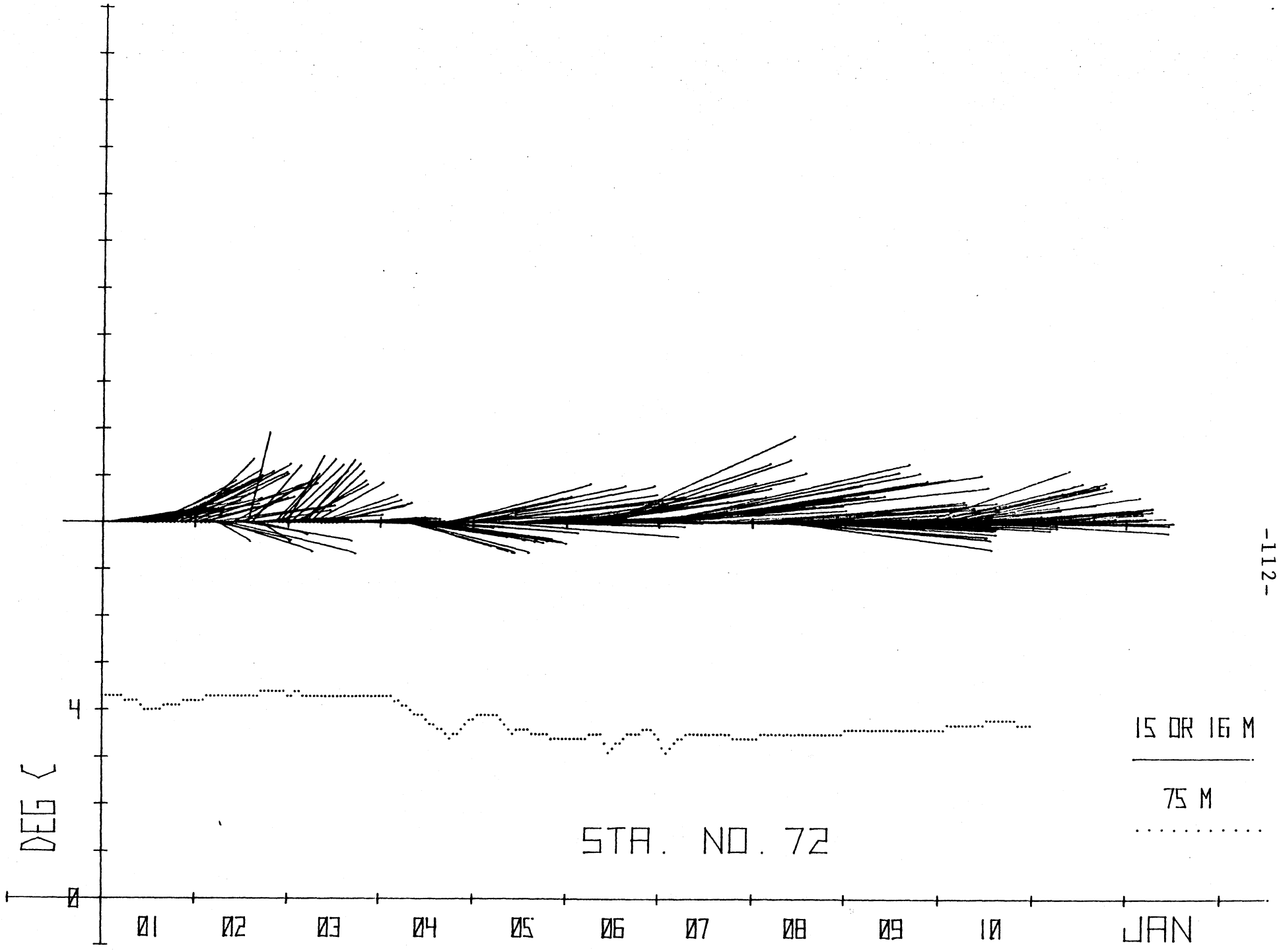
DEG C
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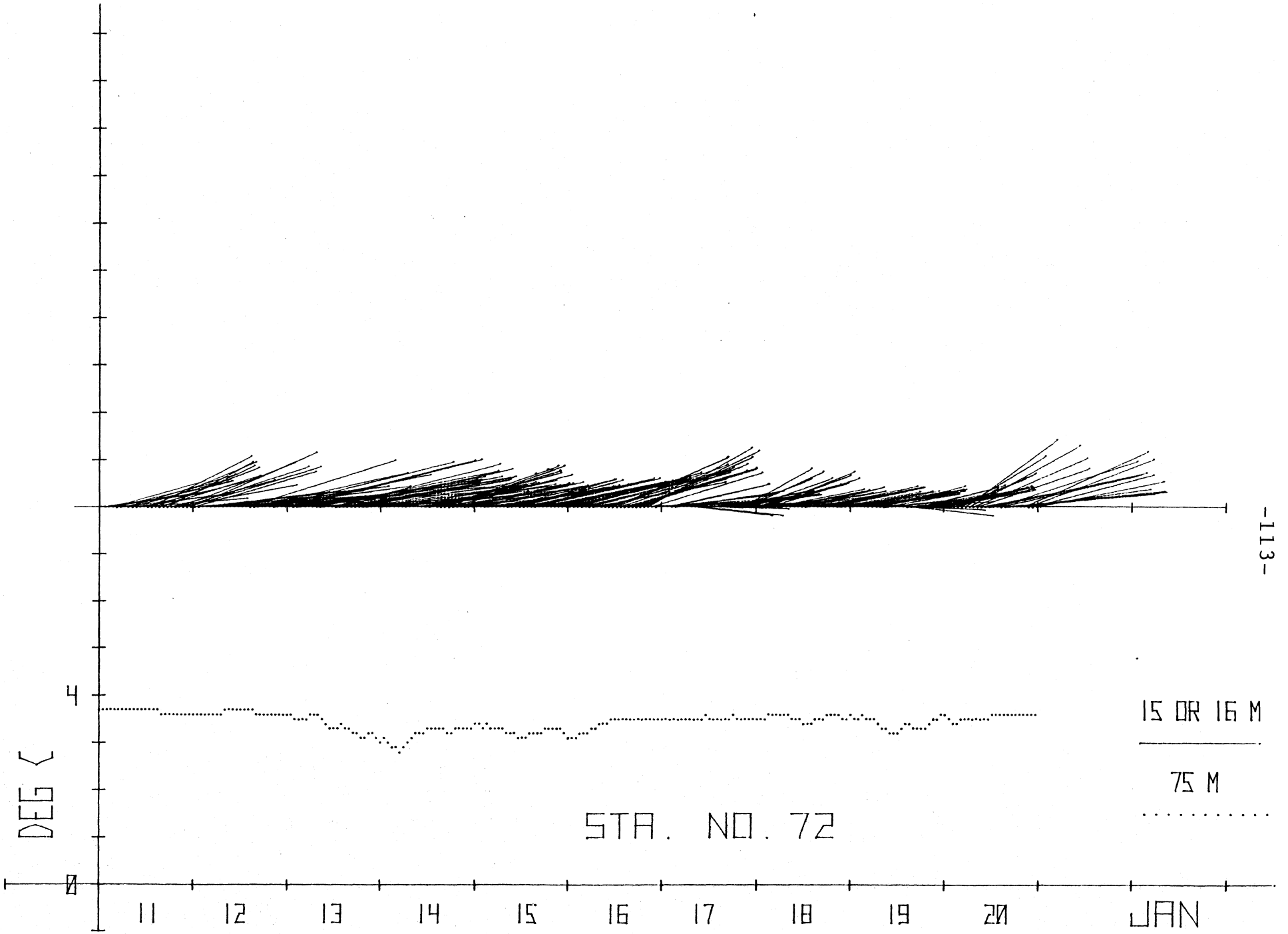
JAN
STA. NO. 72
15 OR 16 M
75 M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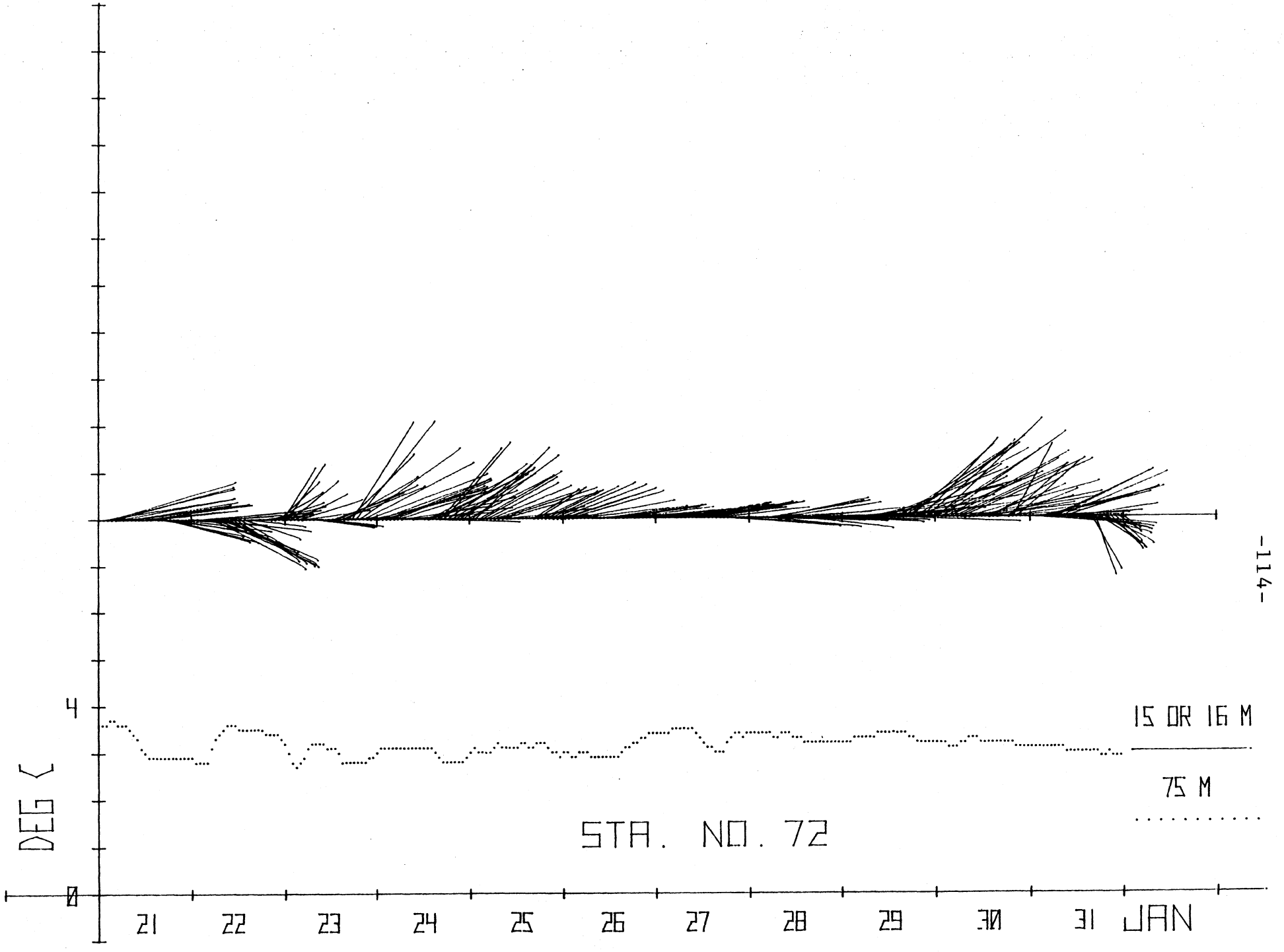
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JAN
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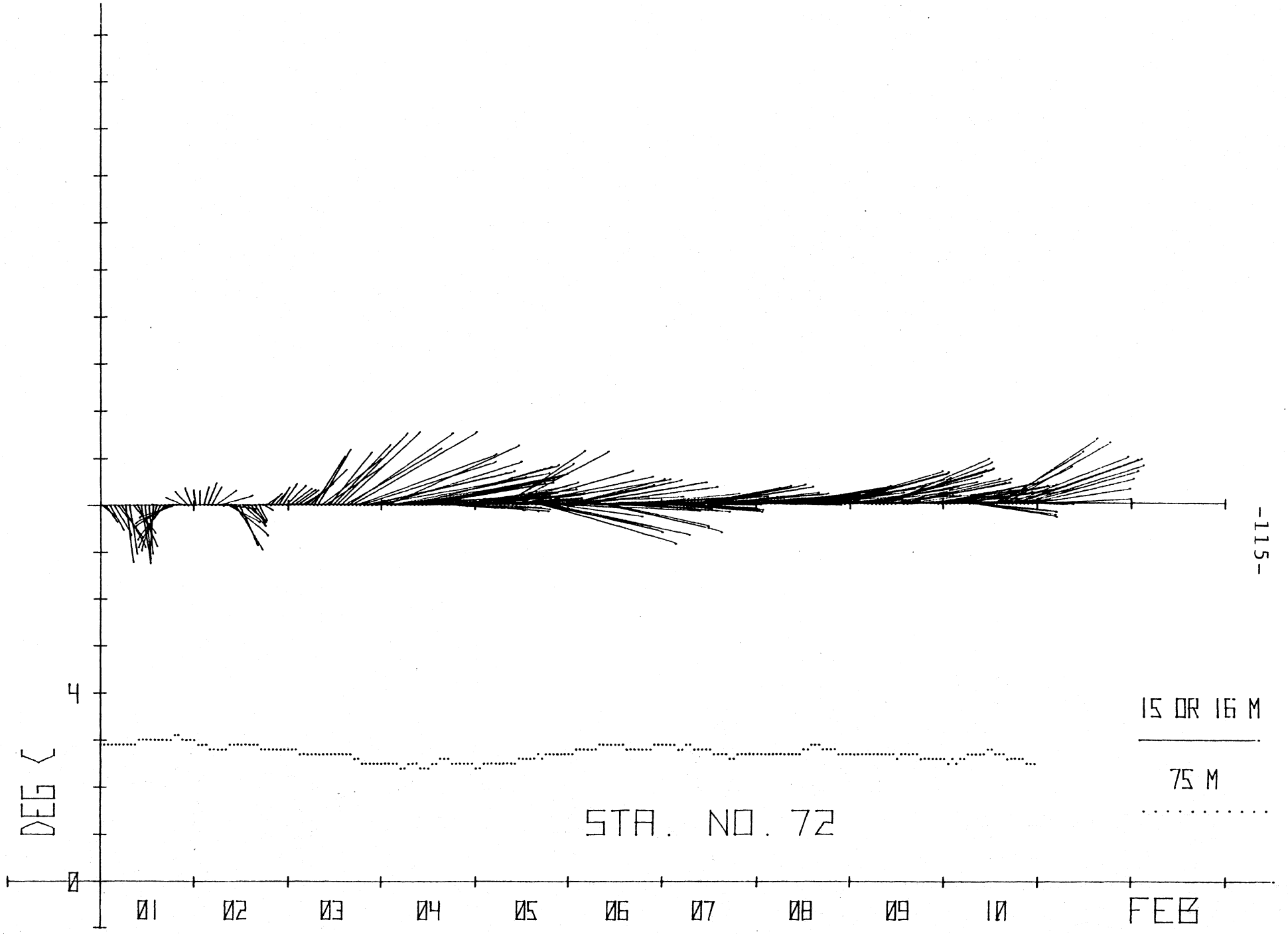
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STA. NO. 72
