A Study of the Wind Regime at an Altitude of about 100 km by the Meteor-Radar Method [and Discussion]

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A study of the wind régime at an altitude of about 100 km by the meteor-radar method

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Wind results obtained by the meteor-radar method at Heiss Island, Obninsk and Molodezhnaya during 1964–8 are described in terms of periodic and prevailing components.

1. Introduction

The meteor-radar method was proposed by Manning, Villard & Peterson (1950) in 1950 and in recent years has been widely used for investigating lower thermosphere circulation. Wind measurements by the meteor-radar method have been carried out in Australia (Elford 1959), England (Greenhow & Neufeld 1961; Muller 1966), U.S.A. (Barnes 1969), France (Spizzichino 1969), U.S.S.R. (Lysenko *et al.* 1969), Canada (Hook 1970), Germany (Jacobs 1958).

In the Soviet Union the meteor-radar method is used at nine stations (Lysenko *et al.* 1969). At three of them – Heiss Island (80.5° N), Obninsk (55° N) and Molodezhnaya (67° S) – the experiments are carried out by the Institute of Experimental Meteorology (I.E.M.). In this paper the wind results obtained by I.E.M. at these sites in 1964–8 are described. In addition, data obtained by B. L. Kashcheyev at Kharkov, K. A. Karimov at Frunze, E. I. Fialko at Kiev, R. P. Chebotaryev at Dushanbe and M. K. Nazarenko at Tomsk and those published in Lysenko *et al.* (1969) have been used here.

2. Equipment and method of measurement

At all observation sites at which I.E.M. carry out wind measurements, equipment with approximately similar characteristics is used: the wavelength is nearly 9 m, pulse power is 50 to 70 kW, pulse length is 20 to 30 μs, pulse repetition frequency is 500 Hz and receiver sensitivity is 2 to 3 μV. For receiving and transmitting five-element yagi aerials are used.

Individual values of radial components of drift velocity V_r are determined from the Doppler frequency change of the reflected wave. Then assuming that the air masses in the meteor zone move horizontally, the horizontal wind velocity V is obtained from the following formula:

$$V = V_r/\cos\theta,$$

where $\theta = \arcsin(h_0/R)$; θ is the elevation, R is the range of the reflecting zone and h_0 is the most appropriate height of the meteor echo which is taken equal to 95 km. So all wind data refer to the mean height of the meteor zone. Two mutually perpendicular wind velocity components, V/EW and V/NS are measured, for which purpose the antennae are oriented alternately in the EW and NS directions.

Using the individual values of drift velocity one can find the average hourly values, which are here used for the investigation of daily variations. Individual values of drift velocity are subject to great fluctuations, resulting primarily from the non-homogeneous, turbulent structure of the wind system in the meteor zone and also from various random measurement errors. Therefore in order to determine the correct average hourly values of the wind velocity it is necessary to have for each hour of the day a few tens of individual values at least. The effective sensitivity of the technique is such that during the day it is not always possible to get the necessary quantity of experimental data. So in order to derive daily variations of the wind velocity, the data obtained for all observing days were grouped together for some particular hour of the day.

Our experimental results have confirmed the previous results (Elford 1959; Greenhow & Neufeld 1961; Muller 1966; Barnes 1969; Spizzichino 1969; Lysenko *et al.* 1969; Hook 1970; Jacobs 1958; Arefjeva *et al.* 1966; Kashcheyev & Lysenko 1967) that the winds in the meteor zone can be satisfactorily approximated by the Fourier series:

