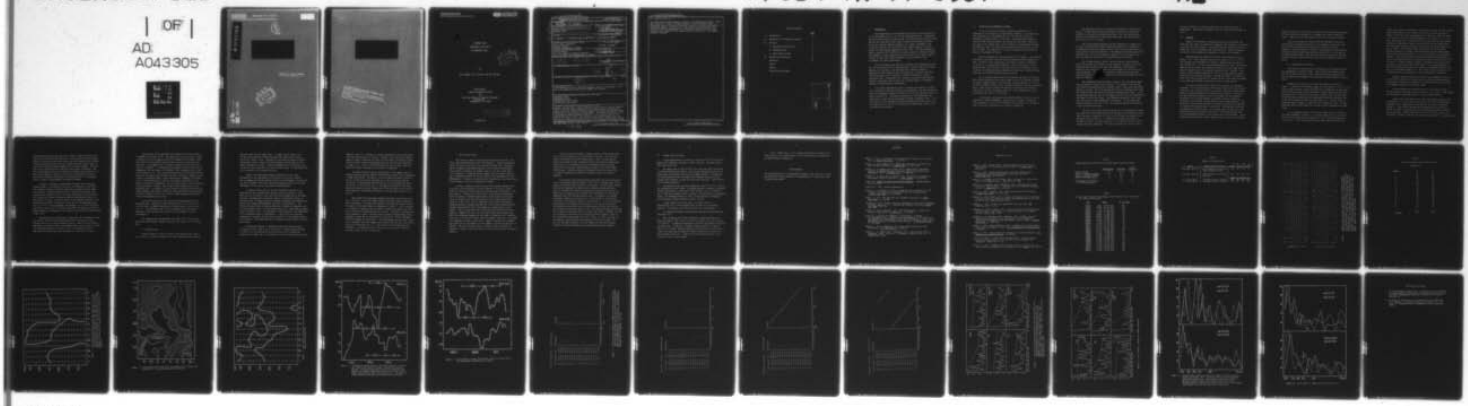
AD-A043 305 CONTROL DATA CORP MINNEAPOLIS MINN RESEARCH DIV F/G 4/1
PERIODIC WIND VARIATIONS AT 65-118 KM AT SASKATOON (52N).(U)
MAY 77 A D BELMONT, G D NASTROM, D N HOVLAND F44620-76-C-0092
UNCLASSIFIED AFOSR-TR-77-0967 NL

| OF |
AD
A043305



END
DATE
FILMED
9-77
DDC

RESEARCH DIVISION

8100 SOUTH 34TH AVENUE, MINNEAPOLIS, MINNESOTA 55440/612-853-8100

CONTROL DATA

AFOSR-TR- 77-0967

(8)

Approved for public release;
distribution unlimited.

RESEARCH DIVISION
BOX 1249, MINNEAPOLIS, MN 55440/612-853-8100

CONTROL DATA
CORPORATION

PERIODIC WIND
VARIATIONS AT 65-118 KM
AT SASKATOON (52N)

by

A.D. Belmont, G.D. Nastrom, and D.N. Hovland

Final Report
Contract F44620-76-C-0092
for
Air Force Office of Scientific Research
Bolling AFB
Washington, D.C. 20332

26 May 1977

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(19) REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

(18) 1. REPORT NUMBER: AFOSR-TR- 77-0967

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

(6) 4. TITLE (and Subtitle): PERIODIC WIND VARIATIONS AT 65-118 km at SASKATOON (52N).

(9) 5. TYPE OF REPORT & PERIOD COVERED: Final Report, April 1976-April 1977

6. PERFORMING ORG. REPORT NUMBER

(10) 7. AUTHOR(s): A.D. Belmont, G. D. Nastrom, ~~and~~ D.N. Hovland

(15) 8. CONTRACT OR GRANT NUMBER(s): F44620-76-C-0092 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS:

Control Data Corporation
Research Division
Box 1249, Minneapolis, MN 55440

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F, 2310A2NP

11. CONTROLLING OFFICE NAME AND ADDRESS:

Director Physics
Air Force Office of Scientific Research
Attn: NP, Bldg. 410, Bolling AFB, D.C. 20332

(11) 12. REPORT DATE: 26 May 1977

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

(12) 39p. (16) 2310

15. SECURITY CLASS. (of this report): None

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DDC
RECEIVED
AUG 25 1977
C

17. DISTRIBUTION STATEMENT (of the ~~abstract entered~~ in Block 20, if different from Report)

(17) A2

18. SUPPLEMENTARY NOTES

To be presented in part at AGA/IAMAP Assembly, Seattle, Aug 22-Sept 3, 1977, and to be submitted for publication Geophys. Res. Letters.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mesosphere Winds
Thermosphere Winds
Periodic Analysis of Winds
Quasibiennial oscillation

radar

altitudes. These analyses also provide

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Periodic time analysis of radio reflection winds from 65-118 km at Saskatoon (52°N), 1969-1976, yield confirmation of component waves' amplitudes and phases previously found by meteor-wind data at highest levels and give their values down to meteorological rocket levels. The newest information is that the semiannual wave progresses downward at a very constant rate of 8 km month^{-1} from 118 to 70 km. The semiannual phase dates suggest that this wave may be caused by the influence of auroral particle precipitation maxima on heating by eventual effects on ozone, or the influence of heating at high

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

either or both (1)

401516

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (Cont'd) A P 1473A)

latitudes during sudden warmings. ~~or both.~~ A three-month wave is also found, ~~and it~~ has twice the rate of phase progression as the semiannual wave. Significant spectral peaks are found near a period of 5 days, particularly in summer. ~~the summer season.~~ At least half of the variance of data spaced at five-minute intervals is ~~in~~ associated with variations of period less than about one-half hour, suggesting that sampling should be performed at the highest possible frequency.

1473 B

TABLE OF CONTENTS

I. Introduction

Wind measurements in the mesosphere have been far less numerous than in the stratosphere below or in the lower thermosphere above. Rawinsondes and small meteorological rockets provide relatively detailed wind data below about 65 km, while meteor-wind radars routinely provide data from about 90-105 km at several stations globally. As a result, knowledge of the circulation patterns from 65-90 km has been largely based on a relative handful of rocket grenade experiments (CIRA, 1972). The wind measurements made at Saskatoon (52°N, 106°W) by the radio reflection technique (Gregory and Stephenson, 1972), extending from about 65-118 km, are thus of special interest as they help connect knowledge of the wind fields of the stratosphere and lower thermosphere.

The ground-based radio reflection technique was developed many years ago, but only recently has it been practical to collect and process large quantities of wind data. The automated data collection system at Saskatoon has been refined so that soundings with 3 km height resolution from 65-118 km can now be obtained at 5-minute intervals on a nearly continuous basis. Processing of the raw data to calibrate them as winds remains a formidable task, and with the increased number of soundings a backlog of unprocessed data accumulated.

This report describes an effort to process the backlog of raw data and to analyze all available wind data from Saskatoon. The data processing effort is documented in detail in Section II, while the analysis results are given in Section III. The physical principles of the measurements and restrictions to the data are discussed by Gregory and Manson (1975). It is noted here only that although the quoted altitudes above about 105 km are too large by up to 5 km due to the existence of group delay effects, data are used here as reported.

II. Optimization of Computation Program

A copy of the wind calculation program was supplied by D. G. Stephenson of the University of Saskatchewan, Saskatoon. The program had been translated from IBM FORTRAN and run at the National Center for Atmospheric Research (NCAR) on a CDC 7600. The program was examined to learn the wind finding procedure, and timing runs were made to determine any parts of the program that could be rewritten to significantly decrease the execution time. The timing runs were made with the data from 10 June 1975 at 1800Z. This seemed to be a typical sounding with winds found at seven of the possible 23 levels.

The first timings were made using the CDC RUN compiler. This compiler was needed to interface with the input and unpacking routines supplied by NCAR. Two parts of the program were identified as potential candidates for revision: correlation and unpacking. Table 1 shows that of a total execution time of 34 seconds, 27 seconds were spent in computing correlations and 3.7 seconds were spent unpacking the input data. Execution times given here are CDC 6600 central processor seconds.

The correlation section was the most obvious candidate for revision. This section consisted of four nested loops of which the innermost computed the sums of lagged products. The innermost loop was rewritten to fit into the 6600 instruction stack which is a group of registers that hold instruction words. Loops that fit instack can execute quickly since the instruction words need to be read from memory only once. This reformulation cut the correlation time from 27 to 12 seconds.

At this point, the program was modified slightly so that it could be compiled with FORTRAN EXTENDED, a compiler that is capable of extensive code optimization. Now the total execution time was down to 10 seconds of which 3 were for correlations and 2.6 were for unpacking.

The unpacking portion of the program was modified by replacing the calls to the NCAR supplied general unpacking routine with instructions tailored to this particular unpacking problem. With these instructions, which use the hardware shifts and boolean operations, the unpacking time was cut from 2.6 to 0.6 seconds.

After the program optimization had been completed, a program incorporating a different wind finding method was supplied by Dr. Stephenson. An examination of the new program revealed that only the unpacking section could readily be made more efficient. The changes that had been made to the unpacking logic of the old program were applied to the new program also. The total execution time of the new program was now 4.8 seconds.

The 26 tapes listed in Table 2 were processed to retrieve winds. Each file contained the raw data for one sounding. The first step in the processing was to reformat the nine-track tapes sent from Saskatoon. Several of the shorter input tapes were consolidated onto one reel for the winds processing. The data were not quality checked at this point but were merely copied to [illegible] format suitable for the CDC 6600 on which the winds would be computed.

The reformatted tapes were used as input to the winds program which had been modified to make it more efficient. The outputs of the program were cards and listings which were actually saved on tape rather than being punched or printed. One card contained the wind for one height level along with identification and various intermediate parameters and flags. A card was generated sometimes even if the program could not carry the computations far enough to find a wind value. The listings contained the winds along with the results of many intermediate calculations. If the program was unable to produce a wind for a level, the listing contained an explanation of the problem with the data.

The final step in the winds processing was to consolidate the output. The cards were sorted chronologically and rewritten to a blocked nine track tape to be sent to Saskatoon. A total of 33,192 cards were produced from the tapes listed in Table 2. Dr. Stephenson also sent the October to December 1975 cards to Oxford University to be compared with data from the Pressure Modulator Radiometer. The tapes containing the listable output were also rewritten in a format suitable for use at the University of Saskatchewan. These tapes contained a total of 1,905,076 printed lines of output.

III. Analysis

Based on the frequency of observations and the time periods over which they were taken, the analysis of Saskatoon wind variability conveniently is divided into three classes: variations longer than a month, variations longer than a day, and gravity/tidal wave variations. Before discussing the results, the available data summarized in Table 3 are discussed.

Observations during 1969-1973 were taken from publications (e.g., Manson, et al., 1974), research reports (e.g., Gregory, et al., 1973), or from working charts furnished by A. Manson. Whenever there was data for more than one hour each day, only noon observations were used. The plotted numbers from the reports were transcribed directly to punch cards along with an estimated date for each given vertical profile. In Table 3, the number of hourly medians indicated for 1969-1973 is the number of values extracted from the sources mentioned. Because the number of soundings on which each value was based was not always available, each value was counted as one observation whether presented as a daily or weekly median.

All other data reflected in Table 3 were available as individual soundings. For the period January 1974 through January 1976, daily median values at local noon (18-19 GMT) only were used. The hourly medians were formed by taking components of the individual wind vectors at each level, and then selecting the median value of this sample for each component. Although the use of hourly medians, as opposed to means, reduces the occurrence of wild values, further quality control seemed necessary. The deviations from the annual and other long period variations were obtained by high-pass filtering the data at each level. The high-pass filter had 50% response at period 61 days. If a filtered value was more than three standard deviations removed from the mean of the filtered values, then the corresponding data point in the original series was discarded. As the standard deviation of the filtered values varied by less than 10% between summer and winter at most levels, the quality control procedure was applied to the entire period, January 1974 to January 1976, without regard for season. About 4% of the observations at each level were thus discarded.

