PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Measurement of Ionospheric Drifts over East Siberia, U.S.S.R.

E. S. Kazimirovsky and V. D. Kokourov

Phil. Trans. R. Soc. Lond. A 1972 **271**, 499-508
doi: 10.1098/rsta.1972.0019

Phil. Trans. Roy. S. Lond. A. **271**, 499–508 (1972) [499]
Printed in Great Britain

The measurement of ionospheric drifts over east Siberia, U.S.S.R.

By E. S. Kazimirovsky and V. D. Kokourov
Siberian Institute of Terrestrial Magnetism, Ionosphere and Radio Propagation, Irkutsk, U.S.S.R.

The results of an investigation of horizontal ionospheric drifts over Irkutsk (52° N, 104° E) by the closely spaced receiver method (D1) are presented for 1958–9. The nature of diurnal, seasonal and solar-cycle variations of ionospheric drift patterns are discussed. The measurement of ionospheric drifts was carried out during 1968–9 by the D1 method (2.2 MHz) operating simultaneously at vertical and slightly oblique incidence. The results of this experiment are discussed too.

1. Experimental equipment

Systematic measurements of ionospheric drifts have been carried out at the Siberian Institute of Terrestrial Magnetism, Ionosphere and Radio Propagation since April 1958. We took part in the programme of the International Geophysical Year (I.G.Y.), International Geophysical Cooperation (I.G.C.), International Quiet Sun Year (I.Q.S.Y.) and since the end of 1965 we have undertaken a special programme of observations – round-the-clock observations for 4-monthly periods centred around the solstices and equinoxes. The special equipment was designed at the Ionospheric Research Laboratory for the experimental measurement of ionospheric drifts by the closely spaced receiver method (Mitra-method, D1 (Mitra 1949)). The parameters of the equipment are listed below (Kazimirovksy & Kokourov 1960):

(1) The frequency band, 1.5 to 16 MHz.
(2) Peak transmitter power, 20 kW.
(3) Pulse duration, 100 μs.
(4) Pulse repetition frequency, 50 Hz.
(5) Receiver band-width, 18 kHz.
(6) Transmitting aerial – a vertical split rhombic with wave impedance 700 Ω, the height of the suspension being 40 m.
(7) Receiving aerials – asymmetric dipoles at a height of 10 m.

In 1968 the equipment was supplemented with an additional receiver complex 97 km from the main equipment for the simultaneous measurement of drifts by vertical and oblique sounding. In 1969 analogous movable equipment was designed for studying the so-called 'effective radius' of the equipment.

2. Experimental observations and results

A synoptic programme of drift measurements has been carried out on a fixed frequency of 2.25 MHz. The horizontal drift velocity was evaluated by the 'method of similar fades' (Briggs 1956). For the period 1958–69 about 20000 records were examined and for 7163 of these it was possible to calculate the speed and direction of the ionospheric drift. Data have been obtained for reflexions from the E and E_s regions (the lower ionosphere) and from the F2 region (the upper ionosphere). The results obtained are considered to be the property of movements at the level of reflexion. Histograms of drift speed and direction and diurnal variations of zonal (U) and meridional (V) components of drift speed have been derived for the four seasons, using the median of all the values obtained within 3 h intervals centred on the relevant hour. We assumed: summer – June, July, August; autumn – September, October, November; winter – December, January, February; spring – March, April, May.

In this paper in accordance with the title of the meeting we shall describe mainly the parameters of drift in the lower ionosphere. Because we used a fixed frequency 2.25 MHz, data for

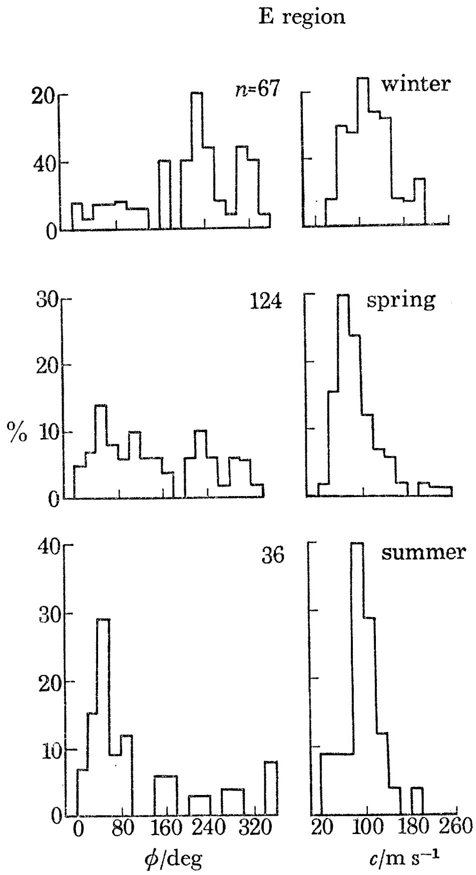

FIGURE 1. Distribution of drift speed (c) and direction (ϕ) for January 1960–May 1964 (E region).

