STRATOSPHERIC TEMPERATURES RELATED

WITH SOLAR ACTIVITY

THESIS

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Preface

With man's entry into space the demands for information on the environment are rapidly increasing. We must determine if man can survive in the regions above our atmosphere and, if so, what protective measures must be taken. We must explore the radiation belts around Earth and measure the cosmic rays both from space and from the sun. Until scientists have thoroughly probed the atmosphere and space above it and identified the environmental dangers, man-in-space will continue to be concerned about the unknowns lurking in the darkness of space.

Information about the atmosphere is obtained from rockets and radiosonde ascents. Rockets ascend to great heights but are sent up infrequently and from widely-separated sites. Radiosondes, on the other hand, reach only to much lower levels but are sent routinely from many stations. The purpose of this effort is to investigate the highest levels being reached by radiosondes to determine if an effect is felt from changes in solar radiation indicated by solar storms. I hope that the work I am reporting in this paper will be useful to other investigators in their efforts to better understand the physical nature of solar radiation.

I wish to thank Major Arthur Vetter for suggestions made and assistance given during the period of study and the preparation of the report. I also wish to thank the U. S. Weather Bureau for the loan of the meteorological summaries which made this report possible.

Loyd C. Garvin

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Abstract

The purpose of this study is to determine if stratospheric temperatures are related with variations in solar activity. Monthly mean 50 mb. temperatures and departures from the mean are determined for selected stations and statistically compared against sunspot and geomagnetic disturbance departures from the mean. Data are divided into summer and winter periods and into three latitudinal regions to determine seasonal and latitudinal variations. 100 mb., 50 mb., and 30 mb. temperatures and 1000 mb. and 30 mb. heights over San Juan are compared against numbers of sunspots. Results indicate that stratospheric temperatures are better related with sunspot numbers than with geomagnetic indicator C_i. Results also indicate a better relationship in low latitudes than in high latitudes, a better relationship in summer than in winter, and an improvement in the relationship with increasing height (over San Juan). Heights at 30 mb. at San Juan show a positive correlation and 1000 mb. heights a negative correlation with increasing numbers of sunspots. It is concluded that increased electromagnetic radiation associated with sunspots increases stratospheric temperatures and high atmospheric densities.

STRATOSPHERIC TEMPERATURES RELATED WITH SOLAR ACTIVITY

I. Introduction

The purpose of this investigation is to determine if stratospheric temperatures are affected by variations in solar activity.

As the annual cycle of solar radiation incident upon the earth's surface gives Earth its seasons, so must variations in solar-energy emissions have an influence upon heating of the earth. To determine if this effect is large enough to be observed in the atmosphere a comparison must be made between reported temperatures and reported solar activity.

The consequence of a direct relationship between these factors is worth consideration. A warming of the atmosphere causes a decrease in density in the region of the warming and a vertical lifting of the air mass above it. This outward push of air results in an increased density in the outer extremities of the atmosphere. Satellites and missiles operating at these levels are subjected to increased drag and a consequent decrease of forward velocity. Since density at the high levels has been assumed to be constant with time in trajectory computations, variations in density could be a serious matter. In ballistic missile operations the increase in drag could mean a decrease in range with the missile falling short of its desired target. In the case of satellites increased drag would result in a more rapid decrease in apogee and a shorter total lifetime.

This study is limited in scope to the comparison of sunspot and geomagnetic disturbance data against stratospheric temperature information as determined from radiosonde reports. It is further limited to the 1951 - 1960 period and to the United States, Alaskan and Puerto Rican data.

Radiosonde data (reports from radio transmitting devices carried aloft by balloons) are now being received from stratospheric regions with ever increasing reliability. However, early in the period (1951 - 1960) the frequency of receipt of data from the stratosphere at 50 millibars (approximately 20 Km) was relatively low. The exact values of derived relationships over this full period, therefore, are subject to question. The general findings, however, are meaningful. Part of the investigation is based on a shorter period of data but with a greater percentage of possible reports with a corresponding increase in validity in relationships found.

This report consists of a statistical determination of correlation coefficients between stratospheric temperatures and sunspots and/or geomagnetic disturbances for latitudinal, seasonal, and altitude variations. The results indicate that stratospheric temperatures are better correlated with sunspots than with geomagnetic disturbance indicators and that the sunspot-temperature relationship varies with latitude, season and altitude.

II. Related Investigations

The inquisitive and reflective nature of man undoubtedly caused the earliest men to wonder how various phenomena about them were related. The foremost of these associations must have involved the sun. The sun appeared, and the temperature rose; it disappeared, and the temperature fell. This relationship, while taken for granted by most, must have intrigued the early "scholars" and caused them to conjecture on the reason for this phenomena. As time went on and men studied the sun more closely they noticed that dark spots appeared on the face of the sun and persisted there for many days. They also noted that these spots appeared and disappeared with a great amount of regularity. These occurrences must have been regarded as of considerable significance by the ancients, for many notations of such are found in the annals of the early Chinese dynasties. Even today, after man has made many discoveries relative to the sun, he is still involved with studies relative to it and its relationship to other happenings known to man.

One of the earliest investigators in recent times, who worked with sunspot information, was Professor Douglas of the University of Arizona. In 1922 he showed that these spots on the sun actually had a direct connection with life on Earth. By comparing the spaces between annular growth rings in trees against the spottedness of the sun he found a direct relationship whereby tree growth was greater during periods of increased numbers of sunspots. At the time it was presumed that greater rainfall actually fell during these periods which caused greater tree growth. However, investigators have been unable to show a direct relationship between rainfall and sunspot numbers. It is possible that other factors than moisture have affected the rate of growth of trees and other vegetation. For example, more sunshine or more ultra-violet light in the solar radiation may have added a stimulation to growth which would not be reflected in a rainfall study (Ref 9:161-168).

The next finding of significance in the study of sunspots was made by Appleton and Naismith. While investigating the fluctuations in the E and F layers of the ionosphere they found that these layers, and by inference the solar ultra-violet radiation causing them, varied directly with the number of sunspots. Between the sunspot minimum of 1933 - 1934 and the maximum of 1937 - 1938 the radiation intensity responsible for the formation of the E-layer was increased by a factor of 2.2, and for the F_1-layer by a somewhat larger amount. This finding was of particular interest to the solar physists for, in contrast to this variation of ultraviolet with sunspots, Abbot and others had shown that in the region of the spectrum directly observable from the ground the sun's output of light and heat was remarkably steady -- the solar constant. Therefore, it was determined that the sun emits a constant amount of observable light but a variable amount of unobservable ultra-violet light (Ref 1:144-148).

Attempts to relate changes in the weather to sunspot numbers have required the efforts of many investigators with variable degrees of success. Clayton, who studied the weather on a world-wide scale, found that sea-level temperatures and pressures over certain regions of the

the earth varied in a manner depending upon the number of sunspots. In the equatorial regions the surface temperatures and sea-level pressures are decreased during periods of maximum sunspot numbers as compared with periods of minimum sunspots. In the higher latitudes the pressures are greater with increasing sunspots, the maximum difference amounting to 0.6 millibars (Ref 9:173).

Willet attempting to explain climatic variations in the past in terms of alterations of circulation types was impressed by the lack of any significant lag-correlations in indices of various features of the circulation and came to the conclusion that the control is not terrestrial but extra-terrestrial (Ref 12:370-381). Shapiro and Ward, following this suggestion, investigated to see if a significant change in the mid-tropospheric circulation pattern (500 millibars) follows large geomagnetic disturbances induced by solar flares. Their results were so obviously negative that they concluded that there was little possibility for the existence of an important relationship between solar corpuscular radiation and either the amplitude or movement of the mid-tropospheric circulation pattern (Ref 7:247-251).

London and others used statistical methods to study the relationship (over a five year period) between geomagnetic storms and height gradients at 100 millibars (approximately 16.5 Km). They concluded that there is no obvious relationship between the two sets of data (Ref 6:1827-1833).

Ward attempted to determine whether a systematic temperature change in or near the Northern Hemisphere auroral zone at 100 and at 50 millibars could be related to anomolous solar corpuscular radiation. The most interesting result at 100 millibars (namely, a maximum temperature departure from normal two or three days after an isolated geomagnetic disturbance) was not in evidence at 50 millibars. He concluded that the absence of a similar maximum at the higher level is reasonably conclusive evidence against a systematic solar effect on the temperature in these regions (Ref 11:256-258).

While studies relating lower-stratospheric temperatures with solar corpuscular radiation have shown negative results, rockets and satellite data in the higher atmosphere indicate that temperature variations exist. The greatest difference in densities (and temperatures) at one place, deduced from rocket observations, occured at Fort Churchill (59° N) between summer days and winter nights. The results differed by more than a factor of ten at 200 Km. Density varied in the Arctic zone depending upon season and time of day. The data showed that at 200 Km the northern atmosphere is two times heavier in the day than at night and two times heavier in the summer than in the winter.

From rocket data over Fort Churchill at 200 Km the summer daytime density (in 1957 at the peak of sunspot activity) was about six times greater than the corresponding density in the temperate latitudes (based on 1951 data when sunspots were near a minimum) (Ref 5:615-623). Since sunspot conditions were not similar at times of these two measurements the suggested latitudinal variation may not be real (Ref 3:1789-1797).

LaGow suggested a reasonable explanation for the diurnal, seasonal and latitudinal variations. During the day, exposure to sun heats the atmosphere and causes an upward expansion producing a large relative increase in the density of the thin air at high altitudes. The effect of solar exposure is greater in summer than in winter and greatest of all during the long day of the Arctic summer when the exposure is nearly continuous (Ref 3:1789-1797).

In addition to this seasonal variation, satellite data has shown large fluctuations of density over periods of a few days or weeks. Jastrow suggests that these variations are a result of atmospheric heating produced by the incidence of streams of energetic particles and radiation from the sun. Furthermore, these fluctuations show a tendency to repeat every 27 days which is the period of rotation of the sun about its axis. Thus it appears that, in addition to the heating and expansion of the atmosphere produced by steady solar exposure, there is a further heating caused by corpuscular or electromagnetic radiation from spots on the surface of the sun (Ref 3:1789-1797).

On 12 November 1960, at approximately the time of occurence of a severe solar storm, the atmospheric drag on Echo I suddenly increased two-fold. The drag remained at this higher level for several days (Ref 4:6). (The average planetary amplitude figure for geomagnetic disturbances rose abruptly from 69 on the 12th to 280 on the 13th and fell again to 49 on the 14th. The relative sunspot numbers rose from the 70's on the 6th to 134 on the 11th and remained at approximately that figure until the 15th and then fell again to the 70's on the 19th.) The increase in drag indicates an increase in density of the air through which the satellite travels. The increase in density is produced by solar particles or electromagnetic radiation heating the atmosphere. The heating causes the outward expansion of the atmosphere with the consequent increase in high level density.

