Search for Tropospheric Responses to Chromospheric Flares*

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ABSTRACT

Surface atmospheric pressures are studied for 5 days before and 10 days after chromospheric flares by the superposed epoch method for 31 meteorological stations in North America. The individual analyses show no statistically significant pressure departures following the flares. No evidence is found for claims that continental and coastal stations exhibit different responses to the flares. No evidence is found for claims that atmospheric pressure responses to flares are amplified with increasing latitude. The composite curve for North American stations shows no statistically significant departures and does not verify the composite curve of previous investigators. However, those chromospheric flares associated with polar cap absorption (PCA) events are followed by surface atmospheric pressure decreases (greater than 3mb) for several days within the polar cap, that are statistically significant in the composite curve for polar cap stations. A "working hypothesis" is presented to account for the pressure changes associated with PCA events. The hypothesis contains a prediction that can be checked, and suggests further study to confirm this positive indication of a solar-tropospheric effect.

Table I

Eastern Line			Central Line			Western Line		
Miami	25°49'N,	80°17'W	Brownsville	25°55'N	97°28'W	San Diego	32°44'N,	117°10'W
Charleston	32°54'	80°02'	Dallas	32°51'	96°51'	Los Angeles	33°56'	118°23'
Washington	38°51'	77°02'	Springfield	37°14'	93°23'	San Francisco	37°37'	122°23'
New York	40°39'	73°47'	Des Moines	41°32'	93°39'	Medford	42°23'	122°52'
Boston	42°22'	71°02'	Minneapolis	44°53'	93°15'	Seattle	47°32'	122°16'
Caribou	46°53'	67°58'	Int'l Falls	48° 36'	93°24'	Annette	55°02'	131°34'
Chatham	47°01'	65°27'	Gimli	50°38'	97°03'	Juneau	58°22'	134°35'
Campbellton	48°00'	66°40'	The Pas	53°58'	101°06'	Norman Wells	65°17'	126°48'
Goose Bay	53°19'	60°25'	Churchill	58°45'	94°04'	Barrow	71°18'	156°47'
Ft. Chimo	58°06'	68°26'	Resolute Bay	74°41'	94°55'			
Frobisher Bay	63°45'	68°33'						
Thule	76°32'	68°45'						

I. Introduction

It is well known that the upper atmosphere responds to solar phenomena. The ionosphere, the radiation belts, the aurora and geomagnetic variations, all have been studied in association with short-term variations of solar activity. However, within the troposphere, while seasonal and diurnal variations are observed in the meteorological variables, the short-term solar variations are not clearly reflected in low-level weather phenomena. In fact, solar-tropospheric studies have often been viewed by the scientific community as existing on the "fringes of respectability". Nevertheless, the advantages to be gained from discovering genuine solar influences, not now included in conventional meteorological analysis, have stimulated adventurous workers to investigate the possibilities.

Duell and Duell (1948) were the first to demonstrate at all convincingly short-term immediate responses of the troposphere to solar-origin disturbances. 1) Using the five most and five least geomagnetically disturbed days in each winter month of low solar activity from 1906-1937 as key days in a superposed epoch analysis, they found the sea-level atmospheric pressure at several European stations to be lower than normal 3

days after disturbed days and higher than normal 3-4 days after quiet days. 2) Working with 51 intense chromospheric flares from 1936-1941, they found a distinct maximum of European sea-level pressure appearing 4-6 days after the flare. The provocative work of the Duells, although lacking both rigorous statistical justification and acceptable physical mechanisms, encouraged others to take up the challenge. In a study resembling 1) above but with many more stations and careful statistical analysis, Craig (1952) found a marked negative correlation between the pressure variations following disturbed days and quiet days for the same location and the same period of time. If the pressure tended to rise after disturbed days, it tended to fall after quiet days, and vice versa. Shapiro (1956), working with sea level pressure data over North America, found a significantly high persistence correlation (5 per cent level)3 to 4 days after large increases in geomagnetic activity, and a significantly low persistence correlation (1 per cent level) about two weeks after the key days. A later study (Shapiro, 1959), with European surface pressure data, confirmed only the earlier high values of the persistence correlation. Macdonald and Roberts (1960). working with three successive winter half-years between 1956-1959, found that 300 mb troughs in the Gulf of

Alaska-Aleutian Islands area are amplified approximately three days after geomagnetically disturbed periods. On the other hand, in three separate studies using 500 mb maps, 3 km. maps, and data from high-latitude stations, Kaciak and Langwell (1952) did not find any relationship between geomagnetically disturbed days and pressure aloft. A dozen years after the original work of Duell and Duell (1948), the situation was still far from clear, yet research in the United States along these lines was essentially discontinued as seemingly unproductive.

A fresh and enthusiastic attack on this difficult problem has recently been launched in a series of USSR papers (Fomenko, 1962; Fomenko et al., 1963; Gnevyshev and Sasonov, 1964; Sazonov, 1965; Kubyshkin, 1965, 1966; Mustel et al., 1965; Mustel, 1966). The main conclusions of these studies may be summarized as follows:

1. Quasistationary corpuscular streams originating from active solar regions (calcium plages) which create recurrent geomagnetic disturbances give rise to a maximum of geomagnetic activity as well as to a maximum of surface atmospheric pressure approximately 6 days after central meridian passage of the active region. The magnitude of the pressure change (1-3 mb) increases with latitude.
2. Chromospheric flares generating sporadic geomagnetic disturbances are followed 3-5 days later by maxima of surface atmospheric pressure (amplitude 2-3 mb) at

Soviet and Scandinavian stations. The geomagnetic activity maximum is found approximately one day earlier.

3. The same chromospheric flares are associated with a minimum of surface atmospheric pressure (amplitude 2-3 mb) at French meteorological stations 3-5 days after the flares. The change from maximum pressure in eastern Europe to minimum pressure in western Europe takes place gradually in moving westward across Europe.

4. Those chromospheric flares associated with solar proton events (approximately 1-300 Mev) produce in the polar caps large surface pressure decreases (5-10 mb) which begin almost immediately after the flare, reach a minimum pressure near the sixth day, and then slowly recover.

Although the above conclusions are based on empirical studies lacking both rigorous statistical verification and acceptable physical mechanisms, we have been encouraged, particularly by the work of Mustel and collaborators, to investigate the problem. Since the sporadic geomagnetic disturbances produced by chromospheric flares are more intense, can be more readily isolated, and may be more easily detectable in possible tropospheric effects, we have confined the current investigation to this situation. Future studies may be directed toward the recurrent geomagnetic disturbances.

In the score of years since Duell and Duell first presented their work our knowledge of solar emissions and their influences within the magnetosphere have increased tremendously. The interplanetary medium has been measured and the interaction of the solar wind with the geomagnetic cavity have been studied. The morphology of the radiation belts and the aurora, and the expansion of the upper atmosphere at times of geomagnetic disturbance have been investigated. Perhaps the time is ripe for a renewed assault on the problem of solar-tropospheric relations.

II. Method of Analysis

The present study attempts to verify the above Soviet conclusions by using surface pressure data at 31 North American meteorological stations ranging over the continent from low to high latitudes. The stations are in three lines of approximately ten stations each, located in eastern, central and western North America. The stations and their locations in geographical coordinates are listed in Table 1. The chromospheric flares producing geomagnetic disturbances that have been selected for study are the identical list of 41 flares from 1956-1960 used by Mustel et al. (1965). This list contains the clearest isolated flares for which overlapping by succeeding disturbances is a minimum. The use of the identical list of flares with different meteorological data should provide a firm check on the stated conclusions.

The method used is the well-known superposed epoch analysis, where the key day is the day of the chromospheric flare. The station atmospheric pressures are studied for 5 days before and 10 days after the key day. Provided that the number of events studied is large enough, other causes of pressure variation will be essentially eliminated by the averaging process.

The superposed epoch analyses for the surface atmospheric pressures at each station were repeated five times (for 0000, 0600, 1200, and 1800 local mean times as well as for the average of the four pressures). Only the 1200 LMT pressures were investigated in the Soviet studies. The daily averages are used here in the hope of reducing "atmosphere noise". The other three pressures are studied here in anticipation of possible physical mechanisms, since there is known to be a dawn-dusk asymmetry in the precipitation of electrons from the radiation belts (Frank et al., 1964) and enhanced fluxes of greater than 10 kev electrons are observed near the midnight meridian during times of geomagnetic disturbance (Fritz and Gurnett, 1965).

The uniform absence of a test for the statistical significance of the pressure departures reported by the Soviet investigators represents a serious weakness.

Consequently, in each of the studies to follow, Student's t-test is applied to the difference of each daily mean from the population mean in order to establish the 5 per cent confidence limits. Departures less than two standard deviations from the population mean can be taken to be without statistical significance.