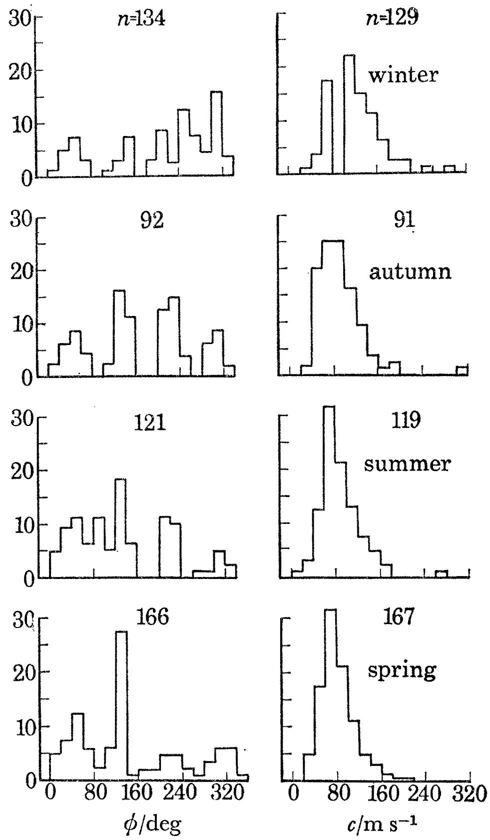

FIGURE 2. Distribution of drift speed (c) and direction (ϕ) for April 1958–January 1960 (E region).

the E region refer to daytime. Figures 1 to 6 (Kazimirovsky & Kokourov 1960, 1966, 1967, 1968; Sukhomazova 1971) depict the histograms of the drift speed and drift direction for the periods: April 1958 to January 1960; January 1960 to May 1964; December 1965 to July 1966; December 1966 to January 1968. It is evident that almost 80 % of all measured speeds are in the interval 40 to 120 m/s. The predominant values in winter were 80 to 100 m/s and in summer 60 to 80 m/s. The predominant directions are to the southwest in winter and to the southeast in summer. For all periods the drift speed is somewhat higher in winter. The directions of drift at the equinoxes are almost random and this is connected with the reversal of the atmospheric circulation at the ionospheric levels (Kazimirovsky 1963). The meridional movements and the seasonal differences in the histograms and diurnal variations are stronger in the E region than

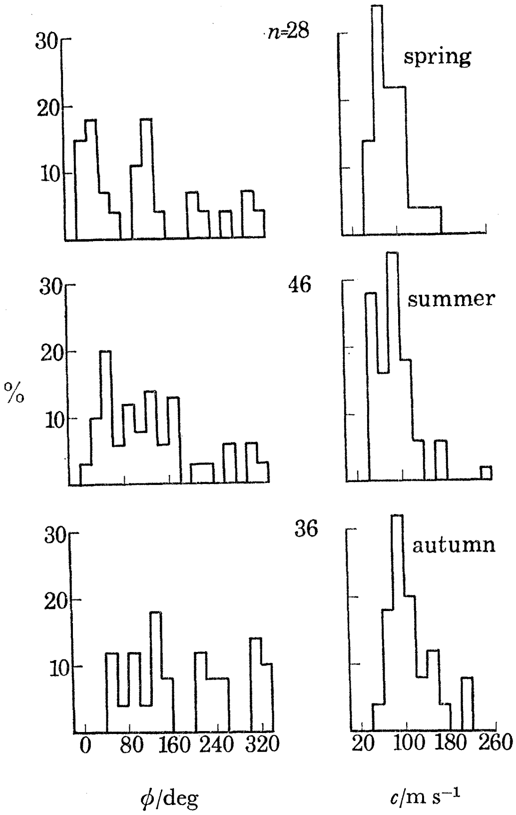

FIGURE 3. Distribution of drift speed (c) and direction (ϕ) for January 1960–May 1964 (E_s region).