III. Analysis of the Problem

In order to determine if atmospheric temperatures are affected by variations of solar activity, the terrestrial factors which affect the temperatures must first be analyzed and procedures used which eliminate or, at least, minimize the effect. After this has been accomplished a comparison can then be made against reported solar activity.

Vertical Motion of Air Masses

Temperatures can be greatly affected by vertical motion, either because of convection processes or the large scale transport of air masses brought about by convergence at one level and divergence above or below it.

In convection, air is lifted adiabatically from a lower level and cools as it rises at a rate faster than the normal decrease of temperature with height. Convection cells are normally relatively small in extent and unpredictable. Convection, however, is restricted to the atmosphere below the tropopause and is not a factor in the stratosphere.

Unfortunately little is known about convergence and divergence in the stratosphere. Meteorologists have studied this mechanism rather extensively in the lower layers where there is greater moisture content and weather is a consequence. However, above the tropopause only academic interest has been shown. It is generally believed though that vertical motion attributed to this cause is appreciably less in the stratosphere than in the troposphere.

Horizontal Motion of Air Masses

Temperatures are also affected by the circulation of air due to the distribution of pressures over the earth. Cold and warm air masses are continually being advected across regions which would, from solar radiation alone, have a different temperature. The magnitude of this type of change is far greater than that which could be expected from variations in solar radiation. Therefore, even in the stratosphere, it is necessary to deal with advection.

Three things can be done to decrease this effect. First, the intensity of the circulation pattern decreases with height above the tropopause. By selecting the highest possible level for this comparison the effect of advection is decreased. Second, advection has greatest effect in the middle and high latitudes where the contrast between the cold Arctic air and the warmer air masses is the greatest. In the tropical regions, which are very seldom invaded by cold outbreaks, advection is a minor factor. By selecting a reliable reporting station in the tropical regions the circulation effect would be further reduced. Third, the effect of advection can be minimized by averaging reports over a period of time and/or over an area. Cold advection into a particular region may be replaced only days later by warm advection. An averaging of temperature reports over a period of time greatly reduces the extremes. Likewise, while cold advection affects one area, another area 500 miles away may have warm advection. An averaging across the entire region would reduce the advection effect.

Criteria

Therefore, the temperature data used in this study must be from as high a level as possible but definitely from the stratosphere. Where possible it should be from tropical stations and averaged over a period of time. When reports from higher latitudes are used they should not only be averaged temporally but also spacially.

Unfortunately radiosonde data have not been received reliably for the mid-stratosphere except during the most recent years. Prior to 1954 few stations received data from 50 millibars (approximately 20 Km) more than 50 percent of the time. Before 1951 very few reports were received from this level. This study, therefore, must be limited to that period since 1951 with major effort concentrated on data since 1953.

Throughout this study the accuracy of reports of temperatures and solar activity is not questioned. It is assumed that if errors were made in the data these errors are randomly scattered throughout the period of the data and have no bias.

The period of comparison should be lengthy enough so that solar activity shows a wide range of values. Figure 1 indicates that the most recent sunspot minimum occurred in 1954 with a maximum in 1957 - 1958. Figure 2 shows C_i data (characteristic index of geomagnetic disturbance caused by solar magnetic field fluctuations associated with solar flares) had a minimum in 1955 and maxima in 1951 and 1960. The period of comparison, therefore, should extend from 1954 through 1960 if at all possible.

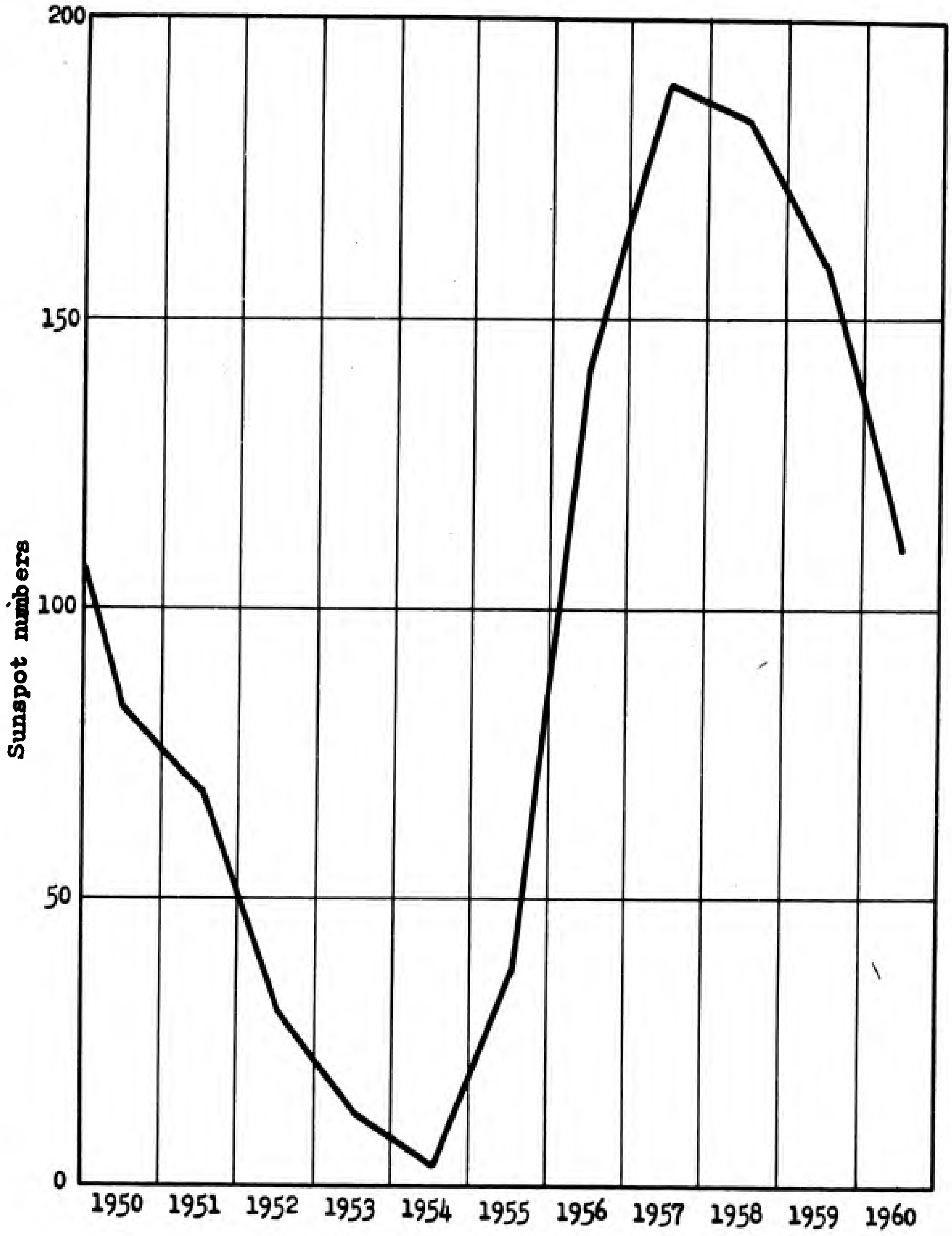

Figure 1. Annual average number of sunspots.

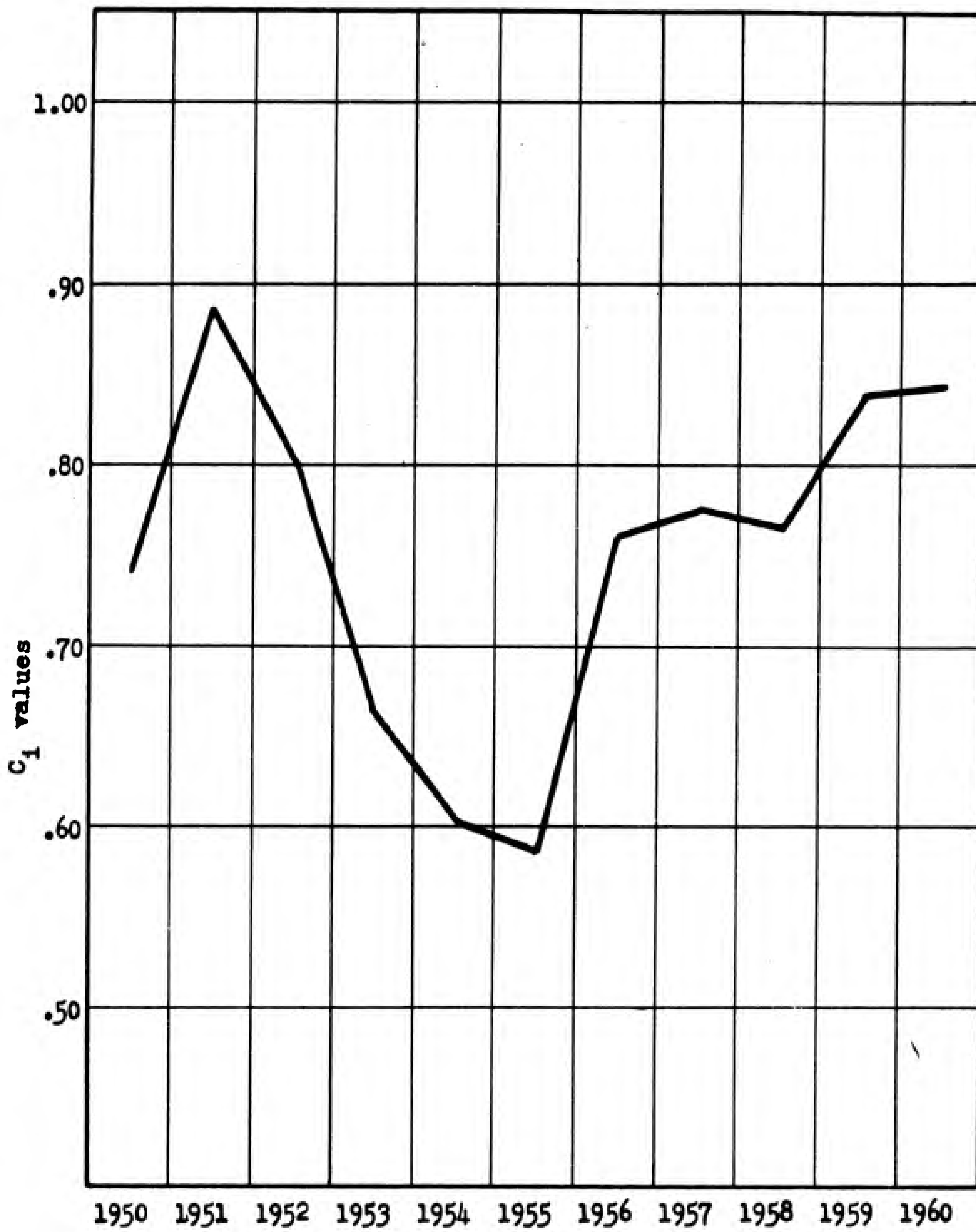

Figure 2. Annual average characteristic index number C_1.

IV. Investigation Procedure

The approach taken was to ascertain if a general relationship between 50 mb. temperatures and sunspots or C_i values could be found. If the relationship existed it should be further examined to see if it varied with height, latitude, season, and time.