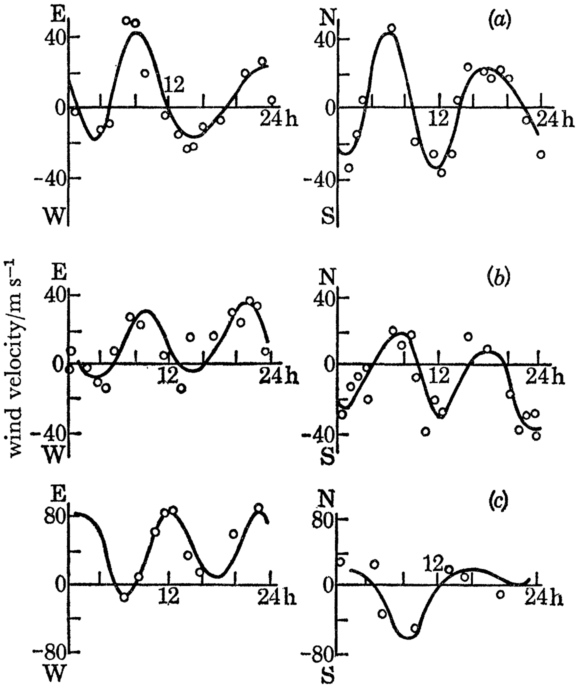

FIGURE 1. Seasonal variations of the average hourly values of wind velocity: the ordinate is the wind velocity (m/s), the abscissa is the local time. (*a*) Obninsk, January 1967; (*b*) Heiss Island, January 1967; (*c*) Molodezhnaya station, May 1967. Positive values are west (from W to E) and south (from S to N) winds.

$$A = A_0 + A_1 \sin \tfrac{1}{12}\pi\ (t+\phi_1) + A_2 \sin \tfrac{1}{6}\pi\ (t+\phi_2) + A_3 \sin \tfrac{1}{4}\pi\ (t+\phi_3),$$

where A_0 is the constant term (prevailing wind); A_1, A_2 and A_3 are the amplitudes of the 24, 12 and 8 h harmonics; and ϕ_1, ϕ_2 and ϕ_3 are their phases.

Typical dependence of the wind velocity on the time of day is shown in figure 1 where the average hourly values of the wind are given by points and the curves are calculated according to the equation given above. Both velocities and directions of prevailing winds, and amplitudes and phases of periodic wind components undergo seasonal and geographical variations.

3. Periodical wind components

At latitude 55° N (Obninsk) the semi-diurnal harmonic dominates over other periodic ones. The amplitudes and phases of this harmonic vary from month to month. According to the data obtained at Obninsk in 1964–8 the amplitude of the semi-diurnal harmonic in different seasons of the year varies from 10 to 40 m/s. A distinctly seasonal variation in the amplitude which repeats from year to year is observed in the zonal as well as in the meridional components. In figure 2 the semi-diurnal harmonic data obtained at Obninsk in 1964–8 are given. The semi-diurnal harmonic amplitudes in November and December are equal to 25 to 30 m/s and the lowest amplitudes are observed in spring and in summer. At the end of summer the amplitudes again increase to about 30 m/s. In October the amplitudes sharply decrease to 10 m/s. The same seasonal variation of the amplitude of the semi-diurnal harmonic was obtained by Greenhow & Neufeld (1961) at Jodrell Bank (53° N, 2° W).

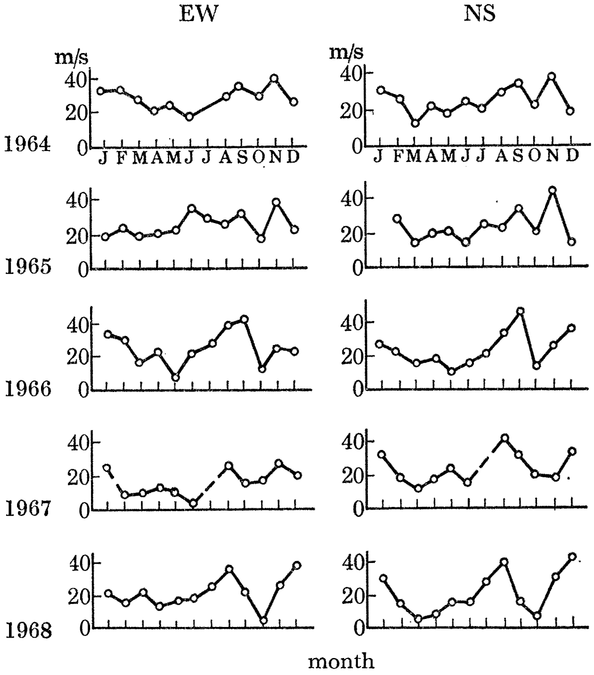

Figure 2. Seasonal amplitude variations of the semi-diurnal wind harmonics, Obninsk 1964–8.