Profiles were taken at 5-minute intervals throughout the 10-day intensive runs in August and October, 1976, although at least 50% of the total possible observations are missing from each series (Table 3). Seasonal or long-term synoptic variations were removed from each intensive observation run by subtracting a parabolic trend line fit to the data by the least-squares method. These data were quality controlled by the same procedure as above, except that the filter had 50% response at period 4.5 hours.

A. Long-period oscillations

This section covers the first four harmonics of the annual wave and the quasibiennial oscillation (QBO). Some of these oscillations can be seen in the time series plots of the observed wind speed presented next, and the amplitudes and phases of the waves from periodic analysis are given later.

Monthly mean profiles of the zonal wind speed (u) are shown in Figure 1. There are no noteworthy changes from the results of Gregory, et al. (1975), which are based on data from 1969-1973, although the two additional years of data used here doubles the number of hourly medians at most levels. The annual wave is clearly seen in Figure 1 and has a phase reversal near 100 km with winter westerlies below and summer westerlies above that level. In the overlap region of these two annual waves, i.e., from 90-100 km, a semiannual wave is present as there are four reversals per year. The semiannual and shorter period waves are not easily seen by inspection at other levels.

It is interesting that a jet of winter westerlies is not found in the lower mesosphere in Figure 1. As the mean speed in the jet is over 60 ms^{-1} both from rocketsonde data (Belmont, et al., 1975) and grenade data (Theon, et al., 1973), the relatively small winter speeds below 80 km in

Figure 1 may reflect an instrument bias toward low speeds. Another possible reason that a winter jet is lacking is that only noon data are used in Figure 1, while the rocket and grenade data at Churchill ($59^{o}N$) are taken at all hours of the day (Nastrom and Belmont, 1975; Theon, et al., 1973). Thus, the diurnal tide is included in the noon data used here and seasonal variations of amplitude or phase of this tide may bias the monthly mean noon wind speeds such that the annual wave below about 80 km appears too small. There is not sufficient data at this time to verify possible seasonal changes in the diurnal tide below 80 km, and the large changes above 80 km described by Fellous, et al. (1975) should not be extrapolated downward. Below 80 km the diurnal tide has relatively large amplitude as seen in the height-time section of mean hourly data for October 13-22, 1976, in Figure 2. Seasonal changes in phase or amplitude would clearly affect the annual cycle of noon winds significantly. As a thorough analysis of tidal winds during each season is being made by the Saskatoon group, tides will not be discussed further here. Until their results are available, it is possible only to acknowledge that tidal biasing may be important.

Finally, possible biasing by the diurnal and semidiurnal tides must be taken into account if the present data are used for developing models of the general circulation. Otherwise the resulting models may be dynamically unstable (Schoeberl and Zalesak, 1976).

The mean monthly noon meridional winds (v) are given in Figure 3. The basic pattern is similar to that of Gregory, et al. (1975). These results are included for completeness and will not be discussed further.

A QBO in zonal wind speed in the lower thermosphere has been noted by Sprenger, et al. (1975) and in the airglow of the lower thermosphere by Fukuyama (1977). Long-period oscillations are also found at Saskatoon (Figure 4). Twelve-month running means of monthly mean noon winds are plotted in Figure 4 and the periods in months between successive maxima or minima are noted. Missing data cause the filter to be quite leaky, and the results in Figure 4 can thus only be used qualitatively. An interpolation technique perhaps could have been used to obtain a complete series, and a better filter could then have been used to more precisely isolate the QBO. However, uncertainties then would merely have been imbedded in the interpolation process which could be no more reliable than the original data, so the present method was deemed adequate for the present purpose. The point here is that variations with a QBO period are present at Saskatoon. The QBO in thermospheric wind is not confined to northern mid-latitudes, for a QBO is also apparent at 100 km in the 12-month running means of meteor wind data at Adelaide (35°S)(Figure 5) from Elford (1977). The Adelaide winds are based on approximately once-weekly soundings.

In order to estimate the amplitudes and phases (time of maximum eastward speed) of the QBO and of the first four harmonics of the annual wave, periodic analysis of monthly mean zonal wind speed was made using the technique of Belmont and Dartt (1973). Tests with sinusoidal waves having periods ranging from 20 to 35 months showed that a 26 month period most reduced the variance and gave the smallest RMS amplitude errors for this period of record. Vertical profiles of the amplitude and phase of the 26-month QBO are given in Figure 6a. Below 118 km, QBO amplitudes range from 1 to 7 ms^{-1}, in good agreement with Sprenger, et al. (1975) who report amplitudes of about 3 ms^{-1} at 90-95 km near 53°N. The phase of the QBO is highly variable, and perhaps the only reliable feature is a 180° shift between 94 and 97 km.

The amplitude of the annual wave (Figure 6b) has a pronounced minimum near 100 km. Below 100 km the phase date is near the winter solstice, and above 100 km it is near the summer solstice. Above 105 km the present amplitudes are slightly larger, and the phase dates about a month later than the corresponding results of Groves (1972). The unexpectedly small amplitudes below about 80 km were discussed in connection with Figure 1.

The amplitude of the semiannual wave (Figure 6c) has three maxima, in agreement with Groves (1972). The phase dates are also similar to those of Groves, but the very regular pattern of propagation with height is much more evident in the present display and does not seem to have been noted previously. The straight line on the phase diagram (fitted by eye) has a slope of 8 km month^{-1}. If downward phase propagation implies upward energy propagation, then the region of excitation of this semiannual wave is near 70 km. Belmont, et al. (1973), have hypothesized that particle precipitation effects in the auroral zone influence the ozone, and hence, thermal and wind fields on a semiannual basis. Recent observational (Randhawa, 1976; Heath, et al., 1976) and theoretical (Thorne, 1977) papers lend support to the particle precipitation hypothesis, and the present results could be explained by that hypothesis. However, there could be other explanations for this semiannual wave. For example, the wind reversals associated with mid-winter sudden warmings could induce a semiannual wave with equinoctial phase dates, as found in Figure 6c near 70 km. However, sudden warmings should induce nearly the same phase at all levels.

The 3-month wave can be identified as the second harmonic of the semiannual wave. Although its amplitude (Figure 6d) is less than 5 ms^{-1} at most levels, its phase progression with height appears exactly double that of the semiannual wave. This is apparently the first time an organized 3-month wave has been detected in the mesosphere or lower thermosphere.

The terannual wave has amplitudes less than 5 ms^{-1} at most levels and has no clear pattern of phase progression with height, so is not shown here.

B. Planetary waves

Planetary waves are those oscillations with periods from 2 days to over a month. At middle latitudes in the lower atmosphere these waves are generally identified as Rossby waves. At higher levels, peaks in the variance power spectrum of meteor wind data have been found at about 5 and 10 days (Teptin, 1972). Stimulated by the modeling results of Geisler and Dickinson (1976), Fraser (1977) has examined the 5-day wave in ionospheric absorption in detail. Muller and Kingsley (1974) and Glass, et al. (1975) have also studied the 5-day wave in meteor winds. A 5-day wave could thus be expected in the present wind data.

Another oscillation which might be anticipated in the lower thermosphere is the approximately 27-day period of the solar rotation. This is suggested by the well-known 27-day cycle in geomagnetic activity and the report by Banks (1977) that significant heating may occur in the lower thermosphere of the auroral zone during disturbed periods.

To examine whether these or any other possible waves are in the Saskatoon wind data variance power spectra are given in Figures 7 and 8. These results are based on local noon daily data averaged over 12 km height intervals, although spectra were also taken at all individual levels, as discussed later. Because of possible seasonal differences, the analysis was made for both summer (May-September) and winter (October-April). The statistical significance of spectral peaks can be tested by comparison with the 95% confidence limit of a first-order Markov "null" model shown by dashed lines in Figures 7 and 8. The assessment of significance is thus independent of the coordinates used for presentation. To help account for missing observations, the number of data points was taken to be the number of pairs at lag one day. The maximum lag used in forming the autocorrelation function was 61 days.

During winter (Figure 7), marginally significant peaks at period 4.8 days are found in both u and v at 85-97 km. A nearly significant peak is found in v at the same period at 70-82 km and, from cross-spectral analysis, has a phase lag of -3° relative to 85-97 km although the coherencysquare is only 0.15. No peaks are found in the spectral band centered near the solar rotation period of 27 days. Between 2 and 3 days period several peaks in Figure 7 exceed the 95% level, but the variety of periods at which they occur does not permit associating them with the 2-day wave discussed by Glass, et al. (1975). At 70-82 km, peaks are found in both v and u at period 15.25 days, although only the former is significant.

The model results of Geisler and Dickinson (1976) suggest that the largest 5-day wave at this latitude (52°N) should be found in the v-component in summer above 80 km. In Figure 8, a nearly significant peak is found at period 4.9 days at 85-97 km, and peaks at 4.4 and 7.2 days are seen at 100-112 km. In the spectral band centered at 30.5 days, peaks are found at all levels in v and at 85-97 km in u, although none exceeds the 95% level. Significant peaks at periods slightly over 2 days are found at all levels in both components, and probably correspond to the 2-day wave of Glass, et al (1975).

Waves which have rapid phase changes with height or which exist over only a portion of one of the height intervals used above might be obscured due to averaging. To examine that possibility the spectral analysis results for summer at individual levels are summarized in Table 4. A dot is entered in the table if a spectral peak is found at a given level and period, while an S is entered if the peak exceeds the 95% level. Forcing at a given period may be expected to induce a spectral peak at several adjacent height levels, although all peaks may not necessarily be significant. Possible frequency shifts with height are ignored here. Using the ad hoc criterion that a peak at five adjacent levels may suggest some organized forcing, then only the 30.5 day period and periods near 4.5, 3, and 2 days would be judged physically meaningful. Corresponding results for winter only confirm the findings discussed before, so are not given here.

C. Short period motions

This section considers those motions with periods less than a few hours, thus including gravity waves and turbulence. Tides were discussed briefly in Section IIIA and are not considered further here, although it must be recognized that higher harmonics of the diurnal and semidiurnal tides could be included in the present results. One aim of this study is to determine if a sampling interval longer than five minutes could be used to adequately resolve the motion systems of the mesosphere and lower thermosphere. If there is a distinct gap in the spectrum, then observations could be spaced at twice the frequency of the gap.

In order to examine the partitioning of the variance among motions with periods from 10 minutes to 6 hours, spectra of the entire 10-day series of individual 5-minute observations during August and October, 1976, were computed. Inspection of those results indicated that prewhitening should be applied. Straightforward removal of the mean daily variation (e.g., see Figure 2) was not used because of the well-known day-to-day variation of the tides. Also, a high-pass filter was not used because differing amounts of missing data under the filter induce differing filter response characteristics which could hamper the interpretation of any results. Thus, at each level each 10-day series was divided into 6-hour segments. Segments with less than 50% complete data were discarded, and each of the remaining segments was detrended by regression with a parabolic trend line in an effort to remove tidal and synoptic variations. An average of 19 segments were used at each level. Lagged covariances up to maximum lag three hours were determined for each segment, and then averaged over all segments. The variance power spectra of these stacked covariances are presented in Figure 9 and 10 for the 94 and 106 km levels, which are typical examples.

Vertical lines are entered in Figures 9 and 10 at the periods where 50% of the total variance is on either side of the line. The lines are always found between 24 and 34 minutes period. Thus, although gravity waves with periods one hour or greater could be resolved with observations spaced, say, 10 or 20 minutes apart, any estimates would be seriously aliased by the relatively large variance contained in the period range 10-25 minutes. Possible aliasing of the present results by motions with less than 10 minutes period cannot be assessed directly, but must be expected.

