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A PRELIMINARY INVESTIGATION OF DOWNWARD COUPLING OF THE STRATOSPHERE AND THE TROPOSPHERE

By

G. S. Nastrom and A. D. Belmont

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ABSTRACT

A pilot study to detect relationships between anomalies in the stratosphere and later anomalies at the surface at the same station has identified two potential relationships. The anomaly of October precipitation at mid- and high-latitude stations appears related to the date the fall reversal of zonal wind occurs; and the magnitude of the anomaly of surface temperature five or six months following a key month appears related to the stratospheric zonal wind speed during the key month. Both relations are statistically significant at the five percent level, and both should be analyzed in more detail for possible use in long range forecasting. Horizontal fields from maps should be used to determine the interlevel relations on a hemispheric or global basis to understand why these relationships exist.

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I. INTRODUCTION

The purpose of this study is to identify anomalous parameters and events in the stratosphere which are precursors of anomalous tropospheric seasonal climatic regimes. The present effort is a pilot study to delineate those stratospheric parameters which are coupled with a later tropospheric condition, and to formulate plans for future studies which will lead to an understanding of how the stratospheric anomalies develop and how they can be used as input for long-range forecasting.

The importance of reliable long-range forecasts is self-evident; however, present numerical weather prediction models are unable to forecast reliably for more than a fraction of a month. Laurman (1975) has reviewed the prospects for extending the forecast period and concludes that empirical approaches to long-range forecasting should be the most useful at this time. The empirical approach followed here is based on the fact that the layers of the atmosphere are intimately coupled and that events in one layer can be associated with events in another layer.

Simultaneous, compensating temperature changes in the troposphere and stratosphere have been recognized for over fifty years, and a simultaneous relation between the decrease of wind at 45-60 km at White Sands and an increase in surface precipitation over New Mexico has been stated by Jetton (1968). Events in the stratosphere which precede events in the troposphere are generally less well documented or accepted than simultaneous events, but some notable cases are available. For example, Drogaytsev (1972) has carefully analyzed the relationship between development of the fall reversal of stratospheric wind and the temperature regime at the surface the following winter. Labitzke (1965) has shown that sudden warmings in the stratosphere are followed by a blocking circulation at sea level in about ten days.

Identification of a relation between a stratospheric event and a later tropospheric event is important, but before the relation can be used to make forecasts with confidence it must be understood. For example, the modeling efforts of Trenberth (1973) and others have led to a relatively good understanding of the processes during a sudden warming, and so the tropospheric blocking after a sudden warming is seen to be a natural outcome of the chain of events. Trenberth states that "blocking and the warming may be regarded as part of the same process, not that the blocking is somehow caused by the warming." Thus, while a description of inter-level relations found in this study is the central theme below, a discussion of possible future efforts to gain better understanding of those relations is also given.

II. DATA

The present pilot study is based on single station analysis of stratospheric and tropospheric anomalies. The seven rocket (MRN) stations listed in Table 1 were selected on the basis of geographical coverage and quantity of data available. While MRN data are available since 1960 at some stations, the number and quality of observations increased steadily through the early 1960's and has remained fairly constant to the present. Thus, the ten year period 1964-1973 was chosen for the present analysis and all anomalies (surface and upper-air) are defined with respect to this period. Monthly means of surface temperature and precipitation were taken from "Monthly Climatic Data for the World." Daily radiosonde data, obtained from the World Data Center, Asheville, were available through 1970; data for 1971-1973 were not received in time to be included in this study.

The MRN data were generally used at 2 km intervals, 20-60 km, although when several adjacent layers indicated a similar relationship with a surface parameter the analysis was repeated using average values of variable height layers. Monthly means and deviations of temperature, zonal and meridional wind speed (T,U,V) were used, along with monthly mean values of the vertical shear or lapse rate. Also used were the dates of the autumn reversal of the zonal wind direction. Those dates are given on a zonal mean basis in Belmont, et al. (1975), but for the present study dates at the individual stations were required, with the finest time resolution possible. The fall reversal is defined here as the last date the zonal wind became westerly after having been easterly for at least five consecutive days. Time-height sections of individual daily soundings were plotted and the reversal progression analyzed. In most cases, the reversal date could be determined within ± three days, and in some cases within ± one day. As discussed in Belmont, et al. (1975), the low-latitude reversal is weak and difficult to define. Thus, the reversal analysis was limited to stations north of 35°N.