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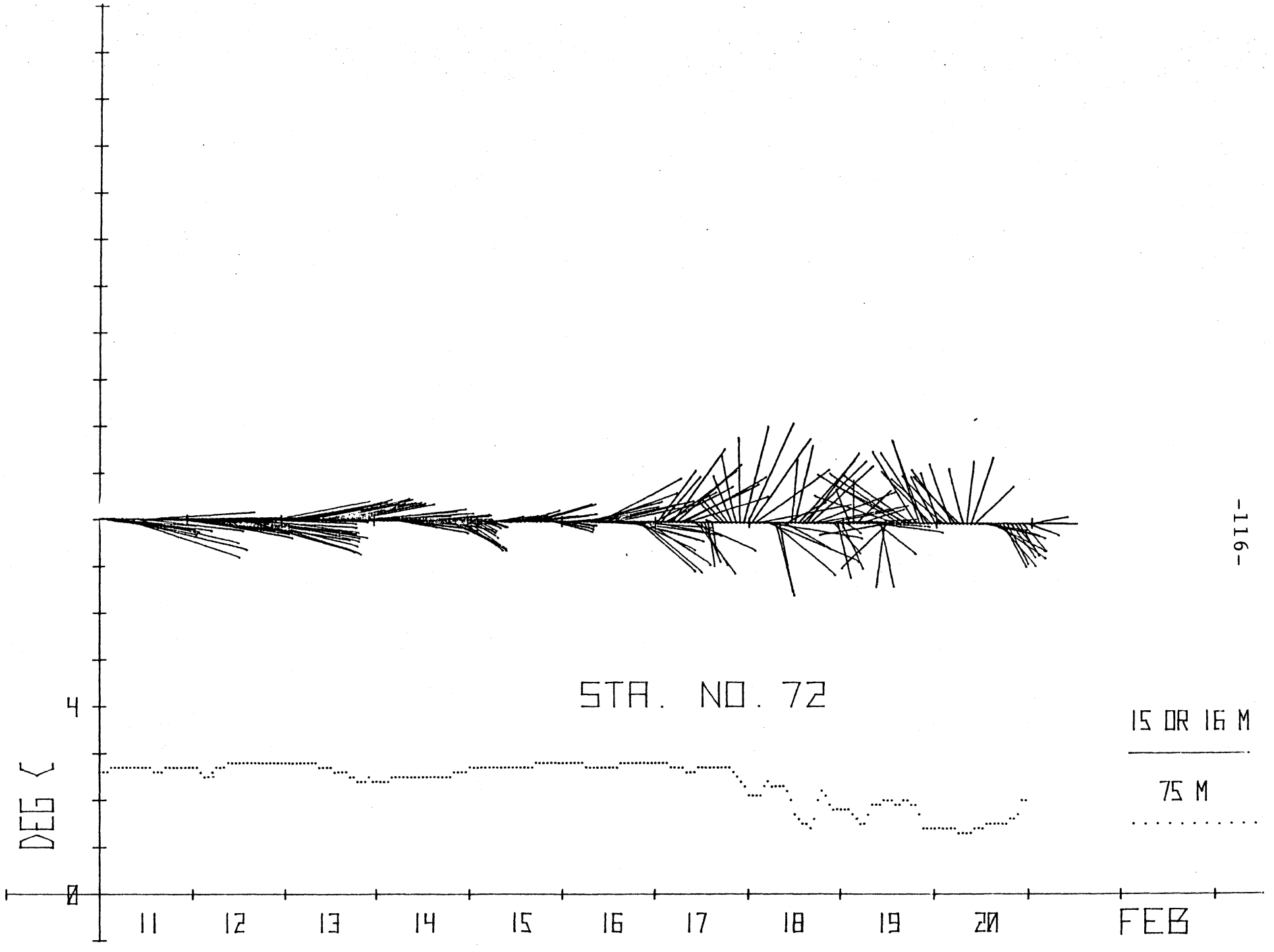
FEB
15 OR 16 M
75 M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15 OR 16 M
75 M
DEG C
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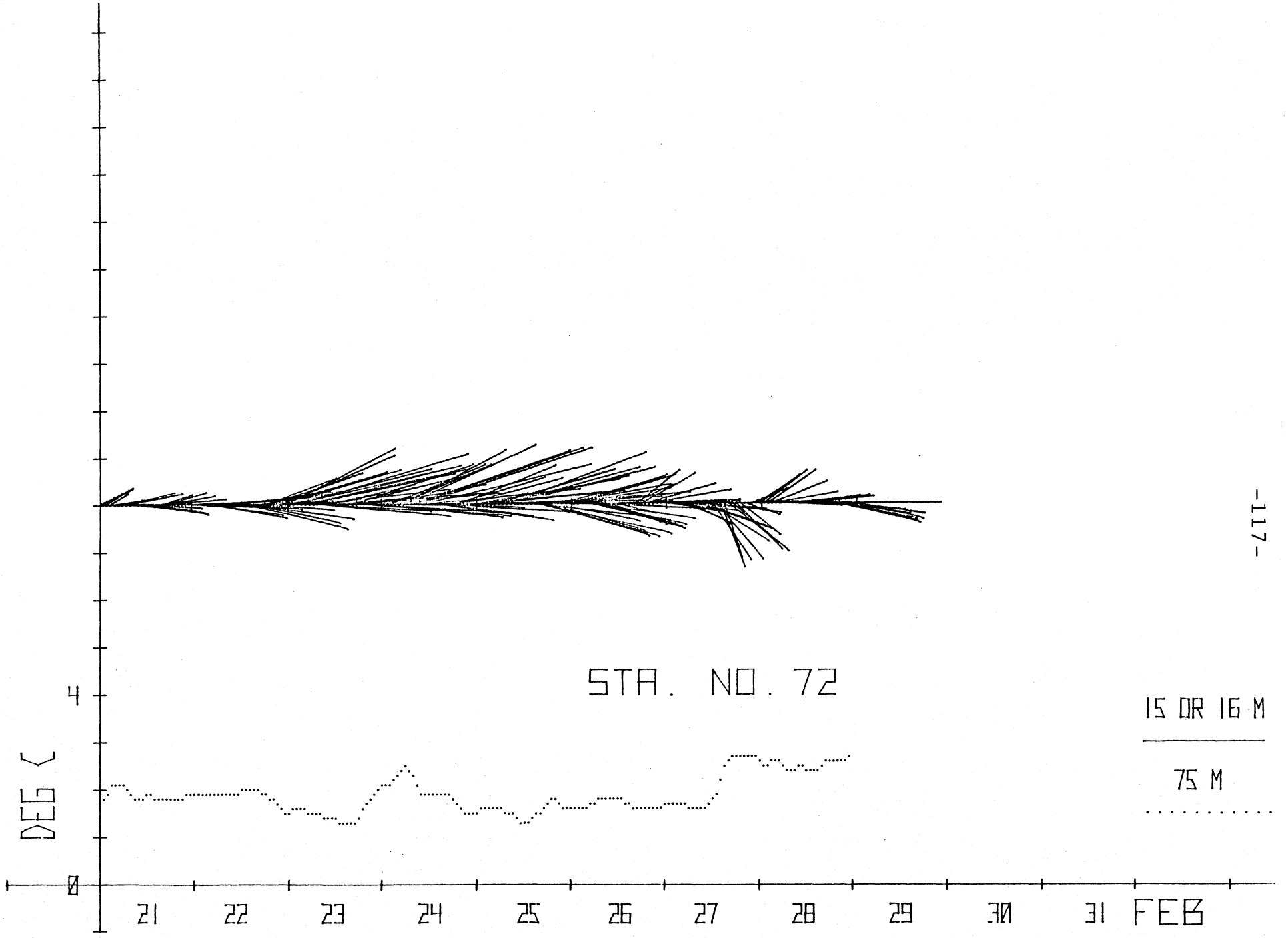
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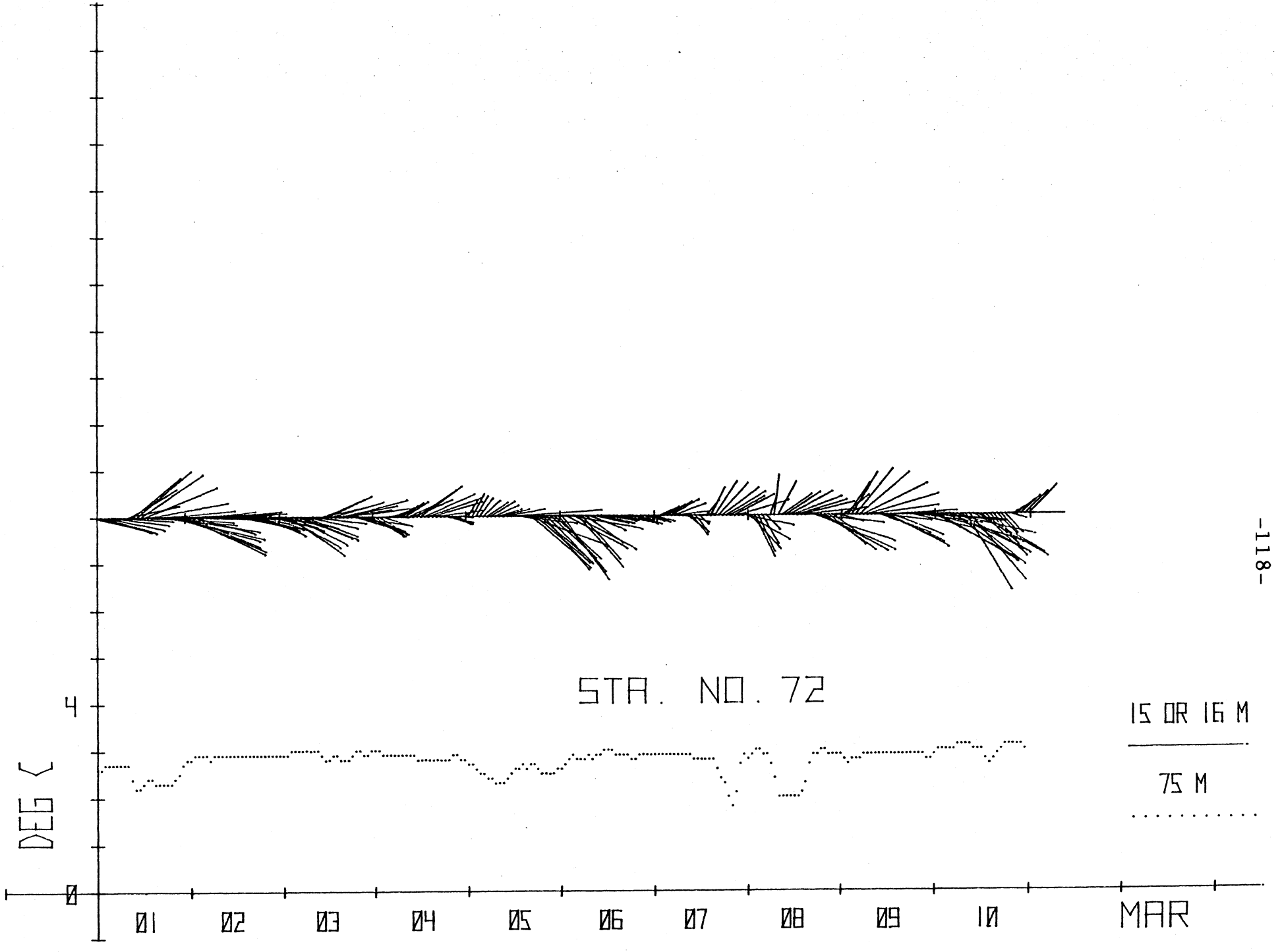
31 FEB
15 OR 16 M
75 M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75 M