In figure 3 the phases of the 12 h harmonic obtained at Obninsk are given. For most of the year the phases of this harmonic are such that the maximum winds are directed towards the north at about 05–06 h L.T. and towards the east at 08–09 h L.T. The seasonal variation in the phase of the 12 h harmonic is well defined. In November to March the maximum velocity towards the north is observed later (by 1–2 h) than in April to August. In September to November the phase of the semi-diurnal harmonic changes abruptly.

As a rule the meridional components pass ahead of the zonal components by about 3 h. This means that the semi-diurnal wind harmonic can be represented by a vector rotating in a clockwise direction.

In most cases the amplitudes of the diurnal component are 3 to 4 times less than the amplitudes of the semi-diurnal component. The phases of the 24 h component vary greatly from month to month. The amplitudes and phases of the 24 h component do not have well defined seasonal features.

At latitude 80.5° N (Heiss Island) the daily wind variations are defined by the 24 and 12 h harmonics. According to the data obtained in 1964–7, the amplitudes of the 24 and 12 h components are approximately the same and are equal to 10 to 20 m/s. Their vectors rotate in a clockwise direction. Phases of the diurnal harmonic are such that maximum winds are directed towards the north at about 12 ± 03 h L.T. and towards the east at 19 ± 03 h L.T. for most months. For the semi-diurnal harmonic the corresponding times are 06 ± 02 h L.T. and 09 ± 02 h L.T. respectively.

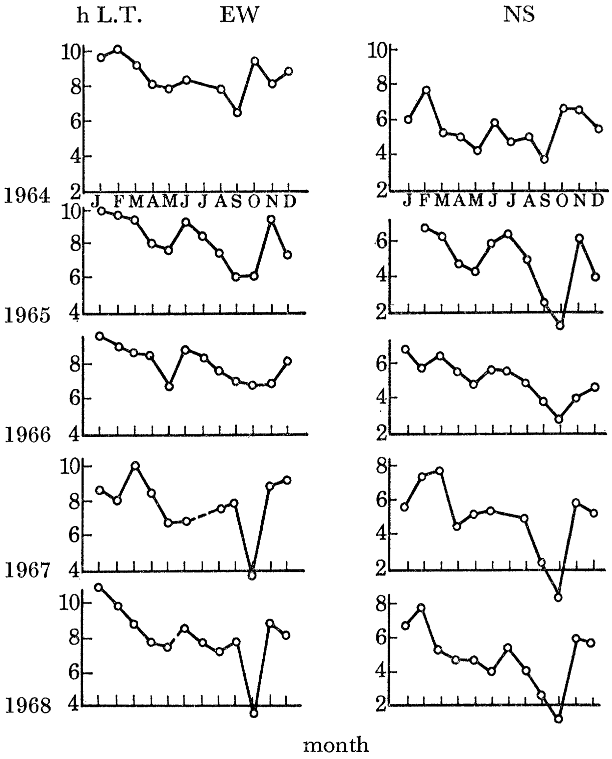

Figure 3. Seasonal phase variations of the semi-diurnal wind harmonics. Obninsk, 1964–8.

According to data obtained in 1967–8 at latitude 67° S (Molodezhnaya) the daily wind variations are due mainly to the semi-diurnal harmonic, which is as a rule greater than the 24 and 8 h harmonics. The harmonic component vectors rotate anticlockwise; this is in agreement with theory (Lindzen 1968).

The amplitudes of the diurnal harmonics lie in the range of 8 to 28 m/s. The phases of these harmonics are such that the maximum value towards the north is reached at 01 ± 03 h L.T. and towards the east at 19 ± 03 h L.T.