III Results

Figs. 1 to 3 are samples of the superposed epoch analyses at 1200 LMT for a low, middle and high latitude station respectively. These figures, as well as the figures to follow, show a central dotted line at the population mean pressure as well as a dotted line on either side at $\pm 2\,\sigma_m$. The ordinary standard deviation of the mean (σ_m) is computed from $\sigma_m = \frac{\sigma}{\sqrt{N}}$ where σ is the standard deviation of the population and N the number of epochs (41 for an individual station) in the analysis. It represents a lower limit since it is based on the assumption of independence of the data, neglecting the positive autocorrelation known to exist in the pressure data for lags up to a few days. In the composite curves to follow, it represents a lower limit for the more important reason of the neglect of the spatial correlation of the pressure data. It is reasonable to be generous and use the lower limit of σ_m to establish the 5 per cent confidence limits at this stage of the game, since we are interested here less in disproving the

claims of previous investigations and more in uncovering possible solar-tropospheric relationships. However, Figs. 1 to 3 show no consistent behavior of atmospheric pressure following chromospheric flares other than random fluctuations about the mean. The well-known increase in the variance in moving from low to high latitude in North America is apparent. Only random fluctuations about the mean are found in all the other 28 individual stations' superposed epoch analyses (not shown). The curves for 0000 LMT, 0600 LMT, 1200 LMT, 1800 LMT and the daily average are essentially the same at any given station, hence in the following figures only the daily average curve is shown with the hope that this curve represents the minimum of "atmosphere noise".

Since the claims of previous investigators indicate different effects at continental and coastal groups of stations, Figs. 4 to 6 show daily-average composite curves for eastern (11 stations), central (10 stations), and western (9 stations) North American stations respectively. No consistent patterns are found. Figs. 5 and 6 show only non-significant random departures about the mean. Fig. 4 shows two "significant" departures before the key days and two after, that can be attributed to the proximity of several of the eastern stations and the resulting high spatial correlation. Further claims of previous investigators

indicate that solar-tropospheric effects become more pronounced the higher the latitude. Figs. 7 to 9 show daily-average composite curves for low (10 stations), middle (10 stations) and high (10 stations) latitudes respectively. No consistent patterns are seen and nothing but random departures about the mean are observed. Fig. 10 shows a daily-average composite curve for all 30 meteorological stations in North America. (Thule is excluded from the composite curves in the interest of having a homogeneous set of data. The last half of the Thule record is available only for the 0100 LMT, 0700 LMT, 1300 LMT and 1900 LMT pressures.) Nothing but random departures are observed. The comparable figure of Mustel et al. (1965), representing the data from 35 meteorological stations, is reproduced in Fig. 11 along with the superposed epoch analysis of the Ap index for the same chromospheric flares. The use of different meteorological data with the same chromospheric flares apparently fails to reproduce the previous results.

In the interest of verifying conclusion 4 of previous investigators the 41 chromospheric flares are divided into two groups. The first group contains the 13 flares associated with solar proton emission (approximately 1-300 Mev) detected by radio absorption methods. These are known as polar cap absorption (PCA) events. The second group contains the remaining 28 flares that are not PCA events. Fig. 12 shows the daily-average superposed epoch analysis

for all 41 events for the three polar cap stations (geomagnetic latitudes greater than 75°); curve a for Thule, curve b for Resolute Bay, curve c for Frobisher Bay, and curve d as composite curve for all three stations. The analysis is repeated in Figs. 13 and 14 separately for PCA and non-PCA events respectively. Examination of the 12 plot ensemble of Figs. 12 to 14 leads to some interesting conclusions and the only positive aspect of the current investigation.

1) The non-PCA curves for the three polar cap stations (Fig. 14a, b, c) have no individual features in common. This indicates that the physical separation of the stations may be sufficient that their responses to the ordinary transient meteorological variations of the pressure field are essentially independent. No statistically significant departures are observed in the three individual non-PCA curves as well as in the composite curve (Fig. 14d), hence no effects of the chromospheric flares are indicated here.

2)a. Fig. 13 for the PCA events shows negative pressure departures for 8 days following the key days for Thule, negative departures for 8 days following the key days for Resolute

Bay, and negative departures for 5 days following the key days for Frobisher Bay (less clear since Frobisher is on the fringe of the polar cap). The pressure decreases do not quite reach the significant level in the individual curves. However, the composite curve (Fig. 13d) indicates pressure decreases for 8 days following the flares reaching and exceeding the significant 5 per cent level on day 5 following the key days. One is tempted to say that solar flares associated with PCA events produce pressure decreases within the polar cap that start almost immediately after the flare and persist for approximately one week.

b. On the other hand, Fig. 13 shows positive pressure departures for 5 days preceding the key days for Thule, Resolute and Frobisher. The above-average pressures do not quite reach the significant level in the individual curves. However, the composite curve (Fig. 13d) indicates above-average pressures for 5 days preceding the flares reaching and exceeding the significant 5 per cent level on days 2 to 5 before

the key days. One may suppose that preceding PCA flares, when the polar cap is free from solar protons, the atmospheric pressure within the polar cap is significantly higher than the population mean of these figures.

c. The long term trend of Fig. 14 (seen most clearly in Fig. 14a and Fig. 14d) might also be due to solar protons. Small proton events confined to the vicinity of the geomagnetic pole are often missed by ionospheric radio absorption methods, and hence included here with the 28 flares listed as non-PCA events.

3) The composite curve for all 41 events (Fig. 12d) still shows the influence of those flares associated with PCA events.

The results of the current investigation related to flares associated with PCA events support rather closely the previous work of Mustel et al., (1965) and Mustel (1966).

IV. Working hypothesis for further study

The polar-cap pressure decrease following PCA onset is a far-from-established clue to a possible solar-tropospheric relationship. The problem warrants further study, since the benefits to be derived from

uncovering a genuine relationship of this type are so great. To guide further study we have adopted a "working hypothesis", which represents a physical mechanism of how pressure variations at high latitudes might be induced by solar-influenced corpuscular fluxes. Like any hypothesis, it makes certain predictions that can be tested and suggests further studies.

Fig. 15 is an idealized sketch in geomagnetic coordinates of the high latitude region above 50° geomagnetic latitude during a PCA event. The shaded region above 75° is assumed under the influence of high energy solar protons and the annular region represents an approximate auroral zone where particle precipitation from the magnetosphere is a maximum. The heating of the polar-cap lower ionosphere by solar protons in the Mev range causes expansion of the atmosphere and outflow from the polar regions with associated pressure reduction. The heating of the auroral zone lower ionosphere by particle fluxes from the radiation belts should also cause expansion and outflow from the auroral zone with associated pressure reduction. Any predictions for the auroral zone would be almost impossible to check, since this region is continuously a sink for particle fluxes from the radiation belts. The precipitating fluxes not only increase with geomagnetic

activity, but shift to lower latitudes as well. However, the "working hypothesis" predicts that the region in between from about 70°- 75° geomagnetic latitude should be a region where pressure increases are observed during PCA events. There are no stations of the current group listed in Table 1 at these latitudes. A future study will test this prediction for the same 41 chromospheric flares. Additional stations within the polar cap will be analyzed to verify the pressure decrease during PCA events. Other lists of PCA events (Bailey, 1964; Malitson, 1963) will be used with high-latitude meteorological data as an independent check of the "working hypothesis".

It must be obvious that the "working hypothesis" is rather primitive. The location of the axis of rotation of the earth, G. P. (geographic pole) in Fig. 15, is off-center with respect to the heat sources. The dynamic solution for this problem will be complicated, and may later prove to be at variance with the initial statement of the "working hypothesis".

V. Summary

Negative Results:

a. The individual analyses of 31 North American meteorological stations by the superposed epoch method show no statistically significant surface atmospheric pressure departures following chromospheric flares.

b. No evidence is found for claims of previous investigators that continental and coastal stations exhibit different responses to chromospheric flares.

c. No evidence is found for claims of previous investigators that atmospheric pressure responses to chromospheric flares are amplified with increasing latitude.

d. The composite curve for the 30 meteorological stations having homogeneous data shows no statistically significant departures associated with solar flares, and does not verify the composite curve of previous investigators.

Positive Result:

a. Chromospheric flares with PCA events are followed by surface atmospheric pressure decreases (greater than 3 mb) for several days within the polar cap. These pressure changes are found to be statistically significant for the composite of the polar cap stations.

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REFERENCES

Bailey, D.K., 1964: Polar-cap absorption. Planet. Space Sci., 12, 495-541.

Craig, R.A., 1952: Surface-pressure variations following geomagnetically disturbed and geomagnetically quiet days. J. Meteor., 9, 126-138.

Duell, B., and G. Duell, 1948: The behavior of barometric pressure during and after solar particle invasions and solar ultraviolet invasions. Smithsonian Misc. Coll., 110, No. 8, 34 pp.

Fomenko, B. D., 1962: Properties of M-type corpuscular streams, found from analysis of their effect on the troposphere. Astron. Zh., 39, 833-839 (Soviet Astronomy-AJ, 6, 653-657).