The spring reversal process is much more erratic than that in the fall. Because of mid-winter stratospheric warmings the zonal flow may experience several changes of direction between January and June. As a result of this behavior, "objective" definitions can be made such that the spring reversal "date" is forced to correlate with nearly any parameter. For this reason the effect of the spring reversal date was not examined here.

III. RESULTS

A. Relation of the Autumn Reversal of Stratospheric Zonal Wind to Precipitation Anomalies

The anomalies of the autumn reversal dates, relative to the mean reversal date at each station, were compared with surface parameters for the autumn and winter months which followed. The reversal date anomaly at 30 km was found to correlate well with the precipitation anomaly in October at the three high latitude stations where reversals could be unambiguously determined for several years. Note in Table 2 that the signs of the anomalies are the same in eight out of ten cases at Churchill and seven of nine cases at Greely and Wallops. The chances of this happening are 5% and 9%, respectively. If the three data sets are assumed independent and combined, the chance of getting twenty-two identical signs out of twenty-eight cases is near 1%.

The magnitude of the precipitation anomaly is marginally correlated with the fall reversal anomaly for those years when the algebraic signs are identical. The linear correlation coefficients and their levels of statistical significance are: Greely, 0.71 (5%); Churchill, 0.53 (~10%); Wallops, 0.67 (5-10%); and all stations, 0.46 (5%).

In an effort to determine if the above relationship could be defined with greater time resolution the weekly precipitation values for October at Wallops and Greely were extracted from Monthly Weather Review when available. No pattern was suggested by this exercise.

A physical reason for this relation is not easily seen. However, it is interesting to note that the relation of October precipitation with reversal date is much stronger than the corresponding relation of precipitation with the 200 mb height or its standard deviation (Table 2). While analysis of horizontal fields is necessary for confirmation, this suggests that the precipitation anomalies may not be due to a particular standing wave pattern or to enhanced traveling waves, but probably to a combination of the phase and amplitude of the predominant standing waves and the number of traveling waves.

The autumn reversal is basically due to cooling near the pole and the associated changes in thermal and height gradients. However, a cursory review of high-altitude synoptic maps shows that circulation features influence the reversal date at a given location. Note that Drogaytsev (1972) found the strongest relation between stratospheric reversals and the following season's surface temperature when he stratified the data according to the location of the earliest reversal. Also, he reports that the location of the earliest reversal coincides with the location of minimum total ozone. This may be pertinent for understanding the present results because of the strong links between the tropopause height and character with total ozone and with weather systems in the lower troposphere. Perhaps the synoptic situation in the stratosphere near reversal time and the morphology of the tropopause should be used to further stratify the present study to find a stronger relationship and to gain understanding of why the above relation exists.

Maps based on radiosonde and MRN data are available for the entire period used here, and could be analyzed to determine synoptic conditions near each fall reversal date. Zonal haromonic analysis can be used to find the amplitude and phase of the predominant wavenumbers in the stratosphere at reversal time and to trace these waves downward into the troposphere and forward in time to October. To study several latitudes without resorting to spherical analysis, it is possible to stratify the years according to curvature of the streamlines at each MRN station at the time of fall reversal (i.e., determine if the station is south of a low, or north of a high). Lastly, the traveling wave energy and the ratio of traveling to standing wave energy should be determined. Because the fall reversal is basically a reordering effect due to radiation losses near the pole, its haste (delay) is probably influenced by dynamic cooling (heating) due to eddy heat flux. In a similar manner, abnormally large amounts of transient wave energy in the troposphere, coupled with the phase of the predominant standing wave, will determine which longitudes are apt to receive the greatest precipitation amounts.

B. Relation of Stratospheric Zonal Wind Speed to Surface Temperature Anomalies

One method of identifying potential relationships is the superposed epoch analysis. In the present study a physically significant key date (or key month) could not be defined, so the following procedure was used: Each of the twelve months, for the ten years, was sorted into two classes according to the sign of the anomaly of the monthly mean zonal wind speed. Thus, for example, of the ten Januaries, those months whose mean wind was higher than the ten year mean, went into the positive group for January. This makes twenty-four groups of months. For each of twelve calendar months, the ten year mean surface temperature was prepared, and the difference, or anomaly, was computed for each of the ten corresponding months. The mean of the absolute values in each group of positive (and of negative) anomalies was next computed, and for each month afterward, for the same calendar year sequence, up to eleven months. The difference of the mean absolute values of the anomalies of surface temperature for each of the two groups of months was then determined for each month, and for each month afterwards. The results were arranged in a 12 x 12 difference array where there are twelve columns for the twelve months, and the rows represent months after the starting month. Note that the year groupings will be different for each starting month.