The general procedure used was as follows: Select temperature reporting stations which could measure a particular relationship, compute temperature means for each month, and list the departures from that mean. Compute sunspot and C_i mean values for the period and list their departures from the mean. Statistically correlate temperatures with sunspots and/or C_i reports.

Statistical Method Employed

Using the departures from the mean with

$X_i = x_i - \bar{x}$ where x = independent variable

$Y_i = y_i - \bar{y}$ y = dependent variable

N = number of pairs of data

the expression for the correlation coefficient is given as:

$$r = \frac{1}{N} \frac{\sum X_i Y_i}{\left(\frac{\sum X_i^2}{N}\right)^{\frac{1}{2}} \left(\frac{\sum Y_i^2}{N}\right)^{\frac{1}{2}}}$$

A correlation coefficient of 0 indicates no relationship between the variables. A correlation coefficient of ± 1 indicates 100 percent interrelationship.

The regression equation

$$Y = aX$$

with

$$a = \frac{\sum X_i Y_i}{\sum X_i^2}$$

gives a measure of the magnitude of y's dependence upon x.

In this study both the correlation coefficient and the regression coefficient are computed and listed in tables.

The significance of a particular correlation coefficient depends upon the number of pairs of data used in making the computation. If a correlation coefficient of .9 were based on only a very few pairs of data it would not necessarily be a valid relationship when more data are added to it. On the other hand if based upon hundreds of pairs of data the addition of more data would have very little effect upon the previously computed value. In this study significance of coefficients are indicated through confidence limits that the true correlation coefficient based upon infinite pairs of data lies between certain values. In all tables wherein correlation coefficients are listed, 90% confidence limits are also given (Ref 8:173-175).

The regression equation coefficient shown in the tables of this report take on meaning when substituted into the regression equation itself.

$$Y = aX$$

From Figure 1, the range of annual average sunspot numbers between the 1954 minimum and the 1957 maximum is found to be approximately 185. And from Figure 2, the C_i range between maximum and minimum is approximately .30. When these values are substituted for X in the regression equation along with the computed regression coefficients the result is an expression of theoretical temperature difference associated with this range of solar activity.

Data Used

Meteorological data used in this study were taken from "Climatological Data, National Summary" published monthly by the U.S. Department of Commerce. These data consisted of monthly mean values of 1400Z temperatures and height at standard pressure levels over the period from June 1951 through December 1960.

Reports of relative sunspot numbers and geomagnetic disturbances were obtained from the Journal of Geophysical Research for the same period.

Exploratory Comparison

Using the entire period of temperature data from June 1951 through

December 1960 the attempt was made to correlate 50 mb. temperatures against C_i values. Twenty radiosonde reporting stations (with alternates) were selected from the U.S. network. The bands of ten stations across the northern and ten stations across the southern parts of the United States as shown in Figure 3 were used. (Specific stations are listed in Appendix A). All stations were listed for each month and averaged together. Then all like months throughout the period were averaged together to get a mean value for January, a mean value for February, etc. Each full-period monthly mean was subtracted from the comparable individual monthly means to determine the monthly departure from the mean. Figure 4 shows these data. Sunspot data for the period were averaged and departures from the mean were computed. These data are shown in Figure 5. A casual comparison of the figures might suggest that no correlation existed. However, the data were compared statistically by correlation coefficient. C_i values were handled in the same manner and correlated with both the 50 mb. temperatures and with sunspots. The results of this investigation are given in Table I.

The column "90% confidence of r" in Table I indicates the upper and lower limits of "r" which could be expected with 90% confidence, if an infinite number of pairs of data were used instead of the 115 pairs. When the upper and lower limits both have the same sign one can say with 95% confidence that the variables are related with that particular sign. When the signs are opposite, and especially when the mid-point between upper and lower is near zero, the relationship between the two variables is questionable.

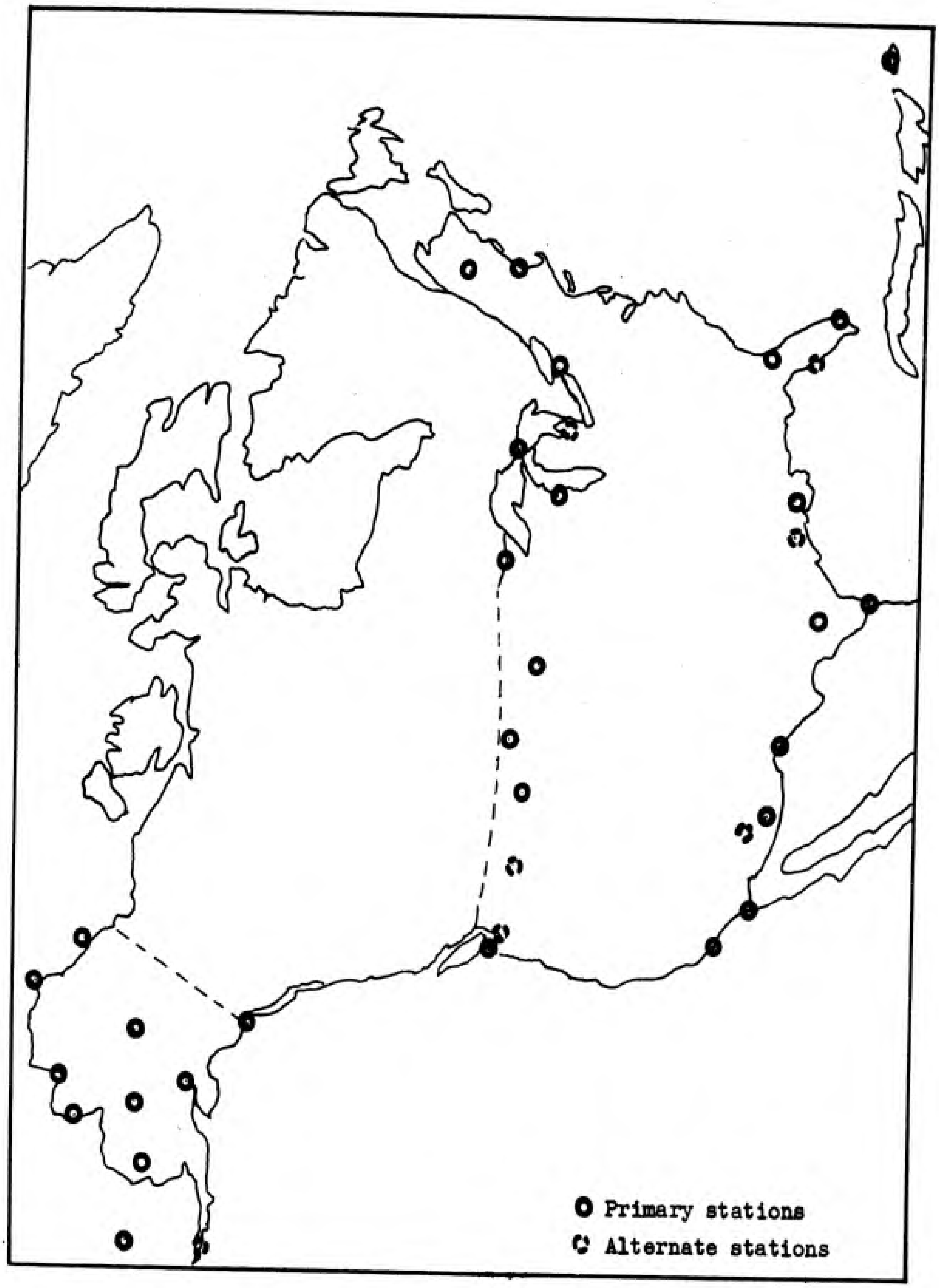

Figure 3. Location of radiosonde stations used in study.

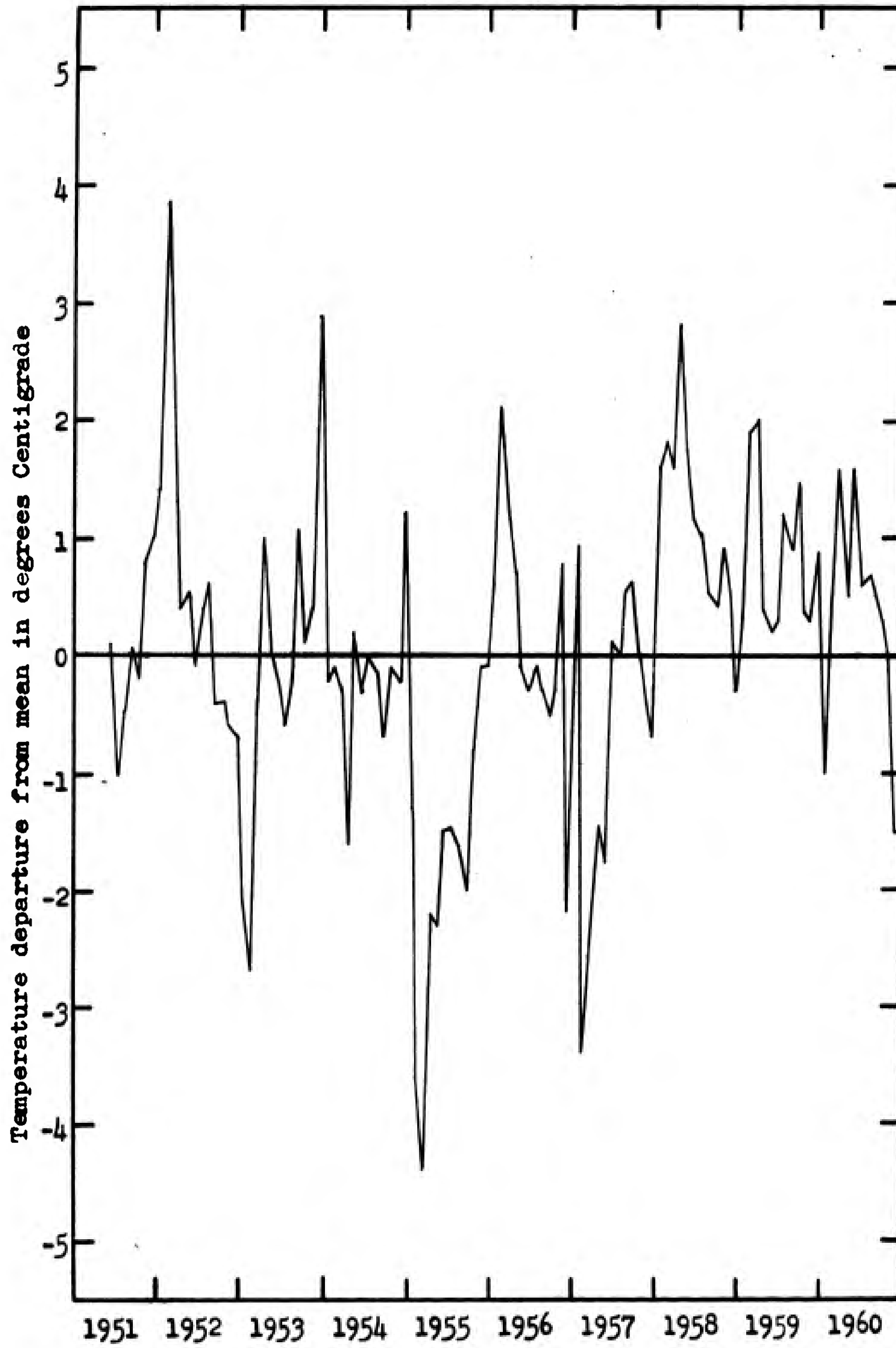

Figure 4. Monthly 50 Mb temperature departure from mean (based on 20 U. S. Stations).