The variations with periods greater than about half an hour have been identified as gravity waves by Manson, et al. (1974), although Teptin (1975) prefers to describe these variations as turbulence. Gravity waves, although individually organized, are expected to be sporadic and polychromatic. Thus, if a long period of data is analyzed, as used initially here or as Teptin used, any gravity wave influence would be smeared out, leaving the impression that only turbulent motions exist. For example, the average correlation coefficient at lag one (i.e., five minutes) at 94 km during the October, 1976 period is 0.28 for u and 0.08 for v. If the only variance were that due to a sinusoid of period one hour, the lag one correlation coefficient would be 0.866; and if the period were one-half hour the lag one correlation coefficient would be 0.50. The observed average coefficients are too small to attribute solely to a single wave action. However, the lag one correlation coefficients over individual six-hour segments (Table 5) are occasionally large enough to be due to waves. On other occasions they are negative, indicating very high frequency (turbulent) motions. The point is that while statistics of large samples are usually desirable, multiple and sporadic phenomena can be superimposed causing ambiguity.

IV. Summary and Conclusions

1. A weak quasibiennial oscillation of less than 7 ms^{-1} from 65-115 km agrees with independent estimates at other locations. The phase shows a 180° shift near 95 km.

2. The annual wave is about 20 ms^{-1} up to 88 km and above 105 km with a pronounced minimum near 100 km. Below 100 km the maximum occurs at the winter solstice and above 100 km near the summer solstice. The data and the results given here may be biased by the seasonal variation in the diurnal tidal component, as data are taken near local noon. Tidal analyses are being made elsewhere.

3. The semiannual wave has three maxima near 10 ms^{-1} at 70, 97, and 118 km, agreeing with Grove's model. The phase displays a remarkably consistent downward progression of 8 km $month^{-1}$ from 118 km in October to 70 km in April. These dates suggest either influence of auroral particle precipitation maxima, and consequent effects on ozone, or the influence of heating at high latitudes by sudden warmings in winter, or both.

4. A weak 3-month wave of less than 7 ms^{-1} has double the phase descent rate of the semiannual wave, of which it is the second harmonic. This appears to be the first notice of a 3-month wave.

5. No consistent terannual wave phase was observed and amplitudes were less than 5 ms^{-1}.

6. Among planetary scale waves, marginally significant peaks at 4.8 days were found in both u and v at 85-97 km in winter, and at 4.4 days in v at 70-82 km. In summer an approximately five-day wave appears at 85-97 km and 100-112 km. In addition, in summer a spectral peak at 7.2 days at 100-112 km, is found. Spectral peaks near 27 days period are not found in winter, but small spectral peaks are found in summer at all levels for v and at middle levels for u. Peaks near two days period are seen at all levels in u and v in both seasons.

7. From 5-minute data, it is concluded that possible aliasing by the large variance in the period range of 10-25 minutes requires observations at highest possible frequencies.

Acknowledgement

The close cooperation of the Atmospheric Dynamics Group, Institute of Space and Atmospheric Studies University of Saskatchewan, in sharing their data is greatly appreciated.

References

Banks, P., 1977: Observations of joule and particle heating in the auroral zone. J. Atmos. Terr. Phys., 39, 179-194.

Belmont, A., and D. Dartt, 1973: Semiannual variation in zonal wind from 20 to 65 km at 80°N-10°S. J. Geophys. Res., 78, 6373-7376.

Belmont, A., G. Nastrom, and H. Mayr, 1974: Significance of semiannual waves in the mesospheric zonal wind and evidence of influence by the geomagnetic field. J. Geophys. Res., 79, 5049-5051.

Belmont, A., D. Dartt, and G. Nastrom, 1975: Variations of stratospheric zonal winds, 20-65 km, 1961-1971. J. Appl. Meteor., 14, 585-594.

CIRA, 1972: Cospar International Reference Atmosphere. Akademie-Verlag, Berlin, 450 pp.

Elford, W.G., 1977: private communication.

Fellous, J., R. Bernard, M. Glass, M. Massebeuf, and A. Spizzichino, 1975: A study of the variations of atmospheric tides in the meteor zone. J. Atmos. Terr. Phys., 37, 1511-1524.

Fraser, G., 1977: The 5-day wave and ionospheric absorption. J. Atmos. Terr. Phys., 39, 121-124.

Fukuyama, K., 1977: Airglow variations and dynamics in the lower thermosphere and upper mesosphere - II. Seasonal and long-term variations. J. Atmos. Terr. Phys., 39, 1-14.

Geisler, J., and R. Dickinson, 1976: The five-day wave on a sphere with realistic zonal winds. J. Atmos. Sci., 33, 632-641.

Glass, M., J. Fellous, M. Massebeuf, A. Spizzichino, I. Lysenko, Yu. Portniaghin, 1975: Comparison and interpretation of the results of simultaneous wind measurements in the lower thermosphere at Garchy (France) and Obninsk (U.S.S.R.) by meteor radar technique. J. Atmos. Terr. Phys., 37, 1077-1088.

Gregory, J., and D. Stephenson, 1972: High altitude winds from radio reflections. Can. Res. Develop, March/April.

Gregory, J., A. Manson, and D. Stephenson, 1973: High altitude winds at Saskatoon, Canada. Report No. 3, Atmospheric Dynamics Group, Univ. of Saskatchewan, 15 pp.

References (Cont'd)

Gregory, J. and A. Manson, 1975: Winds and wave motions to 110 km at mid-latitudes. II. Mean winds at 52°N, 1969-73. J. Atmos. Sci., 32, 1667-1675.

Groves, G., 1972: Annual and semiannual zonal wind components and corresponding temperature and density variations, 60-130 km. Planet. Spa. Sci., 20, 2099-2112.

Heath, D., A. Krueger, and P. Crutzen, 1976: Influence of a solar proton event on stratospheric ozone. NASA-TMX-71173, 12pp.

Manson, A., J. Gregory, and D. Stephenson, 1974: Winds and wave motions to 110 km at mid-latitudes. I. Partial reflection radiowave soundings, 1972-73. J. Atmos. Sci., 31, 2207-2215.

Muller, H., and S. Kingsley, 1974: Long period meteorwind oscillations. J. Atmos. Terr. Phys., 36, 1933-1943.

Nastrom, G., and A. Belmont, 1975: Diurnal stratospheric tide in meridional wind, 30 to 60 km, by season and monthly mean temperatures, 20 to 60 km, at 80°N to 0°N. NASA-CR-137738, 58 pp.

Randhawa, J., 1976: Rocket ozone measurement during an auroa. EOS (abstract only), 57, 301.

Schoeberl, M., and S. Zalesak, 1976: A critical analysis of climatological wind data used in the forecast of radioactive debris cloud movement. NRL Memo. Report 3366, 14 pp.

Sprenger, K., K. Greisiger, and R. Schminder, 1975: Evidence of quasi-biennial wind oscillation in the mid-latitude lower thermosphere, obtained from ionospheric drift measurements in the LF range. J. Atmos. Terr. Phys., 37, 1391-1393.

Teptin, G., 1972: Upper-atmosphere motion, as determined by observations of radio echoes from meteor trails. Izv., Atmospheric and Oceanic Physics, 8, 243-263.

Teptin, G., 1975: Wave motions and turbulence in the upper atmosphere. Izv., Atmospheric and Oceanic Physics, 11, 503-506.

Theon, J., W. Smith, J. Casey, and B. Kirkwood, 1972: The mean observed meteorological structure and circulation of the stratosphere and mesosphere. NASA-TR-375, 77 pp.

Thorne, R., 1977: Energetic radiation belt electron precipitation - A natural depletion mechanism for stratospheric ozone. Science, 195, 287-289.

Table 1

Program execution times given in CDC 6600 central processor seconds

	Correlations	Unpacking	Total Execution
Initial timing	27	3.7	34
Rewrite correlation section	12	3.7	19
Change to FORTRAN EXTENDED	3	2.6	10
Rewrite unpacking section	3	0.6	8
New Program (correlations are done differently)	-	0.6	4.8

Table 2

Raw data tapes received from Saskatoon and processed by CDC (See Table 3 for other available data).

Tape	Dates	No. of Files
TIDE51	4 Apr - 26 May 1974	266
TIDE52	30 May - 30 Jun 1974	189
TIDE53	4 Jul - 30 Jul 1974	233
TIDE54	1 Aug - 23 Aug 1974	245
PARK61	8 May - 9 May 1975	24
PARK62	10 May - 12 May 1975	36
PARK63	13 May - 15 May 1975	37
PARK65	20 May - 23 May 1975	24
PARK66	24 May - 29 May 1975	83
PARK69	7 Jun - 11 Jun 1975	60
PARK70	13 Jun - 17 Jun 1975	61
PARK71	18 Jun - 24 Jun 1975	72
PARK77	10 Jul - 16 Jul 1975	88
PARK78	17 Jul - 22 Jul 1975	107
PARK79	23 Jul - 29 Jul 1975	72
PARK80	30 Jul - 8 Aug 1975	121
PARK84	27 Aug - 5 Sep 1975	141
PARK85	6 Sep - 16 Sep 1975	135
PARK86	17 Sep - 29 Sep 1975	99
PARK87	30 Sep - 10 Oct 1975	156
PARK88	11 Oct - 16 Oct 1975	72
PARK89	17 Oct - 31 Oct 1975	188
PARK90	1 Nov - 14 Nov 1975	169
PARK91	15 Nov - 24 Nov 1975	144
PARK94	11 Dec - 30 Dec 1975	203
WND008	13 Jan - 25 Jan 1976	201

Table 3

Summary of available data

		73	88	103	118 km
Dates	Observational frequency	Number of hourly medians			
Feb 1969 - Aug 1973	Hourly median at local noon once or twice each week	68	102	43	0
Jan 1974 - Jan 1976	Hourly median at local noon each day	324	403	350	329
		Number of observations			
13 - 22 Oct 1976	Continuous data at 5-minute intervals 24 hours per day	382	983	848	491
5 - 14 Aug 1976		223	145	511	600