Fomenko, B.D., I.V. Bonelis and V.V. Kubyshkin, 1963: Latitude and height dependence of atmospheric disturbances caused by type M solar corpuscular streams. Astron. Zh., 40, 700-702 (Soviet Astronomy-AJ, 7, 534-535).

Frank, L.A., J.A. Van Allen and J.D. Craven, 1964: Large diurnal variations of geomagnetically trapped and of precipitated electrons observed at low altitudes. J. Geophys. Res., 69, 3155-3168.

Fritz, T.A., and D.A. Gurnett, 1965: Diurnal and latitudinal effects observed for 10 kev electrons at low satellite altitudes. J. Geophys. Res., 70, 2485-2502.

Gnevyshev, M.N., and B.I. Sazonov, 1964: Influence of solar activity on processes in the earth's lower atmosphere. Astron. Zh., 41, 937-941 (Soviet Astronomy-AJ, 8, 750-753).

Kaciak, W., and P. Langwell, 1952: Relation between geomagnetic activity and pressure variations aloft. J. Meteor., 9, 409-414.

Kubyshkin, V.V., 1965: Solar activity and pressure variations in the troposphere. Astron. Zh., 42, 784-797 (Soviet Astronomy-AJ, 9, 606-616).

Kubyshkin, V.V., 1966: The distribution of solar-tropospheric disturbances over the earth's surface. Astron. Zh., 43, 374-384 (Soviet Astronomy-AJ, 10, 295-303).

Macdonald, N.J., and W.O. Roberts, 1960: Further evidence of a solar corpuscular influence on large-scale circulation at 300 mb. J. Geophys. Res., 65, 529-534.

Malitson, H.E., 1963: Table of solar proton events. Solar Proton Manual edited by F.B. McDonald, NASA Technical Report R-169, 109-117.

Mustel, E.R., 1966: The influence of solar activity on the troposphere in the polar cap regions. Astron. Zh., 43, 365-373 (Soviet Astronomy-AJ, 10, 288-294).

Mustel, E.R., V.V. Kubyshkin and I.V. Bonelis, 1965: Corpuscular streams and cosmic rays of solar origin and their influence on the troposphere. Astron. Zh., 42, 1232-1249 (Soviet Astronomy-AJ, 9, 957-970).

Sazonov, B.I., 1965: A contribution on the sun-troposphere relation. Astron. Zh., 42, 653-655 (Soviet Astronomy-AJ, 9, 500-502).

Shapiro, Ralph, 1956: Further evidence of a solar-weather effect. J. Meteor., 13, 335-340.

Shapiro, Ralph, 1959: A comparison of the response of the North American and European surface pressure distributions to large geomagnetic disturbances. J. Meteor., 16, 569-572.

Figure Captions

Figure 1 Mean surface pressures preceding and following chromospheric flares for Miami at 1200 LMT

Figure 2 Same as Fig. 1 for Minneapolis at 1200 LMT

Figure 3 Same as Fig. 1 for Churchill at 1200 LMT

Figure 4 Mean of daily-average surface pressures preceding and following chromospheric flares for composite of eastern line stations (excluding Thule)

Figure 5 Same as Fig. 4 for composite of central line stations.

Figure 6 Same as Fig. 4 for composite of western line stations.

Figure 7 Same as Fig. 4 for composite of 10 low latitude stations.

Figure 8 Same as Fig. 4 for composite of 10 middle latitude stations.

Figure 9 Same as Fig. 4 for composite of 10 high latitude stations.

Figure 10 Same as Fig. 4 for composite of all 30 North American stations.

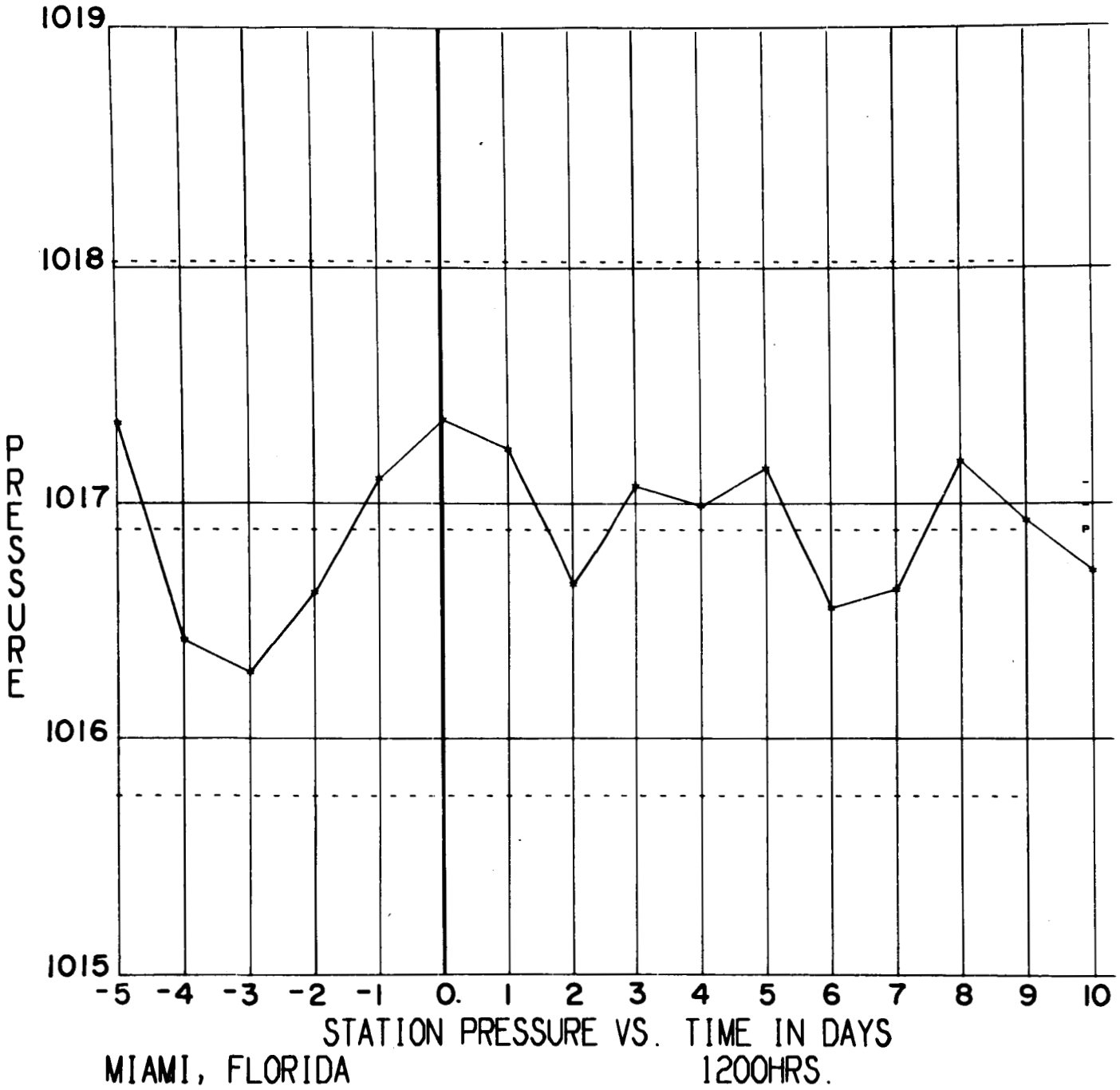
Figure 11 Mean surface pressures preceding and following chromospheric flares for the 35 stations of Mustel et al. (1965) and superposed epoch analysis of Ap index for the same flares.

Figure 12 Mean of daily-average surface pressures preceding and following chromospheric flares for a) Thule b) Resolute Bay c) Frobisher Bay and d) composite of all three stations. The 41 flares are used in the analysis.

Figure 13 Same as Fig. 12 for 13 flares associated with PCA events.

Figure 14 Same as Fig. 12 for remaining 28 flares.