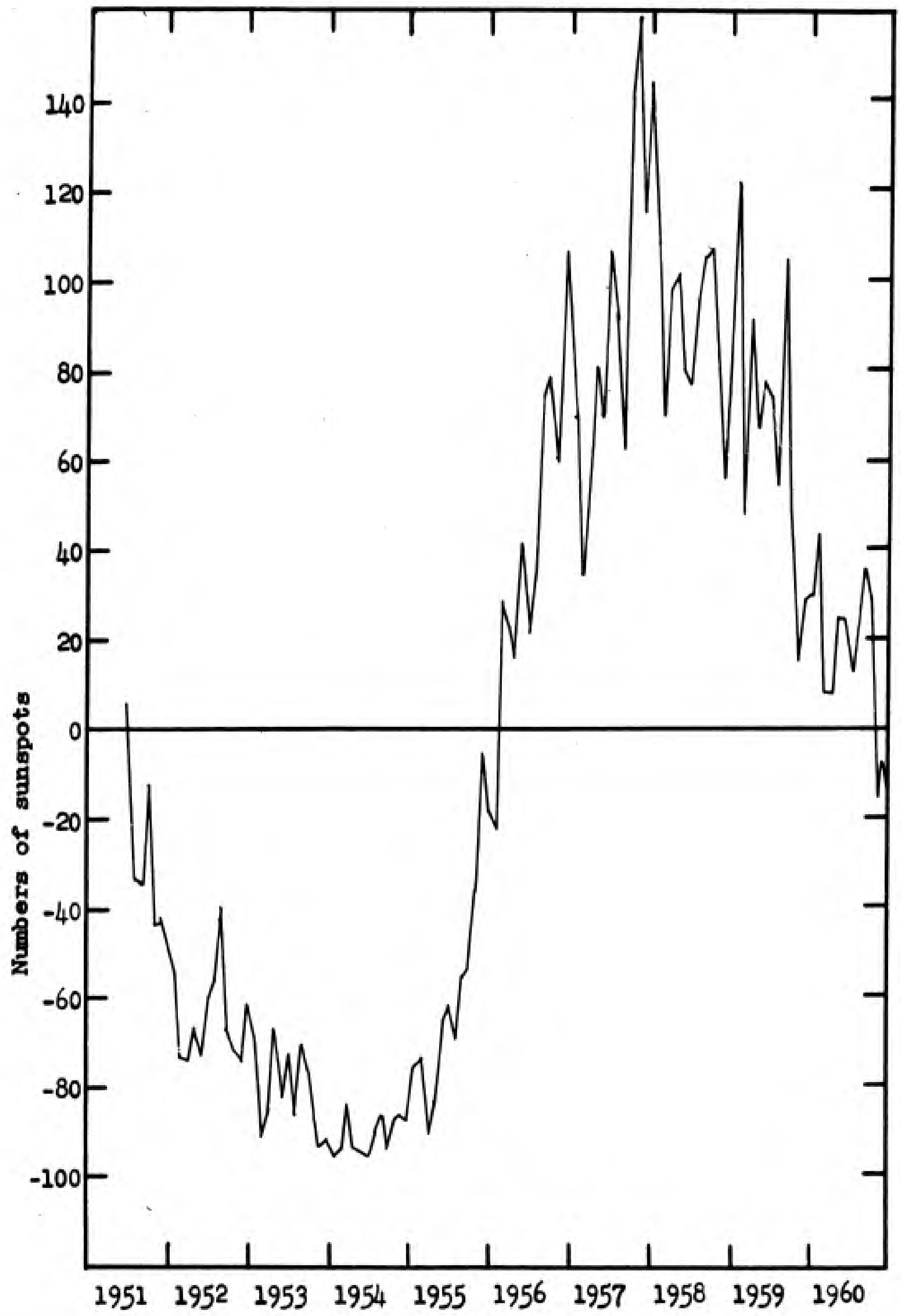

Figure 5. Sunspot number departure from mean (based on mean = 95).

The magnitude of stratospheric warming associated with increased solar activity is determined by substituting the regression coefficient into the regression equation with the range of solar activity representing the independent data. The column labeled "Temp Range" in the table shows the temperature differences computed from the regression coefficient "a" and based on a range of 185 for numbers of sunspots and .30 for C_i values.

Table I

Table of Correlation and Regression Coefficients Relating 50 Mb. Temperatures, Sunspots, and C_i Values over the 1951 - 1960 Period (based on 20 U.S. Stations)

	r			a	Temp Range (°C)
	computed	90% confidence lower	90% confidence upper		
50 mb. temp vs. sunspots	.241	.090	.390	.004	.7
50 mb. temp vs. C_i values	.255	.104	.393	2.04	.6
C_i values vs. sunspots	.281	.132	.418	.001	

This relationship between 50 mb. temperatures and solar activity, both sunspots and C_i, is most encouraging. With more than 90% confidence 50 mb. temperatures can be said to be positively correlated with solar activity since both upper and lower limits are positive. Furthermore, the relationship of C_i with sunspots has been recognized and widely accepted for many years, and, over this period, had approximately the same correlation as stratospheric temperatures had with sunspots. The results of this pilot study warranted further investigation of the relationship.

Latitudinal Variation Study

The next step was to investigate the possible variation of this relationship with latitude. Data from ten Alaskan stations, also shown in Figure 3, were extracted and averaged. Since the availability of Alaskan data in the National Summary was limited to the 1955 and 1960 years, the period of comparison was decreased to those years for all three areas of data. By the same procedure as outlined for the first study, means and departures from means were computed. Figure 6 shows the mean 50 mb. temperature as determined from these six years of data for these particular stations. The variation in the shape of the curves for the three regions suggests that the full effect of advection has not been completely eliminated by the averaging process. The results of this comparison are shown in Table II.

A better relationship existed between 50 mb. temperatures and sunspots at lower latitudes than at higher latitudes ranging from .548 in southern U. S. to .028 in the Alaskan region. The same general relationship was true of 50 mb. temperatures and C_i values except that the extremes were not as great. It should be noted that sunspots and C_i values over this six year period had a correlation coefficient of .280, approximately the same as for the $9\frac{1}{2}$ year period.

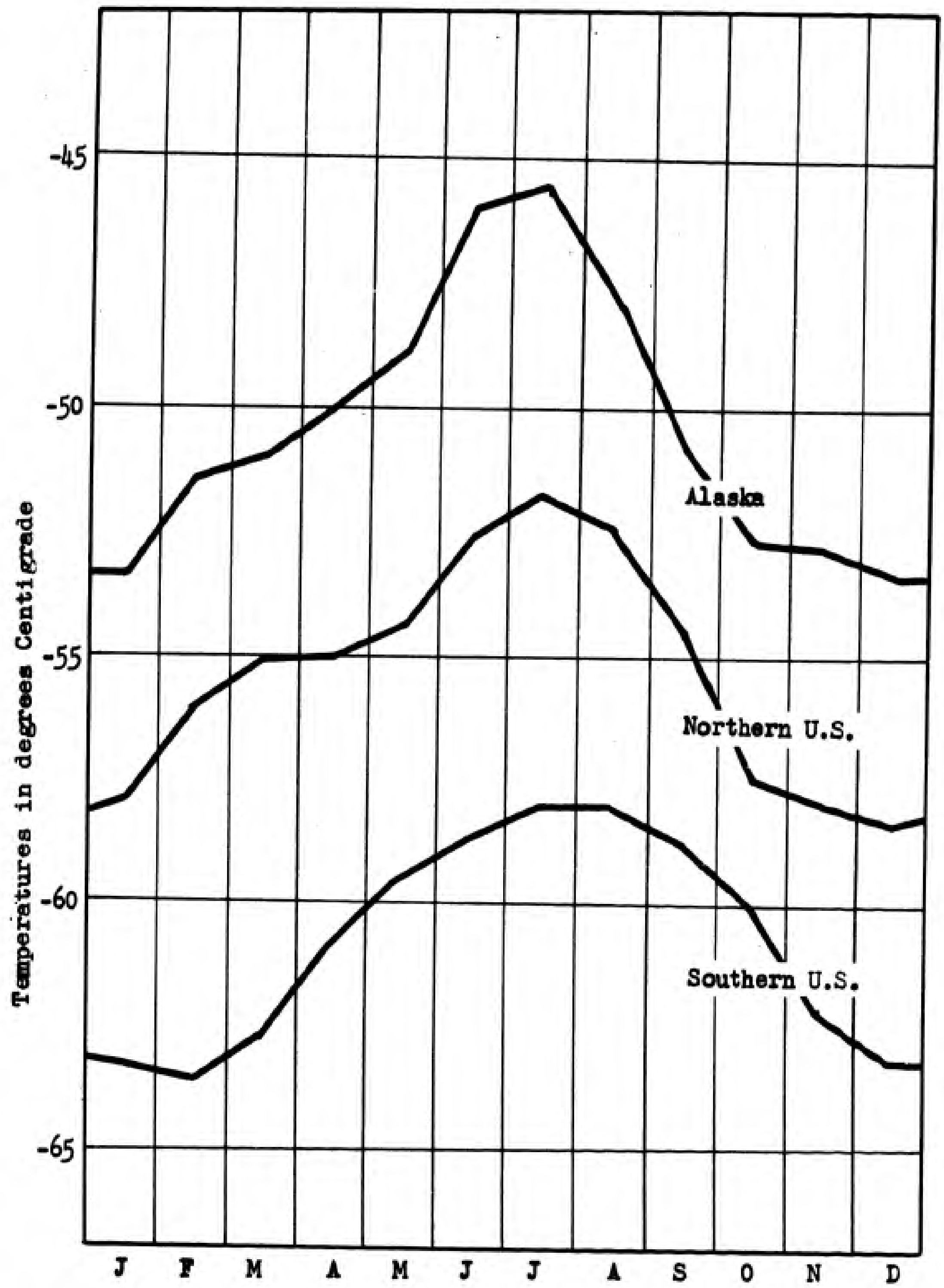

Figure 6. Mean 50 Mb temperatures based on 1955-1960 data.