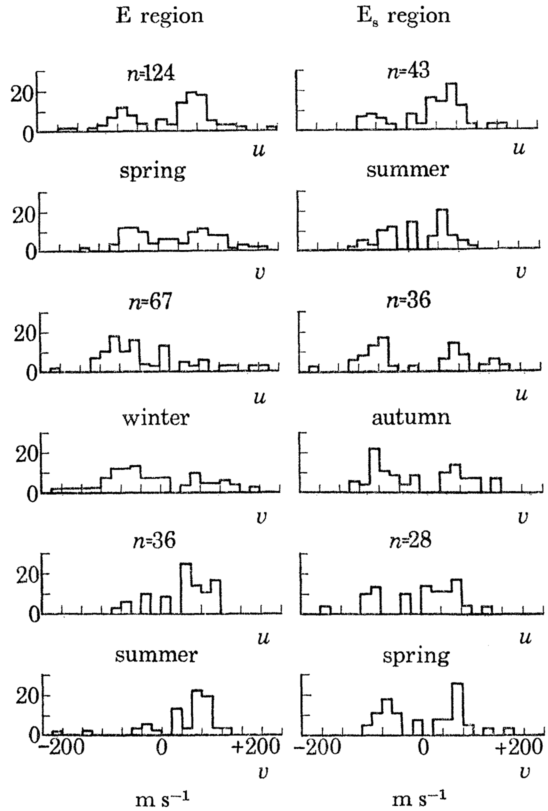

FIGURE 4. Distribution of zonal (u) and meridional (v) components of drift speed for January 1960–May 1964 (E and E_s region).

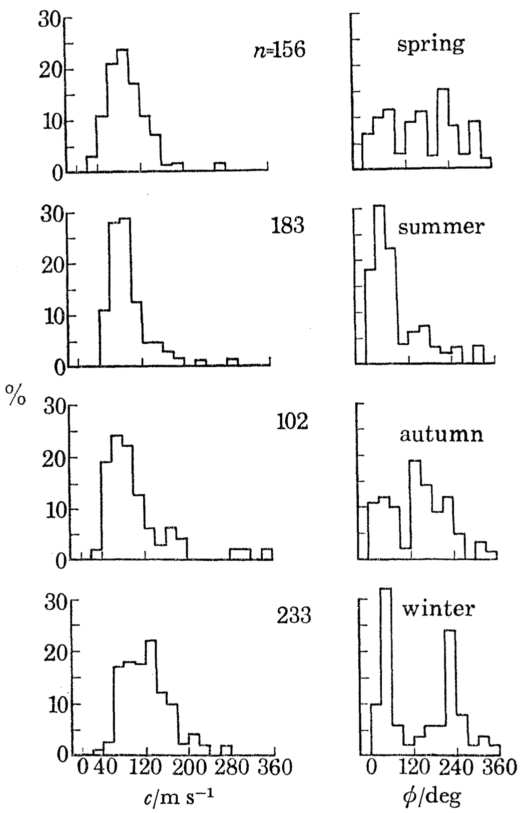

FIGURE 5. Distribution of drift speed (c) and direction (ϕ) for December 1965–July 1966 (lower ionosphere).

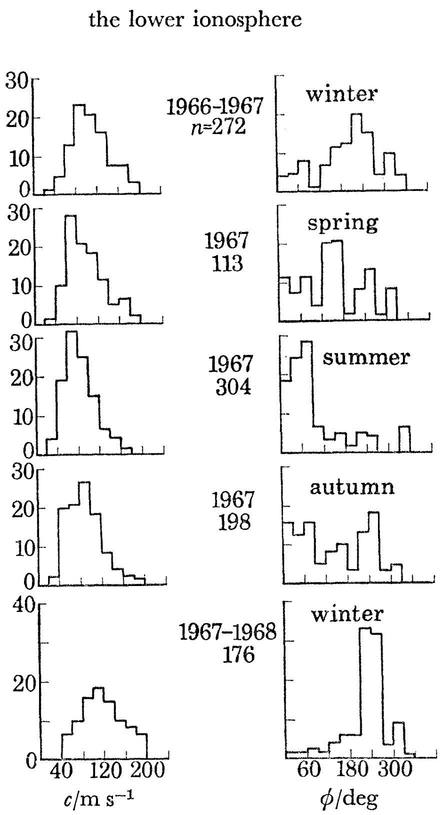

FIGURE 6. Distribution of drift speed (c) and direction (ϕ) for December 1966–January 1968 (lower ionosphere).

the F region. The drift speeds and especially the meridional movement increase with the decrease of solar activity from 1958 to 1964–5.