The amplitude of the semi-diurnal harmonic changes from 15 to 55 m/s and reaches a maximum value towards the north and east at 14 ± 02 h L.T. and at 11 ± 02 h L.T. respectively. In autumn (April to May) the phase changed abruptly by 2π; at this time the maximum wind velocity towards the north was observed at 02 h L.T. and towards the east at 00 h L.T. The phase difference between the EW and NS components for most months is equal to 3 ± 1 h. In July, September and November this difference sometimes reached 5 h. Seasonal and latitudinal amplitude changes of the 24 and 12 h wind harmonics are illustrated in figure 4. In this figure are presented the data obtained at Obninsk and Molodezhnaya in 1967–8 and at Heiss Island in 1966–7. The amplitude values are given by

$$|A| = \sqrt{(A_{\mathrm{NS}}^2 + A_{\mathrm{EW}}^2)},$$

where A_{NS} and A_{EW} are the amplitudes of the NS and EW harmonic components. Here the analogous data obtained in 1952–4 at Adelaide (35° S) are given for comparison (Elford 1959). In figures 4, 5 and 7 the results are given with a displacement of 6 months in order to compare the circulation in the same season of the Northern and Southern Hemispheres. From figure 4*a* it is clear that at Adelaide (35° S) the amplitudes of the diurnal harmonic are at most times greater than those measured at other sites. The smallest values of the amplitude of the 24 h harmonic were observed at middle latitudes in the Northern Hemisphere. It is interesting to note the similar trends shown by this harmonic for both hemispheres from summer to autumn: its amplitude increases in spring and at the end of summer and decreases at the beginning of summer and in late autumn. The most distinct similarity is shown for Heiss Island and Molodezhnaya.

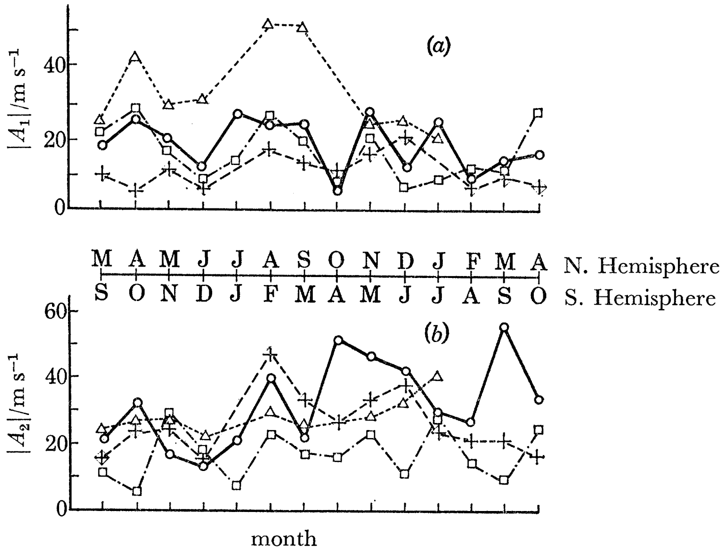

FIGURE 4. Seasonal variations of the amplitudes. (*a*) Diurnal harmonics: (*b*) semi-diurnal harmonics. +, Obninsk (1967–8); □, Heiss Island (1966–7); ○, Molodezhnaya station (1967–8); △, Adelaide (average data for 1952–3).

Similar trends are observed in the variations in amplitude of the semi-diurnal harmonic from month to month (figure 4*b*). The amplitude of this component decreases at the end of spring and increases in summer. At the beginning of autumn the amplitude of the semidiurnal harmonic decreases and then increases during the autumn–winter period again.

The variations of semi-diurnal harmonic phases with latitude are shown in figure 5. Phases of zonal components in both hemispheres coincide well with an accuracy of ± 2 h and phases of the meridional components differ in most cases by 6 h (180°). This is in agreement with the theory of atmospheric tides (Lindzen 1968; Butler & Small 1963) which predicts that the tidal circulation of the Southern Hemisphere represents a mirror image of the circulation in the Northern Hemisphere.

Seasonal variations of the diurnal harmonic phases are very often of a random nature and their comparison is not given here.