Table II

Table of Correlation and Regression Coefficients Relating 50 Mb. Temperatures (for Alaskan, Northern U. S., and Southern U. S. Stations) with Sunspots and C_i Values during the 1955-1960 Period

Variables Related	r			a	Temp Range (^oC)
	computed	90% confidence lower	upper		
Alaska:					
50 mb. temp vs. sunspots	.028	-.168	.222	.001	.2
50 mb. temp vs. C_i	.123	-.072	.312	2.03	.6
Northern U. S.:					
50 mb. temp vs. sunspots	.435	.262	.581	.012	2.2
50 mb. temp vs. C_i	.326	.139	.490	3.58	1.1
Southern U. S.:					
50 mb. temp vs. sunspots	.548	.395	.672	.012	2.2
50 mb. temp vs. C_i	.443	.225	.554	3.91	1.2
C_i values vs. sunspots	.280	.090	.452	.001	

Seasonal Variation Study

Since the relationship varied so markedly with latitude one should expect to find a seasonal effect also. The position of the sun relative to the regions involved apparently determined the dependence of 50 mb. temperatures on solar activity.

The data used in the latitudinal study was divided into summer and winter categories and the same procedure used to find coefficients. Winter data included reports for the months of October through March. Summer included the months of April through September. Table III shows the seasonal variation in the relationship at different latitudes.

Table III

Table of Correlation and Regression Coefficients Relating 50 Mb. Temperatures (for Alaskan, Northern U.S., and Southern U. S. Stations) with Sunspots for Summer and Winter

50 Mb. Temp vs. Sunspots	r			a	Temp Range (°C)
	computed	90% confidence lower	upper		
Alaska:					
Year	.028	-.168	.222	.001	.2
Winter	.011	-.248	.267	.001	.2
Summer	,081	-.180	.333	.002	.4
Northern U.S.					
Year	.435	.262	.581	.012	2.2
Winter	.244	-.014	.473	.007	1.3
Summer	.682	.515	.799	.018	3.3
Southern U.S.					
Year	.547	.395	.672	.012	2.2
Winter	.575	.373	.726	.015	2.8
Summer	.555	.348	.712	.009	1.7

Height Variation Study

To test the dependence of the relationship on height it is necessary to find reliable information for various levels in the stratosphere over an extended period of time. San Juan, Puerto Rico was selected as the best station for this purpose. San Juan is in the tropical zone which undergoes little change in temperature from advection. Therefore, the station could be used without spacially averaging its reports with other neighboring reports. It has a relatively long period of consistently reporting to heights as high as 30 mb. (approximately 24 Km.). Since it was found earlier in the study that the relationship is stronger in the low latitudes the values at San Juan should be large enough to show a vertical variation if it exists.

The number of reports available from San Juan were studied to determine the length of period for the comparison. Figure 7 shows the average number of reports received from the 30 mb. level during the $9\frac{1}{2}$ years of data. Since from 1954 through 1960 at least 50 percent of the possible reports were received, this period was chosen for comparison. The number of reports reaching 20 mb. (approximately 26.5 Km.) was so greatly reduced, except in the most recent period, that the comparison at 20 mb. was not attempted.

Data from 100 mb., 50 mb., and 30 mb. were treated in the same manner as previously described. Figure 8 shows the monthly mean values of the temperature at these three levels over the seven year period. Note that above the tropopause the temperatures increase with height. The tropopause at San Juan is normally near 100 mb. The correlation and regression coefficients for temperatures at these three levels, as compared against sunspots and C_i values, are given in Table IV. An insufficient number of high latitude reports reaching 30 mbs. precluded the determination of altitude variation with latitude.

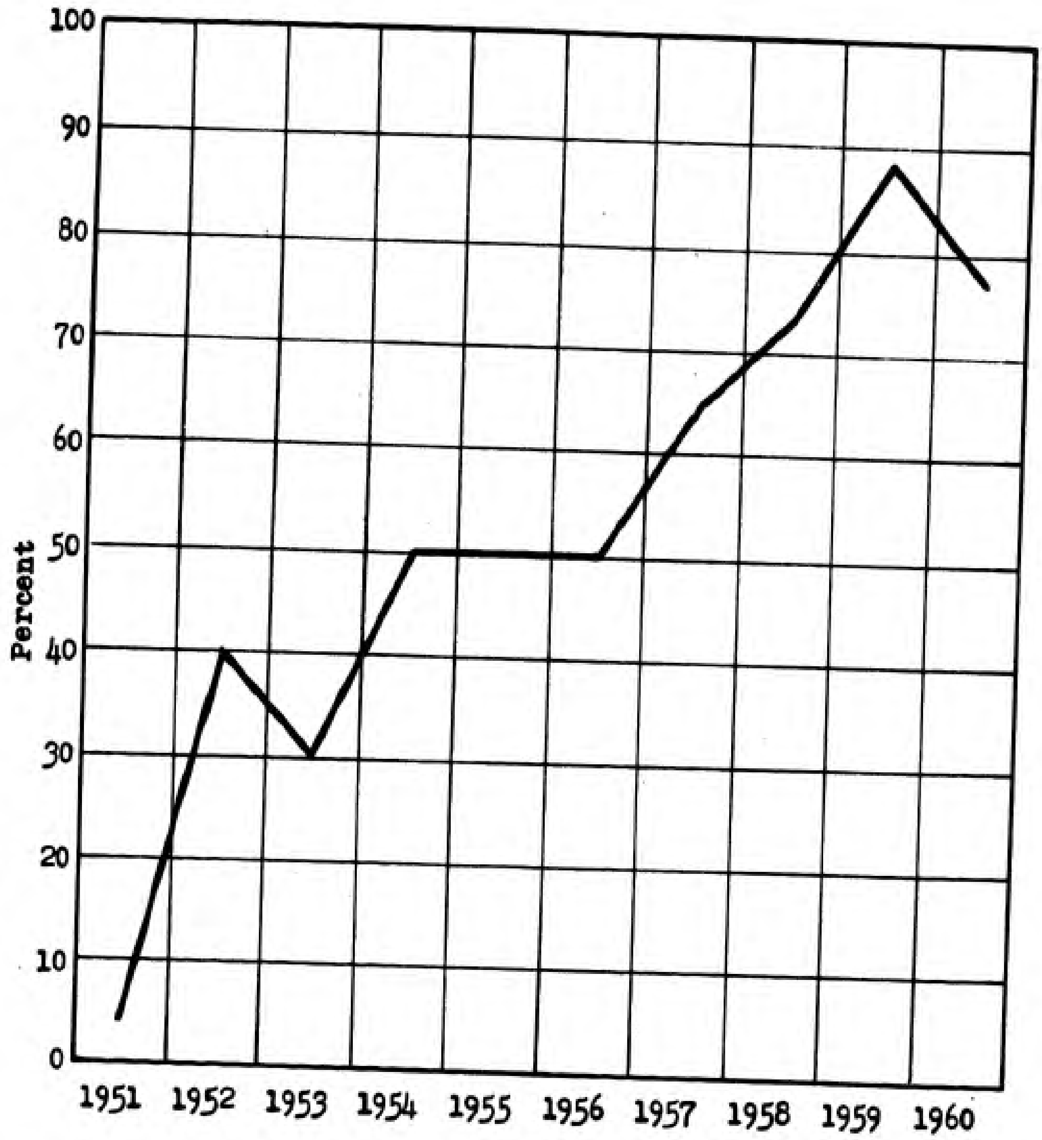

Figure 7. Percentage of possible San Juan radiosonde observations reaching 30 Mb.

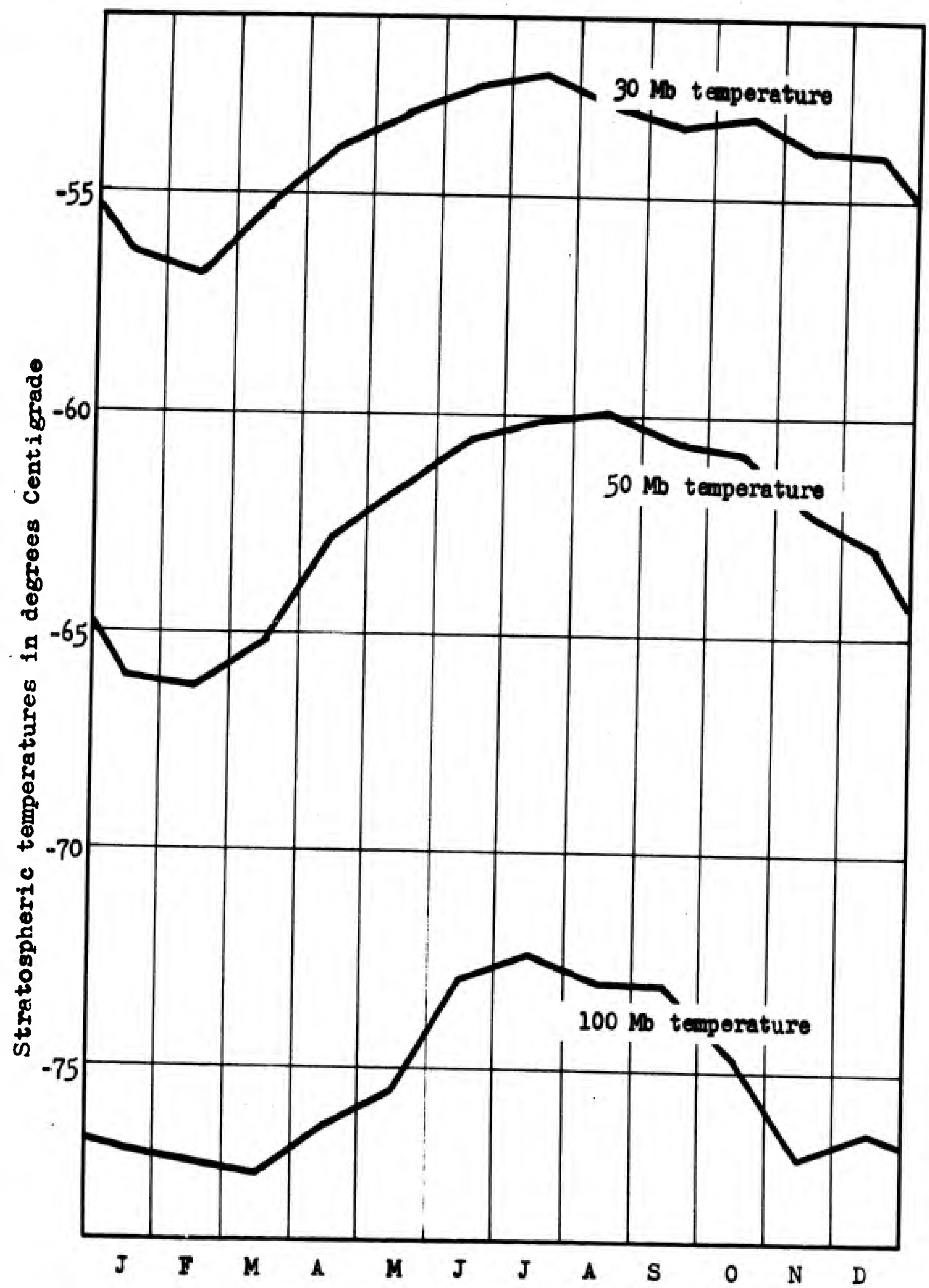

Figure 8. Monthly mean temperature over San Juan during 1954-1960 period.