This procedure was repeated for each height interval and at each station. The largest value was selected from each difference array, and its starting month and number of months after the starting month were noted (i.e., its coordinates in the array). It was found that for the height interval 35-45 km the largest value always occurred five or six months after the starting month and that the starting month progressed systematically with latitude. At some stations large differences were found in the same row in adjacent columns, so the procedure was repeated using averages of adjacent months. Only at Churchill and White Sands did the latter exercise result in larger maximum differences.

Table 3 gives the differences of the mean magnitude of the surface temperature anomalies between the year groups following positive and negative zonal wind anomalies at 35-45 km. For brevity, only the column which contains the largest difference found is presented. The average values for the two groups of months are presented in Figure 1 combined for all five stations. Testing against the null hypothesis indicates that the difference between the two curves in Figure 1 is significant at the 5% level for months five and six.

Grouping the months according to the sign of the anomaly in stratospheric wind speed is admittedly tenuous, particularily when the difference between a positive and negative anomaly may be less than 1 ms^{-1} (e.g., Table 4). However, this procedure yields results which are consistent among all stations used so is reported here in detail. In the absence of a physical explanation for the results, it would be more intuitively satisfying if they pertained to extreme anomalies, so the entire procedure was repeated (after the fact) using only the months in which the extreme anomalies of zonal wind speed occurred. However, that exercise did not yield results having persistence from station to station and is not reproduced here.

In an effort to stratify the surface temperature anomalies according to algebraic sign, the monthly means and anomalies of stratospheric T and V were examined, along with the standard deviations and time and height derivatives of T, U, and V. None of those stratospheric parameters could successfully be employed to stratify the surface temperature anomalies according to sign.

Large surface temperature anomalies are usually associated with a persistent circulation feature, such as a blocking ridge (e.g., Green, 1969) with the algebraic sign of the anomaly determined by whether a station is upstream or downstream of the ridge. This suggests that the relationship reported above may be useful for predicting the occurrence of a persistent circulation feature, but that single-station stratospheric parameters alone are not sufficient to determine at which longitude the ridge axis (or a similar phase-determining characteristic) will be found. Thus, a complete analysis of this relation should concentrate on the development of blocking highs and other quasi-permanent circulation features, and should trace their origin to a particular pattern in the stratospheric circulation. Interlevel wave analysis techniques are well-suited for this purpose and could be applied to the horizontal fields of rawinsonde, MRN, and satellite data taken from available maps. The negative zonal wind speed anomaly at a given station during the key month is related to a shift in phase and amplitude of the predominant standing wave features in the stratosphere. The amplitude and phase anomalies of zonal harmonics in the stratosphere during the key month at each station can be traced forward in time (at the level which has highest coherence with the preceding month) to the fifth and sixth months after the key month. The resulting mean time-height progression will empirically demonstrate the link between the zonal wind speed anomaly and the circulation features at a later time at a particular level. Physical understanding of the chain of events leading to the tropospheric temperature anomalies will probably be gained most readily by adapting one of the many numerical models available in the literature and treating this as an initial value problem. By following the model output forward for five and six months the basic cause for blocking, or other quasi-permanent circulation features, to develop preferentially in one case may be detected.