The harmonic analysis of $U(t)$ and $V(t)$ for the various seasons allowed us to separate out the mean steady components U_0 and V_0 and to evaluate the amplitudes of the periodic components. U_0 and V_0 turned out to be as large as the amplitudes of the harmonics and sometimes they exceeded these amplitudes. For all periods U_0 is directed to the east in summer and to the west in winter in accordance with measurements at other stations of the world (Kazimirovsky 1963; Poljakov, Shchepkin, Kazimirovsky & Kokourov 1968). V_0 is more often directed to the south. The semi-diurnal component as a rule predominates.

We evaluated the scale of irregularities as a parameter $\lambda = cT$, where c is the drift speed and T is the quasiperiod of fading. For the lower ionosphere 100 m $\leqslant \lambda \leqslant$ 800 m and λ = 200 to 300 m predominates.

3. Comparison of observations at two observing sites

Because of uncertainties in interpretation and doubts about the physical significance of results obtained using the D 1 method, it is interesting to compare the results obtained at two points spaced some tens of kilometres apart in order to study the so-called 'effective radius' of the equipment.

The data reported herein (Zakharov, Kazimirovsky & Kokourov 1969; Kokourov, Kazimirovsky, Zakharov & Jovty 1971) have been gathered by means of the D 1 method simultaneously at two sites – one near Irkutsk having coordinates 52° 28′ N, 102° 04′ E and the other at Tory 97 km to the southwest. The pulse transmitter, having 20 kW peak power, is situated at the first site. There are two systems of closely spaced aerials, one at the first site (for vertical soundings) and the other at the second site (for slightly oblique soundings). The reflexion points are thus separated by about 50 km in the horizontal direction and about 3 to 10 km (depending on ionospheric conditions) in the vertical direction. The receiving aerials at Tory were located at a reasonable distance from the transmission lines and other aerials or re-radiating conductors which could alter the electromagnetic field. This was done in order to evaluate the effect on the measurements of re-radiators which were near the receiving aerials at the first site.

Data have been obtained in four monthly intervals at the two solstices and two equinoxes during the period 7 June 1968 to 7 April 1969. The observations were made round-the-clock for two 5 min periods in each hour. A total of 5500 periods occurred and for 2056 of these it was possible to calculate the speed and direction of the ionospheric drift. Table 1 shows the seasonal distribution of the number of measurements for the upper ionosphere (F region) and the lower ionosphere (E and E_s regions). It will be seen from table 1 that the largest number of measurements were obtained for winter, upper ionosphere at vertical incidence, and the smallest number for summer, upper ionosphere at oblique incidence. Long-period fading was observed more often in the case of oblique sounding than vertical sounding, so the number of measurements from Tory is less than from Irkutsk because it is difficult to calculate the drift parameters by the method of similar fades when the records exhibit long-period fading.

Figures 7 and 8 depict histograms of the drift speed and drift direction respectively. It is evident that the distributions of speed from the two sites agree very well for both the upper and lower ionosphere cases. The predominant values and also the seasonal variations (the speed is greater in winter) are in agreement with results obtained from I.G.Y. and I.Q.S.Y. data (Poljakov *et al.* 1968). As far as the directions of the drifts are concerned, the shapes of the various distributions are different. As would be expected, the predominant direction may be singled out more easily in the case of the upper-ionosphere results; at both sites and in all seasons westward drifts were observed.

In the lower ionosphere the directions of drift at the equinoxes are almost random; this behaviour may be associated with a reversal of the atmospheric circulation as a whole. A

TABLE 1. NUMBER OF MEASUREMENTS

	the upper ionosphere		the lower ionosphere	
season	Irkutsk	Tory	Irkutsk	Tory
summer	76	33	252	37
autumn	175	41	202	53
winter	332	175	66	48
spring	161	132	167	106
total	744	381	687	244