Table IV

Table of Correlation and Regression Coefficients Relating 100 Mb., 50 Mb., and 30 Mb., Temperatures with Sunspots and C_i Values at San Juan during the 1954-1960 Period

Variables Related	r			a	Temp Range (°C)
	computed	90% confidence			
		lower	upper		
100 mb. temp vs. sunspots	.118	-.064	.293	.002	.4
50 mb. temp vs. sunspots	.438	.280	.574	.007	1.3
30 mb. temp vs. sunspots	.592	.460	.695	.015	2.8
100 mb. temp vs. C_i	.043	-.139	.223	0.29	.1
50 mb. temp vs. C_i	.169	-.012	.340	1.26	.4
30 mb. temp vs. C_i	.390	.225	.534	4.20	1.3

Time Variation Study

Since all values of temperatures used in this study were monthly means, it was not possible to determine the actual time lag required for sunspot activity to result in a change of stratospheric temperatures. The study of individual daily temperature reports is beyond the scope of this investigation. However, an attempt was made to ascertain, within the limitations of monthly data, the general rate of response. Sunspot data was correlated against 100 mb., 50 mb., and 30 mb. temperature data one month later. Table V is a comparison of correlation coefficients against stratospheric temperatures of the corresponding month and one month later at San Juan

Table V

Table of Correlation Coefficients Relating Sunspots with 100 Mb., 50 Mb., and 30 Mb. Temperatures for the Corresponding Month and One Month later at San Juan

Variables Related	Temp in corresponding month	Temp one month later
100 mb. temp vs. sunspots	.118	.175
50 mb. temp vs. sunspots	.438	.354
30 mb. temp vs. sunspots	.592	.565

The correlation coefficients based on temperatures with no lag and those based on temperatures with one month lag were quite similar. The reason for this relationship was due to sunspot numbers not changing appreciably from one month to the next. Since a complete sunspot cycle requires about 11 years the numbers of sunspots reported for any two successive months should not be greatly different.

To further study how directly the stratospheric temperatures reacted to changes in sunspot numbers a comparison was made between monthly changes in 30 mb. temperature departures from the mean and monthly changes in sunspot numbers. This procedure was repeated for 30 mb. temperature changes with one month lag and with two months lag. Table VI shows results of this effect using San Juan data.

Related Pressure Variations

The variation of temperature over San Juan indicates that with higher

Table VI

Table of Correlation Coefficients Relating 30 Mb. Temperature Changes with Different Lags Against Solar Activity Changes Based on San Juan Data

Variables Related	r		
	computed	90% confidence lower	90% confidence upper
Sunspot changes vs. current month temp change	.168	-.013	.339
Sunspot changes vs. one-month lag temp change	.059	-.124	.238
Sunspot changes vs. two-month lag temp change	-.049	-.228	.133
C_i changes vs. current month temp change	-.038	-.218	144

sunspot numbers a warmer, less-dense atmosphere exists between 100 mb. and 30 mb. This must be associated with an outward transport of air above 30 mb., a lowering of sea-level pressures, or a compensating cooling of the layer of air between 100 mb. and sea-level. In order to clarify this matter a comparison was made between sunspot numbers and 30 mb. height departures from the mean and 1000 mb. (approximately sea-level) height departures from the mean. Table VII lists the results of this comparison.

Table VII

Table of Correlation Coefficients Relating 30 Mb. and 1000 Mb. Height with Sunspots over San Juan

Variables Related	r		
	computed	90% confidence	
		lower	upper
Sunspots vs. 30 mb. heights	.548	.408	.663
Sunspots vs. 1000 mb. heights	-.139	-.312	.043

A study of atmospheric "explosive warming" in connection with solar activity was not attempted in this investigation. Since only monthly values of temperatures were used a detailed comparison could not be undertaken. A cursory look at reported dates of warming did not reveal an obvious association. However, a thorough investigation might well identify a useful relationship between solar activity and explosive warming.

V. Discussion of Results

The correlation values determined for the full period of available data were not as good as might be hoped because of the frequent lack of receipt of data early in the period. However, the values were sufficiently encouraging to warrant further investigation.

Latitudinal and Seasonal Variation

In the calculation of latitudinal variations in the relationship, it must be pointed out that the area of Alaska is small enough that with a persistent circulation pattern the effect of advection cannot be completely discounted even after averaging over the month and over an area. Furthermore, the lowest point in the solar activity cycle (1954) was not included in the study. In spite of these limitations, however, there is sufficient evidence to indicate that sunspots are better correlated with 50 mb. temperatures in low latitudes than in high latitudes, with the correlation being negligible in the most northerly regions. Also, sunspots are better correlated with stratospheric temperatures than are C_i values (except possibly in the most northerly region).

In the study of the seasonal variation in the relationship between sunspots and 50 mb. temperatures one should recognize that the amount of data used for each of the seasons is only one-half of the total number of observations. The value of these statistical findings is therefore decreased in comparison with other values in this study as can be seen from the 90% confidence figures. With only 36 points for comparison in each of the seasons the reliability of correlation coefficients is definitely lowered. However, a general comparison of the findings shows that in summer a better relationship exists than in winter, especially in the higher latitudes. The small reversal of this effect in the southern U. S. zone, as indicated in Table III, is believed to be caused by the size of the statistical sample available and not representative of the actual physical behaviour. In winter the relative decrease of duration of electromagnetic radiation reaching the 20 Km. level is much greater in the high latitudes than in the low latitudes.

The latitudinal and seasonal variations in the relationship are attributed to the combination of sunlight duration and differences of solar intensity caused by directness of the sun's rays (Figure 9). When the sun's rays strike the earth more obliquely the intensity is decreased at the lower levels because of the rays having traversed greater amounts of atmosphere allowing for greater energy absorption before reaching the 50 mb. level.

In the Arctic regions the intensity of electromagnetic radiation is relatively low throughout the whole year. In winter both the intensity and duration are at a minimum and the warming at 20 Km. is very little. In summer, even though duration is greatest and intensity is increased, the obliqueness of the rays apparently causes a greatly increased warming at levels above our level of investigation but only small effect at 20 Km.

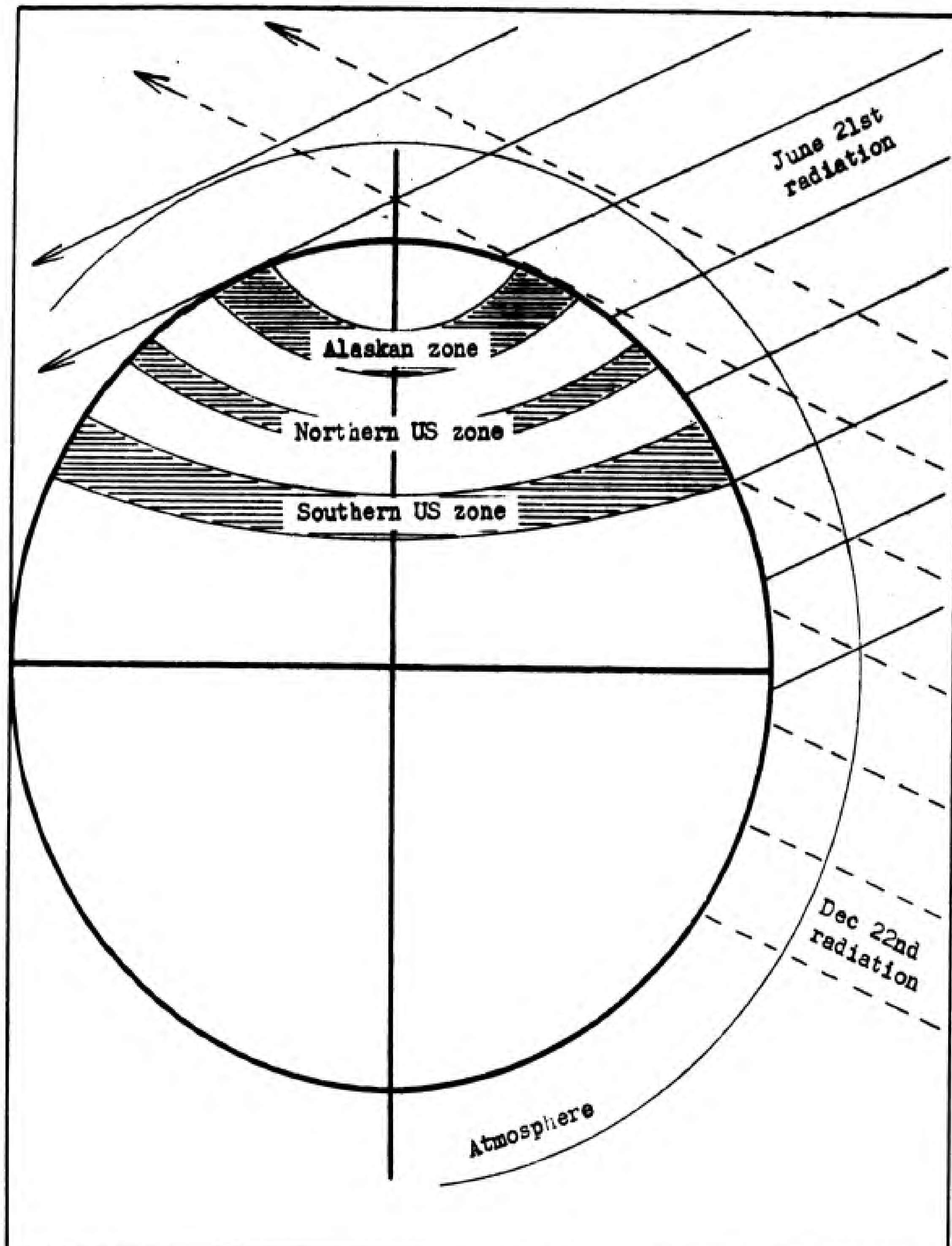

Figure 9. Annual variation of solar radiation incident on latitude zones used in study.

In the mid-latitude belt the seasonal difference in correlation coefficient is the greatest, .244 in winter and .682 in summer. Even if the accuracy of these values is discounted somewhat because of sample size, the difference is still significant. The duration of summer sunlight is greatly increased, and the solar rays strike the earth more directly resulting in greater intensity both from smaller angle of incidence and decreased attenuation in higher levels.

Variation with Height

The vertical variation of the relationship from San Juan data requires little comment. The warming is greater at 20 Km. than at 16.5 Km. and greater at 24 Km. than at 20 Km. Determination of a level of maximum correlation, unfortunately, was not possible because of insufficient numbers of reports above 30 mb. The relationship may continually improve with increasing height. Later investigations will be required to determine this matter. The vertical variation at other latitudes will likewise need be postponed until a reliable amount of data can be accumulated.