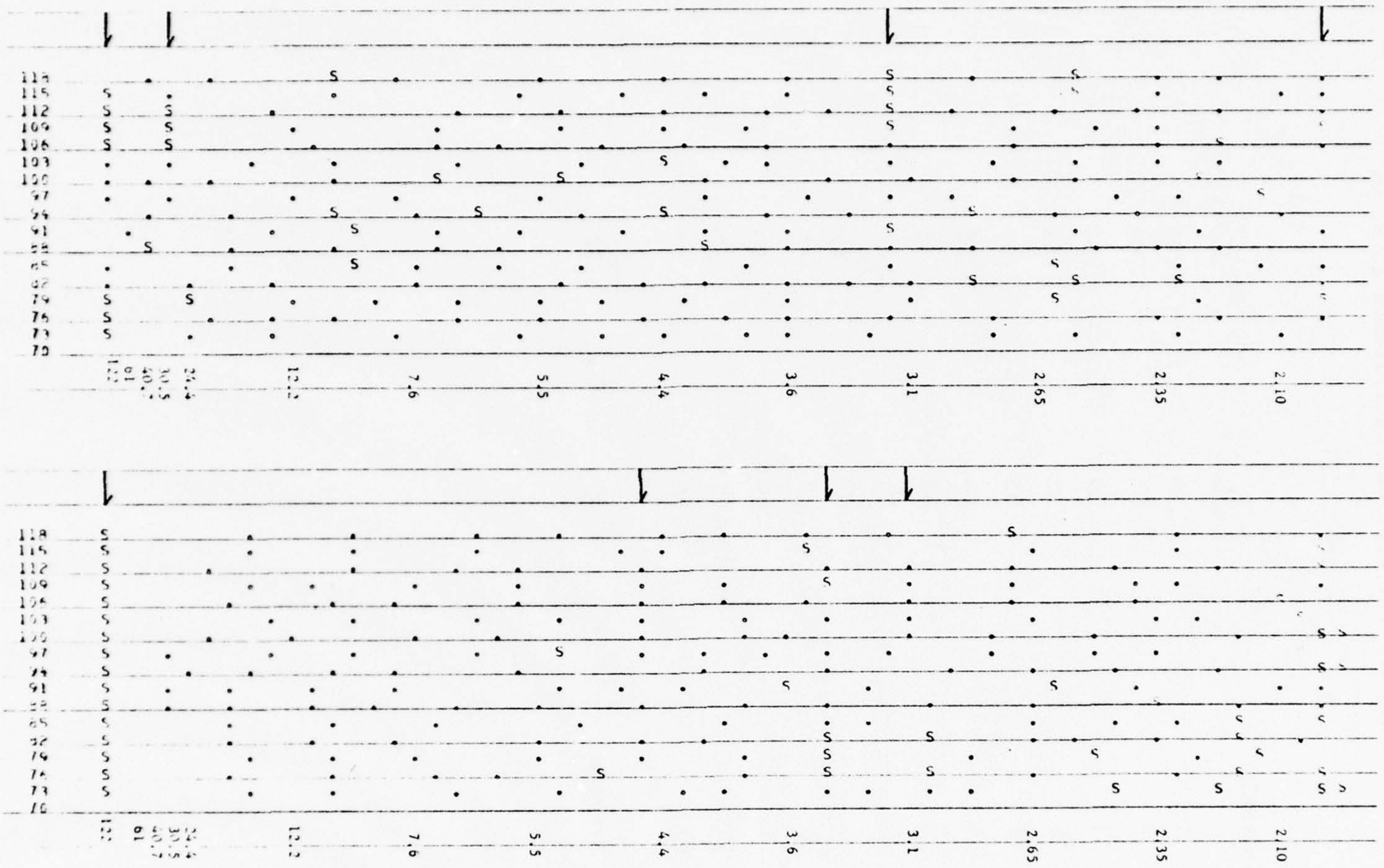


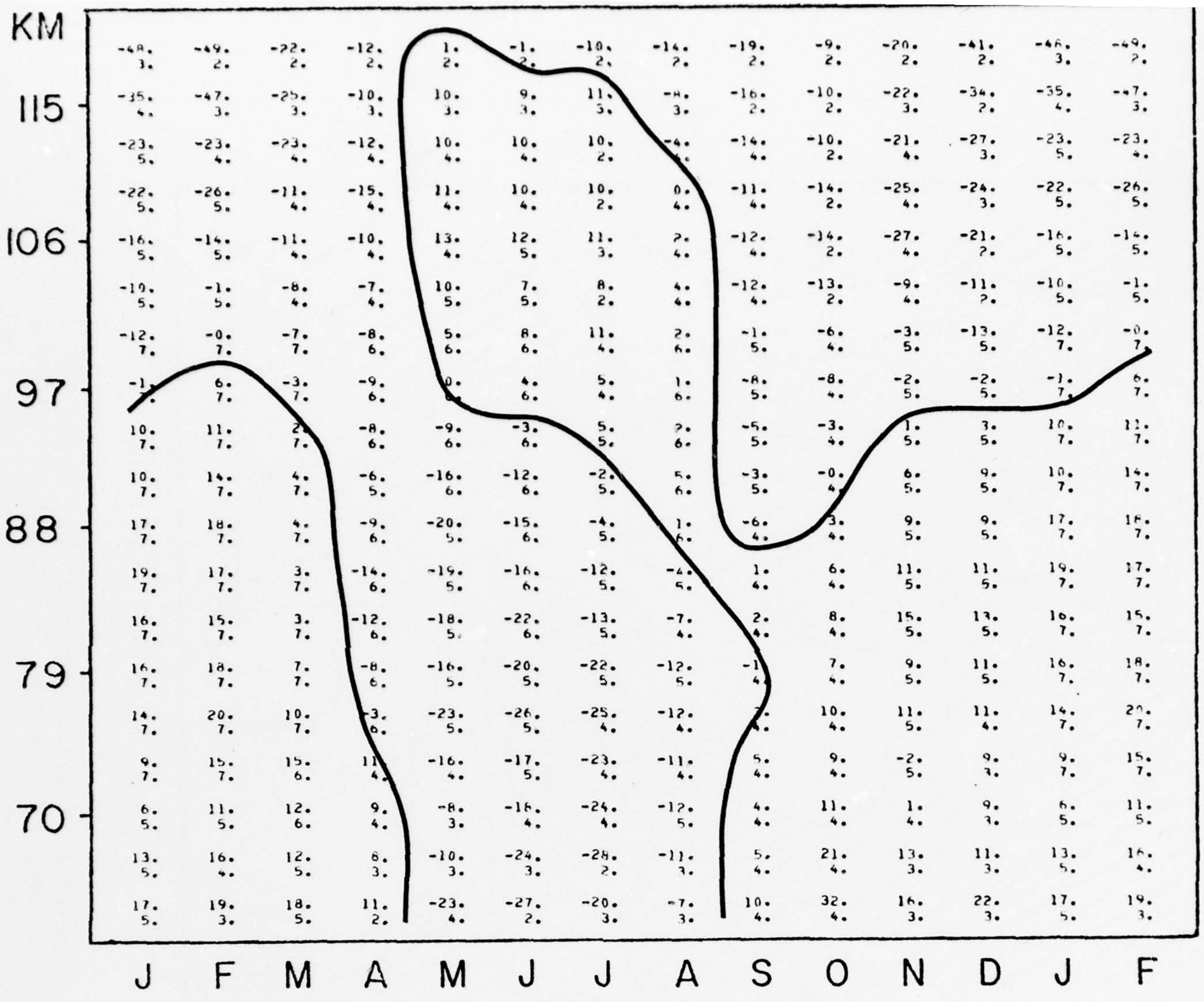
Table 4. Variance power spectrum analysis results at individual levels. A dot is entered if the spectral density at a given frequency is a relative maximum, and an S is entered if it exceeds the 95% significance level. Arrows above the Table indicate that five or more adjacent levels have maxima at the indicated frequency. Periods, in days, corresponding to selected frequencies are entered at the bottom and height (km) is at the left of each chart. Upper; v-wind; lower, u-wind.

Table 5

Lag one correlation coefficients at 94 km

October 1976

Segment		u	v
1		.26	.09
2		.34	-.03
3		.19	.04
4		.28	.64
5		.35	.32
6		.04	-.10
7		.43	-.18
8		.36	-.47
9		-.07	-.66
10		.27	.29
11		.44	.40
12		-.11	.35
13		.54	.12
Average	=	0.28	0.08



KM	J	F	M	A	M	J	J	A	S	O	N	D	J	F
	-48. 3.	-49. 2.	-22. 2.	-12. 2.	1. 2.	-1. 2.	-10. 2.	-14. 2.	-19. 2.	-9. 2.	-20. 2.	-41. 2.	-46. 3.	-49. 2.
115	-35. 4.	-47. 3.	-25. 3.	-10. 3.	10. 3.	9. 3.	11. 3.	-8. 3.	-16. 2.	-10. 2.	-22. 3.	-34. 2.	-35. 4.	-47. 3.
	-23. 5.	-23. 4.	-23. 4.	-12. 4.	10. 4.	10. 4.	10. 2.	-4. 4.	-14. 4.	-10. 2.	-21. 4.	-27. 3.	-23. 5.	-23. 4.
	-22. 5.	-26. 5.	-11. 4.	-15. 4.	11. 4.	10. 4.	10. 2.	0. 4.	-11. 4.	-14. 2.	-25. 4.	-24. 3.	-22. 5.	-26. 5.
106	-16. 5.	-14. 5.	-11. 4.	-10. 4.	13. 4.	12. 5.	11. 3.	2. 4.	-12. 4.	-14. 2.	-27. 4.	-21. 2.	-16. 5.	-14. 5.
	-19. 5.	-1. 5.	-8. 4.	-7. 4.	10. 5.	7. 5.	8. 2.	4. 4.	-12. 4.	-13. 2.	-9. 4.	-11. 2.	-10. 5.	-1. 5.
	-12. 7.	-0. 7.	-7. 7.	-8. 6.	5. 6.	8. 6.	11. 4.	2. 6.	-1. 5.	-6. 4.	-3. 5.	-13. 5.	-12. 7.	-0. 7.
97	-1. 7.	6. 7.	-3. 7.	-9. 6.	0. 6.	4. 6.	5. 4.	1. 6.	-8. 5.	-8. 4.	-2. 5.	-2. 5.	-1. 7.	6. 7.
	10. 7.	11. 7.	2. 7.	-8. 6.	-9. 6.	-3. 6.	5. 5.	2. 6.	-5. 5.	-3. 4.	1. 5.	3. 5.	10. 7.	11. 7.
	10. 7.	14. 7.	4. 7.	-6. 5.	-16. 6.	-12. 6.	-2. 5.	5. 6.	-3. 5.	-0. 4.	6. 5.	9. 5.	10. 7.	14. 7.
88	17. 7.	18. 7.	4. 7.	-9. 6.	-20. 5.	-15. 6.	-4. 5.	1. 6.	-6. 4.	3. 4.	9. 5.	9. 5.	17. 7.	18. 7.
	19. 7.	17. 7.	3. 7.	-14. 6.	-19. 5.	-16. 6.	-12. 5.	-4. 5.	1. 4.	6. 4.	11. 5.	11. 5.	19. 7.	17. 7.
	16. 7.	15. 7.	3. 7.	-12. 6.	-18. 5.	-22. 6.	-13. 5.	-7. 4.	2. 4.	8. 4.	15. 5.	13. 5.	16. 7.	15. 7.
79	16. 7.	18. 7.	7. 7.	-8. 6.	-16. 5.	-20. 5.	-22. 5.	-12. 5.	-1[illegible] 4.	7. 4.	9. 5.	11. 5.	16. 7.	18. 7.
	14. 7.	20. 7.	10. 7.	-3. 6.	-23. 5.	-26. 5.	-25. 4.	-12. 4.	[illegible] 4.	10. 4.	11. 5.	11. 4.	14. 7.	20. 7.
	9. 7.	15. 7.	15. 6.	11. 4.	-16. 4.	-17. 5.	-23. 4.	-11. 4.	5. 4.	9. 4.	-2. 5.	9. 3.	9. 7.	15. 7.
70	6. 5.	11. 5.	12. 6.	9. 4.	-8. 3.	-16. 4.	-24. 4.	-12. 5.	4. 4.	11. 4.	1. 4.	9. 3.	6. 5.	11. 5.
	13. 5.	16. 4.	12. 5.	6. 3.	-10. 3.	-24. 3.	-28. 2.	-11. 3.	5. 4.	21. 4.	13. 3.	11. 3.	13. 5.	16. 4.
	17. 5.	19. 3.	18. 5.	11. 2.	-23. 4.	-27. 2.	-20. 3.	-7. 3.	10. 4.	32. 4.	16. 3.	22. 3.	17. 5.	19. 3.

Figure 1. Consolidated monthly mean zonal wind speeds (ms^{-1}) at local noon at Saskatoon, 1969-January 1976. The number of years for which data are available for each month and level is given beneath the mean wind speed. Positive winds are from the west. January and February are repeated to provide continuity of patterns.