Interesting data on the latitudinal variations of the semi-diurnal harmonic were obtained during simultaneous measurements of the meteor zone wind régime in September 1965–February 1966 at seven stations of the U.S.S.R.: Heiss Island, Obninsk, Kharkov, Kiev, Dushanbe, Frunze and Tomsk (Lysenko *et al.* 1969). In figure 6 the variation of amplitude with latitude is shown. For all months except October (EW component) and December (NS

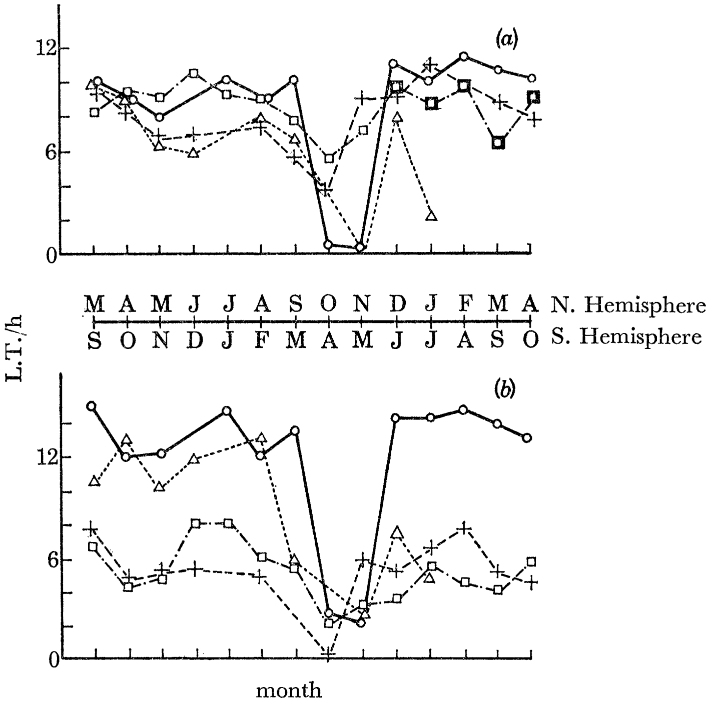

FIGURE 5. Seasonal variations of the semi-diurnal harmonic phases: (*a*) The EW components, (*b*) the NS components. Symbols are the same as in figure 4.

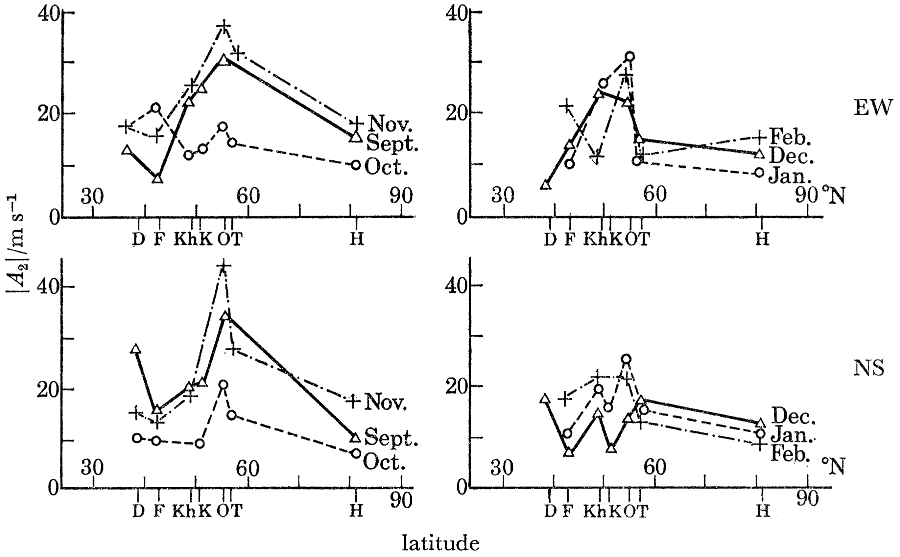

FIGURE 6. Latitudinal variations of the semi-diurnal harmonic amplitude in September 1965–February 1966. Ordinate is the amplitude (m/s), abscissa is the northern latitude (D) Dushanbe, (T) Tomsk, (H) Heiss Island, (F) Frunze, (Kh) Kharkov, (O) Obninsk, (K) Kiev. Symbols are the same as in figure 4.

component) the amplitude of the semi-diurnal harmonic had a well-defined maximum in the region 50 to 60° N. The time at which the maximum of the 12 h harmonic towards the north was observed differed greatly in some months between the various sites. The time was approximately the same (about 06–07 h L.T.) in November and January at all stations. In September and October at high latitudes the vector was oriented towards the north earlier (01–02 h L.T.) than at low latitudes (04–06 h L.T.). On the other hand, in December and February at high latitudes it was oriented later (07–08 h L.T.) than at most lower latitudes.