Time Variation

The rate at which solar activity affects stratospheric temperatures could not be determined from the monthly data used. However, from the study involving changes in departures from the mean, one can see that the effect is almost totally felt during the month in which the stimulus was recorded. The correlation coefficients for lag months (see Table VI) are too small to show significance. Likewise the correlation coefficient relating temperature change with changes of reported values of C_i is too small to be considered meaningful.

Solar Activity Indicators

Throughout this entire study it is noted that in general sunspots show better correlation with stratospheric temperatures at the levels of comparison than does the indicator of geomagnetic disturbances, with the single exception of the Alaskan area. Since sunspots and solar flares are positively correlated and, when flares are noted, they are found to exist in the immediate vicinity of sunspots, the positive correlation between stratospheric temperatures and C_i values (representing flares) is naturally expected. The better relationship between sunspots and temperatures suggests, therefore, that sunspots and the associated increase of ultra-violet radiation are more influential in controlling the mid and low latitude, 20 Km. level stratospheric temperatures than are flares and their associated corpuscular and electromagnetic radiation. In the high latitudes the computed correlations were too weak to be included in this suggested generalization.

Related Pressure Variation

The calculation of correlation coefficient for sunspots vs. 30 mb. and 1000 mb. height departures from the mean indicates that during periods of increased sunspottedness the stratosphere over San Juan is warmed and expanded vertically. Unless there exists a compensating cooling at some higher level, which appears to be highly unlikely, the density in the outer regions of the atmosphere must be increased accordingly. The negative correlation coefficient at 1000 mb., which corraborates Clayton's findings, indicates that with this vertical transport of air there is a small, high-level, horizontal transport toward higher latitudes.

Solar Effect on Atmosphere

Based upon the results of this study and the works of earlier investigators the following effects of solar activity on the atmosphere are suggested. During periods of increased numbers of sunspots the planetary atmosphere is greatly warmed from the absorption of increased amounts of ultra-violet associated with sunspots. The levels of warming depend upon duration of sunlight, angle of incidence of incoming rays, and the oxygen and ozone content of the atmosphere. In general the warming effect reaches lower into the atmosphere in the tropics than in the Arctic regions. The upper limits of the warming are unknown, but may extend to the outer limits of the atmosphere. This warming pushes the upper atmosphere outward and greatly increases the density in the outer regions of the atmosphere. The increased drag on satellites, while generally believed to be best correlated with strong flares, may be the result of absorption of the increased amounts of ultra-violet from both sunspots and any associated flares rather than warming from corpuscular radiation. The one day delay in increased satellite drag after the flare is noted, which has heretofore been suggested to be indicative of the delay required for the transfer of particles, may be the time required for the increased ultra-violet to be absorbed and the vertical atmospheric expansion to take place.

VI. Conclusions

During periods of increased sunspottedness, increased amounts of ultra-violet enter the atmosphere and when absorbed by oxygen and ozone increase the temperature in the stratosphere.

The amount of temperature increase caused by increased numbers of sunspots is greater in summer than in winter, is greater in low latitudes than in high latitudes, and is greater with increasing heights (at least in the tropical areas).

The increased warming of the stratosphere occasioned with increased numbers of sunspots results in an outward extension of the atmosphere and the associated increase of density in the outer limits of the atmosphere. This density increase may be a significant factor in satellite and missile operations.

VII. Recommendations

It is recommended that work be initiated to determine the time rate of increase of atmospheric warming associated with increases in numbers of sunspots. A statistical comparison of daily numbers of sunspots and stratospheric temperatures on a simultaneous, hemisphere-wide, one-day, two-day, and three-day lag basis might provide interesting results.

It is recommended that simultaneous determinations of 20 and 200 Km. densities over various regions of the earth, and under different solar activity conditions, be initiated to find if variations are appreciable.

It is further recommended that investigations be initiated to determine the effect density variations can have on ballistic missile operations.

It is finally recommended that the possibility of a relationship between explosive warming and solar activity be investigated.

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Appendix A

List of Stations Used in the Study

Alaska	Northern U. S.	Southern U. S.
Anchorage	Albany (or Buffalo)	Brownsville
Barrow	Bismark	Burrwood
Barter Is.	Caribou	El Paso
Bethel	Glasgow	Hilo (or San Juan)
Fairbanks	Great Falls	Jacksonville
St. Paul Is.	Green Bay	Miami
Kotzebue	International Falls	Santa Maria (Pt. Arguello)
McGarth	Portland Me.	San Antonio
Nome	Sault Ste. Marie	San Diego
Yakutat	Tatoosh Is.	Tuscon
	Alternates	
King Salmon	Flint	Lake Charles
Cold Bay	Seattle	Pheonix
	Spokane	Tampa

Appendix B

Table of Sunspot Numbers During 1959-1960 Period

	1950	51	52	53	54	55*	56	57	58	59	60*
Jan	102	60	41	27	00	20	74	165	203	217	139
Feb	95	60	23	03	01	21	124	130	165	143	104
Mar	110	56	22	10	11	05	118	157	191	136	104
Apr	113	93	29	28	02	11	111	175	196	163	120
May	106	109	23	13	01	30	137	165	175	172	120
June	84	101	36	22	00	33	117	201	172	169	109
July	91	62	39	09	05	26	129	187	191	150	119
Aug	85	61	55	24	08	40	170	158	300	200	131
Sept	51	83	28	19	02	42	173	236	201	145	125
Oct	61	52	24	08	07	59	155	254	182	111	81
Nov	55	52	22	02	09	90	202	211	152	124	87
Dec	54	46	34	03	08	77	192	239	188	125	83

* Provisional numbers from Zurich

Appendix C

Table of C_i Values During 1950-1960 Period

	1950	51	52	53	54	55	56	57	58	59	1960
Jan	.68	.77	.82	.70	.49	.63	.94	.67	.78	.74	.69
Feb	.70	.90	.94	.61	.80	.67	.68	.70	.96	.95	.69
Mar	.66	.90	1.04	.83	.81	.75	.89	.96	1.09	.72	.76
Apr	.75	1.00	1.02	.74	.71	.72	.89	.89	.83	.71	1.07
May	.75	.85	.91	.62	.44	.55	.89	.56	.75	.79	.88
June	.65	.82	.75	.54	.36	.54	.78	.76	.80	.76	.82
July	.66	.84	.65	.70	.51	.44	.63	.63	.85	.95	.82
Aug	.82	.92	.65	.77	.61	.44	.67	.65	.69	.88	.83
Sep	.85	1.13	.87	.85	.88	.63	.67	1.05	.62	1.06	.76
Oct	.91	.84	.75	.66	.74	.58	.62	.72	.68	.78	.97
Nov	.76	.82	.61	.60	.54	.59	.92	.85	.42	.83	.91
Dec	.73	.84	.68	.40	.37	.48	.54	.82	.75	.81	.92

Appendix D

Mean temperatures and departures from normal for 20 U. S. Stations in degrees Centigrade (9½ years data)

	Mean	1951	52	53	54	55	56	57	58	59	1960
Jan	-60.8		1.4	-2.1	-0.2	-1.3	0.6	0.9	1.6	0.3	-1.0
Feb	-59.9		3.8	-2.7	-0.1	-3.6	2.1	-3.4	1.8	1.9	0.5
Mar	-58.9		1.3	-0.4	-0.3	-4.4	1.2	-2.6	1.6	2.0	1.6
Apr	-58.1		0.4	1.0	-1.6	-2.2	0.7	-1.5	2.8	0.4	0.5
May	-56.9		0.5	0.1	0.2	-2.3	-0.1	-1.8	1.7	0.2	1.6
June	-55.7	0.1	-0.1	-0.2	-0.3	-1.5	-0.3	0.1	1.1	0.3	0.6
July	-55.2	-1.0	0.4	-0.6	0.0	-1.5	-0.1	0.0	1.0	1.2	0.7
Aug	-55.3	-0.5	0.6	-0.2	-0.1	-1.6	-0.3	0.5	0.5	0.9	0.5
Sept	-56.7	0.1	-0.4	1.1	-0.7	-2.0	-0.5	0.6	0.4	1.5	0.3
Oct	-58.8	-0.2	-0.4	0.1	-0.1	-0.8	-0.3	0.0	0.9	0.4	0.0
Nov	-60.0	0.8	-0.6	0.4	-0.2	-0.1	0.8	-0.4	0.5	0.3	-1.5
Dec	-60.2	1.0	-0.7	2.9	1.2	-0.1	-2.2	-0.7	-0.3	0.9	-1.5

Mean temperatures and departures from normal for Alaska (six years data in degrees Centigrade

	Mean	1955	1956	1957	1958	1959	1960
Jan	-53.4	1.1	-3.1	-5.2	5.1	-0.5	2.5
Feb	-51.4	-2.8	2.1	-0.3	0.1	1.0	0.1
Mar	-51.0	-5.3	3.4	-1.1	-2.4	6.3	-1.0
Apr	-50.1	-1.3	1.6	-3.2	-2.8	0.8	4.7
May	-48.9	-1.7	0.8	-0.3	-0.4	0.5	0.8
June	-46.0	-1.3	0.5	-0.4	-0.5	0.6	1.2
July	-45.6	-1.8	0.5	0.0	0.1	1.2	0.0
Aug	-47.8	-0.2	0.6	-0.7	0.3	0.3	-0.4
Sept	-50.8	0.3	0.5	-0.1	-0.6	-0.4	0.3
Oct	-52.8	1.6	0.1	-1.6	0.4	-1.9	1.2
Nov	-52.9	-0.7	-3.1	-2.3	5.3	-1.9	2.9
Dec	-53.3	-5.3	-3.2	-4.7	0.7	9.1	3.3

Appendix D (cont'd)

Mean temperatures and departures from normal for Northern U. S. stations (six years data) in degrees Centigrade

	Mean	1955	1956	1957	1958	1959	1960
Jan	-58.0	0.0	-1.0	0.7	0.4	0.0	-0.2
Feb	-56.4	-3.9	2.2	-3.5	2.0	3.1	0.4
Mar	-55.2	-3.4	1.1	-3.5	0.5	3.0	2.1
Apr	-55.1	-3.0	1.0	-2.4	2.8	1.0	0.5
May	-54.4	-2.6	0.3	-2.4	2.2	0.9	1.6
June	-52.7	-2.1	-0.9	0.2	1.6	0.5	0.9
July	-51.8	-2.6	-0.6	0.0	1.2	1.3	0.5
Aug	-52.4	-2.2	-0.2	0.7	0.5	1.2	0.2
Sept	-54.5	-2.2	-0.3	0.5	0.4	1.6	-0.2
Oct	-57.4	-1.0	-0.7	-0.2	1.3	0.8	-0.4
Nov	-58.0	-0.2	0.6	-0.9	2.0	-0.1	-1.6
Dec	-58.4	0.6	-3.5	-0.5	0.7	2.8	-0.2

Mean temperatures and departures from normal for Southern U.S. stations (six years data) in degrees Centigrade