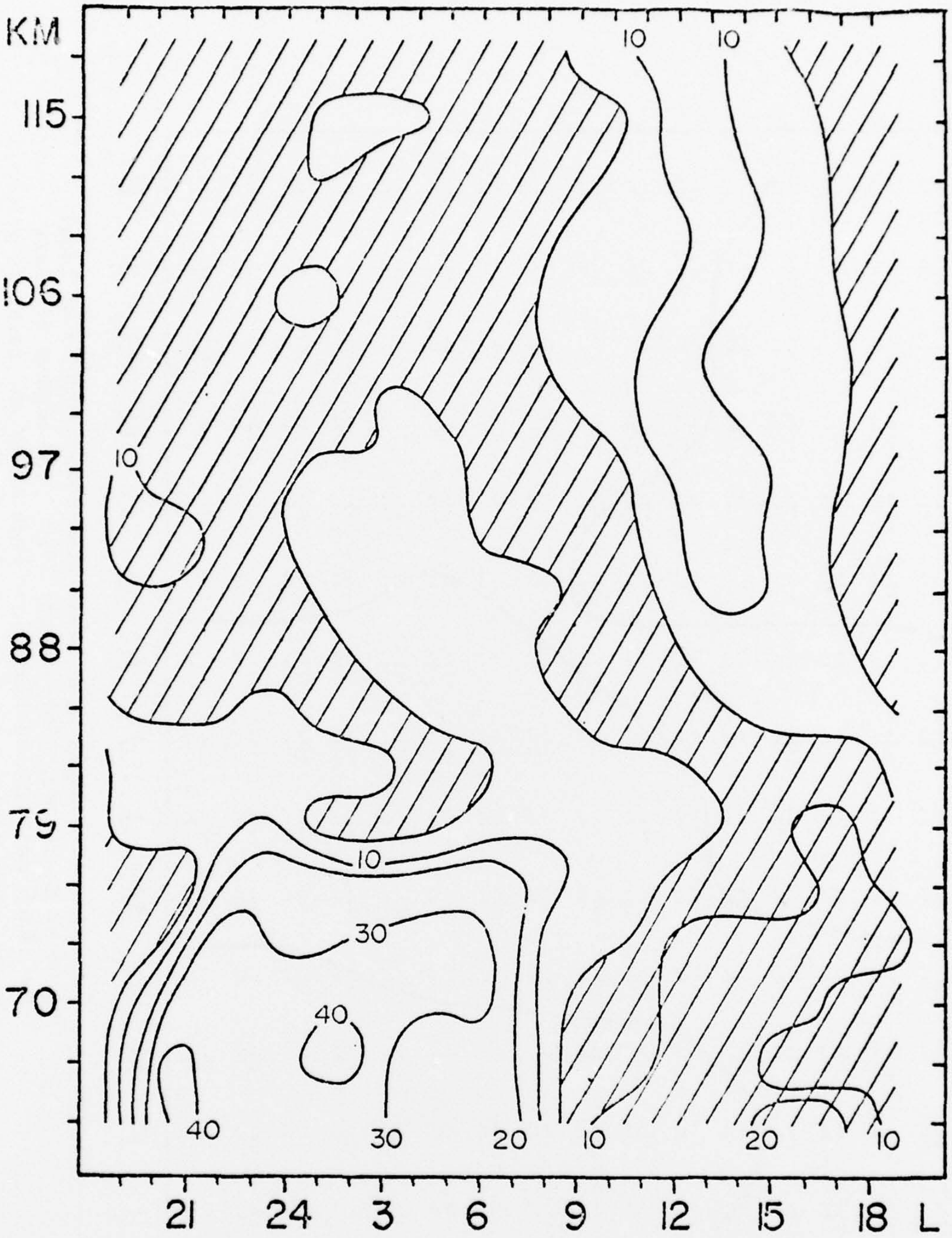


Figure 2. Consolidated hourly mean zonal wind speeds (ms^{-1}) during 13-22 October, 1976. Winds from the west are hatched.

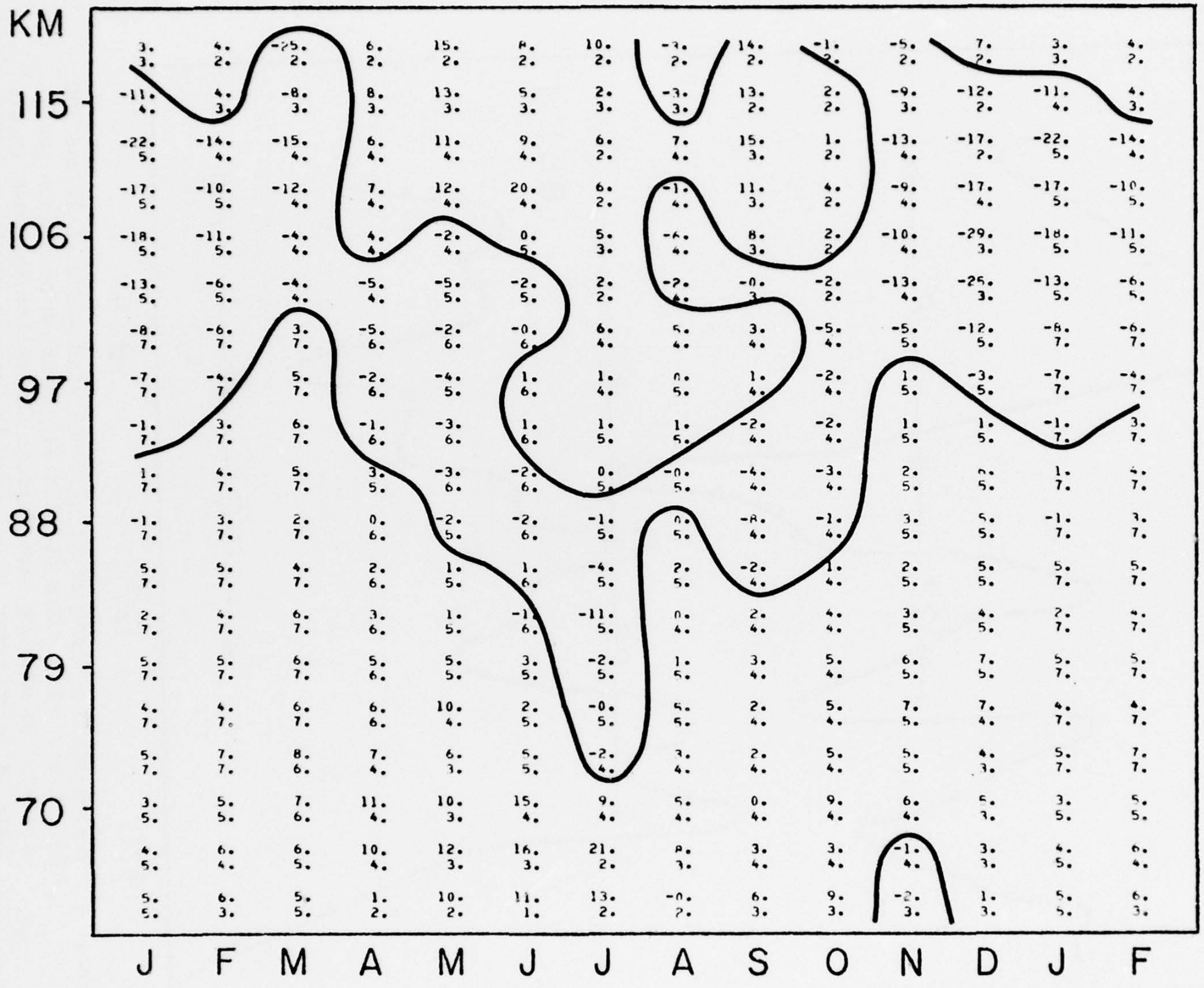


Figure 3. As in Figure 1 except for meridional wind speeds. Positive winds are from the south.

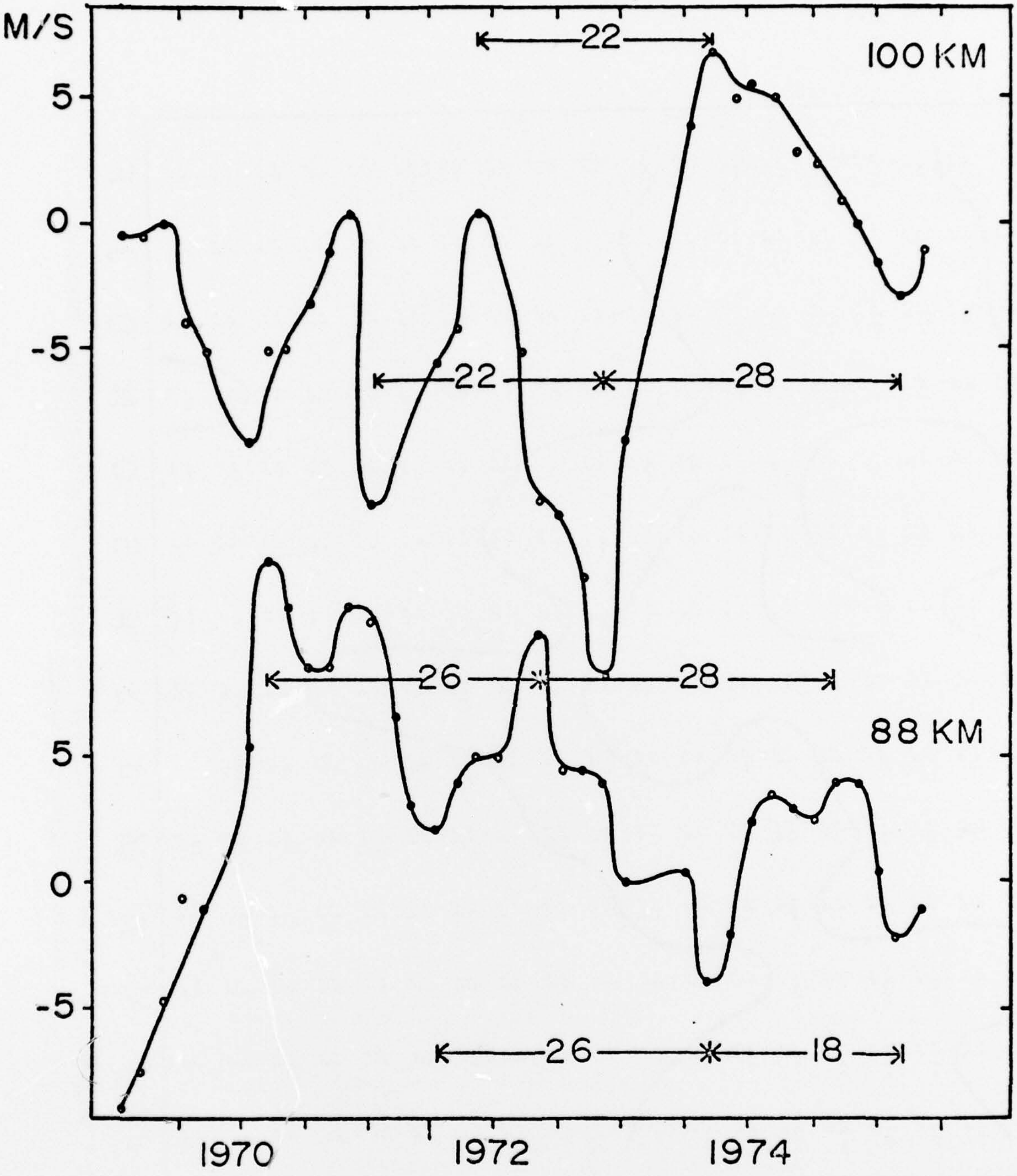


Figure 4. Twelve-month running means of zonal wind speed at 88 and 100 km. Every other value is plotted, although some data are missing. As missing data degrade the filter response (e.g., there is an apparent annual wave leakage at 100 km in 1971), these results must be used only qualitatively. The number of months between successive like-extrema have been entered.