DEG C
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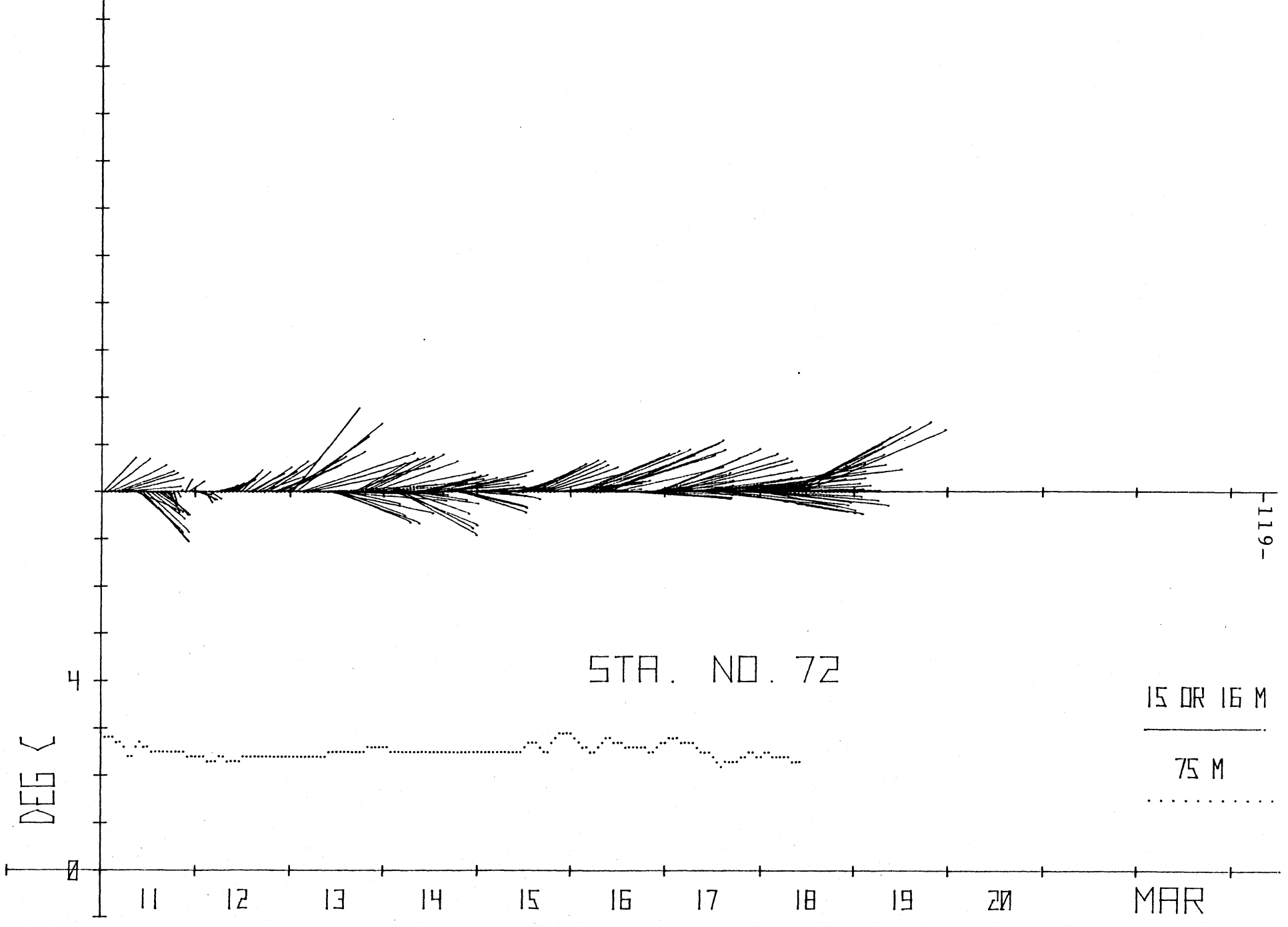
MAR


STA. NO. 72
15 OR 16 M
75 M
DEG C
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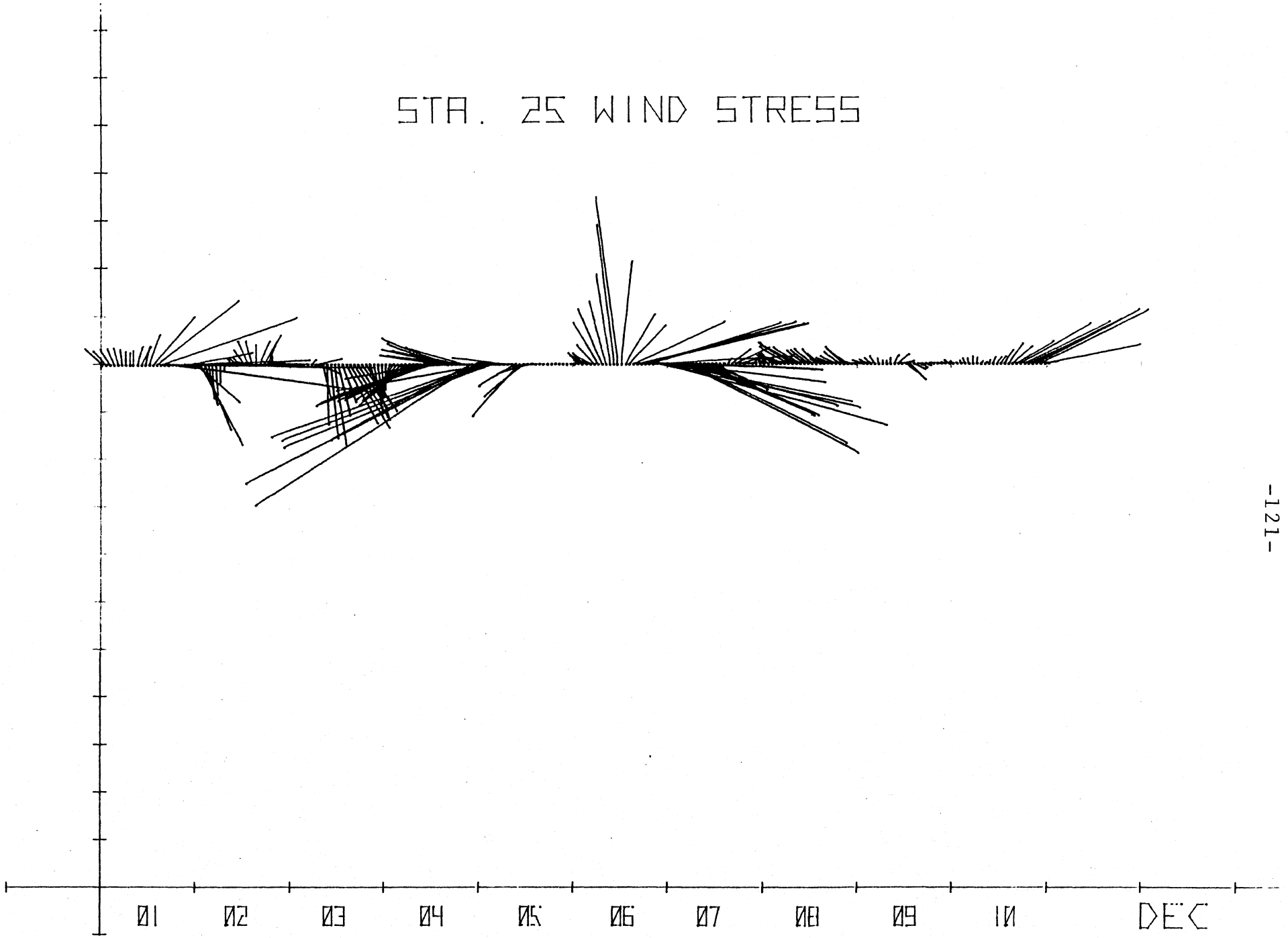
Time-series plots of wind stress

Presented on the next pages are vector time-series plots of the quantity $\underset{\sim}{V}\,|\underset{\sim}{V}|$, where $\underset{\sim}{V}$ is the wind vector pointing in the direction the wind is going as measured at land station 25 (see Fig. 1). In the plots, each tic mark on the vertical axis represents an increment in the square of the wind speed of 25 $m^2 s^{-2}$. (A wind stress of 1 dyne cm^{-2} at the lake surface is produced by a wind with a speed of roughly 8 m s^{-1}, measured at a height of 10 m.) There are gaps in the Sta. 25 data; when available, data from Sta. 22 or 29 are plotted as well to help fill these gaps. North is at the top of the plots.