	Mean	1955	1956	1957	1958	1959	1960
Jan	-63.2	-2.9	1.8	0.6	2.3	0.2	-2.1
Feb	-63.6	-3.0	2.3	-3.0	1.8	1.0	0.8
Mar	-62.8	-4.6	1.4	-1.6	2.7	1.0	1.2
Apr	-60.9	-1.6	0.1	-0.7	2.5	-0.5	0.2
May	-59.5	-1.7	-0.2	-0.9	1.3	-0.4	1.7
June	-58.7	-0.9	0.3	0.1	0.6	0.0	0.3
July	-58.0	-0.9	-0.1	-0.5	0.5	0.5	0.3
Aug	-58.1	-1.1	-0.5	0.1	0.3	0.5	0.6
Sept	-58.8	-1.9	-0.7	0.6	0.2	1.3	0.7
Oct	-60.1	-0.6	0.1	0.1	0.3	-0.1	0.4
Nov	-62.2	0.2	1.0	0.3	-0.9	0.5	-1.3
Dec	-63.1	0.5	0.4	0.4	0.0	0.3	-1.5

Appendix E

30 Mb.

Mean Temperatures and Departures from Mean at San Juan (seven years of data) expressed in degrees Centigrade

	Mean	1954	1955	1956	1957	1958	1959	1960
Jan	-56.3	-2.2	-4.0	0.8	0.2	2.9	2.4	0.2
Feb	-56.8	-0.3	-1.0	2.7	-4.8	-0.4	1.1	2.6
Mar	-55.2	-1.3	-0.6	0.1	-1.7	1.3	-0.3	2.5
Apr	-54.0	-1.5	-0.3	-0.3	-2.0	2.5	-0.2	1.7
May	-53.1	-1.7	-1.1	0.0	0.1	2.3	-0.2	0.4
June	-52.5	-2.4	-1.6	-1.0	1.2	2.2	0.4	1.1
July	-52.2	-1.8	-2.1	-0.9	1.0	2.1	1.3	0.7
Aug	-52.9	-2.2	-1.1	-0.8	0.8	1.0	2.2	0.4
Sept	-53.4	-2.7	-1.7	-1.8	0.4	1.3	2.3	2.2
Oct	-53.1	-2.0	-2.8	-1.1	0.2	2.2	1.8	1.8
Nov	-54.0	-4.6	-0.3	-0.7	0.5	2.2	2.0	1.0
Dec	-54.0	-1.1	0.1	-0.3	2.0	0.3	0.1	-1.2

50 Mb.

Mean temperatures and departures from normal at San Juan expressed in degrees Centigrade (seven years data)

	Mean	1954	1955	1956	1957	1958	1959	1960
Jan	-66.0	-1.6	-2.5	0.7	2.5	0.7	2.1	-1.6
Feb	-66.2	1.0	-3.8	1.4	-1.0	-1.2	3.4	0.0
Mar	-65.1	0.4	-2.2	0.2	-0.8	-0.3	1.7	0.7
Apr	-62.8	-0.5	-1.4	-0.7	-0.3	0.9	1.3	1.0
May	-61.6	-0.1	-2.3	0.6	-0.6	1.4	0.5	0.2
June	-60.5	-1.3	-0.4	-0.4	-0.4	1.2	0.8	0.3
July	-60.1	0.0	-0.5	-0.5	1.0	0.8	-0.7	-0.2
Aug	-59.9	0.0	-0.7	-0.6	0.1	0.0	1.0	0.1
Sept	-60.6	-1.2	-1.3	-1.2	-0.2	0.6	1.4	1.7
Oct	-60.8	0.9	-1.7	-0.2	-0.9	0.9	0.1	0.7
Nov	-62.2	-0.4	-1.5	0.4	-0.8	1.1	0.6	0.6
Dec	-63.0	3.1	-0.1	0.5	0.2	-1.1	-1.9	-1.0

Appendix E (cont'd)

100 Mb.

Mean temperatures and departures from normal at San Juan expressed in degrees Centigrade (seven years of data)

	Mean	1954	1955	1956	1957	1958	1959	1960
Jan	-76.9	0.4	-0.9	-1.2	0.8	1.1	-0.5	0.4
Feb	-77.1	-0.1	0.0	-0.6	1.3	1.1	0.5	-1.9
Mar	-77.5	0.5	0.3	-1.2	-0.5	0.5	-0.9	-1.3
Apr	-76.3	0.3	0.2	-0.8	1.3	0.3	-0.6	-0.5
May	-75.5	0.5	-0.6	0.4	0.5	0.2	1.2	-1.0
June	-72.9	0.5	-2.4	1.1	0.8	-0.7	1.6	-1.1
July	-72.3	-0.3	-1.1	0.0	0.4	0.3	0.0	0.6
Aug	-73.0	0.2	-1.0	-1.1	1.2	0.4	0.1	0.5
Sept	-73.0	1.7	-1.6	0.5	-0.5	0.6	-0.8	0.4
Oct	-74.7	1.9	-3.7	0.2	0.8	0.9	-0.4	0.3
Nov	-77.0	-0.3	-0.5	-1.4	0.5	1.5	0.9	-0.4
Dec	-76.4	3.6	-3.2	-1.6	1.2	0.1	0.2	-0.4

Appendix F

Mean heights and departures from normal at 30 Mb. pressure surface over San Juan (expressed in meters).

	Mean*	1954	1955	1956	1957	1958	1959	1960
Jan	727	-46	-87	-58	11	108	75	-1
Feb	721	-8	-75	7	-72	26	101	23
Mar	747	-2	-32	-9	-75	55	67	-2
Apr	798	-35	-25	-72	-54	125	30	29
May	865	-27	-47	-20	-17	89	31	-12
June	946	-53	-46	-55	31	67	31	23
July	1001	-6	-71	-59	58	94	4	-17
Aug	1012	5	-51	-62	48	33	16	11
Sept	977	-28	-56	-84	28	66	23	49
Oct	911	-43	-87	-45	-1	79	34	63
Nov	824	-71	-27	-32	5	78	22	25
Dec	769	-26	-31	-14	68	14	-14	4

* +23,000 meters

Mean heights and departures from normal at 1000 Mb. pressure surface over San Juan (expressed in meters)

	Mean	1954	1955	1956	1957	1958	1959	1960
Jan	148	9	-3	-12	26	-16	0	13
Feb	151	-3	1	7	4	-7	13	-12
Mar	148	2	14	7	-1	-16	1	-4
Apr	144	12	0	2	12	-10	-9	-7
May	141	-1	4	10	7	-13	0	-9
June	150	0	0	8	0	-6	0	-3
July	155	-5	-2	11	0	3	-4	-4
Aug	140	3	-8	14	2	-10	-1	3
Sept	127	9	-3	7	1	-4	-2	-5
Oct	125	5	-3	-1	-4	-1	6	0
Nov	128	5	2	-8	5	2	-5	-1
Dec	140	-1	2	11	1	2	-14	-4

Appendix G

Summary Data in Determination of "r" and "a"

X ---sunspots

Table	N	Y	$\sum X_i Y_i$	$\sum Y_i^2$	$\sum X_i^2$	r	a
I	115	50 mb temp	2630.5	194.2	614,412	.241	.004
II	72	50 mb temp Alaska	297.8	452.5	252,962	.028	.001
II	72	50 mb temp Nor. US	3110.1	199.6	252,962	.435	.012
II	72	50 mb temp Sou. US	3043.0	122.7	252,962	.548	.012
III	36	50 mb T,Alaska,winter	79.9	391.5	130,329	.011	.001
III	36	50 mb T,Alaska,summer	217.1	61.0	118,633	.081	.002
III	36	50 mb T,Nor US,winter	1009.0	119.5	130,329	.244	.007
III	36	50 mb T,Nor US,summer	2101.1	80.1	118,633	.682	.018
III	36	50 mb T,Sou US,winter	1999.3	92.8	130,329	.575	.015
III	36	50 mb T,Sou US,summer	1043.7	29.9	118,633	.555	.009
IV	84	100 mb temp San Juan	773.7	100.3	432,574	.118	.002
IV	84	50 mb temp San Juan	3203.1	123.5	432,574	.438	.007
IV	84	30 mb temp San Juan	6256.1	258.8	432,574	.592	.015
V	83	100 mb T,one-mo. lag	113.9	100.1	431,349	.175	.0003
V	83	50 mb T,one-mo. lag	2550.2	121.0	431,349	.354	.006
V	83	30 mb T,one-mo. lag	5903.1	254.0	431,349	.565	.014
VI	83	30 mb T ch,no-lag	504.6	175.0	53,699	.164	.009
VI	82	30 mb T ch,one-lag	217.0	171.4	53,683	.059	.004
VI	81	30 mb T ch,two-mo lag	-149 .4	170.4	53,647	-.049	-.003
VII	84	30 mb heights	167552	215935	432,574	.548	.387
VII	84	1000 mb heights	-6149	4504	432,574	-.139	-.015

X --- C_i

Table	N	Y	$\sum X_i Y_i$	$\sum Y_i^2$	$\sum X_i^2$	r	a
I	115	50 mb temp	6.168	194.2	3.019	.255	2.04
II	72	50 mb temp Alaska	3.358	452.5	1.656	.123	2.03
II	72	50 mb temp Nor. US	5.938	199.6	1.656	.326	3.58
II	72	50 mb temp Sou. US	6.482	122.7	1.656	.443	3.91
IV	84	100 mb temp San Juan	.655	100.3	2.233	.043	0.29
IV	84	50 mb temp San Juan	2.817	123.5	2.233	.169	1.26
IV	84	30 mb temp San Juan	9.399	258.8	2.233	.390	4.20
VI	83	30 mb T change,no lag	- .771	175.0	2.383	-.038	-0.33

Vita

Loyd Clinton Garvin was born on [redacted] near [redacted], [redacted], the son of William Asa Garvin and Mamie Scott Garvin. After completing his work in 1937 at [redacted], he enrolled at Northwestern State College, Alva, Oklahoma, where he pursued a course in teacher's training. In May 1942 he was graduated with the degree of Bachelor of Arts with majors in education and mathematics. He enlisted as a Meteorology Cadet in June, 1942 and received instruction in meteorology at the University of California at Los Angeles and at the University of Chicago. He received his commission as Lieutenant in the U. S. Army and, during World War II, served in the Air Corps as a meteorologist. In 1946 he accepted a regular commission in the U. S. Army and transferred to the Air Force with its inception. He attended New York University during the 1949 - 1950 period and in June, 1950, was graduated with the degree of Master of Science in Meteorology. He served as Director of the High Wycombe Forecast Center in England from 1953 to 1955, Chief of the Evaluation and Development Division, Hq. Air Weather Service from 1956 to 1958, and Chief of Technical Services and Requirements Division, Hq. Air Weather Service from 1958 to 1959. In June 1959 he entered the Air Force Institute of Technology as a student of Astronautics.

Permanent address: [redacted]

This thesis was typed by Mr. Merrill G. Corkum

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