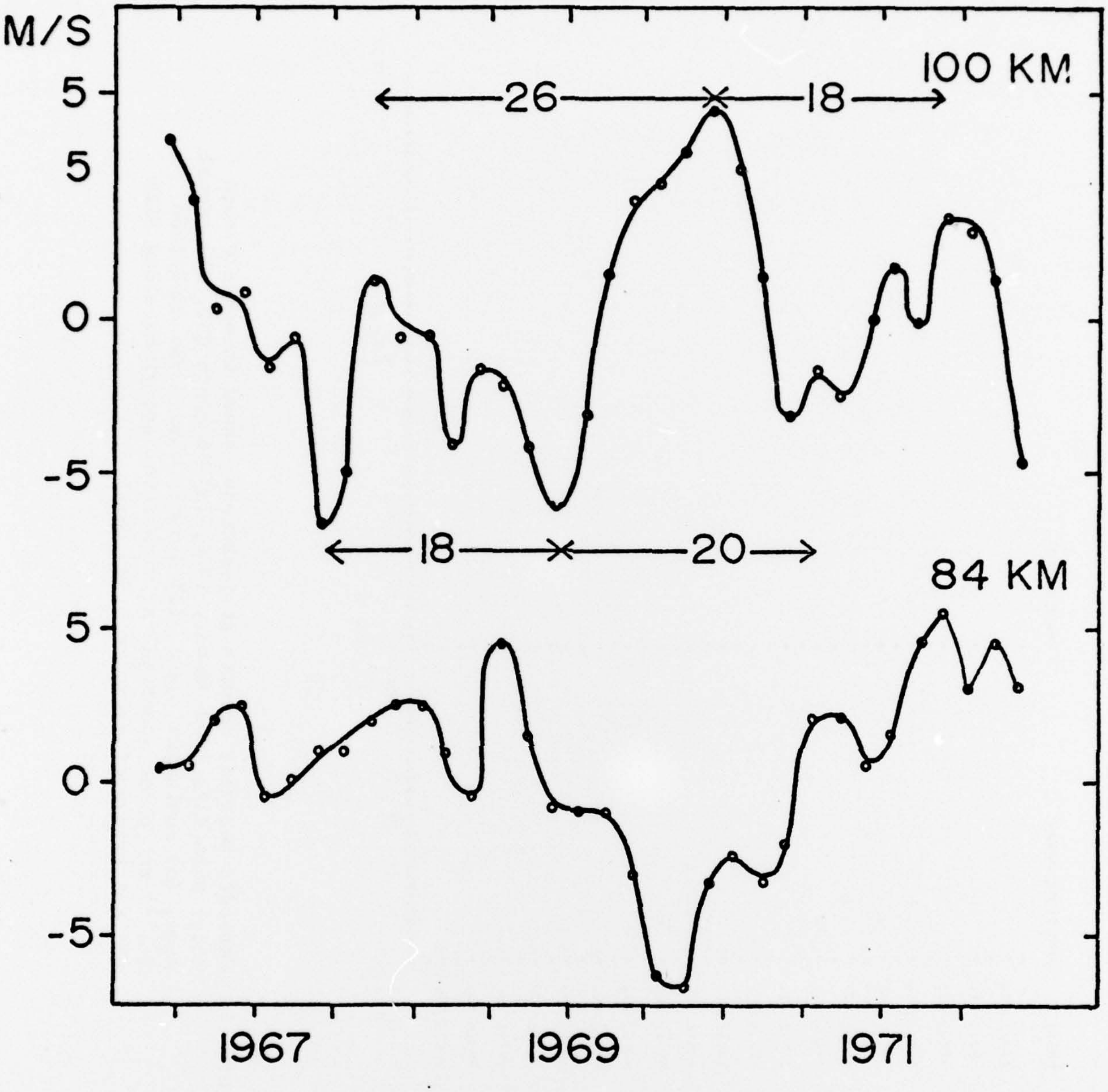


Figure 5. As in Figure 4, except for Adelaide (35°S) at 84 and 100 km. The time series at Adelaide are complete.

Fig. 6(a) QBO(26MO) WAVE   SASKATOON ZONAL WINDS

```
HT(KM) AMPLITUDE   PHASE

  118  11.3± 3.4   110.± 18.
  115   6.2± 3.0    80.± 35.
  112   7.1± 2.8    77.± 25.
  109   6.9± 2.6   118.± 24.
  106   4.1± 2.3    72.± 45.
  103   6.3± 2.3   119.± 23.
  100   4.4± 1.6  -179.± 26.
   97   2.7± 1.5   142.± 45.
   94   2.2± 1.4   -74.± 52.
   91   1.8± 1.2  -102.± 58.
   88   5.1± 1.6   -85.± 18.
   85   4.0± 1.5   -55.± 24.
   82   3.8± 1.4   -99.± 24.
   79   1.5± 1.1   -81.± 64.
   76   1.8± 1.2    36.± 56.
   73   1.3± 1.2    98.± 71.
   70   1.5± 1.3  -167.± 73.
   67   2.6± 1.7   -60.± 54.
   64   1.6± 2.1    -4.± 88.
```

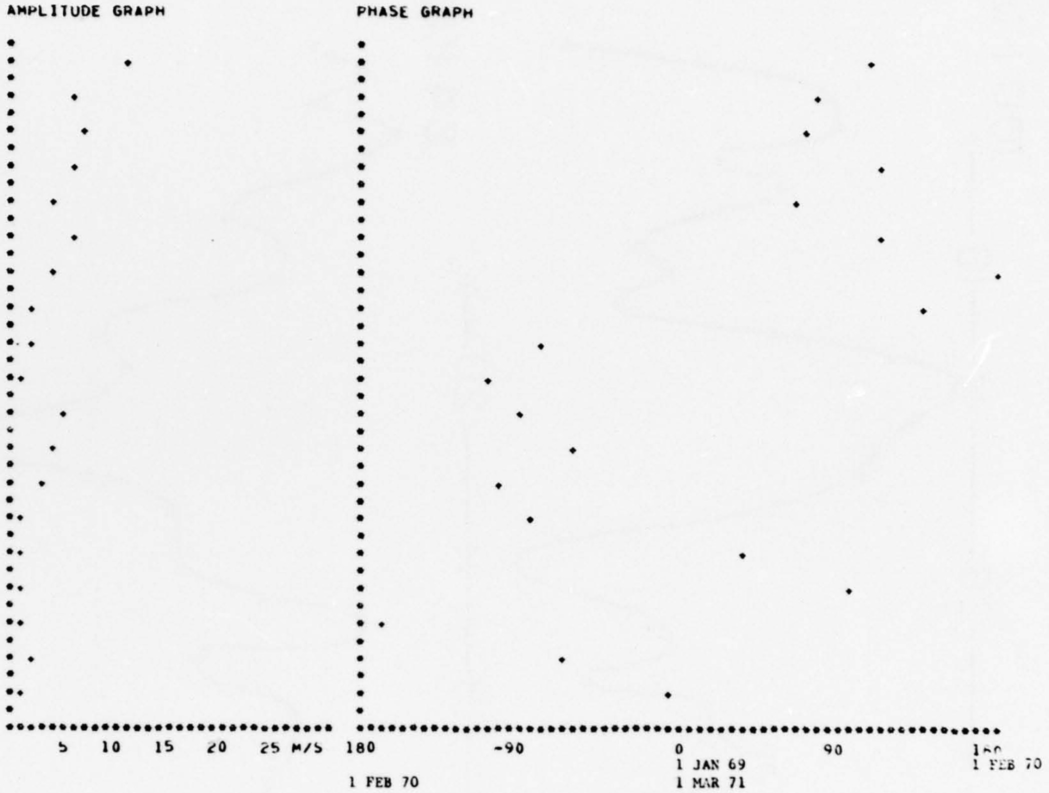


Figure 6. Periodic analysis results at Saskatoon, based on monthly mean local noon data 1969-January 1976; (a) 26-month QBO, (b) annual wave, (c) semiannual wave, (d) 3-month wave. The amplitude (ms^{-1}) and phase (degrees) at each level are given along with the RMS errors of estimate. See text.

Fig. 6(b) ANNUAL WAVE SASKATOON ZONAL WINDS

```
HT(KM) AMPLITUDE   PHASE

 118   20.2± 3.6  -174.± 10.
 115   26.3± 3.4   180.±  7.
 112   23.7± 3.0   172.±  7.
 109   22.7± 2.7   171.±  7.
 106   23.8± 2.7   174.±  6.
 103   10.3± 2.3   149.± 13.
 100    1.9± 1.4   169.± 65.
  97    2.8± 1.5    24.± 41.
  94   10.3± 1.6    -8.±  9.
  91   13.9± 1.5   -14.±  6.
  88   18.3± 1.6   -11.±  5.
  85   20.4± 1.6   -11.±  4.
  82   19.2± 1.5    -8.±  4.
  79   19.8± 1.5     3.±  4.
  76   22.9± 1.6    -3.±  4.
  73   19.3± 1.8     6.±  5.
  70   18.7± 1.9     5.±  5.
  67   21.8± 2.9    -3.±  6.
  64   22.4± 4.8   -11.±  9.
```

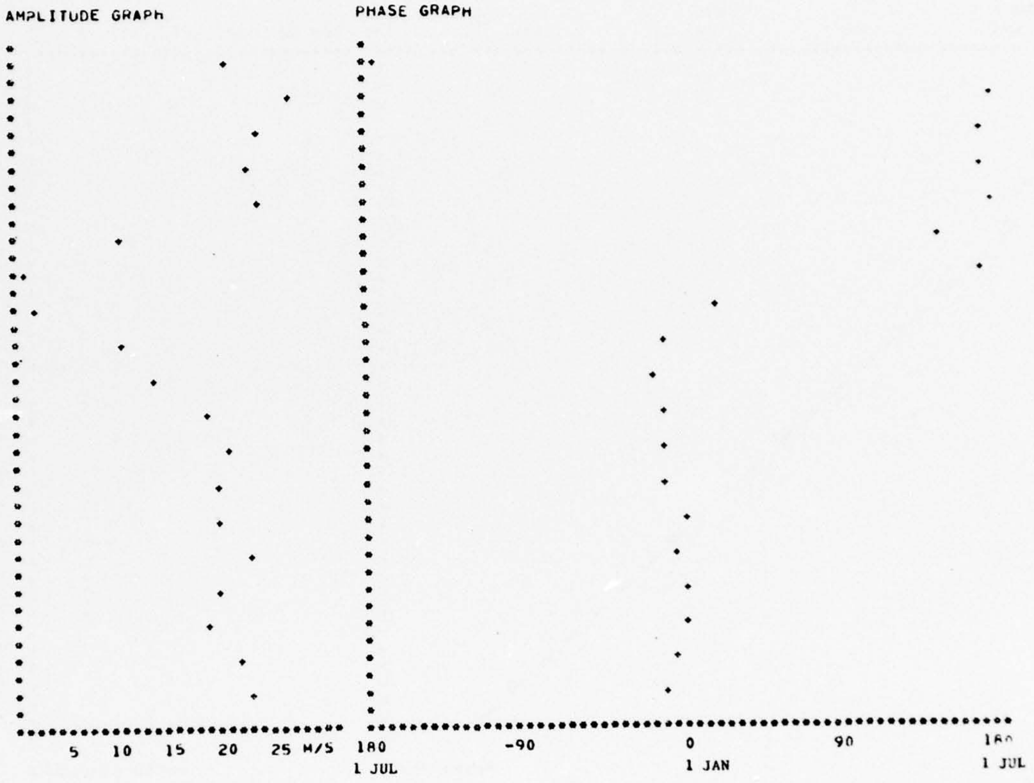


Fig. 6(c) SEMI.ANN WAVE SASKATOON ZONAL WINDS

HT(KM)	AMPLITUDE	PHASE
118	12.0± 3.5	-126.± 17.
115	10.9± 3.3	-108.± 18.
112	7.5± 2.8	-60.± 24.
109	5.2± 2.4	-38.± 33.
106	5.8± 2.4	-16.± 29.
103	7.1± 2.2	-17.± 20.
100	9.3± 1.7	1.± 12.
97	10.3± 1.7	32.± 10.
94	8.2± 1.6	45.± 12.
91	5.5± 1.5	82.± 15.
88	3.9± 1.5	94.± 25.
85	5.7± 1.6	120.± 16.
82	4.4± 1.4	136.± 21.
79	5.8± 1.4	169.± 16.
76	9.2± 1.5	178.± 12.
73	9.7± 1.5	-173.± 10.
70	11.7± 1.6	-162.± 9.
67	11.7± 2.4	179.± 13.
64	9.7± 4.0	152.± 26.