STA. 25 WIND STRESS
01
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DEC


STA. 25 WIND STRESS
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14
15
16
17
18
19
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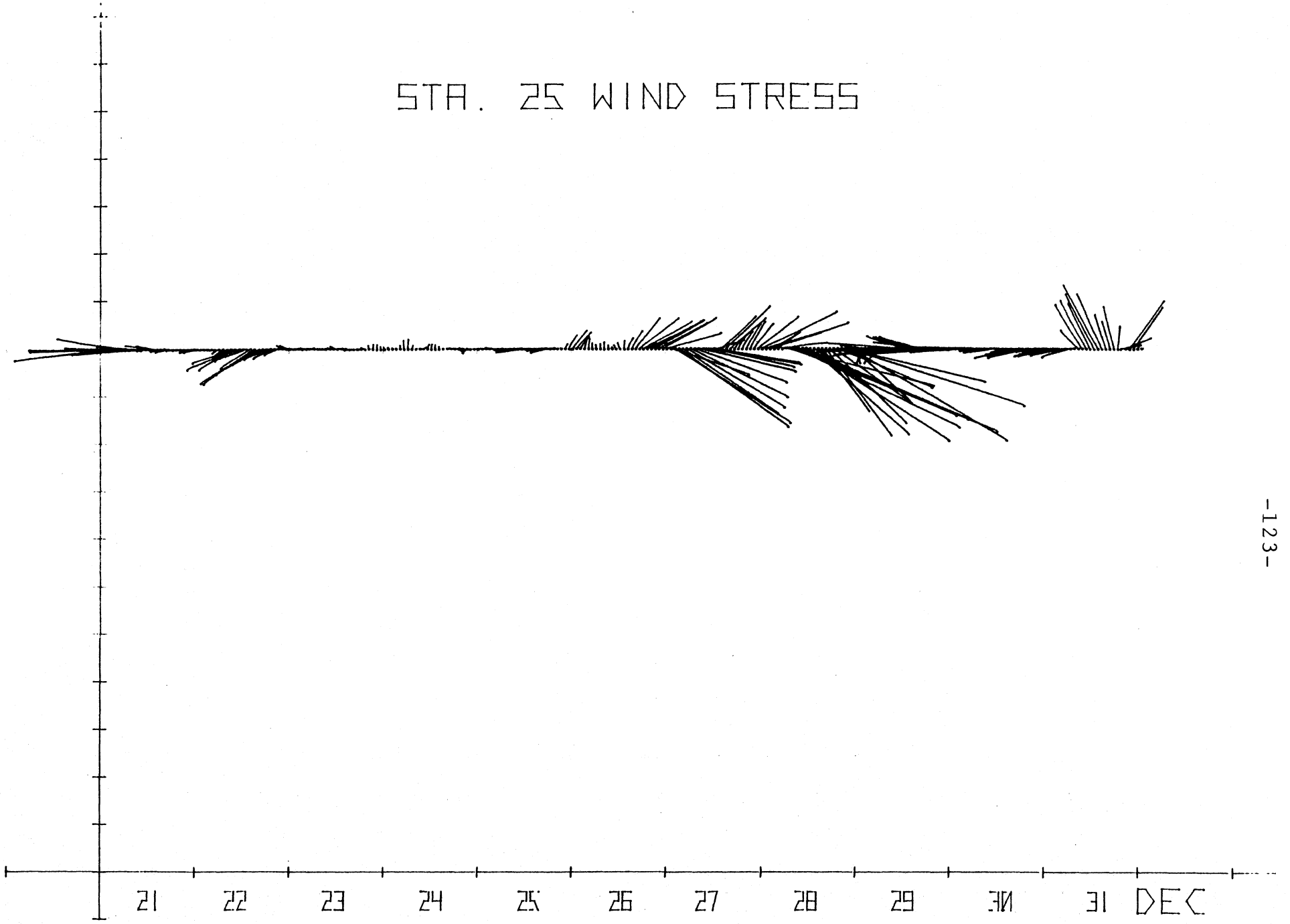