C. Correlation Studies of MRN and Surface Anomalies

Correlation coefficients between stratospheric anomalies of T, U, and V and surface temperature and precipitation anomalies were computed using monthly data for each of the individual twelve months, with the months grouped by season, and for the entire time period. MRN data were used at nine individual height intervals, 20-60 km, and averaged in three layers (20-32, 34-46, 48-60 km). Correlation coefficients were computed from lags zero through eleven months. Also, the analysis was repeated using seasonal data (with four three-month seasons where summer is defined as June, July, and August) and correlation coefficients were computed from lags zero through seven seasons. The following chart summarizes these correlation studies:

Stations		7
Height Levels	x	12
MRN Parameters	x	3
Surface Parameters	x	2
Months/Seasons	x	$\left[\begin{matrix}12\\4\end{matrix}\right.$
Lags	x	$\left[\begin{matrix}12\\8\end{matrix}\right.$
Total Correlations	=	161,280

Each value was statistically tested and those which passed the 5% significance level were flagged. The values were printed in a variety of formats to expidite comparison of levels or stations. Large correlation coefficients were occasionally found, but no more often than expected by chance, and in most cases they were not reproduced at another station nor did they show a pattern of progression with time or height.

At Kennedy and Antigua the correlation coefficients between temperature at the surface and stratospheric T and U are persistently large (Table 5) during the warm half-year (April-September). However, it is well-known that surface temperature anomalies are persistent at tropical latitudes and, because of the quasi-biennial oscillation, stratospheric temperature and zonal wind anomalies also are persistent at low latitudes. Thus, while this result is consistent with known processes its usefulness does not seem significant.

van Loon and Jenne (1975) report that persistence between seasons is not generally a useful tool for forecasting surface temperature anomalies. However, as monthly data often show greater persistence than seasonal data, the above correlation study was repeated with monthly data using the residuals of surface temperature and precipitation anomalies after autoregression at each lag. This procedure did not improve the results.

IV. SUMMARY

In the present pilot study relationships between stratospheric anomalies or events and later surface temperature and precipitation anomalies at the same station have been sought. This single-station analysis has identified two relationships which may be useful for forecasting purposes, and which may have intrinsic value for understanding the coupling between the stratosphere and troposphere. The anomaly of precipitation received in October at stations north of 35°N is found to be related to the date the zonal wind changes direction at that station. Also, the magnitude of surface temperature anomalies five and six months following a key month are found to depend upon the stratospheric zonal wind speed during the key month at each station. Both relations are statistically significant at the 5% level, but before either can be applied with confidence they must be analyzed further. The analysis of horizontal fields was beyond the scope of this study, but must be included in future studies designed to diagnose the preceding relationships. It seems likely that the anomalies used here reflect patterns in the large-scale circulation, both in the stratosphere and in the troposphere, and that understanding of tropospheric-stratospheric coupling will eventually be in terms of the large-scale circulation.

A further reason for analyzing horizontal and vertical fields, rather than isolated variables at a single station, is to take account of dynamic coupling processes. For example, several writers have attempted to link varying seasonal climatic regimes at mid-latitudes to the tropical quasi-biennial oscillation (most recently, Folland, 1975), and others (e.g., Winstanley, 1973) have tried to link low-latitude precipitation to the strength of the circumpolar vortex. Vertical coupling between atmospheric layers should be analyzed because the large-scale changes in upper level (20-80 km) circulation may also influence the lower atmosphere just as it is known that the reverse is true. Bugayeva, et al. (1975), report a slight increase in the success at the 500 mb level of a numerical prediction scheme when stratospheric forecasts are included. The radius of correlation of meteorological variables generally increases with height, and a stratospheric link may be very important for understanding atmospheric teleconnections and other seasonal climatic changes. Thus, interlevel hemispheric or global patterns must be examined as a whole.

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TABLE 1. Station list.

MRN STATION	LAT(N)	LONG(W)	NO. OF MONTHLY MEANS, 1964-73, 40 KM TEMP.	WIND	SURFACE STATION	LAT(N)	LONG(W)	RADIOSONDE STATION	LAT(N)	LONG(W)
GREELY	64.0	145.7	91	107	Fairbanks	64.8	147.9	Kotzebue	66.9	162.6
CHURCHILL	58.7	93.8	112	112	Churchill	58.7	94.0	Churchill	58.7	94.0
WALLOPS	37.8	75.5	108	118	Washington	38.8	77.0	Washington	38.8	77.0
POINT MUGU	34.1	119.1	114	118	Santa Maria	34.9	120.5	Los Angeles	33.9	118.4
WHITE SANDS	32.4	106.5	108	120	El Paso	31.8	106.4	El Paso	31.8	106.4
KENNEDY	28.5	80.5	111	111	Miami	25.8	80.3	Miami	25.8	80.3
ANTIGUA	17.1	61.8	102	103	Raizet	16.3	61.5	Antigua	17.1	61.8

TABLE 2. Anomalies of the fall reversal at 30 km, October precipitation anomalies, and 200 mb heights. The reversal is defined as the last date the zonal wind became westerly after having been easterly for at least 5 consecutive days. (Negative anomaly means reversal was earlier than normal.)