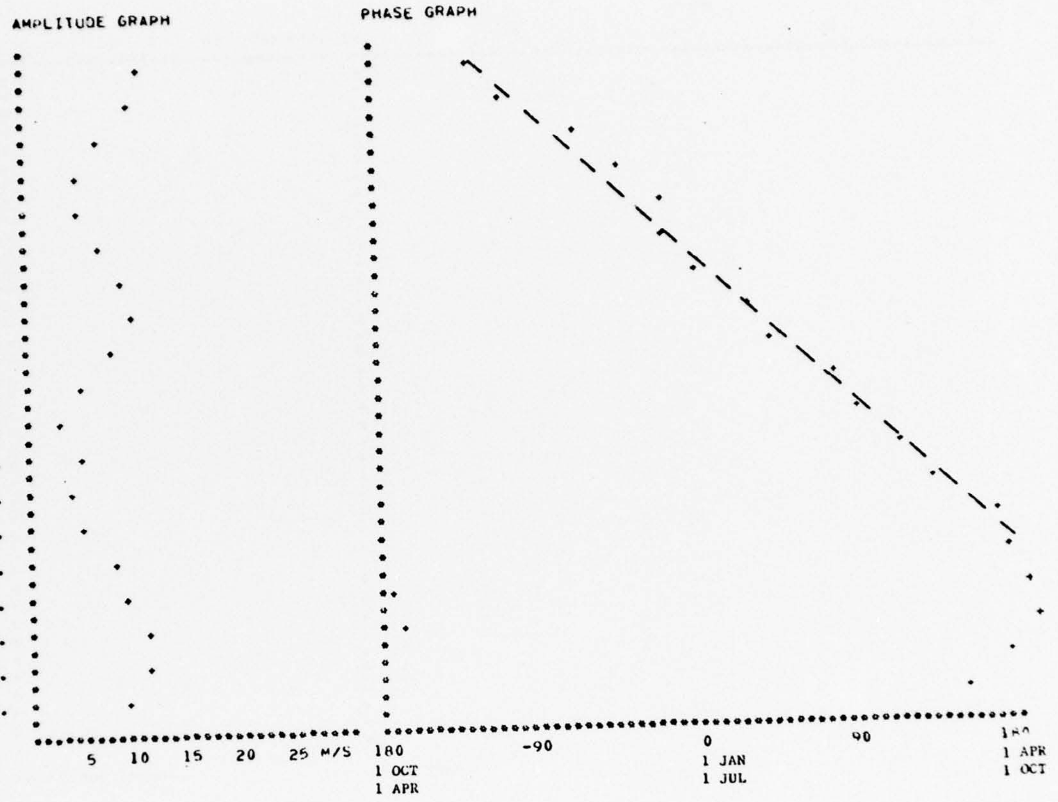
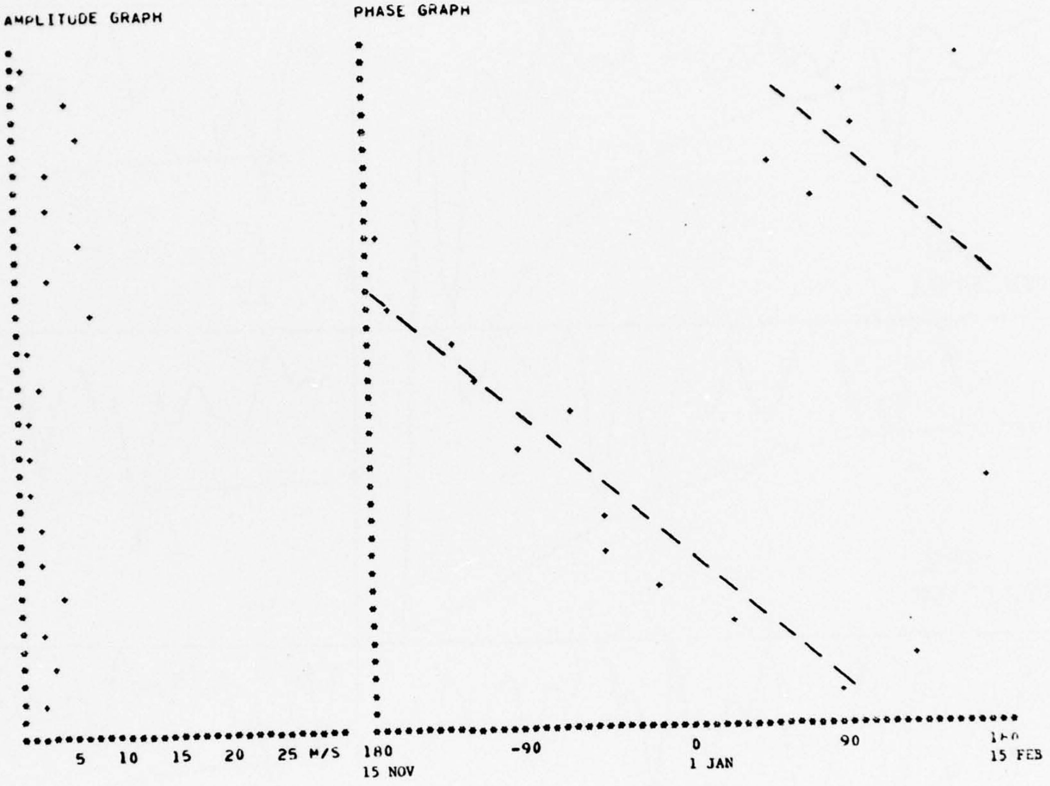


Fig. 6(d) 3-MONTH WAVE SASKATOON ZONAL WINDS

HT(KM)	AMPLITUDE	PHASE
118	2.0± 2.4	161.± 82.
115	5.7± 2.9	92.± 38.
112	6.9± 2.7	98.± 26.
109	3.2± 2.2	48.± 57.
106	3.3± 2.2	74.± 56.
103	6.3± 2.2	-174.± 23.
100	3.7± 1.6	168.± 31.
97	7.1± 1.7	-164.± 15.
94	1.8± 1.3	-127.± 61.
91	2.6± 1.3	-118.± 36.
88	1.8± 1.3	-65.± 59.
85	.7± 1.1	-91.± 86.
82	1.9± 1.2	172.± 56.
79	2.3± 1.3	-46.± 43.
76	2.1± 1.3	-46.± 52.
73	4.5± 1.6	-13.± 22.
70	2.4± 1.5	28.± 54.
67	3.9± 2.1	128.± 42.
64	2.9± 3.0	89.± 76.



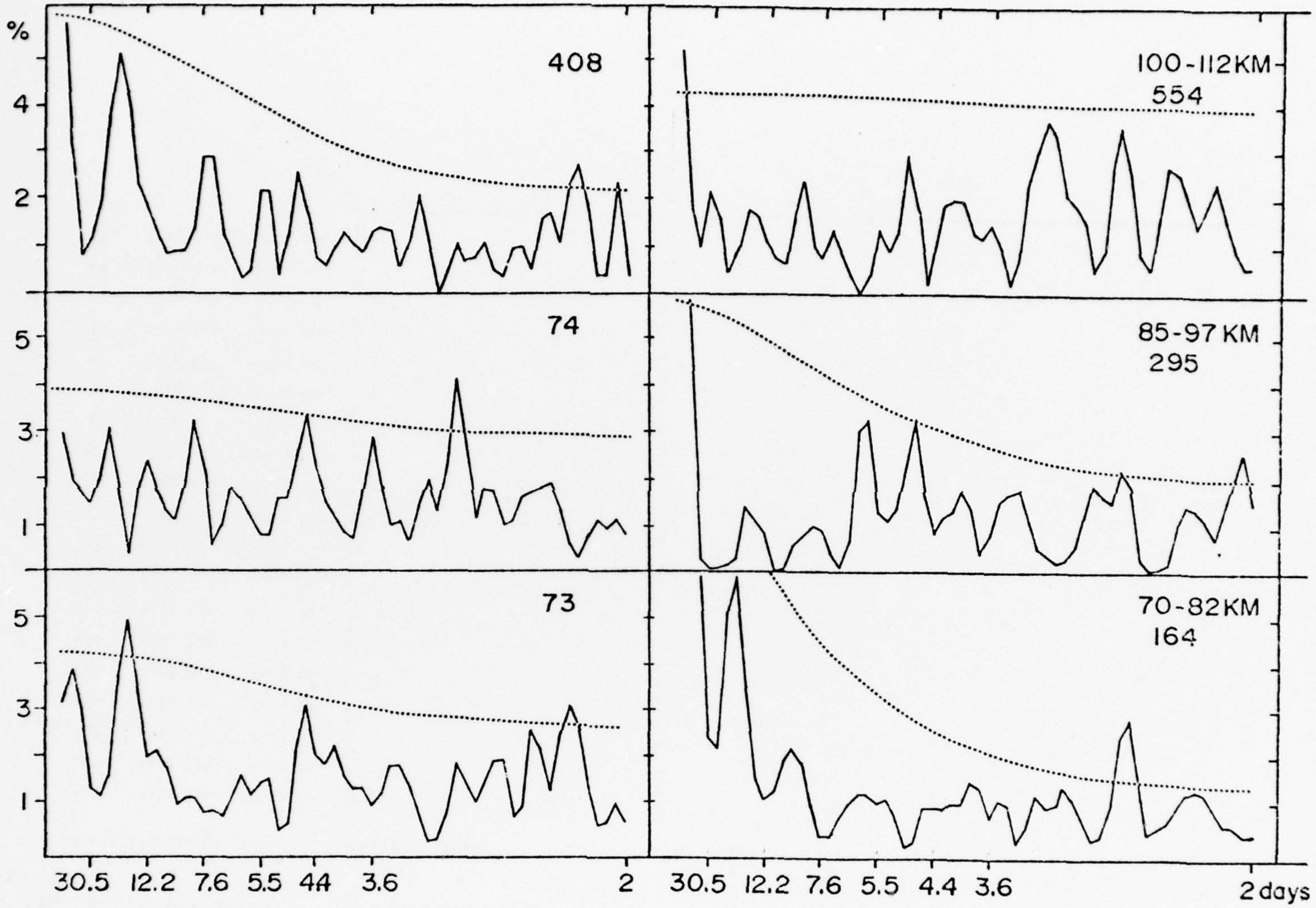


Figure 7. Variance power spectra during winter (Oct-Apr) of daily local noon data averaged over the given height intervals. The ordinate is percent of total variance; the total variance (m^2s^{-2}) is given at the upper right of each chart. Left: meridional wind. Right: zonal wind. The dotted lines are the 95% significance level.