DEC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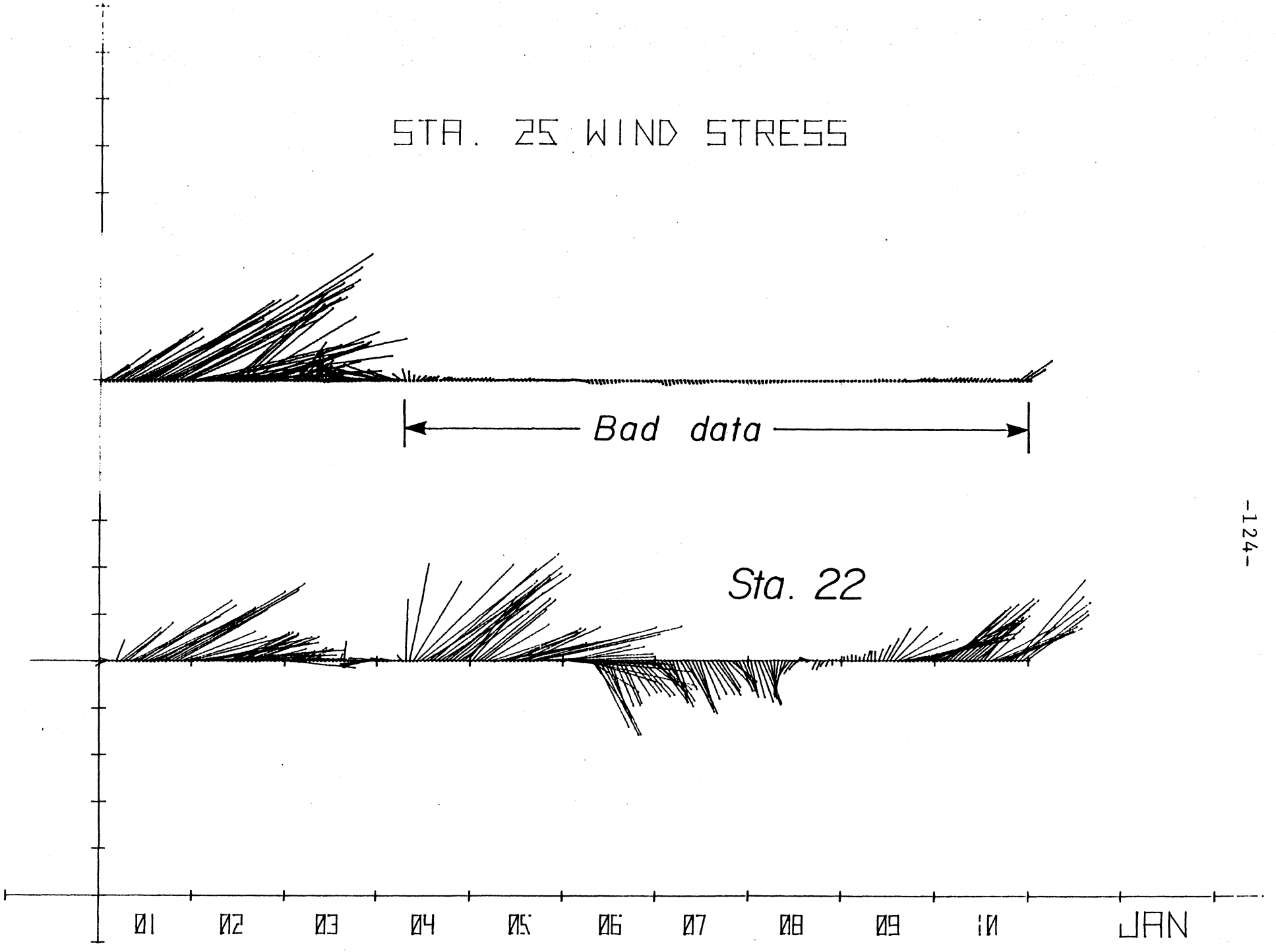
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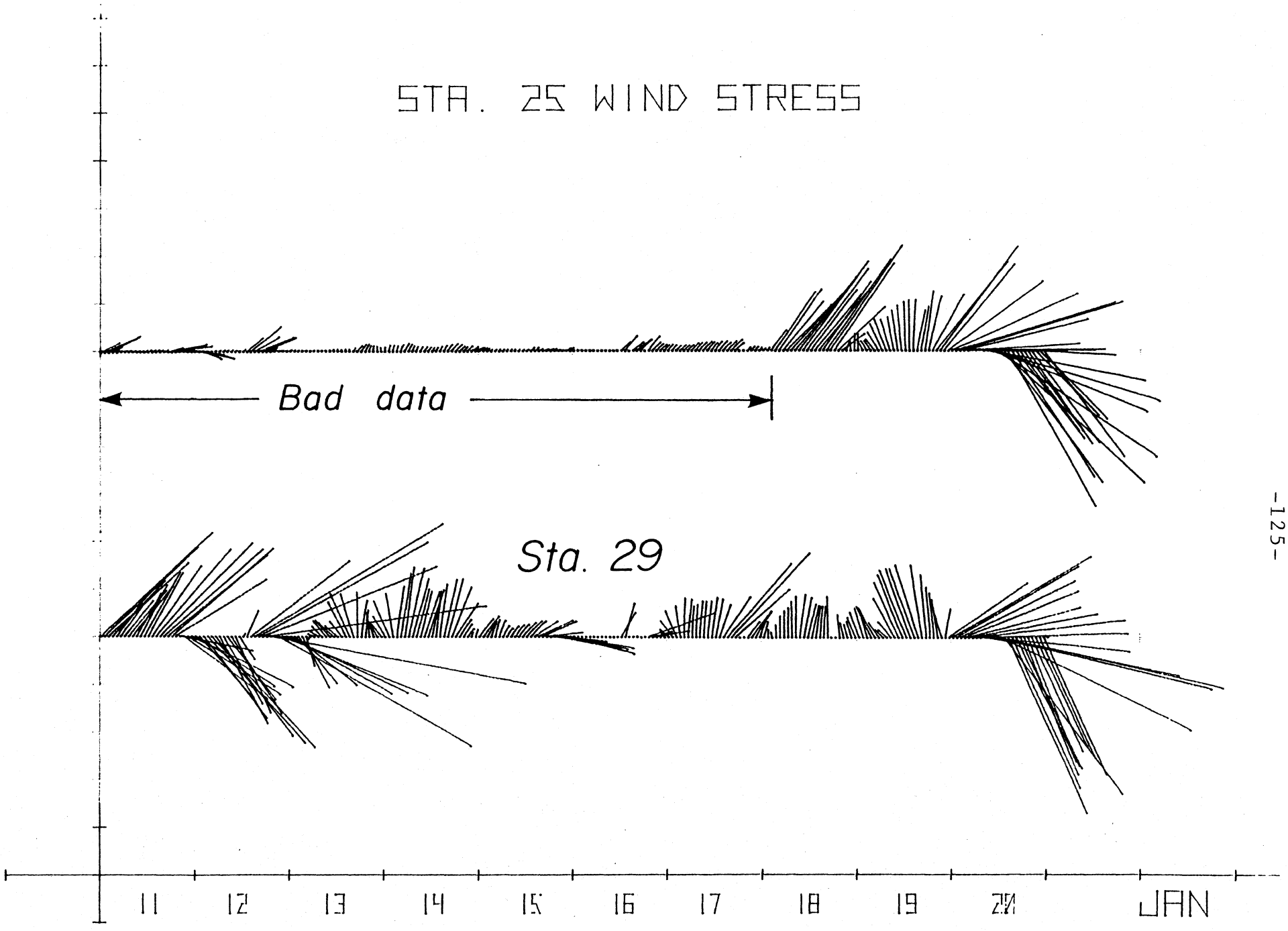
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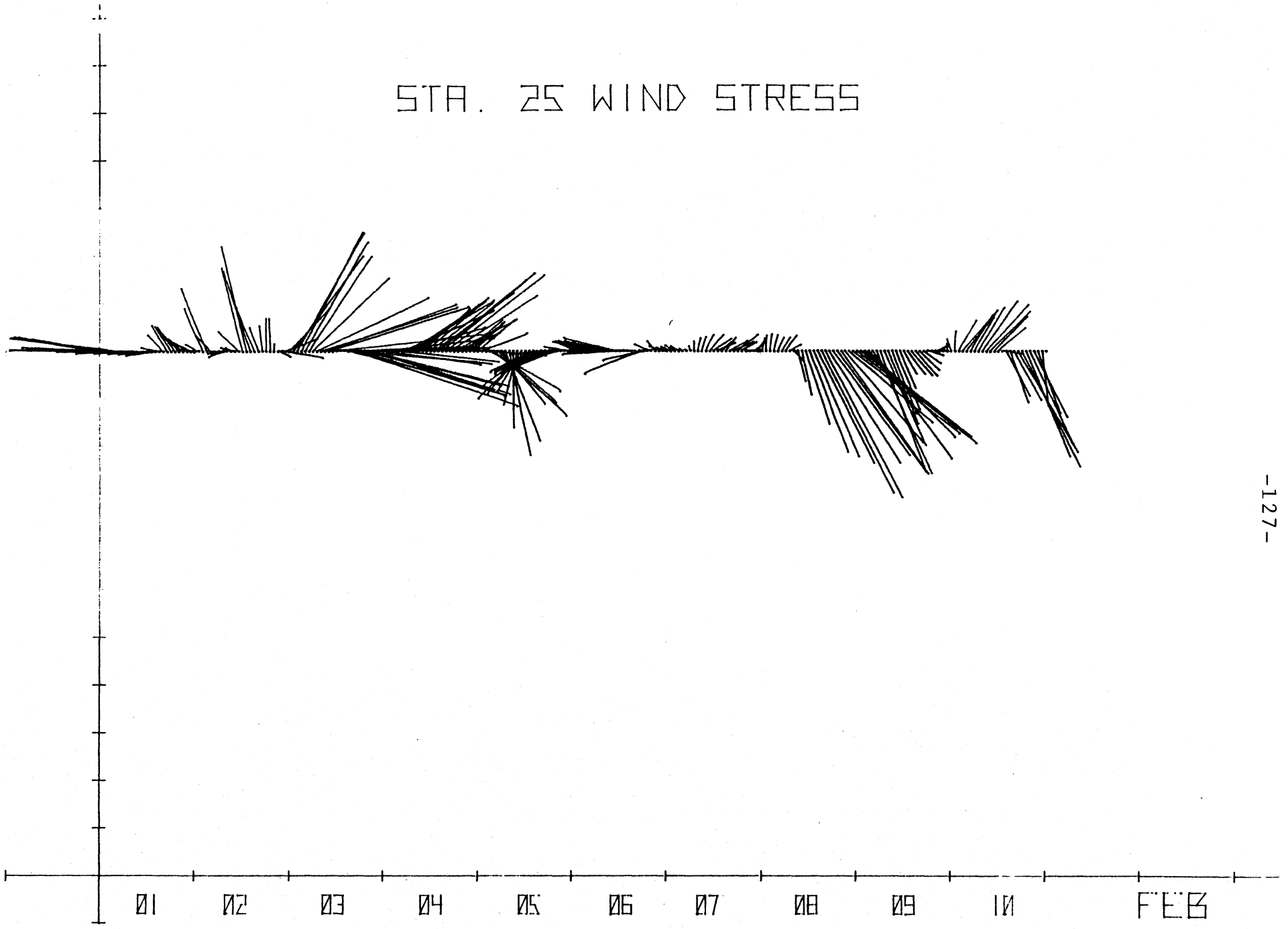