	GREELY (Mean Reversal=30 Aug)				CHURCHILL (Mean Reversal=28 Aug)				WALLOPS (Mean Reversal=5 Oct)			
Year	Reversal Anom. (Days)	Oct Precip Anom. (mm)	200 mb Height Oct (m)	200 mb σ_h Oct (m)	Reversal Anom. (Days)	Oct Precip Anom. (mm)	200 mb Height Oct (m)	200 mb σ_h Oct (m)	Reversal Anom. (Days)	Oct Precip Anom. (mm)	200 mb Height Oct (m)	200 mb σ_h Oct (m)
1964	0	-7	11331	103	-5.7	-37	11526	149	MSG.	-	-	-
1965	-8	-1	11211	107	-3.7*	3	11538	120	-8.2	-15	12006	174
1966	-2	-13	11234	121	-4.7	-27	11460	84	4.8	46	12062	114
1967	MSG.	-	-	-	-8.7	-12	11533	122	-6.2	-34	12068	151
1968	-10	-12	11242	139	7.3	2	11572	114	3.8	7	12045	190
1969	-5	-17	11492	138	6.3	4	11470	199	-2.2	-45	12142	167
1970	-1*	27	11296	117	2.3	58	11617	137	9.8*	-22	12076	115
1971	-7*	15	-	-	1.3	3	-	-	-5.2*	81	-	-
1972	10	3	-	-	5.3*	-17	-	-	17.8	16	-	-
1973	23	4	-	-	0.3	27	-	-	-14.2	-31	-	-

* Exceptions to rule.

TABLE 3. Differences of the mean magnitude of the anomaly in surface temperature between years following a negative anomaly and years following a positive anomaly in zonal wind speed at 35-45 km. The selection of starting months is described in the text. Units are tenths of ^{o}C. The largest value in each column is underlined.

	STATION	GREELY	CHURCHILL	WALLOPS	PT. MUGU	WHITE SANDS
	STARTING MONTH	SEP	JUL/AUG	JUNE	JUNE	MAY/JUNE
MONTHS AFTER STARTING MONTH	0	-1.0	-1.4	6.0	-3.7	-3.6
	1	8.7	1.5	-0.3	1.4	-3.2
	2	5.5	6.9	4.1	-0.5	-1.9
	3	10.9	0.2	-8.6	-4.2	-3.4
	4	-3.7	5.7	-0.4	-0.6	-0.3
	5	38.3	18.6	-1.3	4.3	5.8
	6	38.5	-1.4	13.4	7.2	3.0
	7	-13.0	-4.5	-0.9	6.9	-2.0
	8	8.6	-3.7	-4.3	-5.6	-0.7

TABLE 4. Mean monthly zonal wind speed anomalies at 35-45 km during the key month at MRN stations. Key months are defined in the text. Speeds are in ms^{-1}. M is missing.

STATION	KEY MONTH	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
GREELY	SEP	-1.2	5.2	1.9	1.6	0.9	-2.4	-1.3	M	1.7	-6.5
CHURCHILL	JUL/AUG	1.0	-0.5	0.6	-0.8	0.1	-0.4	2.0	-0.3	-1.4	-0.2
WALLOPS	JUN	2.5	0.6	2.5	3.0	-1.1	-2.5	1.6	-5.0	-1.6	0.1
PT. MUGU	JUN	1.8	0.7	0.9	2.1	-0.7	-1.4	0.9	-4.9	-1.9	2.1
WHITE SANDS	MAY/JUN	0.1	-0.3	-0.3	5.8	-1.3	4.0	-0.7	-4.0	-3.5	1.3

TABLE 5. Correlation coefficients of anomalies in surface temperature with stratospheric (a) U and (b) T, based on monthly data for April - September. Lags, in months, are for stratospheric data with respect to surface data. The number of data pairs (N) is given only if a value exceeds the 5% significance level. Correlation coefficients are times one hundred.