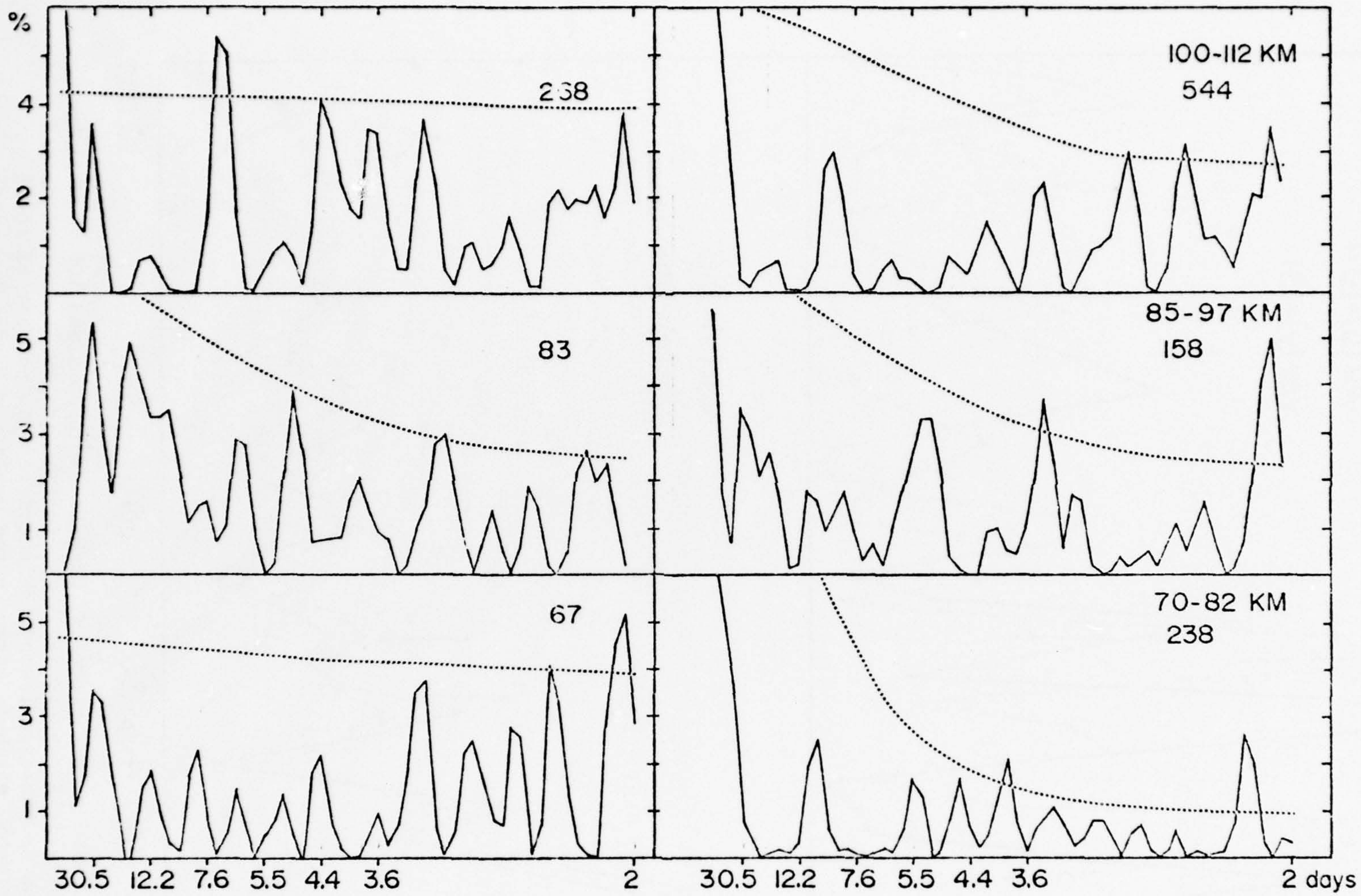


Figure 8. As in Figure 7, except for summer (May-Sep).

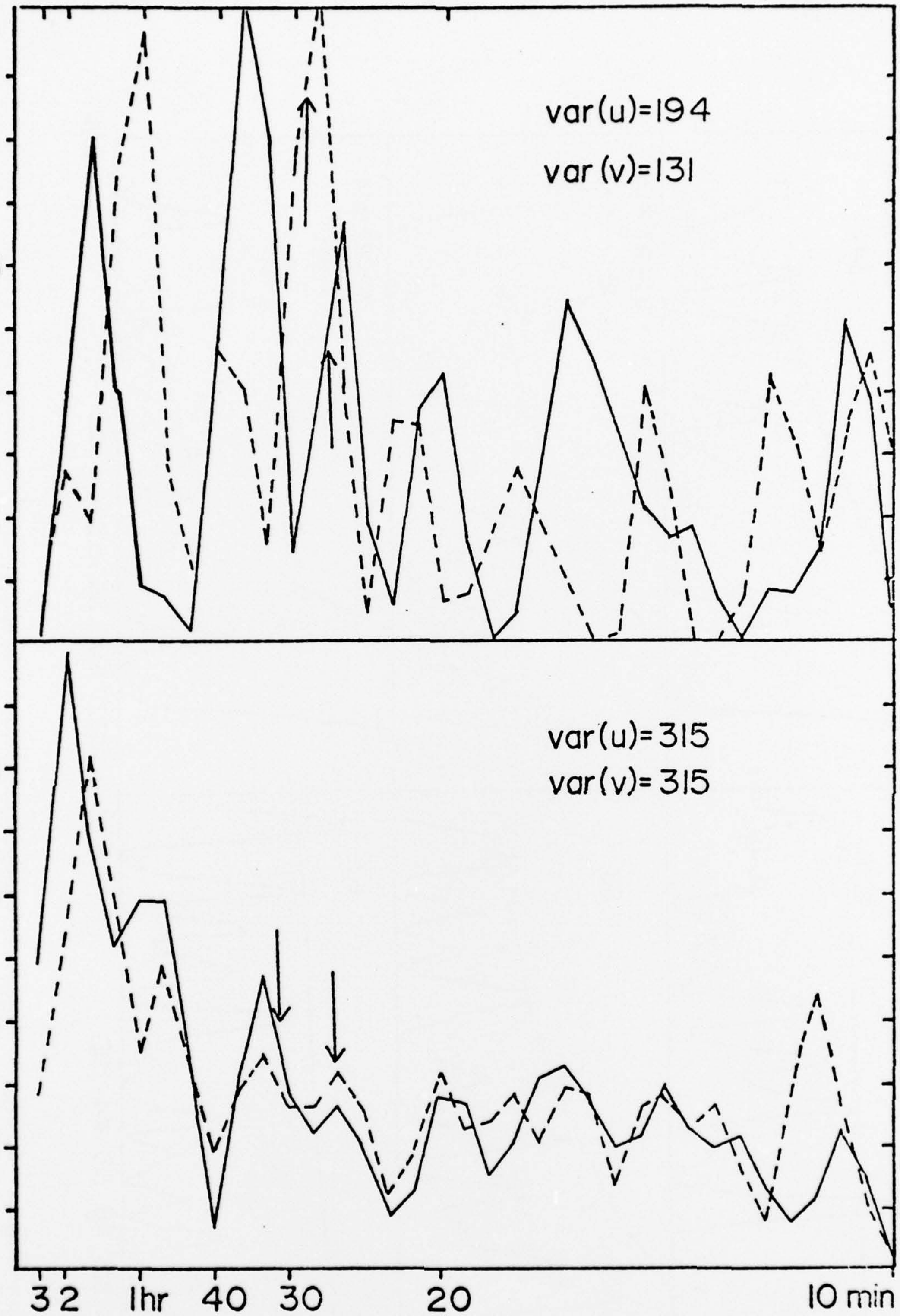


Figure 9. Variance power spectra of wind at 94 (upper) and 106 (lower) km during 5-15 August, 1976. Solid line is zonal wind and dashed line is meridional wind. The ordinate is percent of total variance, which is given on the upper right of each chart. Vertical arrows are entered at the point where 50% of the variance lies beneath the curve on either side of the arrow.

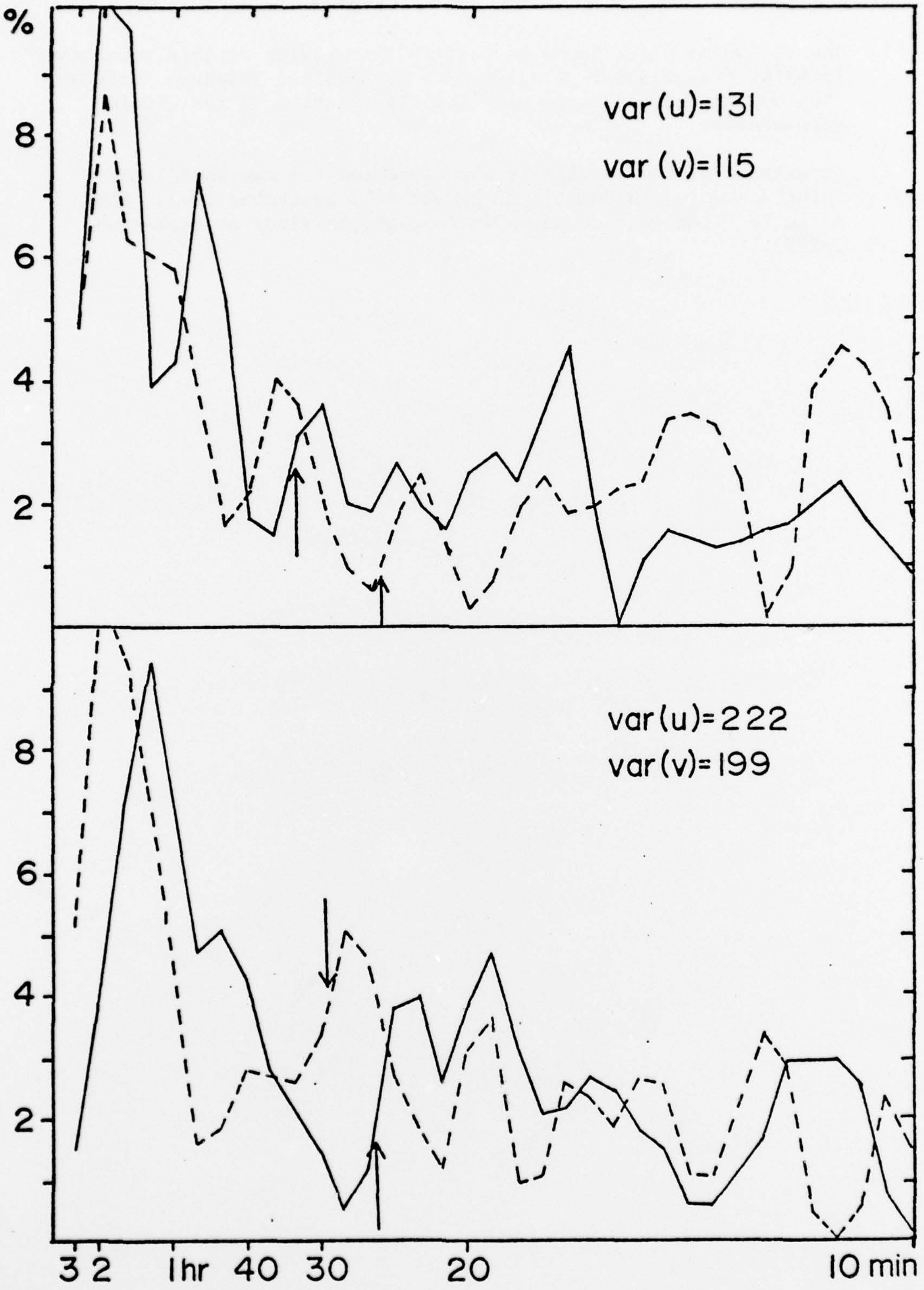


Figure 10. As in Figure 9, except for 13-22 October, 1976.

Publications and Papers

1. The following paper based in part on the results of this research, is being prepared for submission to Geophysical Research Letters: "The QBO in thermospheric wind and its relation to the QBO in geomagnetism."

2. An extract of the results is also accepted for the IAGA/IAMAP Joint Assembly, in Seattle, 22 August to 3 September 1977. The title is " Long-period waves in mesospheric winds at Saskatoon (52^{o}N)."