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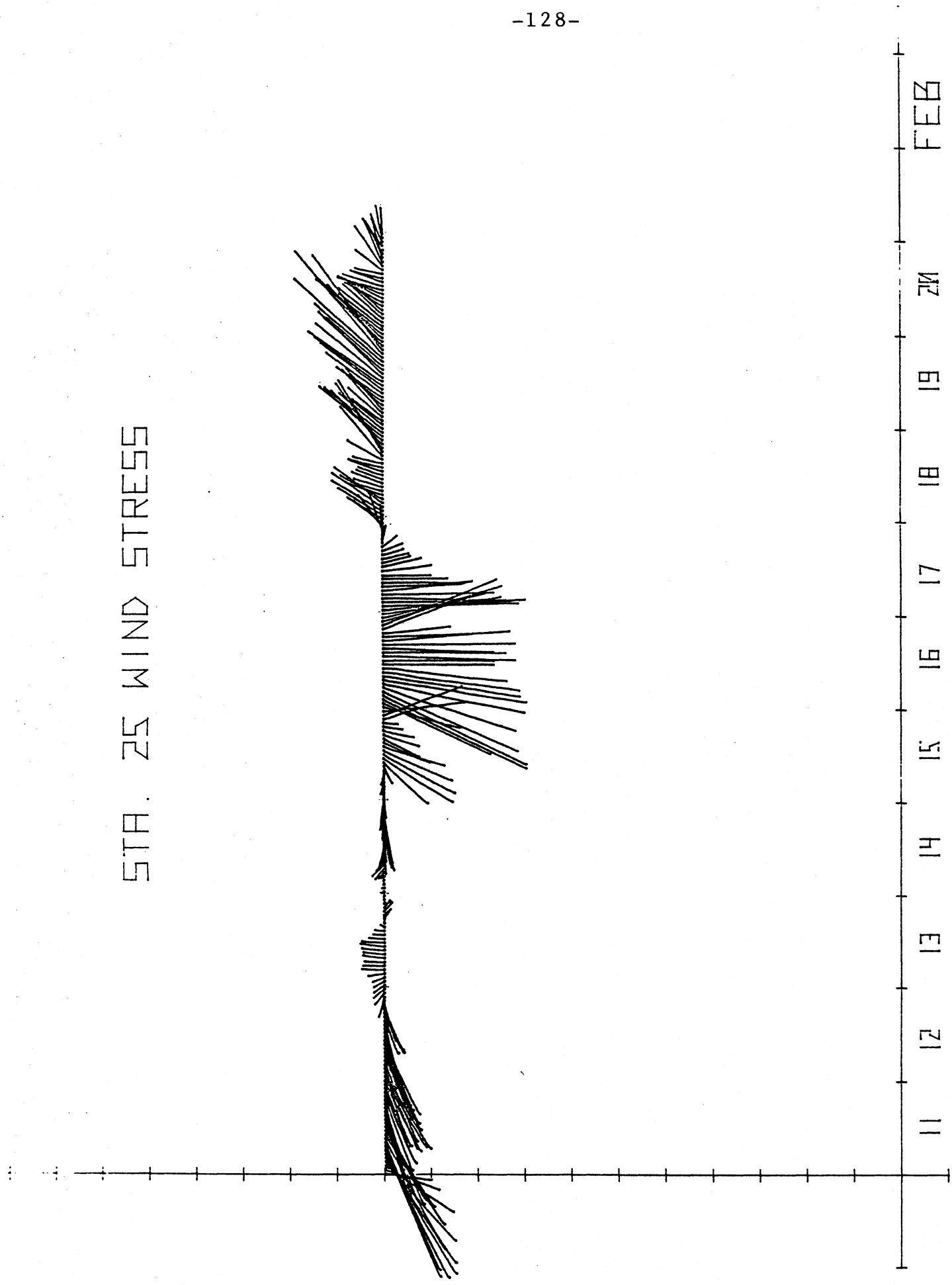
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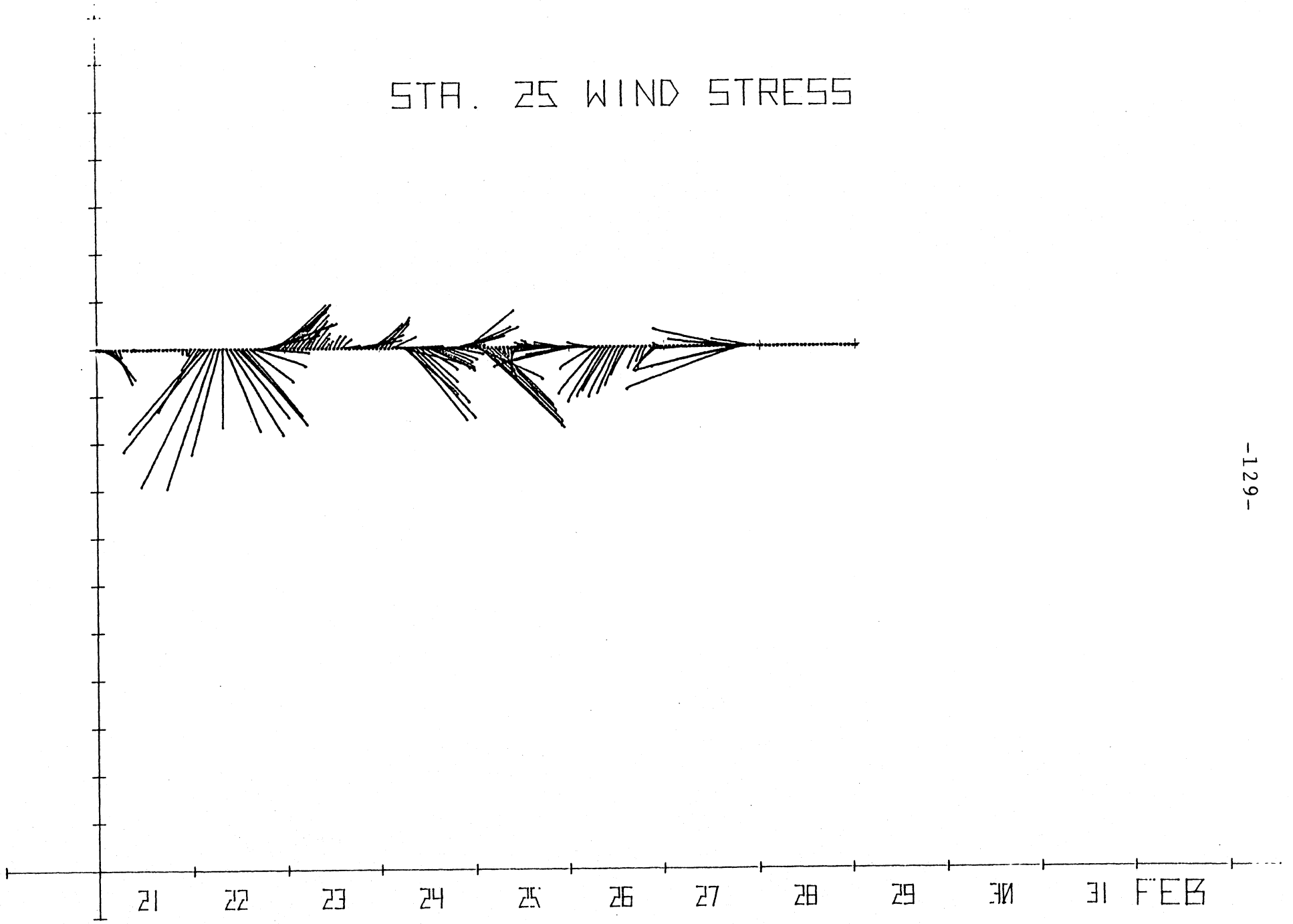
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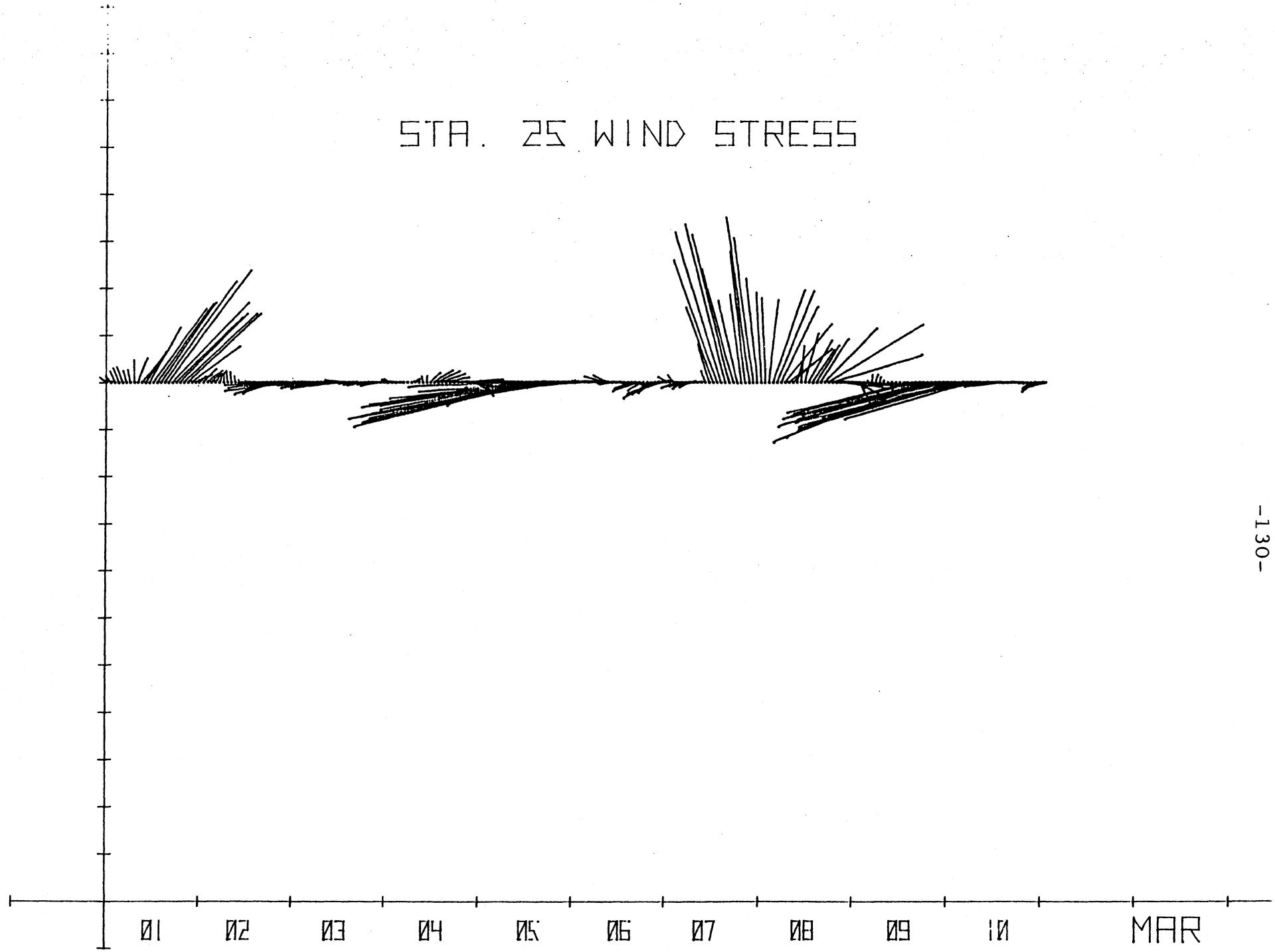