	ANTIGUA												KENNEDY											
KMS/LAG	0	1	2	3	4	5	6	7	8	9	10	11	0	1	2	3	4	5	6	7	8	9	10	11
(a) 45-55	-28	-20	-28	-34	-20	-38	-9	-2	-9	-30	-36	-16	-10	2	-23	-12	-44	-21	-28	-22	-28	-24	-23	-24
N =				37		40					39						55		54		51			
35-45	-11	-16	-1	-20	-2	3	3	14	9	-1	2	-3	-27	-26	-18	-11	-39	-14	-19	-9	-14	-1	5	5
N =																	55							
(b) 45-55	-35	-3	-25	-37	-32	-34	-32	-35	-46	-21	-19	-46	1	9	19	16	17	31	2	-2	7	26	21	7
N =	36			39	41	41	44	44	42			37						54						
35-45	-26	-18	0	-40	-13	-29	-13	3	-19	-17	-26	-28	12	7	32	33	26	26	22	31	39	35	34	22
N =				48		48									54	55				54	52	50	49	

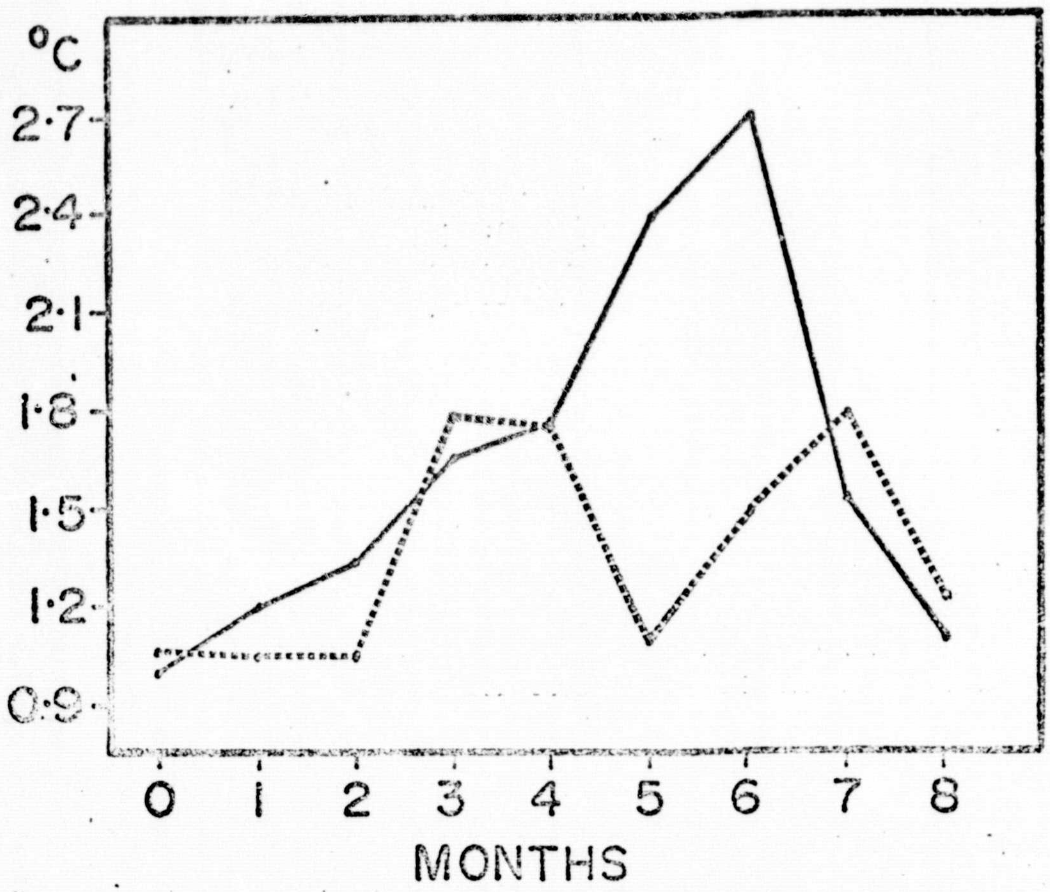

Figure 1. Mean magnitude of anomalies of surface temperature at five MRN stations up to eight months following the starting month (see text). Dashed curve is for positive anomaly in zonal wind speed at 35-45 km the starting month, solid curve is for negative anomaly in zonal wind speed.