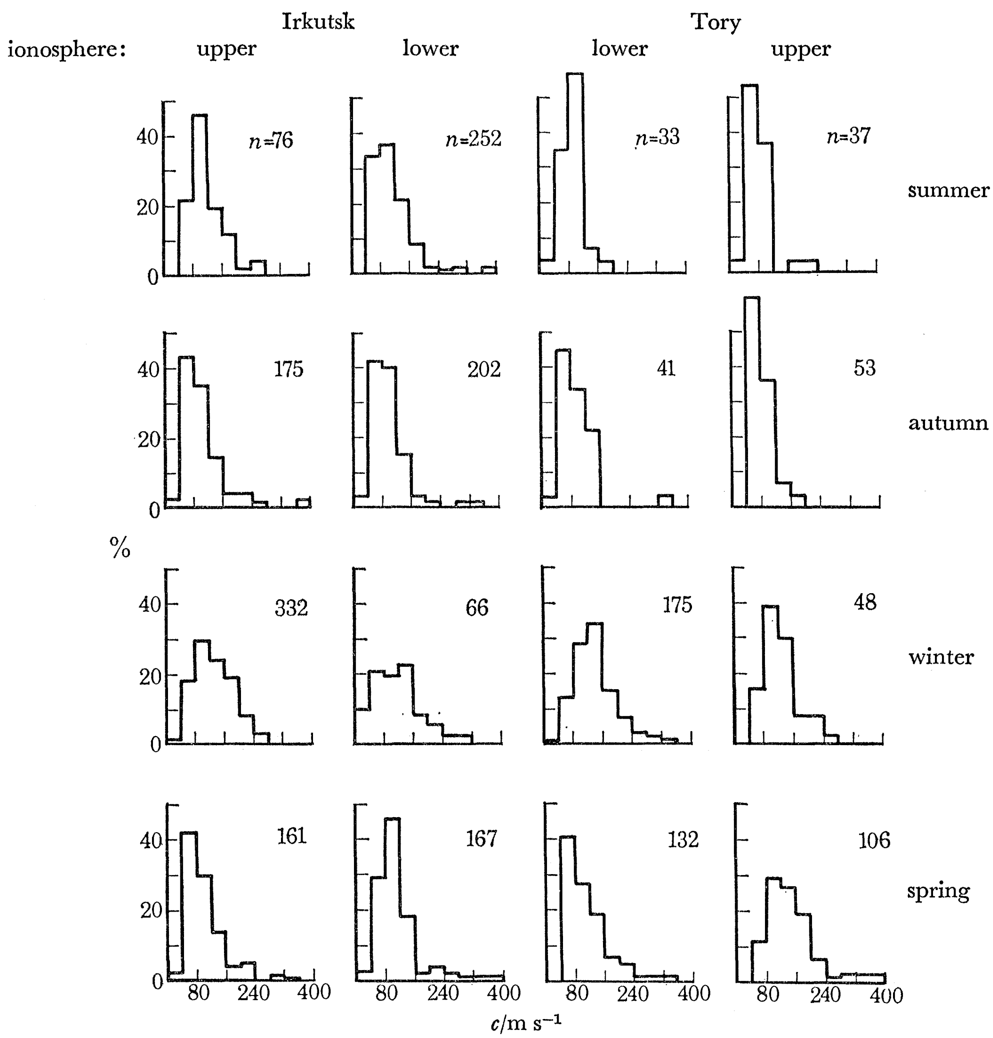

FIGURE 7. Distributions of drift speed for two sites.

predominantly eastward drift is observed in summer and a westward one in winter in accordance with recent results obtained from I.G.Y. and I.Q.S.Y. data (Poljakov *et al.* 1968). Some differences between the distributions of drift directions at Irkutsk and Tory may be due to the fact that different numbers of measurements were recorded at the two sites rather than to the fact that the reflexion points were separated.