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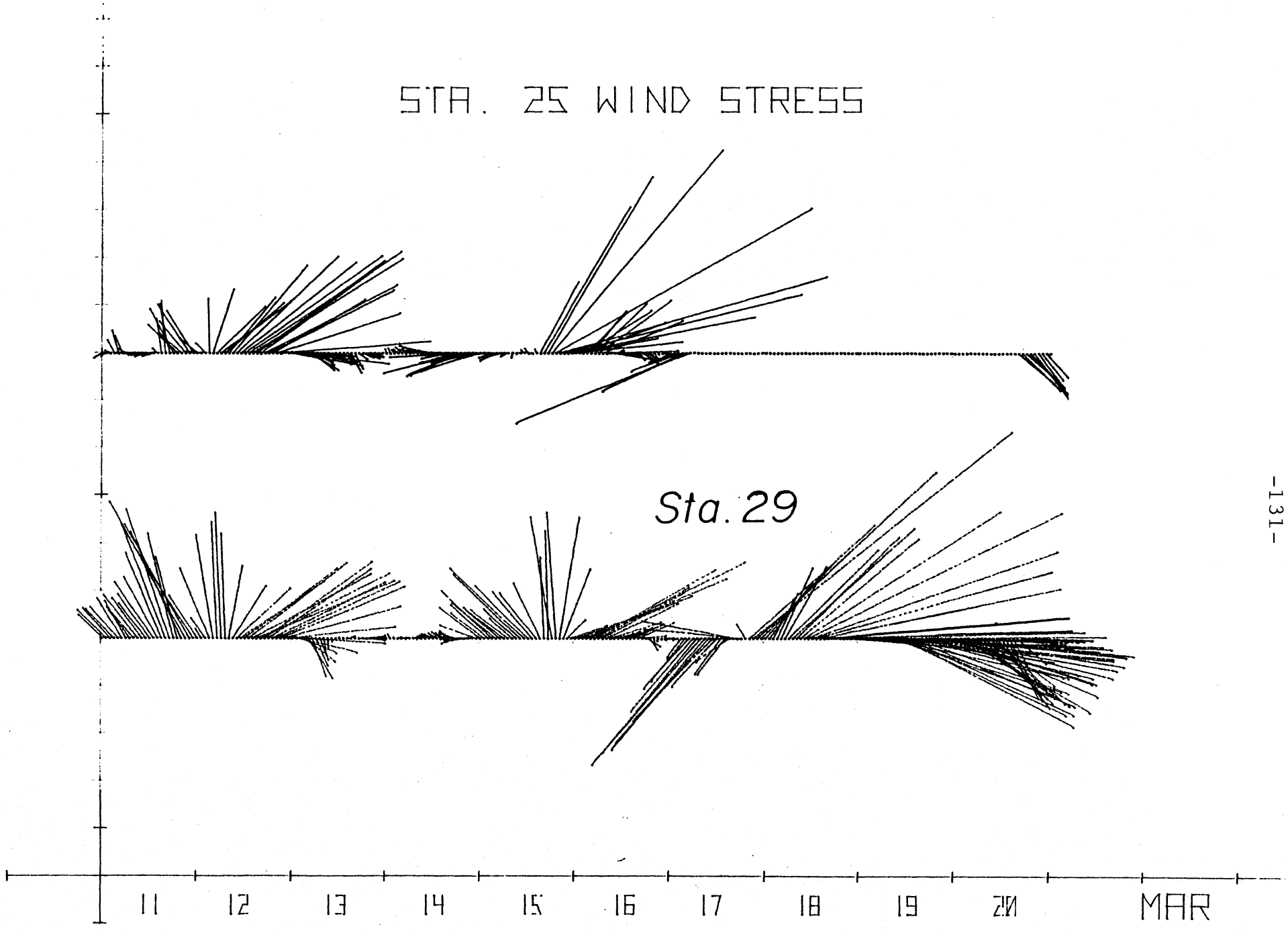
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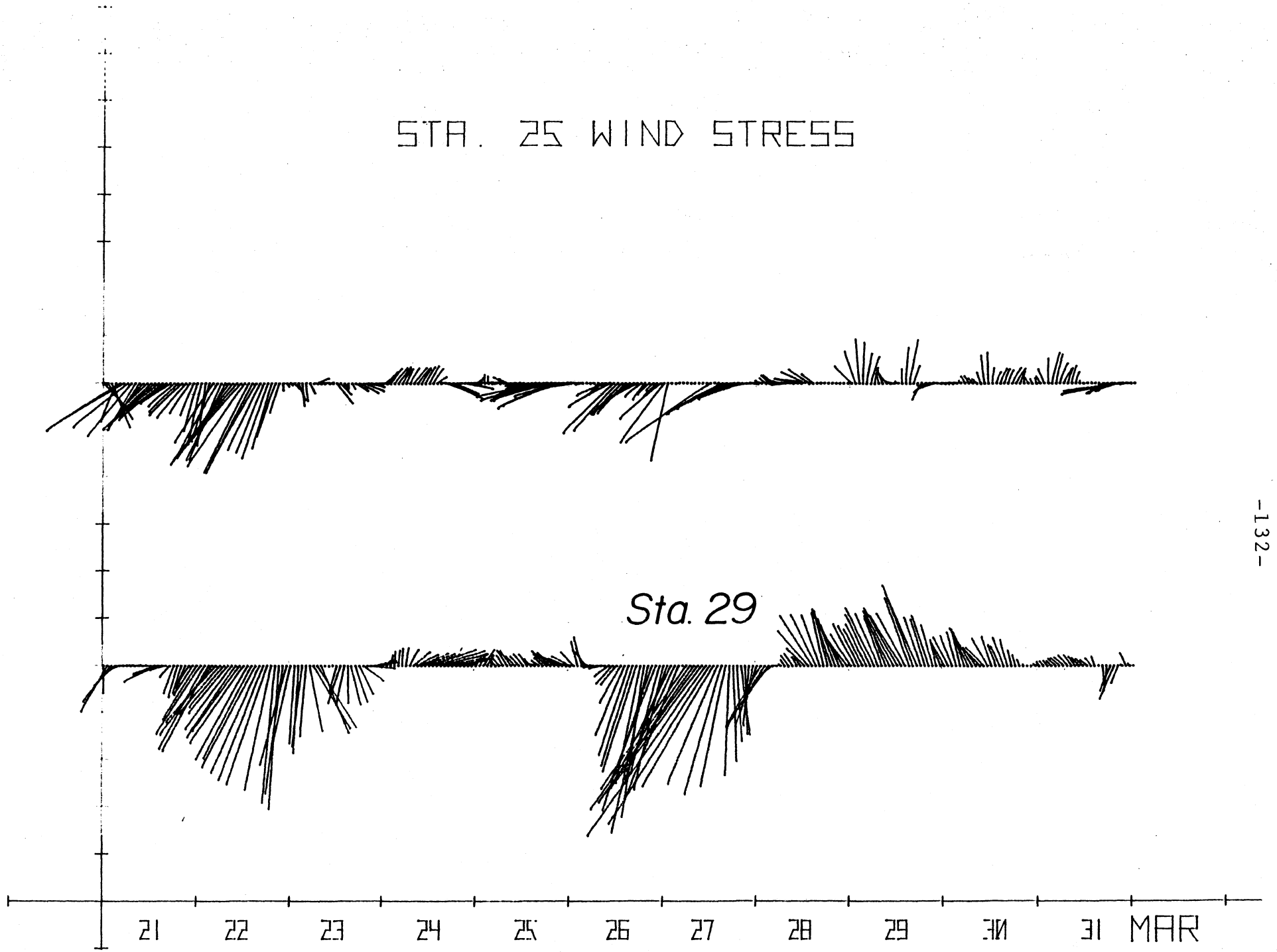
STA. 25 WIND STRESS
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