Figure 15 Idealized sketch in geomagnetic coordinates of region above 50° geomagnetic latitude illustrating "working hypothesis".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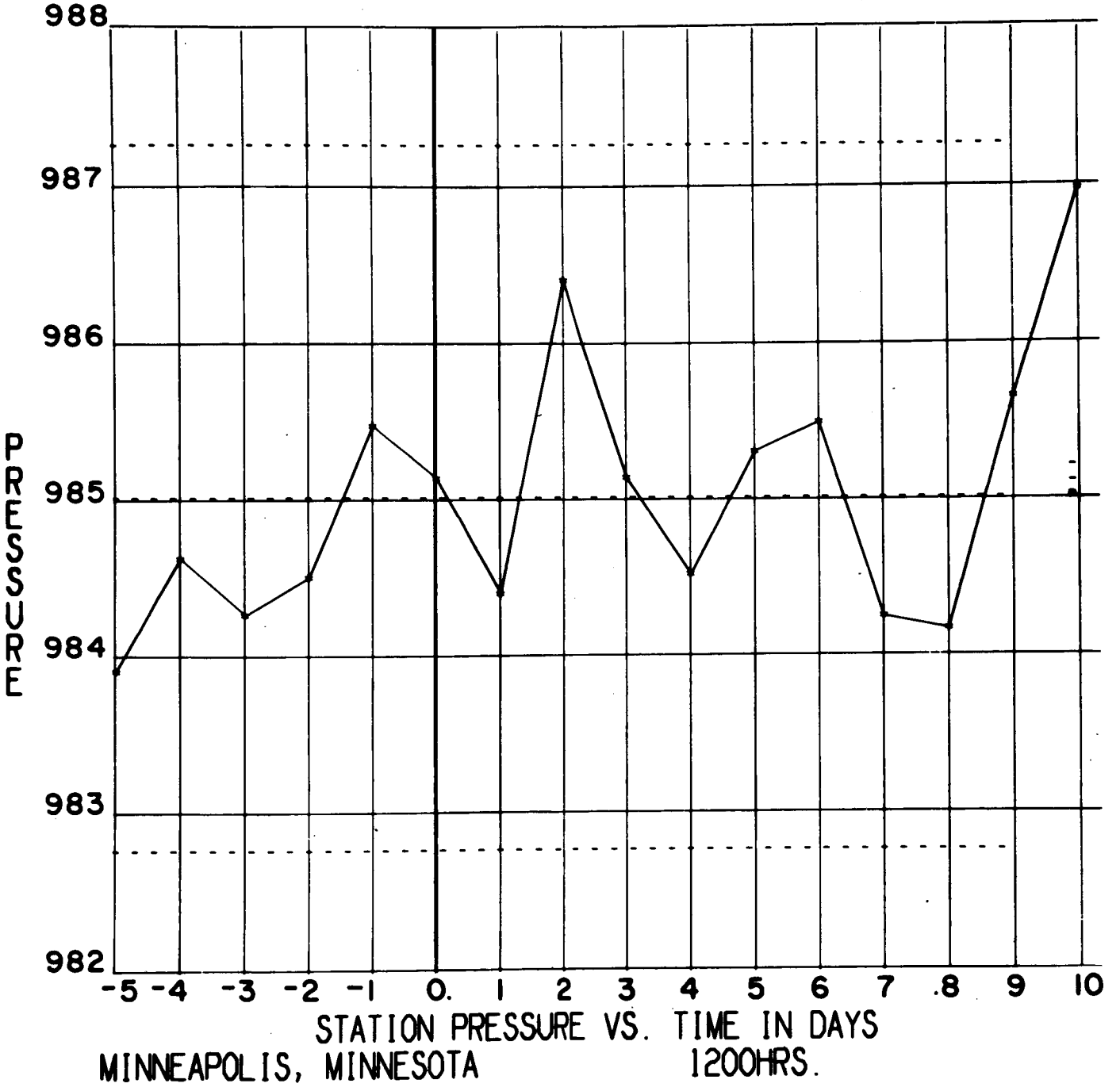
STATION PRESSURE VS. TIME IN DAYS
MIAMI, FLORIDA
1200HRS.

Fig. 1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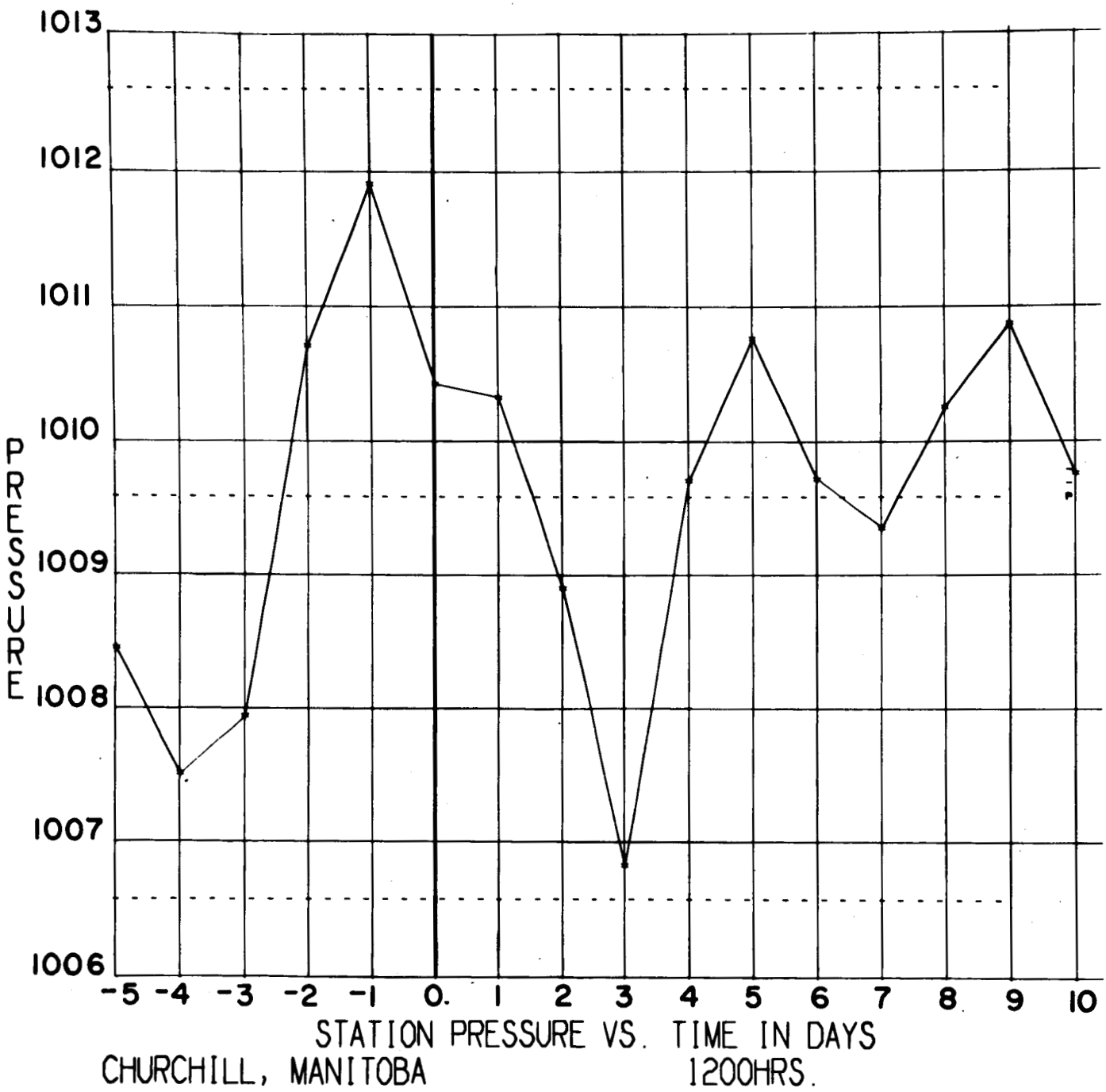
MINNEAPOLIS, MINNESOTA
1200HRS.

Fig. 2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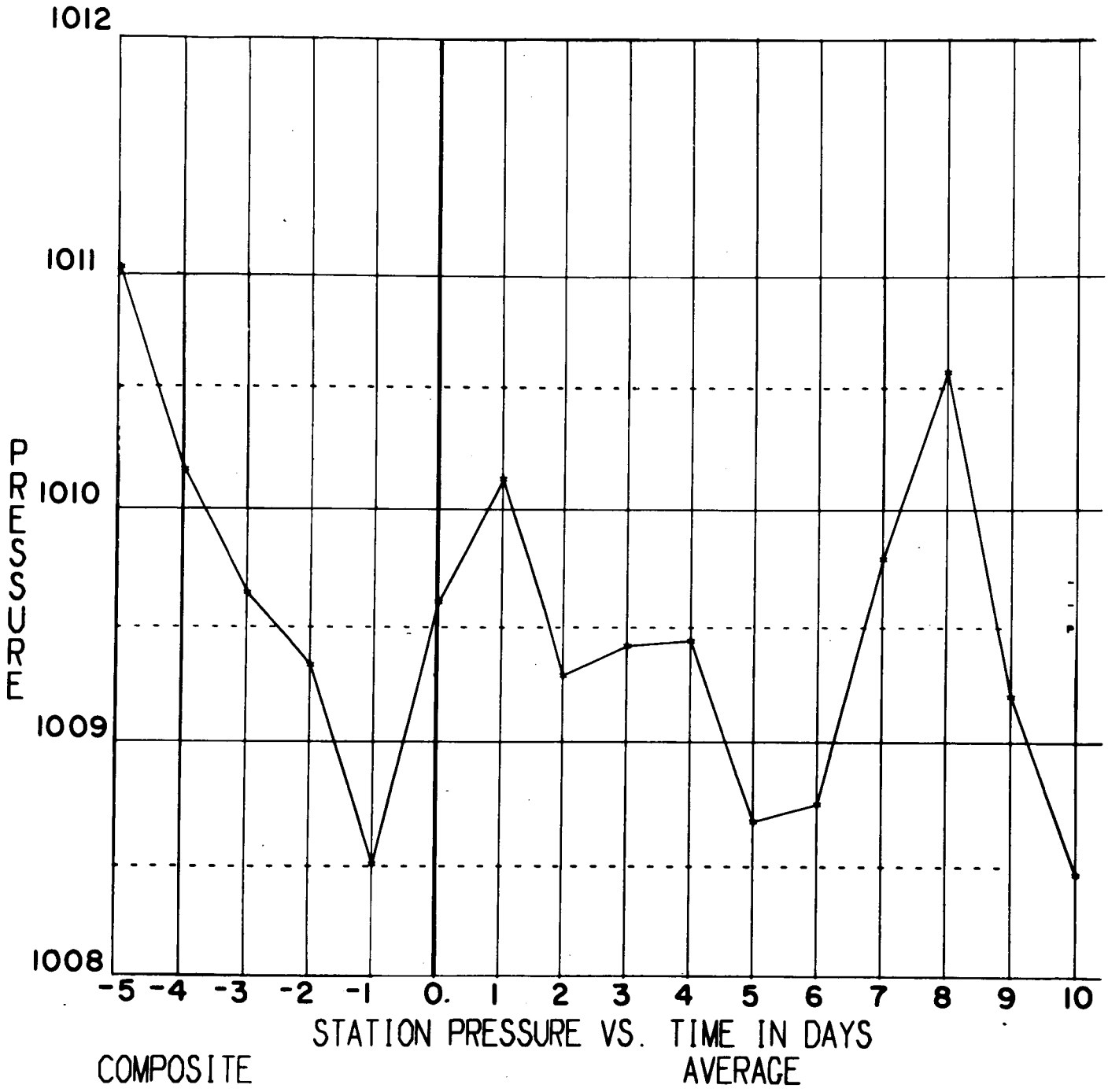
STATION PRESSURE VS. TIME IN DAYS
CHURCHILL, MANITOBA
1200HRS.