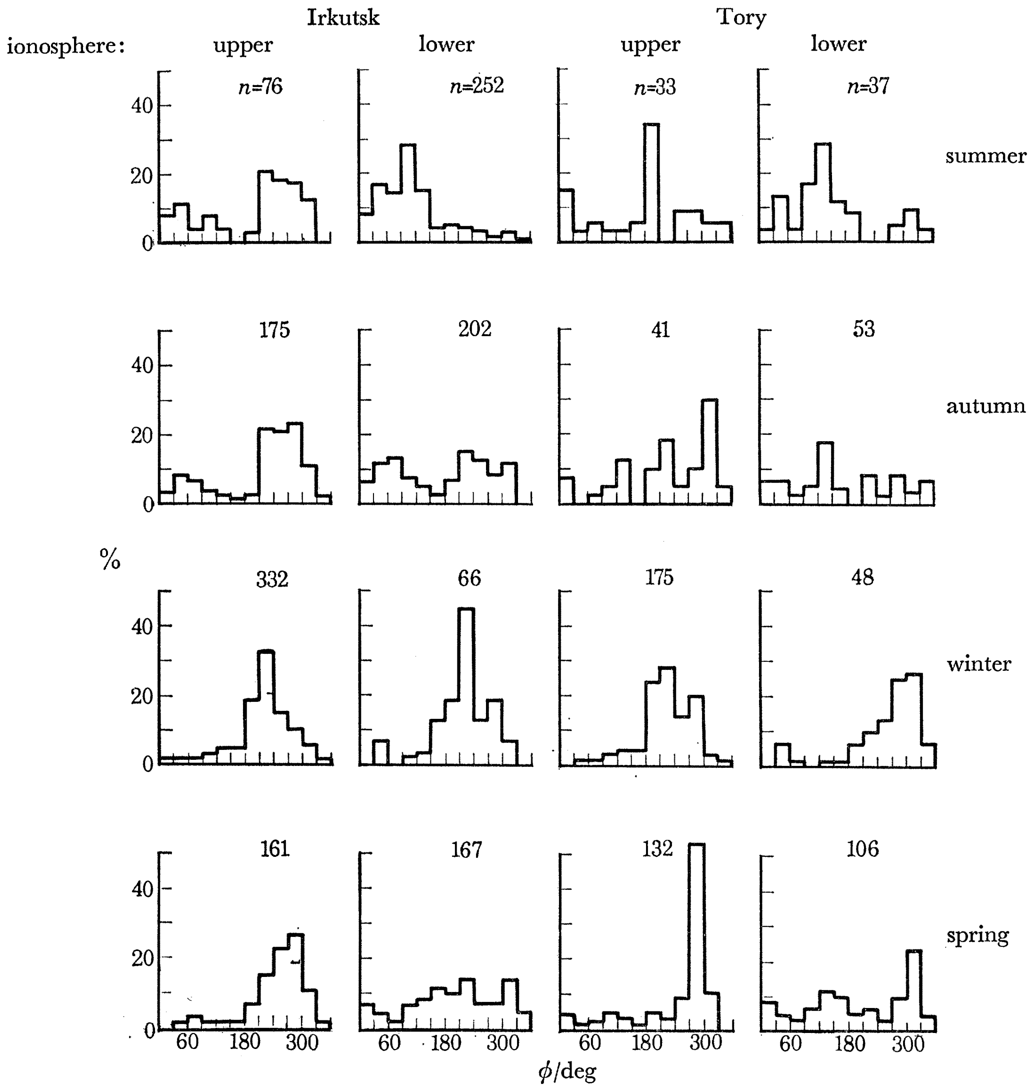

FIGURE 8. Distributions of drift direction for two sites.

The hourly values, $U(t)$ and $V(t)$ of the zonal (E–W) and meridional (N–S) components respectively were obtained by using the median of all the values obtained within 3 h intervals centred on the relevant hour. In this way diurnal variations were computed for each season. As an example of such data, figure 9*a* shows the variations averaged for all measurements in winter, and figure 9*b* shows the variations only for the measurements made simultaneously at the two sites in winter. Velocities directed towards the north and east are considered positive and those towards the south and west are negative. The midnight and noon values and the shapes

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF

of the corresponding curves are in good agreement but, even in the case of the simultaneous measurements, there are some discrepancies between $U(t)$, $V(t)$ from the two sites.

The results of harmonic analysis of $U(t)$ and $V(t)$ for the curves shown in figure 9*a* are given in table 2. Here

$$U,\, V = A_0 + \sum_i A_i \sin\,(it+\phi_i).$$

The steady component of the time variation and the diurnal and semidiurnal components are shown in table 2. In cases where it was not possible to obtain results for all 24 h in a day, A_0 and A_2 have been computed for the 12 h interval from 18 h L.T. to 06 h L.T. The steady

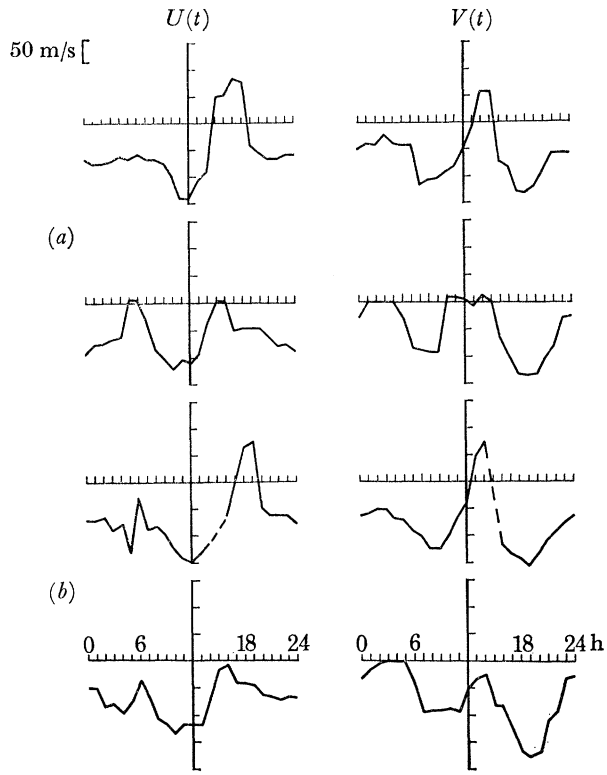

FIGURE 9. Mean diurnal variations of E–W and N–S components of drift speed in winter. (*a*) All measurements; (*b*) simultaneous measurements only.