Regularities in the behaviour of the 8 h harmonic were not observed.

4. Prevailing winds

Seasonal and geographic variations in the prevailing winds are clearly seen from the data shown in figure 7 where the results of above-mentioned measurements at Obninsk, Molodezhnaya and Heiss Island are given. For comparison the data obtained at Adelaide are also presented (Elford 1959).

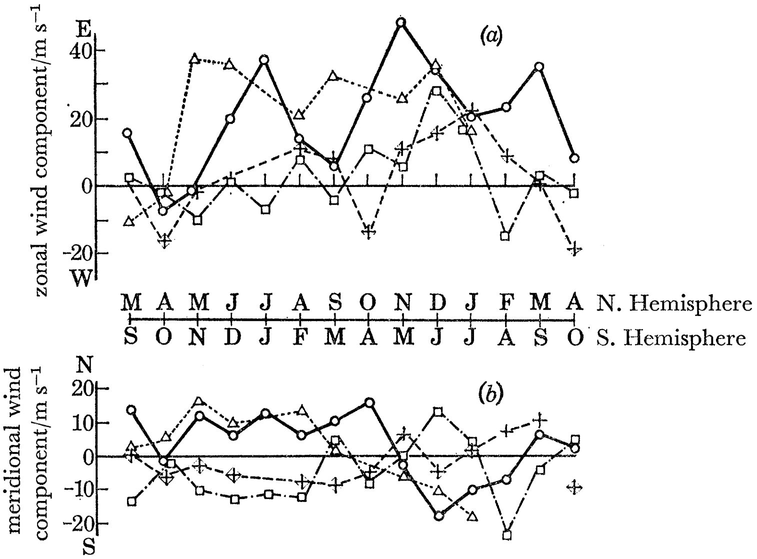

Figure 7. Seasonal variations of the prevailing winds for the Northern and Southern Hemispheres. (*a*) The zonal components; (*b*) the meridional components. Symbols are the same as in figure 4. Positive values are west (from W to E) and south (from S to N) winds.

Figure 7*a* shows that in the Northern as well as in the Southern Hemisphere the west zonal winds prevail for most of the year. In spring the wind changed its direction to the east at all the sites considered. At Heiss Island the east wind was observed in other months and seemed to result from sudden warmings in the upper atmosphere at high latitudes.

It is clear from figure 7*a* that the autumn zonal wind reversal was not observed at Molodezhnaya and Adelaide. Reconstruction of the circulation at this period according to the Molodezhnaya data showed only a tendency for the zonal wind direction to change.

It should be noted that zonal wind velocities in the lower thermosphere of the Southern Hemisphere are much greater than in the Northern Hemisphere.

Figure 7*b* illustrates the meridional wind behaviour. In the summer months in both hemispheres the winds are directed to the equator and in winter they are directed to the pole. Such behaviour agrees with recent concepts of meridional circulation of the upper atmosphere (for example Kochanaski 1963; Groves 1969), according to which air flows from the summer hemisphere to the winter one. It is noted that the meridional intensity is less than the zonal one, this difference being better defined for the Southern Hemisphere. Geographic and seasonal variations of the prevailing winds are illustrated by the results of the simultaneous measurement mentioned above (Lysenko *et al.* 1969).

Directions of air mass motion over sites situated in the European part of the Soviet Union (except Heiss Island) differ significantly from the directions over sites situated in the Asian part. Prevailing wind directions over Heiss Island were the same as for Dushanbe, Frunze and Tomsk for all the months, except February. This can be seen from the data in figure 8 where the directions of air mass displacement are shown by arrows.

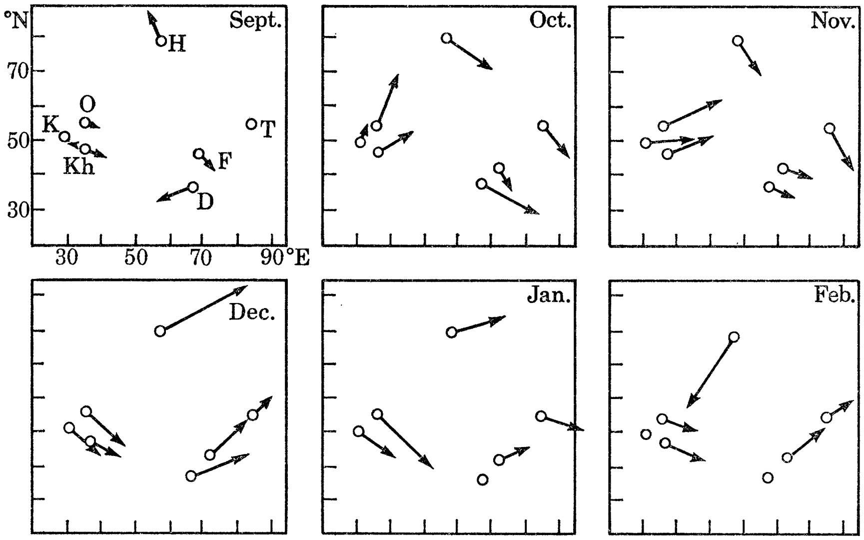

Figure 8. Geographic variations of the prevailing winds in September 1965–February 1966. Ordinate is the north latitude, abscissa is the east longitude.

During the autumn months (September) over Kiev, Obninsk and Kharkov weak (3 to 4 m/s) NW winds were observed, and over Heiss Island and Frunze SE winds occurred; NE winds with greater velocities were found over Dyushambe (5 to 12 m/s). In October and November over the European part of the Soviet Union SW winds occurred with velocities of 15 to 20 m/s and winds of nearly the same intensity were observed above the Asian part of the Soviet Union.

In winter as well as in autumn wind velocities at middle latitudes were equal to 12 to 20 m/s, and at high latitudes in December and February velocities increased to 30 to 35 m/s. Over Kharkov, Obninsk and Kiev winter circulation is characterized by a change of wind direction to the NW in comparison with the autumn circulations. At other stations the wind changed its direction to the SW. The only exception was the circulation in February over Heiss Island when the wind direction changed from the SW to NE. At the same time a growth in meridional flow intensity was observed; the velocity of the meridional wind component was approximately 1.5 times larger than the corresponding zonal values.

Comparison of the meteor wind measurements obtained at Manchester in 1953–8 (Greenhow & Neufeld 1961), Kharkov in 1961–3, 1964–5 (Lysenko 1963; Kashcheyev & Tsesevich 1965; Kashcheyev & Suvorov 1967), Sheffield in 1964–5 (Muller 1966), Kazan in 1964–5 (Zadorina *et al.* 1967) and Obninsk in 1964–8 indicates a similarity of prevailing circulation above these sites. For most of the year the zonal prevailing winds are west winds and only during the spring–autumn months (March to May, September and October) do the winds change their directions to the east. The autumn reversal is observed less regularly than the spring one; in some cases only a velocity decrease of the west wind is observed in the autumn wind system.

The behaviour of the prevailing meridional wind components over the observing sites is nearly the same.

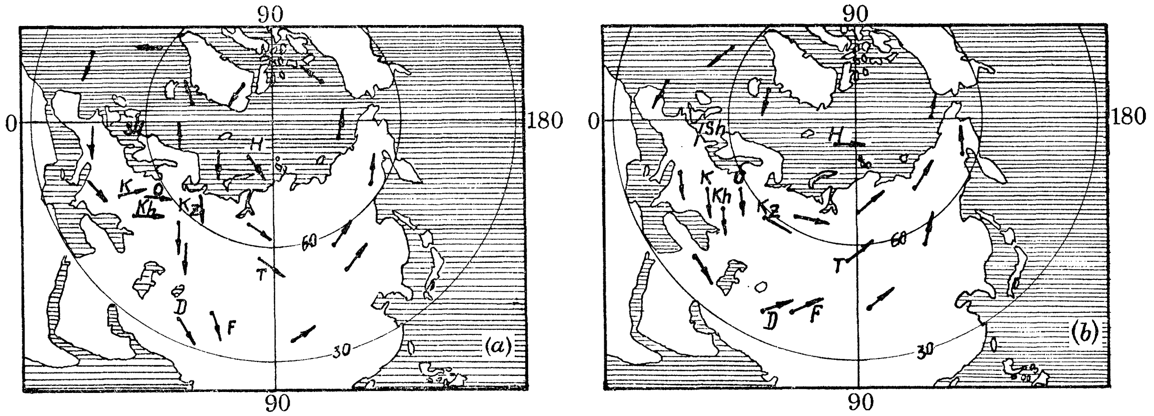

FIGURE 9. Tentative models of prevailing circulation in the meteor zone over Eurasia and the Arctic. (*a*) Autumn, (*b*) winter, (Sh) Sheffield, (Kz) Kazan; the rest of the symbols are the same as in figure 6.

However, such similarity is not necessarily representative of results for large regions of the atmosphere even within a relatively narrow latitude range because as our experiments have shown latitudinal and longitudinal effects may result from the orographic influence of continents and oceans (Belyach & Trubnikov 1966; Ryazanova, Trubnikov & Shcherba 1967).

From rocket sounding data obtained during the IGY and IQSY it follows that the circulation in the stratosphere and lower mesosphere is of cyclonic character in the autumn and spring months at high and middle latitudes. It is shown in Pchelko (1967) that stratospheric circulation is dependent on the form of pressure structure existing at lower levels of the atmosphere. It seems that similar relations between circulation in the stratosphere and the wind régime in the lower thermosphere exist. If this supposition is true then on the basis of the data obtained during the simultaneous measuring periods and the use of information on the structure of the stratosphere (Pchelko 1967), one can build up a general picture of the prevailing circulation in the meteor zone over Eurasia and the Arctic for the autumn and winter months. The nature of the prevailing wind variations in October and November 1965 (see figure 8) makes it possible to suppose that at this time in the meteor zone as well as in the stratosphere (Pchelko 1967), a cyclone with two centres existed. Evolution of the winter circulation (December, January) in the meteor zone was accompanied by a circular cyclonic formation similar to the stratospheric one.

Tentative models of the prevailing circulation for the periods considered are given in figure 9*a*, *b*. Here the measured average values of the wind velocity and direction for October–November 1965 and December 1965–January 1966 are shown by arrows with indexes O, H, Kh, K, D, F, T. In this figure similar data for Sheffield (Muller 1966) (Sh) and Kazan (Zadorina 1967) (Kz) obtained in 1964–5 are given.

The above-mentioned peculiarities of the February circulation over Heiss Island are produced by the pressure of anticyclonic centres at high latitudes. It should be noted that an analogous circulation in February was observed over Heiss Island in the stratosphere during other years (1958–63) (Ryazanova 1967). The similarity of February circulation over Heiss Island in the stratosphere and in the meteor region confirms the supposition about the effect of pressure distribution in the stratosphere on the air–mass movement at higher levels of the atmosphere.

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Discussion

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An anomalous prevailing wind at meteor heights over Heiss Island is noted during February 1966. Stratospheric data from Heiss Island for February 1966 have been published by Quiroz (1969)† and show that extraordinarily high winds of 198 m/s from 173° were observed on 1 February 1966. During February a major stratospheric warming occurred and winds remained from the south over Heiss Island throughout the month.

† Quiroz, R. S. 1969 *Mon. Weath. Rev.* **97**, 541.

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Evidence of a prevailing semi-diurnal tide between 100 and 130 km from incoherent scatter observations at Nançay

(SUMMARY ONLY)

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A correlation method applied to the wind and temperature data obtained between 95 and 140 km from incoherent scatter experiments shows a prevailing semi-diurnal oscillation whose phase propagates downwards. The wavelength is about 50 km. It may be either the same mode as observed at lower altitudes (S_2^2), but with a wavelength shortened by viscosity, ion drag and heat conduction, or mode S_2^4 whose source has to be found.