Fig. 3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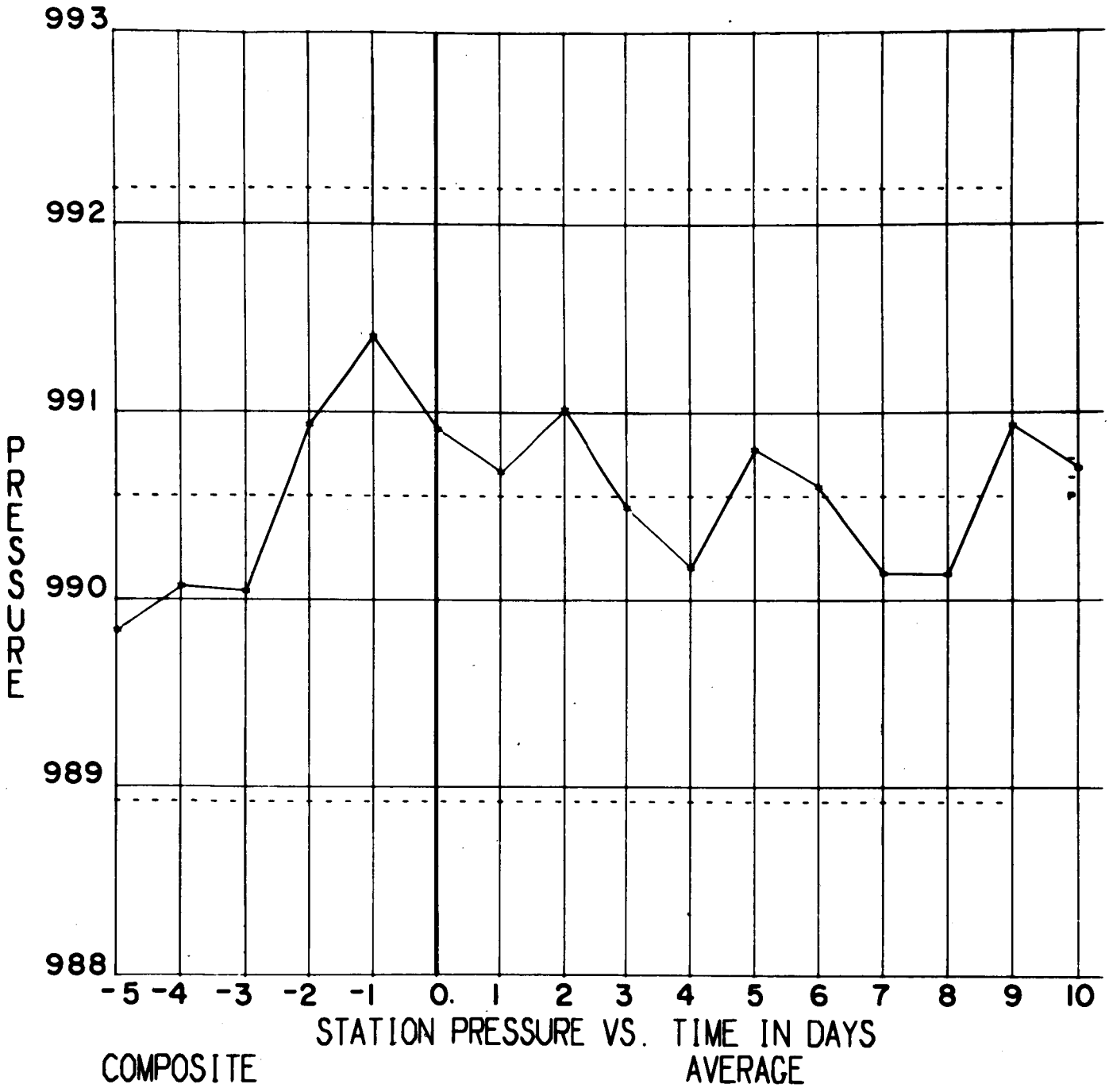
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 4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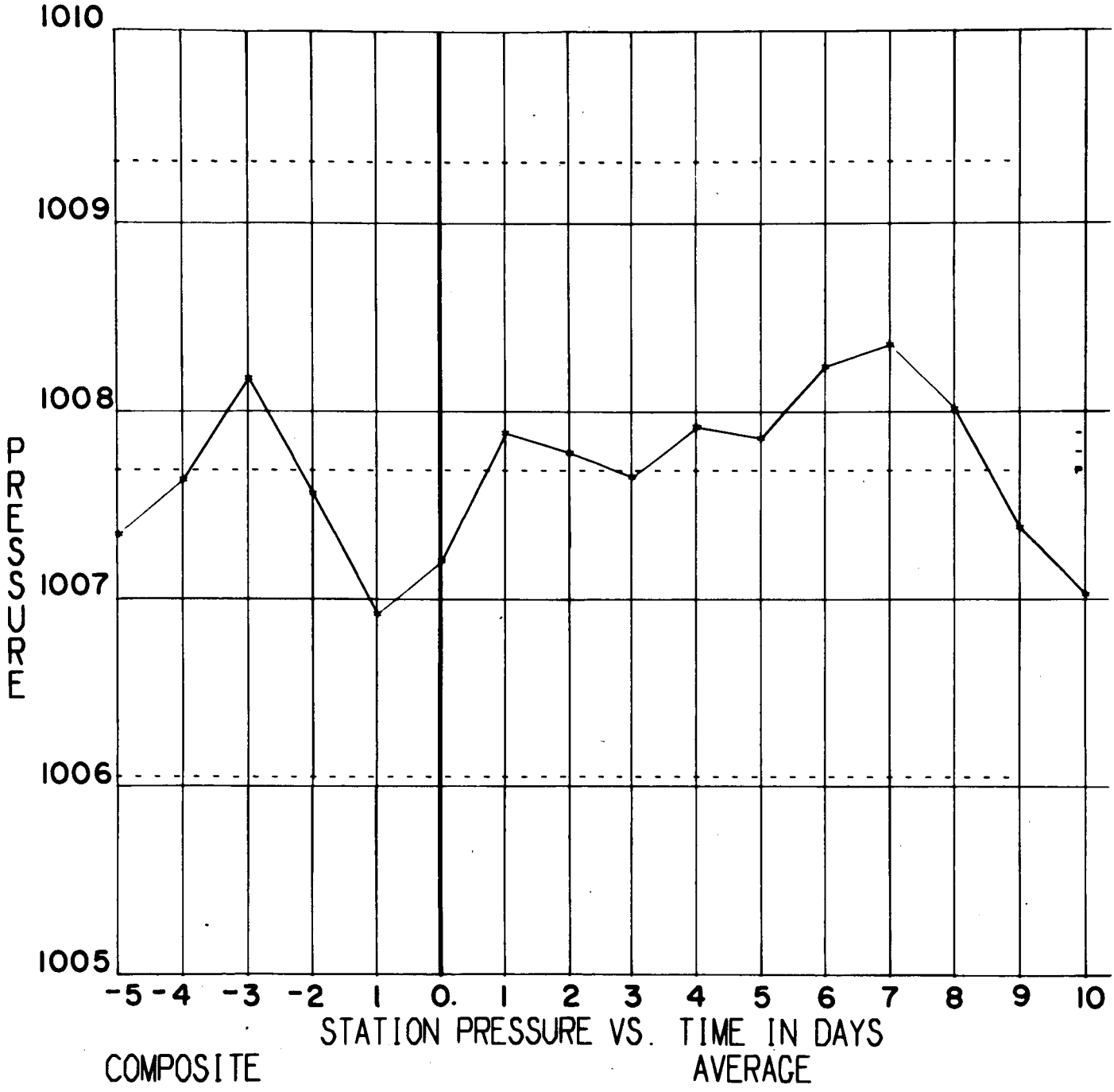
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 5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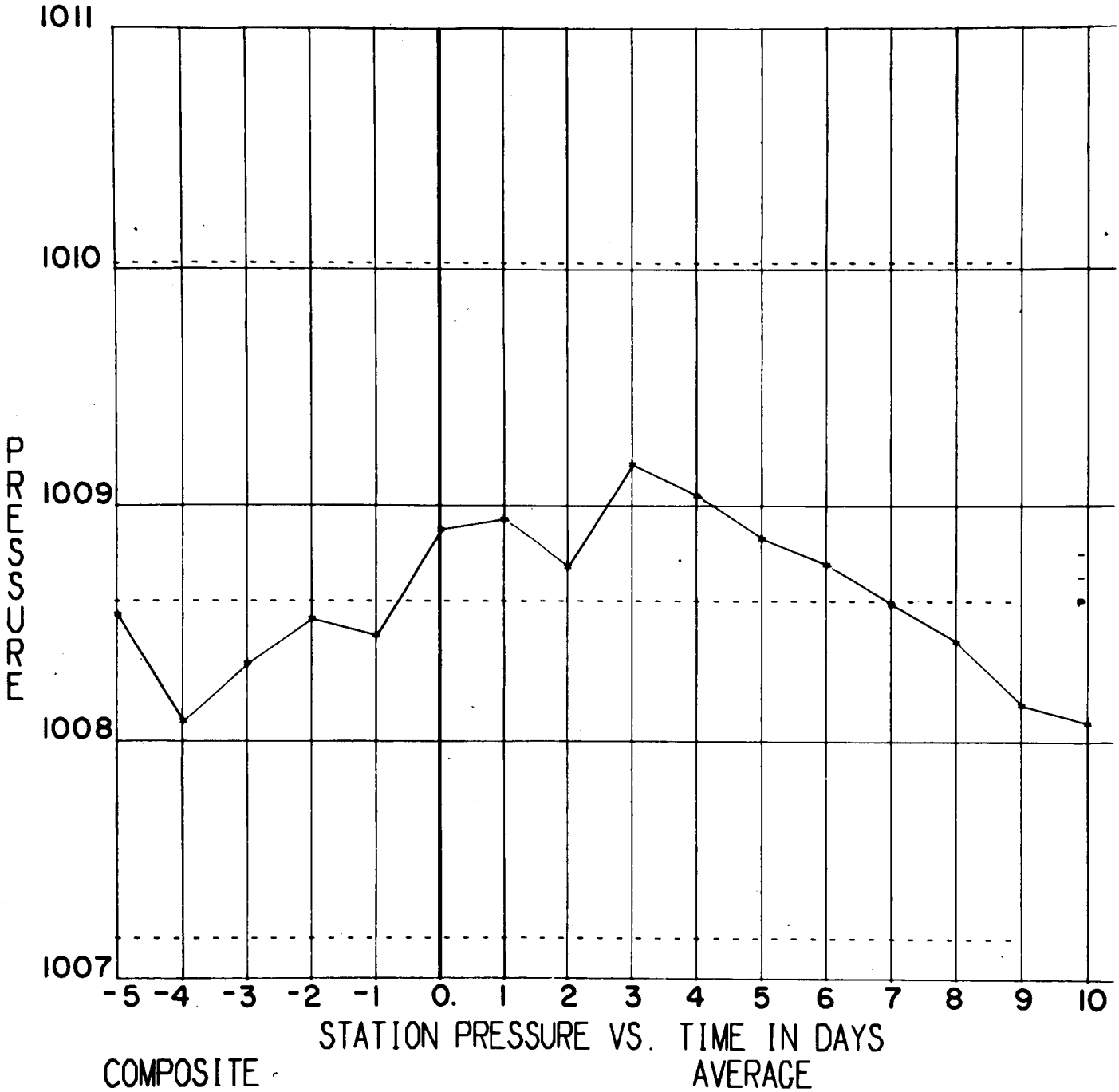
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 6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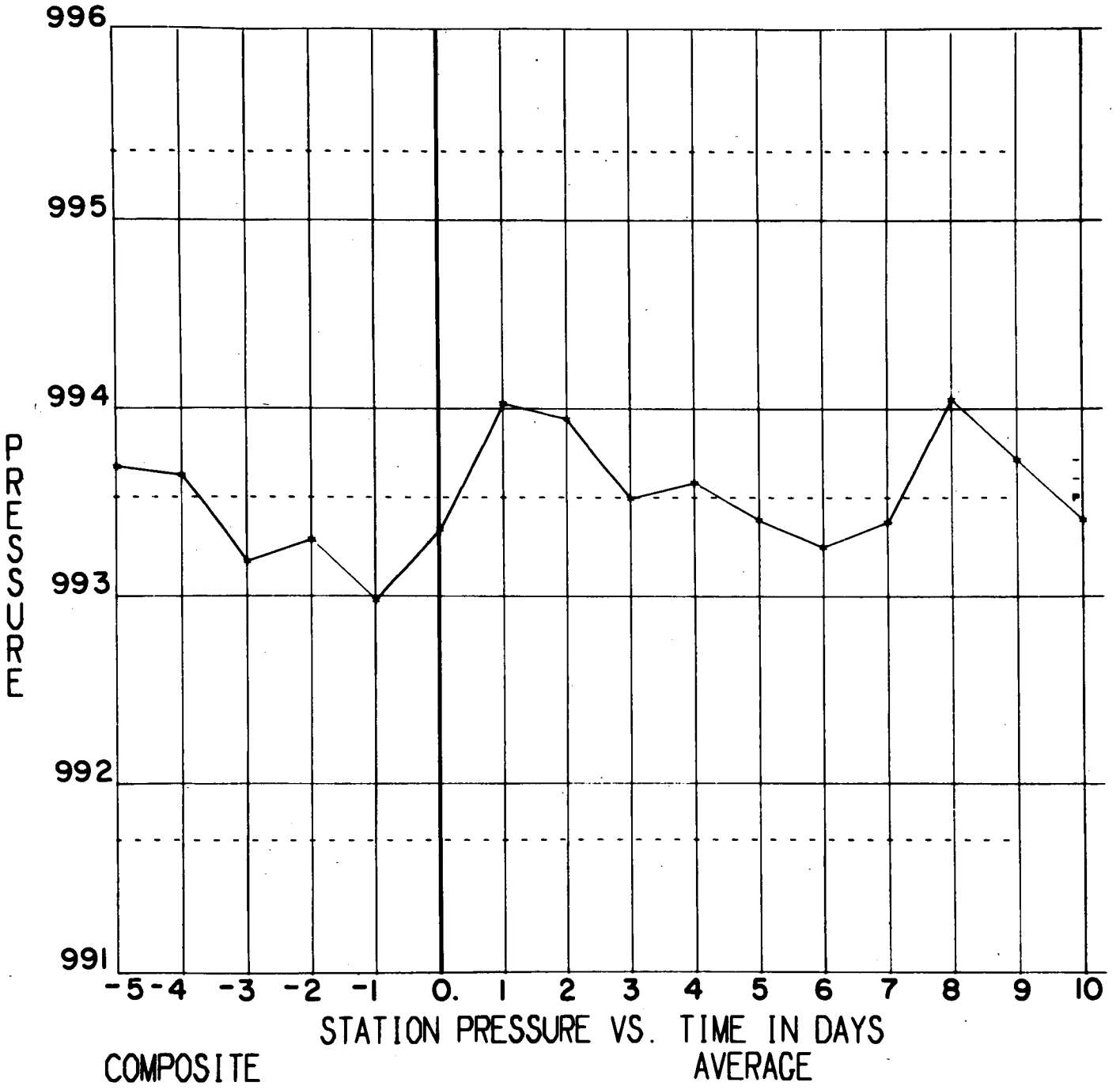
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 7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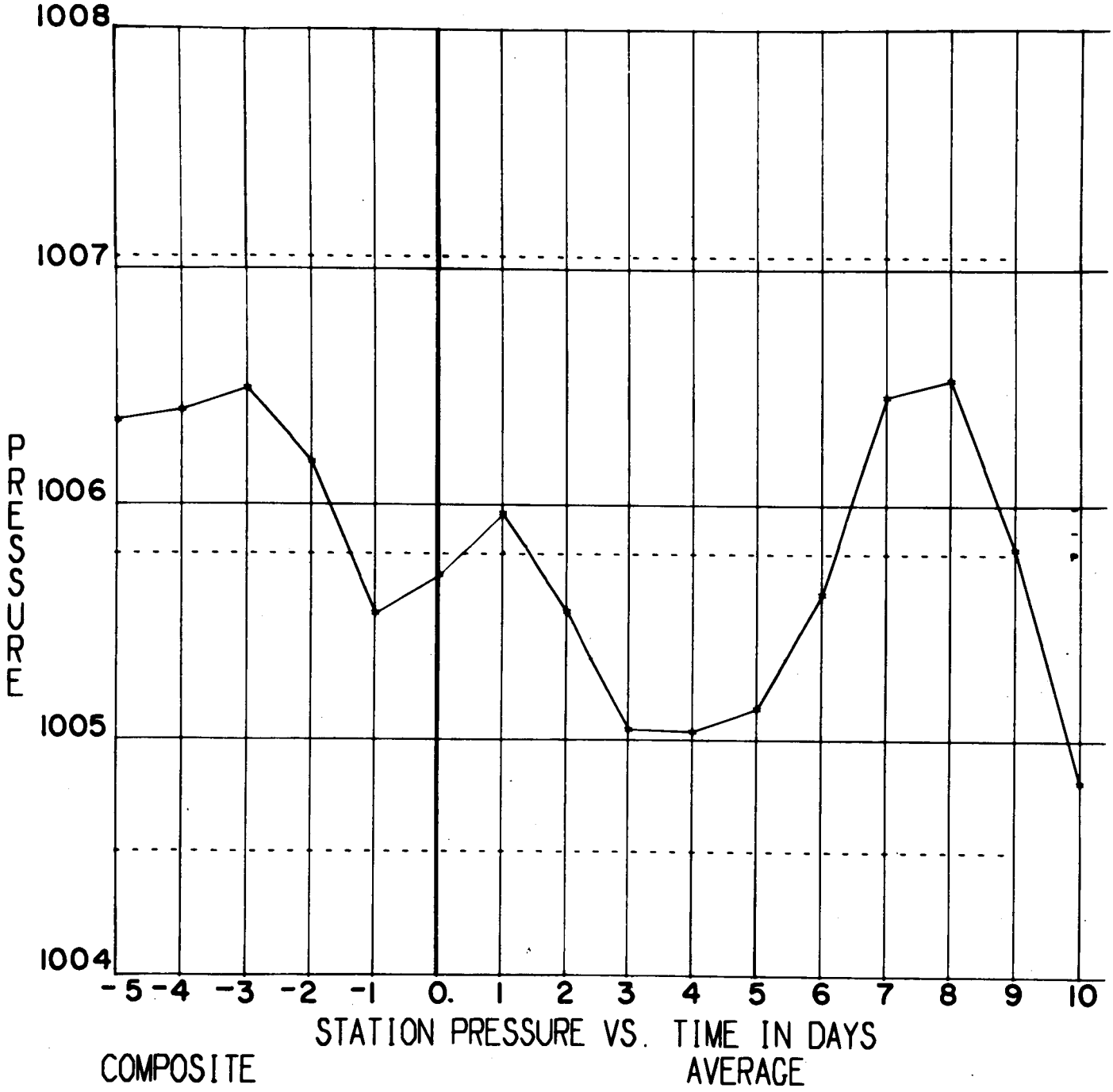
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 8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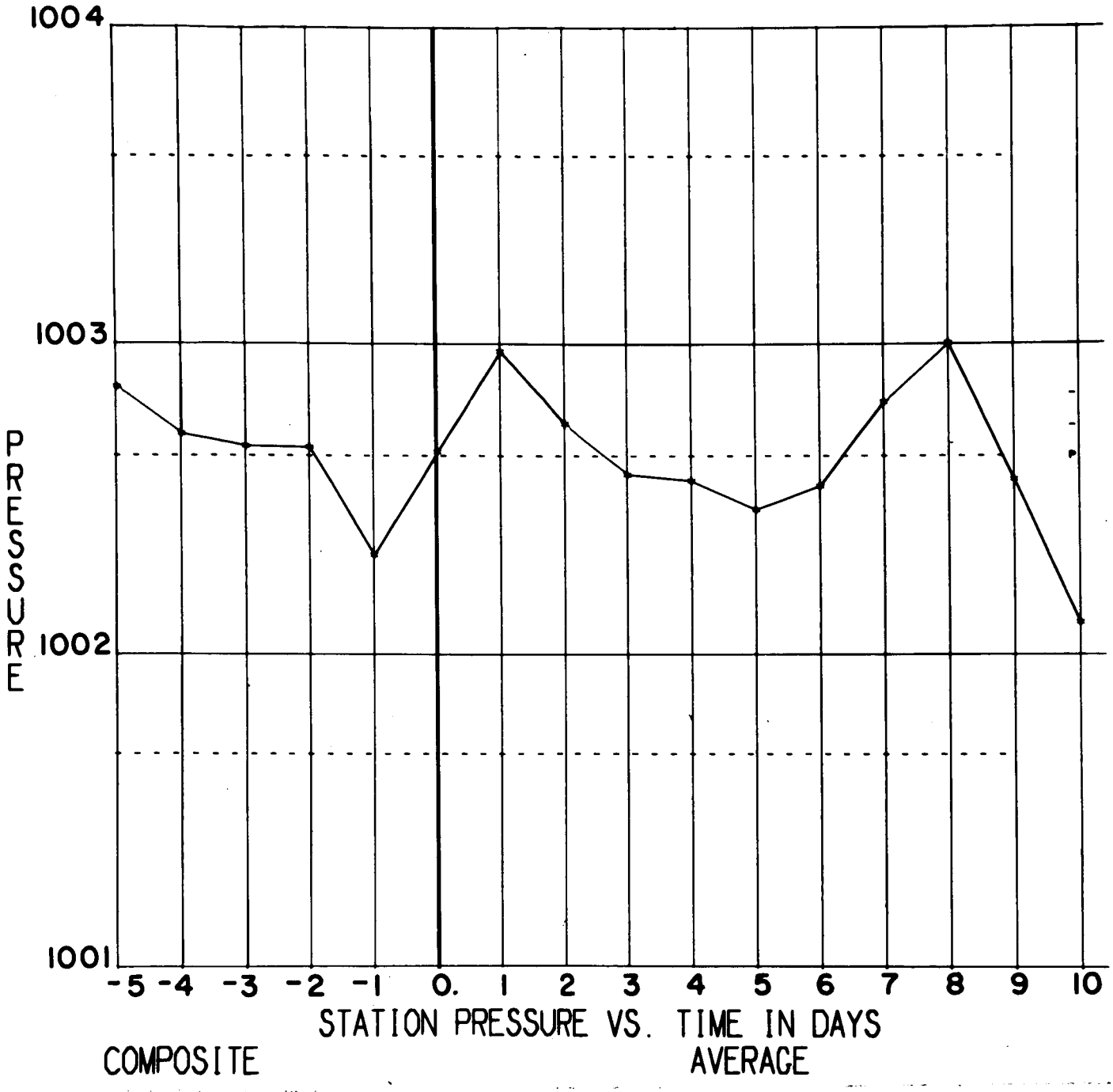
STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig 9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PRESSURE
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STATION PRESSURE VS. TIME IN DAYS
COMPOSITE
AVERAGE