zonal drift in the upper ionosphere is directed towards the west and the steady meridional drift is directed towards the south for both sites and for all seasons. In the upper ionosphere in winter the diurnal component is the predominant one for both $U(t)$ and $V(t)$.

In the lower ionosphere the steady zonal drift is directed towards the east in summer and towards the west in winter. The meridional drift varies very irregularly and the direction of the steady meridional drift coincides at both sites only in winter (when the quantities of data available are almost the same – see table 1).

The measurements made simultaneously are the most interesting to analyse. The discrepancies between the drift speeds and directions have been computed for simultaneous periods at the two sites. Histograms are presented in figure 10 for $\Delta\phi$ (difference of azimuths) and 'shear', S, where

$$S = \sqrt{\{(\Delta U)^2+(\Delta V)^2\}}/d$$

ΔU and ΔV are the differences between the respective components and d is the horizontal distance between the reflecting points. There were no significant differences between the values of S obtained in the different seasons, so figure 10 shows histograms for the whole period of measurement.

It is evident that the most probable value of S is of the order of $10^{-3}\ s^{-1}$; this is not very large. The difference between the directions is generally less than 30° which is within the limits of

TABLE 2. THE RESULTS OF HARMONIC ANALYSIS OF THE CURVES SHOWN IN FIGURE 9*a*

	summer 1968			autumn 1968			winter 1968–9			spring 1969		
	A_0	A_1	A_2	A_0	A_1	A_2	A_0	A_1	A_2	A_0	A_1	A_2
the upper ionosphere												
Irkutsk	—	—	—	−69.0	—	7.5	−57.2	43.8	54.0	−58.5	12.5	8.8
	—	—	—	−2.1	—	19.0	−63.0	12.1	48.2	−12.1	19.3	6.1
Tory	—	—	—	−37.2	—	54.6	−61.5	16.0	43.6	−66.4	—	19.8
	—	—	—	−16.5	—	28.9	−50.2	18.7	61.9	−1.8	—	23.0
the lower ionosphere												
Irkutsk	64.0	—	28.4	−37.1	51.8	27.5	−50.3	—	74.0	−12.9	28.7	49.2
	8.0	—	39.2	4.6	1.6	33.5	−53.2	—	19.3	−24.6	50.8	35.3
Tory	11.0	55.0	22.6	−30.2	32.0	37.3	−54.8	—	29.8	1.9	23.5	75.0
	−24.5	12.8	37.8	−7.4	36.4	48.8	−14.5	—	84.8	0.9	55.8	38.0

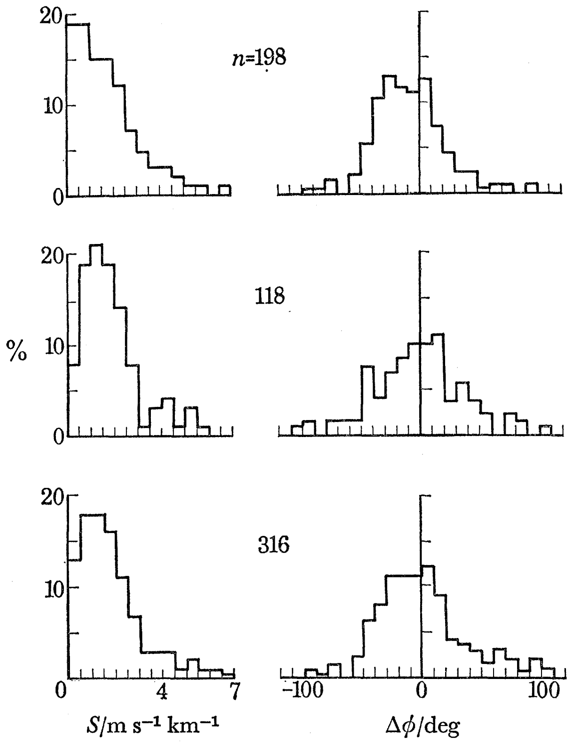

FIGURE 10. The distributions of S and $\Delta\phi$.

experimental error (Briggs 1956). It is possible, however, that some asymmetry of the $\Delta\phi$ distribution (especially for the upper ionosphere case) may be due to differences between the heights of the reflexion points. Unfortunately, the small number of measurements available did not allow us to investigate the dependence $\Delta\phi(\phi)$.