Fig. 10

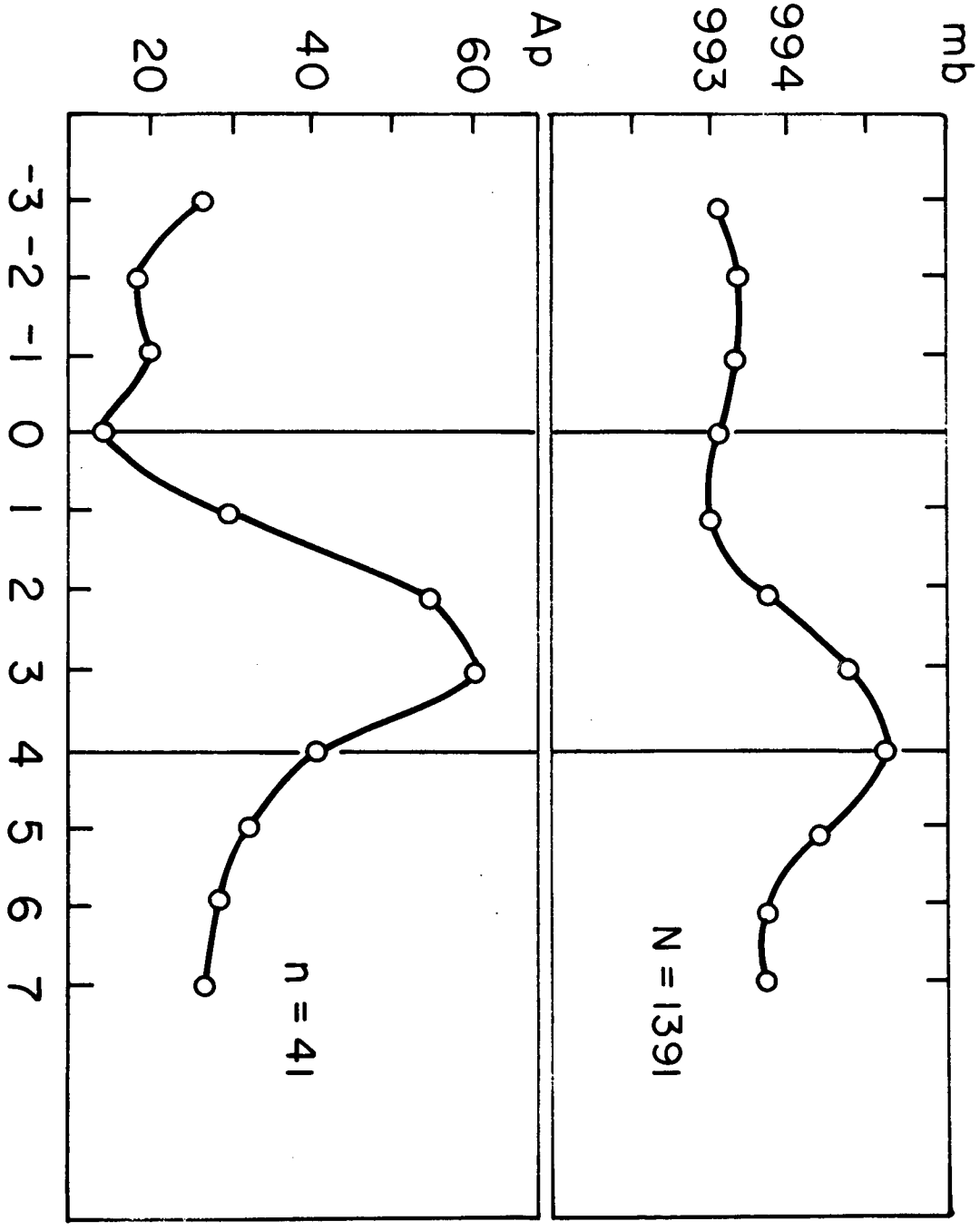

Fig. 11

Fig. 12 Fig. 13 Fig. 14

(a)

(b)

(c)

(d)

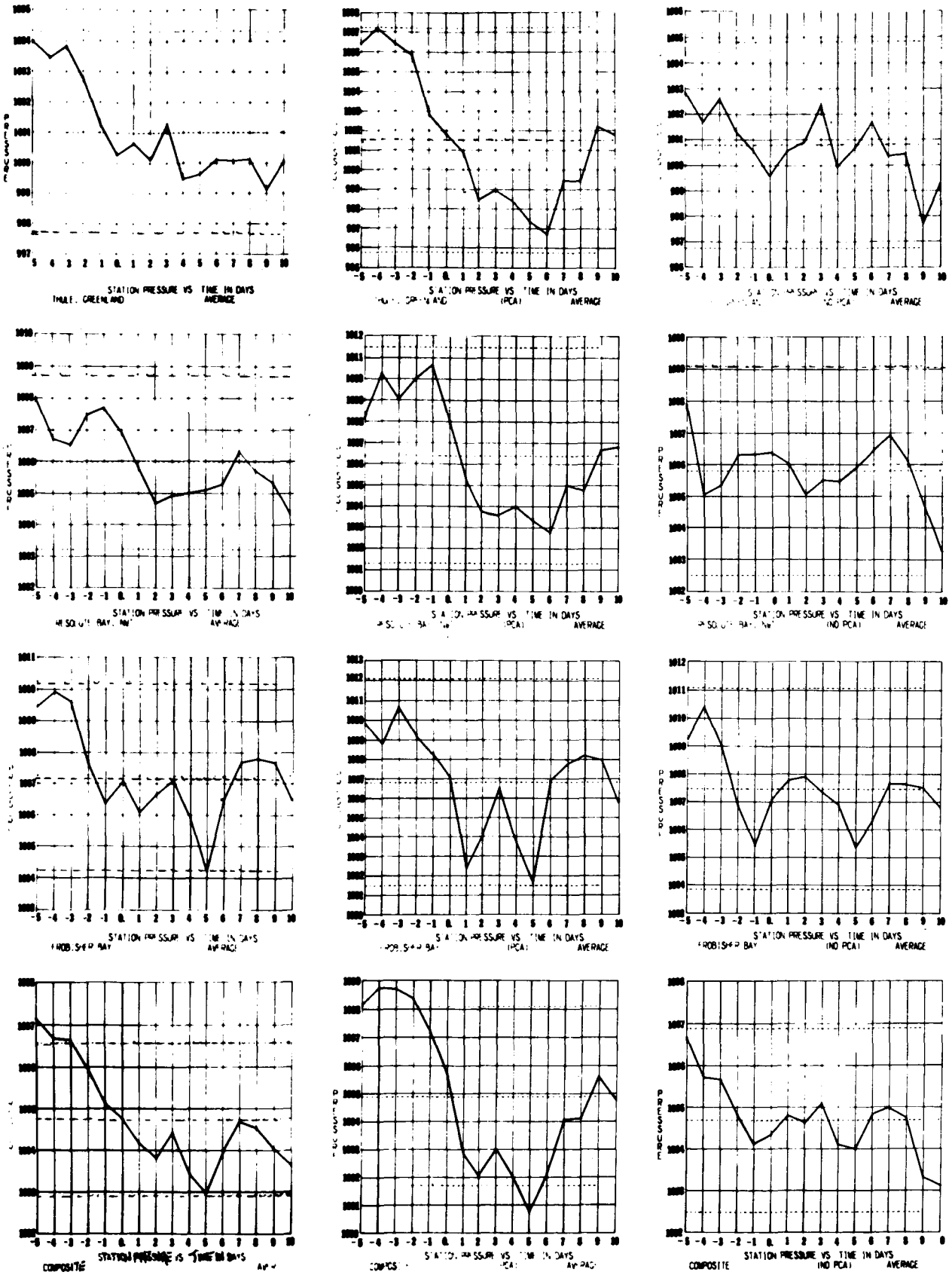

Fig. 12, 13, 14.

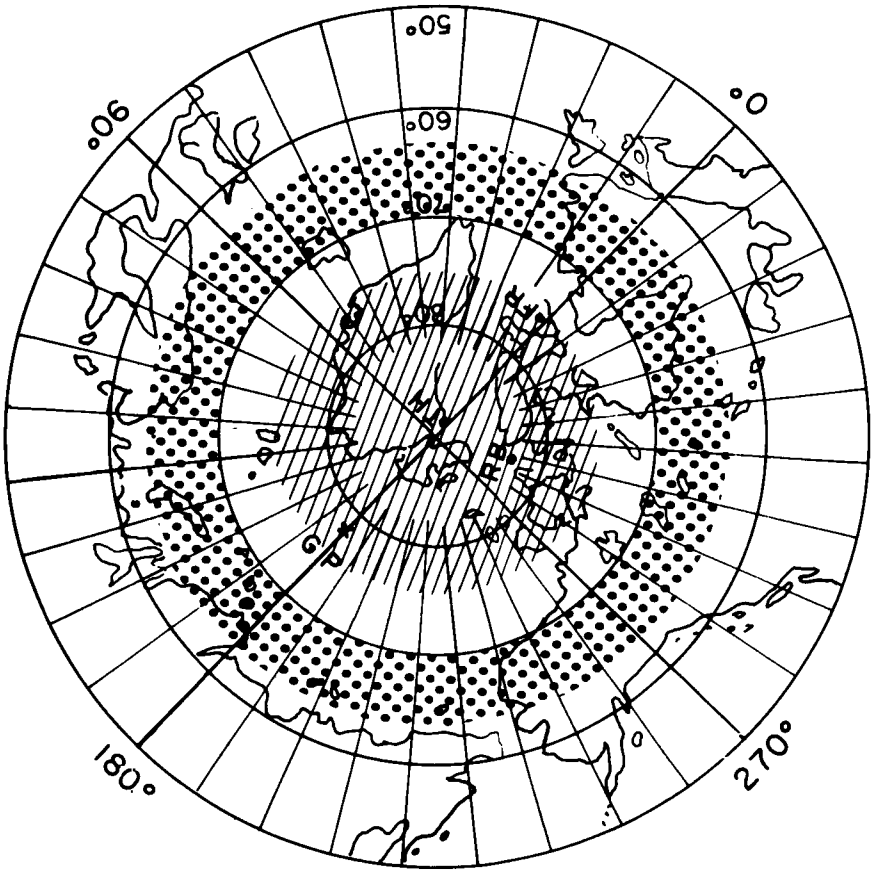

Fig. 15