The observed discrepancies between the sets of results obtained from the simultaneous measurements may reflect real differences between the behaviour at the two reflexion points

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

or they may be due to inadequacies in the amount of data available. It seems possible that discrepancies between the direction histograms (figure 8) may arise because the reflexion points were separated, but it seems likely that the discrepancies between the diurnal variations of velocity are merely the result of inadequate data.

In order to check this suggestion, the cross-correlation coefficients between the values of $U(t)$ were computed for the following groups of data:

(1) Different sites but all data for the particular seasonal period.

(2) Different sites but only for simultaneous measurements.

(3) One site but for different quantities of data within the same period. This was done separately for Irkutsk and for Tory.

Analogous computations were made for $V(t)$. The values of the cross-correlation coefficients were all high, but when results from different sites were used the values were on average 1.4 times as high as in the case of different quantities of data which all came from the same site. It seems, therefore, that the discrepancies between the results of simultaneous measurements can be explained only in terms of statistical scatter.

Thus, measurements show that the average values of ionospheric drifts obtained by both vertical and oblique soundings agree well with the generally accepted atmospheric circulation pattern at ionospheric heights. The effect of re-radiators, etc., on the drift measurements, which were made using the close-spaced receiver method, is negligible, and the 'effective radius' of the equipment used is not less than 50 km.

Some discrepancies between the results obtained during simultaneous measurements at two sites appear to be due to the vertical and horizontal distances between the reflexion points. This effect is appreciable for the lower-ionosphere results.

The experiments with the movable equipment confirmed this conclusion. The discrepancy between simultaneously obtained drift parameters increased with increasing distance between the sites. This discrepancy is more than a methodical error. It was found that the deceleration of fading for the oblique sounding is more than the theoretically expected one (Booker, Ratcliffe & Shinn 1950):

$$T = T_0 \sec i,$$

where T is the period of fading for the oblique incidence and T_0 is the period for the vertical incidence.

Thus, the experimental investigations of ionospheric drifts over east Siberia (1958–69) allow us to assume that the main features of ionospheric movements have been observed. Further investigations must be carried out in order to study the short-period dynamical processes in the ionosphere, to study the role of ionospheric drifts in space–time ionospheric variations, to improve the methods of measurements and treatment of data, and to obtain the 'climatological' features of ionospheric circulation for the study of relationships between ionospheric dynamics and atmospheric dynamics as a whole.

References (Kazimirovsky & Kokourov)

Booker, H. G., Ratcliffe, J. A. & Shinn, D. N. 1950 *Phil. Trans. R. Soc. Lond.* A **242**, 579.

Briggs, B. H. 1956 Instruction Manual, IGY, Part 5.

Kazimirovsky, E. S. 1963 *Geomagnetism and aeronomy* **3**, 463.

Kazimirovsky, E. S. & Kokourov, V. D. 1960 In *Researches of the irregularities in the ionosphere*. Publishing House of the Academy of Sciences, USSR, no. 4.

Kazimirovsky, E. S. & Kokourov, V. D. 1966 *The results of observations and investigations at the period of IQSY* **2**, 105.

Kazimirovsky, E. S., Kokourov, V. D. & Chernobrovkina, N. A. 1967 *Geomagnetism and aeronomy* **7**, 351.
Kazimirovsky, E. S. & Kokourov, V. D. 1968 *The investigations of geomagnetism, aeronomy and solar physics* **3**, 46.
Kokourov, V. D., Kazimirovsky, E. S., Zakharov, V. N. & Jovty, E. I. 1971 The simultaneous measurements of ionospheric drifts by vertical and oblique sounding. *J. atmos. terr. Phys.* **33**, 943.
Mitra, S. N. 1949 *Proc. IEE* **96**, 505.
Poljakov, V. M., Shchepkin, L. A., Kazimirovsky, E. S. & Kokourov, V. D. 1968 *Ionospheric processes*. Novosibirsk: Nauka, Siberian Section.
Sukhomazova, G. N. 1971 The investigation of ionospheric movements over Irkutsk at 1966 (in the Press).
Zakharov, V. N., Kazimirovsky, E. S. & Kokourov, V. D. 1969 *Geomagnetism and aeronomy* **9**, 935.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES