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RETROSPECTIVE ANALYSIS OF LONG-TERM REGIONAL FEATURES OF THE DYNAMIC REGIME OF THE IONOSPHERE OVER THE SOUTH OF EASTERN SIBERIA

D.S. Khabituev
Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia, Khabituev@iszf.irk.ru

M.A. Chernigovskaya
Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia, cher@iszf.irk.ru

Abstract. We have carried out a statistical analysis of a huge array of archival experimental data on the dynamic regime of the ionosphere over Irkutsk, obtained by a radiophysical spaced-receiver method with a small base of a radio signal reflected from the ionosphere during vertical ground-based radio sounding near Irkutsk in 1958–1982. Statistical long-term characteristics of drifts of ionization irregularities over the region of the south of Eastern Siberia were obtained. We confirmed clear differences in the nature of the dynamic regime of the lower and upper ionosphere. The motion of ionization in the zonal direction is shown to be more regular than the meridional drift. We determined the characteristic seasonal features of variations in magnitudes and directions of horizontal drift motions at heights of E and F ionospheric regions. The lower ionosphere is characterized by high variability and seasonal variations in motion velocities. In winter, the zonal component of the horizontal ionization drift velocity is directed to the west; in summer, to the east. At the heights of the upper ionosphere, the dynamic regime is more regular. The prevailing zonal direction of the motion of ionization irregularities to the west is observed for all seasons (heights above 230 km). The meridional component of the horizontal drift velocity mainly has a southerly direction. Thus, the horizontal drift of plasma irregularities at the heights of the upper ionosphere is, on the whole, directed to the southwest with the zonal direction predominating.

Keywords: ionospheric dynamics, spaced-receiver method, long-term variations, seasonal variations, lower and upper ionosphere, statistical data analysis.

INTRODUCTION

When describing features of the space-time distribution (typical or anomalous) of any geophysical parameter characterizing atmospheric processes, first of all it is necessary to have information about climate norms of behavior of the characteristic under study. Long-term average characteristics (averages and median values) of atmospheric parameters (annual, seasonal, monthly, daily, etc.), their repetition are called climate norms; the corresponding values for individual days, months, years, etc. are considered as a deviation from these norms.

According to the decision of 2014, the World Meteorological Organization (WMO) considers the average meteorological parameter statistically obtained from a long-term series of homogeneous observations in a given region over a 30-year period to be the climate norm. The period 1961–1990 has been taken as the reference and stable period. Climate norms should be updated every 10 years, shifting the reference period by 10 years. Increasingly new climate norms will be compared with the period 1961–1990 to identify trends in climate change.

The standard definition of climate refers to mean values and trends in meteorological parameters in Earth's lower atmosphere up to the tropopause. Yet, in terms of explaining climate drivers, such a definition is distinctly narrow [Kazimirovsky et al., 2006]. The terms “meteorology” and “climatology” are currently applied to the middle and upper atmosphere, including the ionosphere. This is a very complex combination of physical, chemical, and biological effects. Systemic interdisciplinary approaches to studying the variability of the solar-terrestrial relations provide further insight into short-term (space weather) and long-term (space climate) changes. They can also be applied to various areas of human activity (for example, human activity in space and the need to improve the reliability of technological systems whose performance depends on environmental changes) with respect to global climate change.

The importance of examining long-term trends in solar-terrestrial relations has been emphasized by many studies [Rishbeth, 1997; Danilov, 2012; Kazimirovsky et al., 2006; Danilov, Konstantinova, 2020; Laštovička, 2022]. It will take several decades to conclusively establish the reality of the long-term changes. Rishbeth [1997] suggests there are four possible causes for the long-term changes in the ionosphere: 1) global warming in the lower atmosphere, accompanied by cooling in the middle and upper layers of the atmosphere; 2) chemical pollution of the atmosphere caused by natural (e.g., volcanic) and anthropogenic factors; 3) long-term variations in solar activity; 4) secular variations in the geomagnetic field.

This paper presents the results of statistical analysis of archival long-term series of homogeneous measurements of parameters, which characterize features of the dynamic regime of the ionosphere in the E- and F-regions, near Irkutsk (52° N, 104° E) in 1958–1982.

DATA

The experimental basis for the statistical analysis we perform in this paper is archival observational data on the dynamic regime of the ionosphere, obtained by the radiophysical method of spaced reception of a radio signal, reflected from the ionosphere during ground-based vertical radio sounding, which provides information about the motion of inhomogeneous structure in ionospheric ionization distribution.

Systematic measurements of the drift of ionization irregularities, also known as traveling ionospheric disturbances (TIDs), were started in April 1958, from the first days of the Institute of Solar-Terrestrial Physics (in those years, the Siberian Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (SibIZMIR)). Special equipment for experimental measurements of ionospheric drifts by the method of closely spaced receivers (the spaced-receiver method D1) was developed at SibIZMIR's Ionosphere Dynamics Laboratory [Kazimirovsky, Kokourov, 1979; Petrukhin, 2015]. With the scientific results of the analysis of experimental data obtained in those years, SibIZMIR researchers took an active part in the worldwide research programs: the International Geophysical Year (IGY, 1957–1958), the International Geophysical Cooperation Year (IGC, 1959), the International Quiet Sun Year (IQSY, 1964–1965).

Drifts at heights of the E- and F-regions were observed at a measuring complex (Figure 1, *a*) consisting of a transmitting point (1) emitting signals in a shortwave (SW) range (2.2 MHz operating frequency), located in Zuy village (52°28' N, 102°04' E, 30 km north of Irkutsk); a control and measuring center (2), and three spaced receiving antennas (3) also located in Zuy village. Parameters of the equipment are described in [Kazimirovsky, Kokourov, 1972; Kazimirovsky, Kokourov, 1979]. The receiving antennas are parallel to each other, located at vertices of a right triangle, whose legs are 120 m long (about the length of a radio wave), and oriented in latitudinal and longitudinal directions. Measurements were carried out 24 hours a day; each observation session lasted for 5 min. To calculate the drift velocity, radio reflections from the E- and E_s-regions were used during the day; and from the F-region, at night.

An electromagnetic pulse is emitted upward and reflected from the corresponding ionospheric layer (Figure 1, *a*). For radio waves reflected from the ionosphere, the reflection region is a diffraction screen formed by ionization irregularities. In the reflection region, signal characteristics such as amplitude, phase, propagation direction, polarization, group delay, etc. change. That is why the pattern of the field of characteristics of signal distribution in the Earth surface carries information about properties of the irregularities forming it. A received radio wave reveals variations in the direction perpendicular to the wavefront. This is due both to the drift of the diffraction screen as a whole and to changes of its structure in motion. The information about the drift velocity is obtained by measuring the signal field parameters (diffraction pattern) at several points of the Earth surface (see Figure 1, *a*). The TID drift velocity was calculated as half the velocity of the diffraction pattern on Earth.

The ionization horizontal drift velocity vector was calculated from shifts of the records of time variations $R(t)$ in amplitudes reflected from the ionosphere and recorded by signal receivers (see Figure 1, *b*), using the similar fading method [Kazimirovsky, Kokourov, 1979]. The similarity method assumes that the distance between receiving points is smaller than the linear dimensions of scattering centers, the diffraction pattern does not change its structure during the motion of the screen over the receiving antenna system, the drift velocity remains, on average, constant during the session. It is also supposed that the diffraction pattern is isotropic.

Generalization of long-term measurements of ionospheric motions, comparison and mutual calibration with experimental measurements by other methods (rocket launches, radar of meteor trails, photographing of artificial luminous clouds, D3 method), as well as with model calculations allowed us to conclude that in the D- and E-regions the averaged drift velocities obtained by the D1 method coincide with the neutral wind velocity. For the F-region it has been reliably established that the D1 method provides information only about the drift motions of ionization irregularities; identifying these

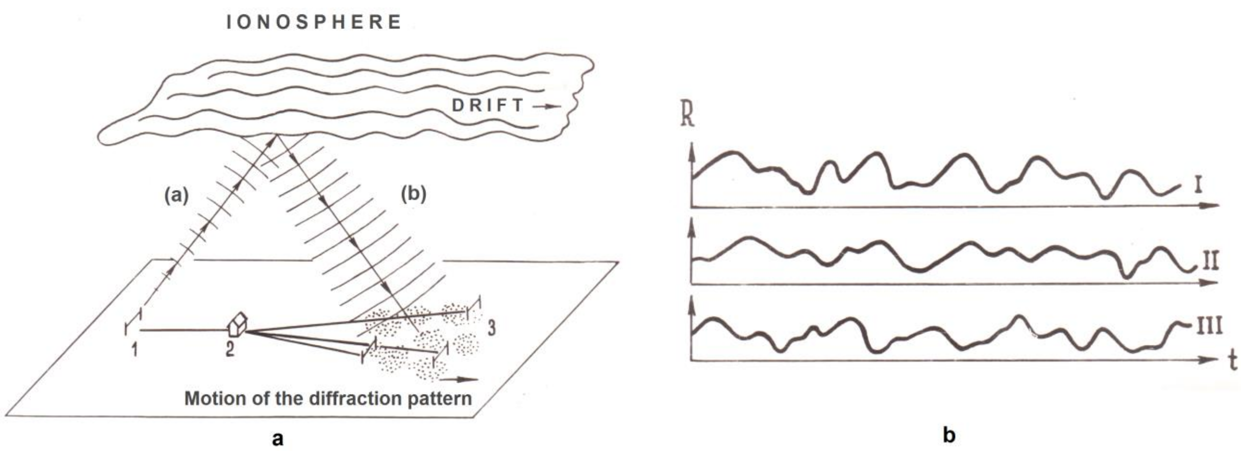

Figure 1. Layout of the complex for drift measurements by the D1 method (*a*); recording of amplitudes of a signal reflected from the ionosphere for three spaced antennas (*b*)

motions with the neutral wind velocity is incorrect. These features of the D1 method should be taken into account when physically interpreting measurement results (see [Kazimirovsky, Kokourov, 1979] and references therein).

Measurements at this experimental complex were carried out from April 1958 to November 1982. The time interval of interest spans three incomplete solar cycles: from the maximum of cycle 19 (1958), entire cycle 20, and to the descending phase of cycle 21. Until September 1973, recordings were filmed; later, digital recordings were taped. The experimental data acquired at the complex in Zuy village were published in 1968–1984 in 18 issues "Results of ionospheric observations. Measurements of horizontal irregularity drifts in the ionosphere". These collections of the latest information materials were a supplement to the collection of scientific papers "Research on Geomagnetism, Aeronomy, and Solar Physics" published those years at SibIZMIR (since 2015, the journal Solar-Terrestrial Physics). Tables contain the date and time of measurement, the drift velocity vector modulus **V** (m/s) and azimuth **Φ** (deg), as well as its zonal and meridional components V_x, V_y.

A result of the longstanding work of researchers was the development of a global empirical model of motions in the E- and F-regions [Kazimirovsky et al., 1994], which was included as an integral part in the International Reference Ionosphere IRI-90.

To carry out the statistical analysis presented in this paper, we have digitized ionospheric drift measurement data and have created an archive of drift velocities in the ionosphere. We have developed a program [Khabituev, Chernigovskaya, 2022] capable of reading vertical sounding data in various archival formats, formatting the data, as well as displaying ionization velocities.

STATISTICAL ANALYSIS OF MEASUREMENT DATA

For the statistical analysis we have used the entire array (29585 measurements) of archival experimental data for almost 25 years from April 1958 to November 1982. We analyzed distributions of the drift velocity vector modulus **V** (m/s) and direction **Φ** (deg), as well as its zonal V_x (+ eastward) and meridional V_y (+ northward) components. The drift velocity direction (azimuth) **Φ** was measured clockwise from the direction to the north. Figure 2 illustrates the altitude-time distributions of zonal V_x (see Figure 2, *a*) and meridional V_y (see Figure 2, *b*) ionization drift velocities at 100–350 km. The distribution of the number of measurements by year is shown in Figure 2, *c*, *d*. Until 1965, there were few measurements.

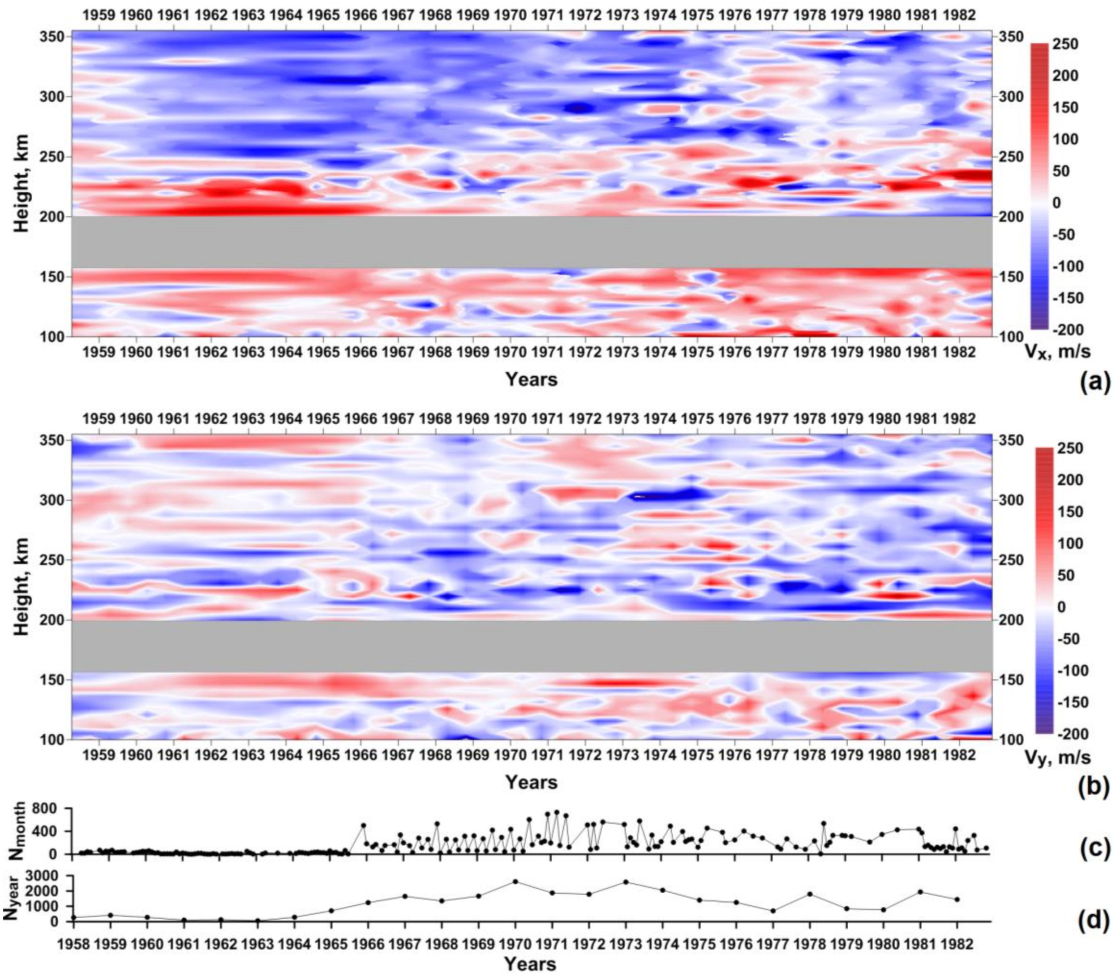

Figure 2. Altitude-time distributions of zonal V_x (*a*), meridional V_y (*b*) drift velocities and time distributions of the number of monthly average (*c*) and annual average (*d*) measurements

In accordance with the generally accepted international programs of coordinated observations in those years, measurements were carried out hourly 3–4 days a month. Analysis of the ionospheric drift parameters has shown that the ionization motions, despite high time-to-time variability, exhibit stable average space-time characteristics. It became obvious that correct quantitative analysis of motion parameters in the ionosphere required regular synoptic measurement programs. Quarterly monthly observations, and then longer ones, were therefore performed since the end of 1965. The measuring complex in Zuy became one of the essential facilities in the global network of ionospheric stations. The largest number of measurements is seen to be made in the late 1960s – early 1970s. During those years, experiments were also actively carried out to verify the D1 method adopted: the experiments “Radius” [Kazimirovsky et al., 1971] and “Strela” [Kazimirovsky, 1976].

The most general analysis of the altitude-time distributions of the zonal V_x (see Figure 2, *a*) and meridional V_y (see Figure 2, *b*) ionization drift velocity components shows that the zonal drift is more regular than the meridional one. The prevailing direction for the upper ionosphere (above 230 km) is westerly for all seasons (Figure 2, *a*). Directions in the lower ionosphere vary widely. We did not use experimental data for 160–200 km for analyzing the altitude-time distributions of V_x and V_y (gray color in Figure 2, *a*, *b*) in order to avoid interpolation errors since very few measurements were made in this altitude interval. This circumstance will be considered further in the analysis of histograms of the parameters characterizing the motion of ionization irregularities in the ionosphere.

Then, statistical analysis was conducted separately for the E-region (to 120 km) and for the F-region (above 120 km). The experimental data arrays contained 11031 and 18554 measurements for the E- and F-regions respectively.

Figures 3, 4 exhibit long-term time variations in monthly average (smoothed over three months) zonal (Figures 3, *a*; 4, *a*) and meridional (Figures 3, *b*; 4, *b*) components of the ionization drift velocity vector in the E- and F-regions. Also shown here are the numbers of annual average measurements in the E- (Figure 3, *c*) and F-regions (Figure 4,*c*).

The presence of stable seasonal variations in the components of the horizontal drift velocity of ionization irregularities at the E-region heights can be seen quite distinctly. There is a great variability in the atmospheric circulation of neutral gas in the lower ionosphere. In the E-region, the southwestward motion of ionization irregularities prevails in winter (negative V_x and V_y along dashed lines in Figure 3, *a*, *b*). In summer, V_x changes its direction to easterly (see Figure 3, *a*). The prevailing direction is to the northeast, less often to the southeast (1974–1977, 1979–1980) (see Figure 3, *b*).

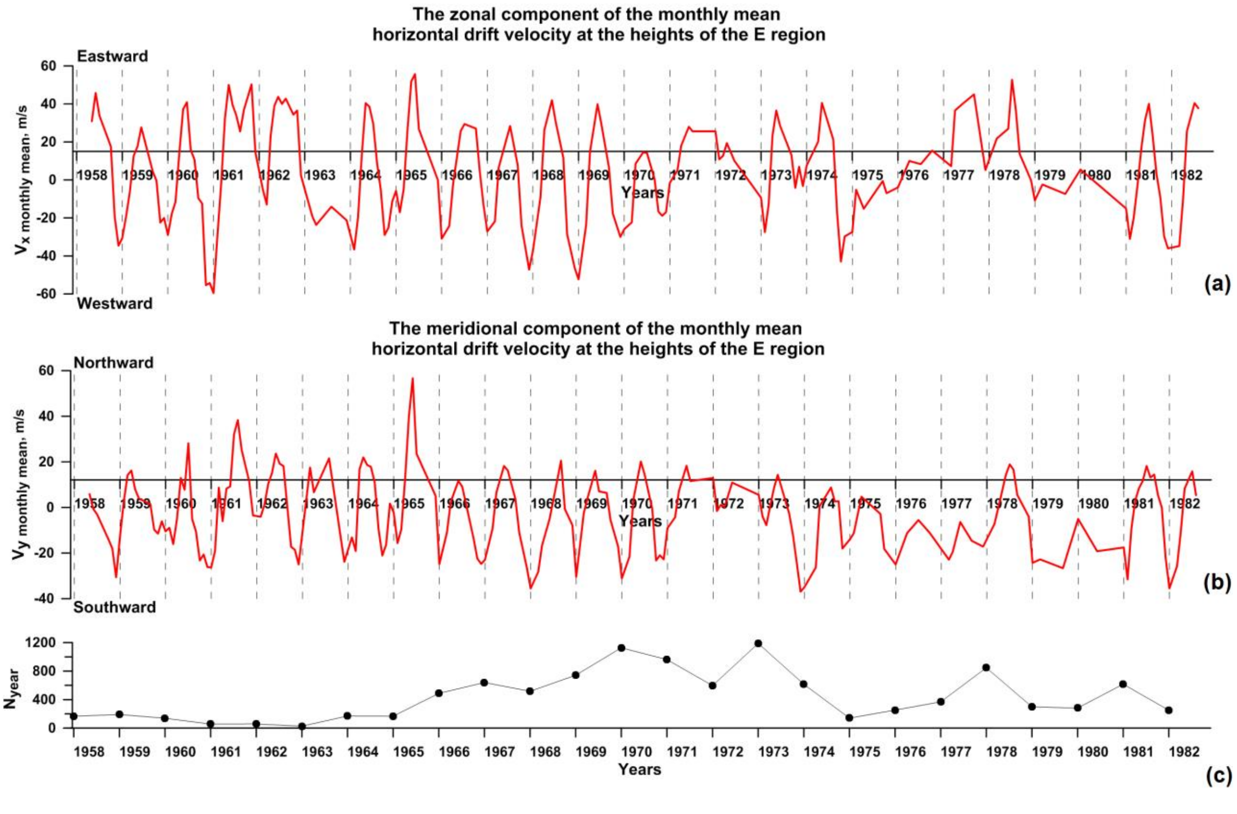

Figure 3. Zonal (*a*) and meridional (*b*) components (smoothed over three months) of the monthly mean horizontal drift velocity in the E-region; the number of annual average measurements in the E-region (*c*)

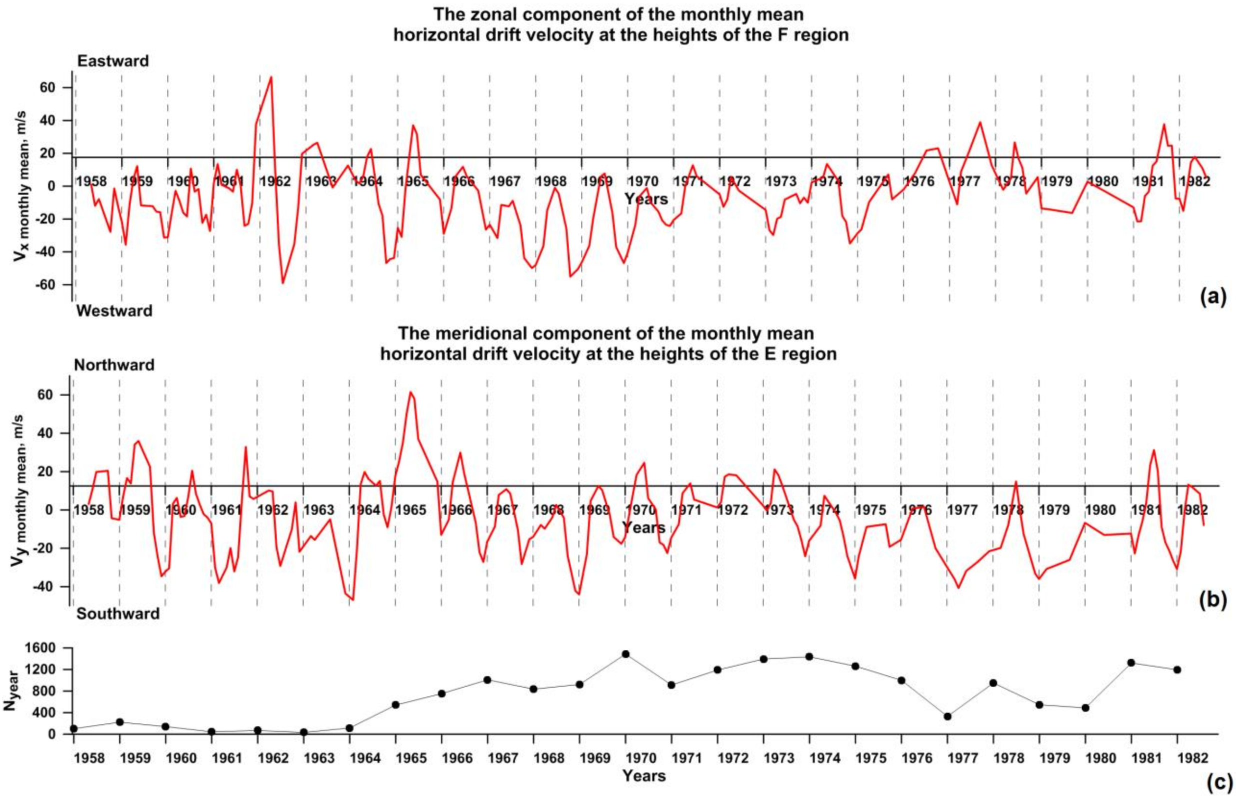

Figure 4. The same for the F-region

Dynamic regime variations in the F-region are significantly different. In the upper ionosphere, the westerly zonal direction of ionization irregularities surely prevails for all seasons. This is especially evident for the years when a large number of experimental measurements were carried out – 1967–1976 (Figure 4, *a*, as in Figure 2, *a*). The meridional horizontal drift velocity component is predominantly southward (Figure 4, *b*). Thus, the horizontal drift of plasma irregularities in the upper ionosphere is generally directed to the southwest with the zonal direction prevailing.

At all heights of the ionosphere, the velocities are higher in winter than in summer. This is especially evident for the meridional component (southward V_y) in the E-region (Figure 3, *b*), as well as for both horizontal ionization drift velocity components (westward V_x; southward V_y) in the F-region (Figure 4, *a*, *b*). Amplitudes of seasonal variations in V_x in the E-region (in winter, to the west; in summer, to the east) are roughly comparable (Figure 3, *a*).

Figures 5, 6 display the main features of statistical distributions of the parameters characterizing the motion of ionization irregularities in the ionosphere. The most probable altitudes of reflection of vertical sounding radio signals when measuring drifts in the E-region are 108-112 km (Figure 5, *e*). Most drift measurements in the E-region are performed at 96–120 km. The most probable values of the zonal and meridional drift velocity components are –40÷–60 m/s (Figure 5, *a*, *b*). The most probable direction of ionization irregularities is southwesterly (Figure 5, *a*, *b*). This is confirmed by the distribution of the most probable velocity vector directions (azimuths) 210°–240° (Figure 5, *d*) with the drift velocity vector modulus 60–80 m/s (Figure 5,*c*), although the northeasterly direction of ionization irregularities is also widespread (Figure 5, *a*, *b*, *d*).

Figure 6, *e* indicates that the most probable altitudes of reflection of vertical sounding radio signals when measuring drifts in the F-region are 260–280 km. Most drift measurements in the F-region are performed at 96–120 km. Particularly noteworthy is the interval 120–140 km, where more than 3500 measurements have been made. The altitudes from 120 to 160 km in their general dynamic properties are presumably closer to the E-region (Figure 5, *e*). There are very few measurements at 160–200 km. This might be due to technical characteristics of the experimental set employed. The most probable values of the zonal drift velocity component are –50÷–100 m/s; and those of the meridional component, 0÷–50 m/s (Figure 6, *a*, *b*). The most probable direction of ionization irregularities is southwesterly (Figure 6, *a*, *b*). This is confirmed by the distribution of the most probable velocity vector directions (azimuths) 240°–270° (Figure 6, *d*) with the drift velocity vector modulus 80–100 m/s (Figure 6, *c*). The northeasterly direction of ionization irregularities is also common to find (Figure 6, *a*, *b*, *d*).

Using monthly average (over each month of the entire observation period) zonal V_x and meridional V_y horizontal ionization drift velocity components (smoothed time series are shown in Figure 3, *a*, *b* and Figure 4, *a*, *b*), we have calculated long-term monthly mean values (norms) of the velocity components V_x and V_y and standard deviations of individual measurements from averages. We have thus obtained the long-term annual

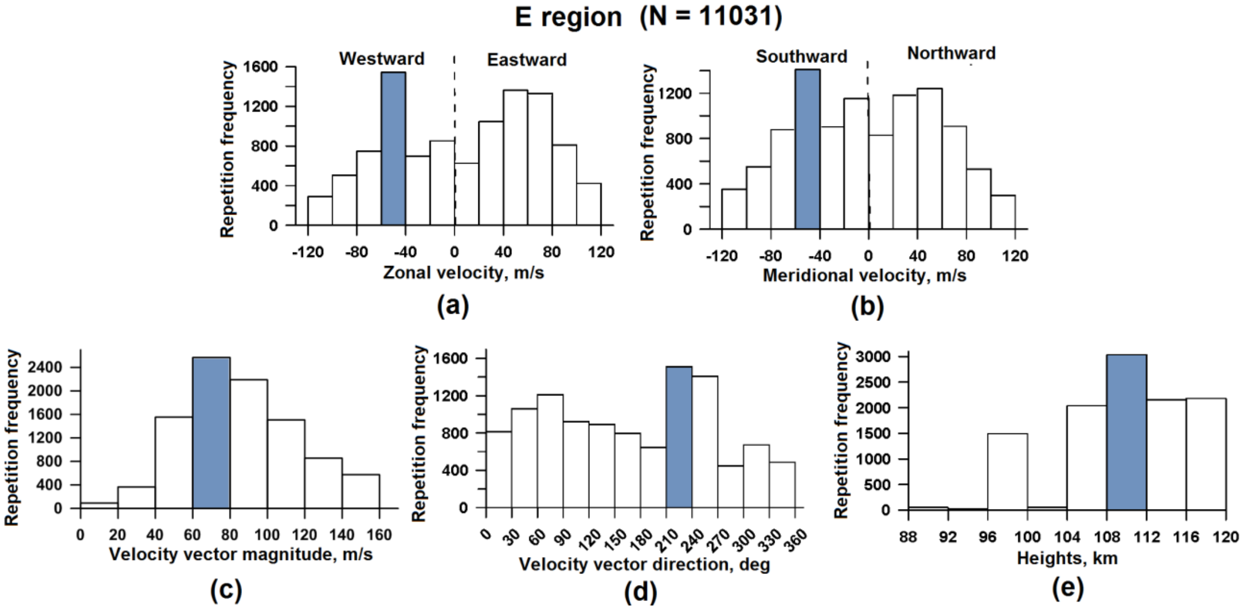

Figure 5. Frequency histograms of the zonal V_x (*a*) and meridional V_y (*b*) components, the modulus (*c*) and direction (*d*) of the ionization irregularity drift velocity vector, as well as the signal reflection altitude (*e*) for the E-region

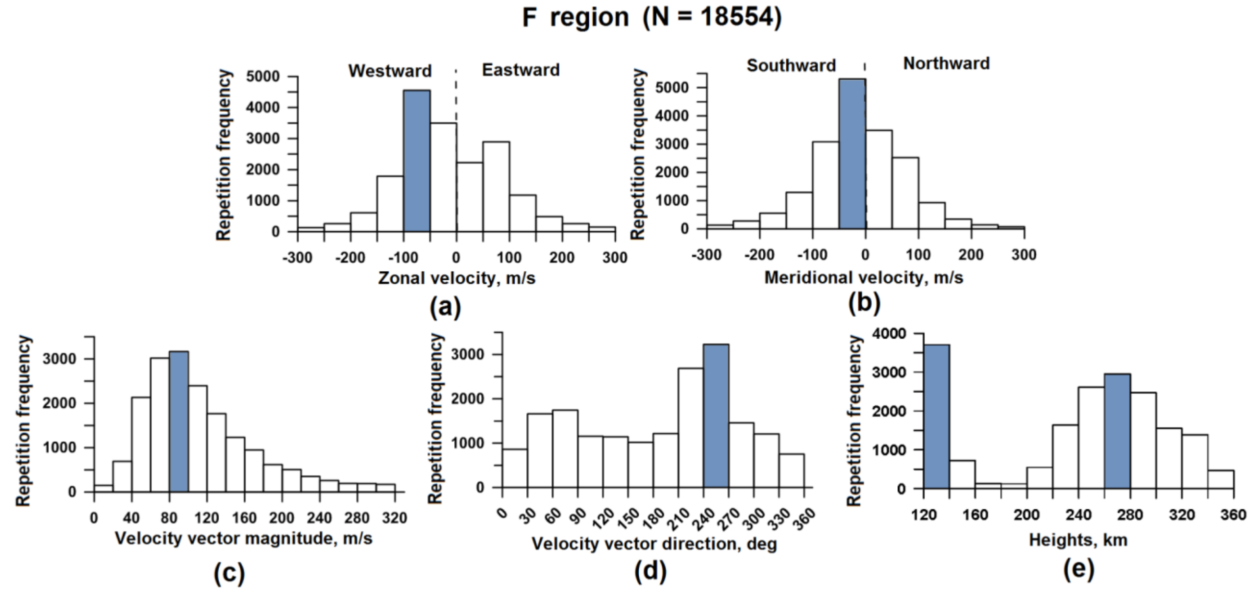

Figure 6. Frequency histograms of the zonal V_x (*a*) and meridional V_y (*b*) components, the modulus (*c*) and direction (*d*) of the ionization irregularity drift velocity vector, as well as the signal reflection altitude (*e*) for the F-region

average variations in the zonal and meridional horizontal drift velocity components in the E- and F-regions (Figure 7). The most extensive statistics have been collected for the winter months (December, January) when sounding the F-region — ~8000 measurements (see Figure 7, *f*); in summer, there are much fewer measurements — ~3000. The situation is reverse for the E-region: the smallest number of measurements in winter — 1700; the largest number of measurements in summer — over 4500. The main characteristic altitude and seasonal features of the dynamic regime in the E- and F-regions, considered above when discussing Figures 3–6, are readily confirmed. This is the prevailing westward (see Figure 7, *d*) and southward (Figure 7, *e*) motion for all seasons in the upper ionosphere. In the lower ionosphere, the eastward motion prevails in summer; the westward one, in winter (Figure 7, *a*). The meridional component is clearly seen to move southward in the winter months (Figure 7, *b*). For the long-term monthly average norms of the velocity components V_x and V_y, an increase in horizontal velocities in winter as compared to the summer solstice and equinoxes is confirmed (Figure 7, *a*, *b*, *d*, *e*).

DISCUSSION OF THE RESULTS OF EXPERIMENTAL DATA ANALYSIS

Statistical analysis of the entire extensive array of archival experimental information about the dynamic regime

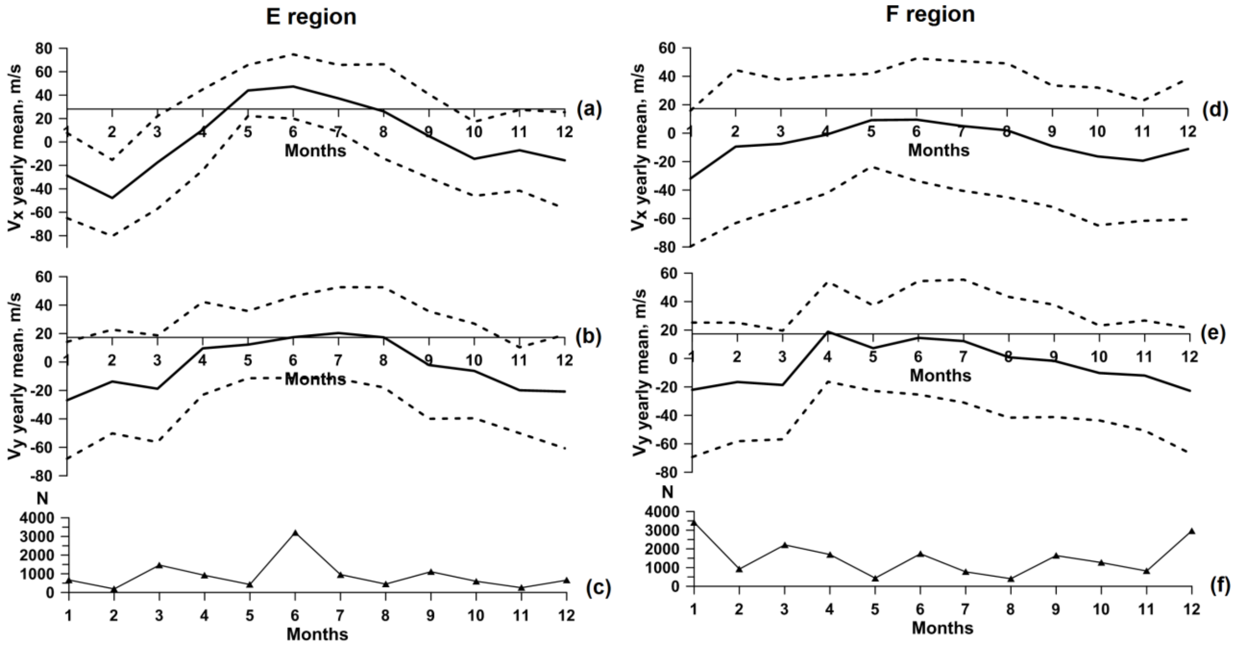

Figure 7. The long-term annual average variation in the zonal (*a*, *d*) and meridional (*b*, *e*) horizontal drift velocity components (solid lines), and standard deviations (dashed lines), as well as the total number of measurements for months of the year in the E- and F-regions (*c*, *f*)

of the ionosphere for 1958–1982 has not been performed before. Scientific analysis was carried out for individual seasons or time intervals according to schedules of joint measurements under the worldwide research programs (IGY, IGC, IQSY), or for scientific experiments to verify the radiophysical method D1 adopted [Kazimirovsky et al., 1971; Kazimirovsky, 1976; Kazimirovsky, Kokourov, 1979]. It should be understood that those years the entire procedure of experimental data processing and graphical representation of scientific analysis results was performed manually, was labor and time consuming. It was almost impossible to statistically analyze an array containing ~30000 measurements. The results of the retrospective statistical analysis are therefore new and highly relevant today, despite its being based on old archival experimental data. Statistical estimates are of scientific interest because they provide information about the long-term (climatic) norms of ionization motion parameters in the E- and F-regions over the south of Eastern Siberia. The results of the presented statistical analysis are representative and reliable because a large amount of observations have been processed; they were obtained by a uniform method and processed using a uniform methodology.

Note that the results of this retrospective statistical analysis do not contradict, but confirm and expand the conclusions made earlier when obtaining experimental data by the large team of researchers led by V.M. Polyakov, V.D. Kokourov, E.S. Kazimirovsky. The theoretical basis of experimental radiophysical measurements and the scientific results were summarized in the scientific monographs [Polyakov et al., 1968; Kazimirovsky, Kokourov, 1979]. The classical method of spaced reception of radio signals reflected from the ionosphere or transmitted through the ionosphere is often used in modern observational experiments to find TID characteristics.

Studying ionospheric processes is a very difficult task since the ionosphere is not an isolated system in the classic sense. As part of near-Earth outer space it interacts closely both with the underlying layers of the neutral atmosphere and with the magnetosphere. Dynamic and electrodynamic processes play an essential role in this case. Information on the regional climatic features of the dynamic regime of the ionospheric region under study is extremely useful, sometimes simply necessary, for understanding the physics of the observed variations in the ionospheric parameters considered. Knowing climatic norms of dynamic parameters and considering regional features of the dynamic regime of the ionospheric region under study are therefore very useful and in some cases necessary conditions for understanding the physics of observed variations in the ionospheric parameters of interest, for correct analysis of experimental data, for verifying new ionospheric observation methods, for testing experimental information processing techniques. Nowadays, the Department of Near-Earth Space Physics of ISTP SB RAS continues experimental measurements of the parameters of motion of ionization irregularities and neutral gas in the ionosphere.

Ionospheric plasma drift can be calculated using data from the Irkutsk Incoherent Scattering Radar (IISR). Shpynev [2000] presents a method for calculating the ionospheric plasma drift along the radar line of sight by analyzing IS signal power spectra. Then, an approach was developed which takes into account the ionospheric plasma transfer along the geomagnetic field lines [Shpynev et al., 2010]. It was used to explore the possibility of employing IS data to analyze meridional neutral wind dynamics and variations. An alternative method based on the analysis of IS signal autocorrelation functions is presented in [Shcherbakov et al., 2015a; Shcherbakov et al., 2015b].

Statistical analysis of the data on parameters of medium-scale (MS) TIDs, obtained by the short-wave radar in Ekaterinburg and the SuperDARN radar in Hokkaido, is presented in [Oinats et al., 2016]. In the upper ionosphere, the predominant direction of MS TEDs at night is southwesterly (~210° azimuth). According to the Hokkaido SuperDARN radar data, the most probable daytime velocities of TIDs are 60–100 m/s in the E-region and 110–180 m/s in the F-region. According to the Ekaterinburg IS radar data, TID velocities in the F-region are 30–90 m/s [Oinats et al., 2016]. These estimates of the ionization drift velocities agree well with the results of our statistical analysis (see Figures 5, 6).

An important application of the studies into the dynamics of ionospheric irregularities is the possibility of subsequent model estimation of the neutral wind velocity in an ionospheric region of interest [Oinats et al., 2016; Tolstikov et al., 2022]. But here a difficult problem arises about identifying the generation source of observable TIDs. Most often, TIDs are a manifestation of internal gravity waves (IGWs) [Perevalova, Oinats, 2020] generated either in the auroral oval region during geomagnetic storms or in the underlying neutral atmosphere during meteorological disturbances (sudden stratospheric warmings; baroclinic type instabilities generated in a jet stream as a result of structural transformations of the circumpolar vortex; tropical cyclones, etc.). Long-term studies have shown that in the daytime mid-latitude MS TIDs typically originate from IGWs. Nonetheless, various ionospheric plasma instabilities can also be a source of TIDs [Perevalova, Oinats, 2020].

Tolstikov et al. [2022] have proposed a universal method for estimating zonal and meridional neutral wind velocities from the statistics of observations of the two-dimensional phase velocity vector of MS TIDs obtained by any instrument. The method involves classifying observable TIDs into IGW-induced TIDs and TIDs of a different physical nature. To do this, the measured MS TID parameters are checked for compliance with Hines's dispersion relation, which relates the wave vector and the IGW frequency with known parameters of the propagation medium [Hines, 1960]. If the dispersion relation is fulfilled, the hypothesis of IGW filtration by the neutral wind is applied. According to this hypothesis, the amplitude of IGWs should increase (decrease) when they propagate antiparallel (parallel) to the neutral wind direction. If the main sources of MS TIDs are IGWs, the time dynamics of MS TID azimuths within 24 hours should be determined by the neutral wind. When IGWs propagate with the wind, their amplitude decreases greatly due to dissipation; whereas when they propagate against the wind, their amplitude increases. Hence, the observation probability increases for the MS TIDs propagating in the direction opposite to the neutral wind at the observation height. On the contrary, in the direction coinciding with a strong neutral wind the probability of observing MS TIDs is much lower. Thus, maxima in the time distribution of MS TID azimuths should coincide with the directions opposite to the azimuths of the strongest winds that are most frequently observed in this season and at this time of day [Tolstikov et al., 2022].

CONCLUSIONS

The study has provided average statistical long-term characteristics of ionization irregularity drift — the so-called background characteristics of horizontal ionospheric motions — over the mid-latitude region of the south of Eastern Siberia. The following results have been obtained.

1. We have statistically analyzed the multiyear archive (29585 measurements) of homogeneous measurements of horizontal ionization drift velocities in the E- and F-regions near Irkutsk (52 ° N, 104 ° E) for almost 25 years, from April 1958 to November 1982. We examined separately the E-region (to 120 km; 11031 measurements) and the F-region (above 120 km; 18554 measurements).

2. The statistical analysis yielded long-term average characteristics (annual, seasonal, monthly) of the dynamic ionospheric parameters, their repetition and variability (amplitude of variations, standard deviations).

3. The altitude-time distributions of the zonal and meridional ionization drift velocity components V_x, V_y show that the zonal drift is more regular than the meridional one.

4. We have confirmed the apparent differences in the nature of the dynamic regime of the lower and upper ionosphere. By the upper ionosphere we mean the F-region heights above 200 km. The most probable altitudes of reflection of vertical sounding radio signals when measuring drifts in the F-region are 260–280 km. Most drift measurements in the F-region are performed at 96–120 km. By the lower ionosphere we mean the heights of 120 to 160 km. The most probable altitudes of reflection of vertical sounding radio signals when measuring drifts in the lower ionosphere are 108–112 km and 120–140 km. Most drift measurements in the lower ionosphere were made at 96–140 km.

5. The most probable direction of motion of ionization irregularities in the lower ionosphere is southwesterly (velocity vector azimuths 210°–240°) with the drift velocity vector modulus 60–80 m/s. The northeasterly direction of ionization irregularities is also common. The most probable values of the zonal and meridional drift velocity components are –40÷–60 m/s.

6. The most probable direction of motion of ionization irregularities in the upper ionosphere is southwesterly (velocity vector azimuths 240°–270°) with the drift velocity vector modulus 80–100 m/s. The northeasterly direction of ionization irregularities can also take place. The most probable values for the zonal drift velocity component are –50 ÷–100 m/s; and for the meridional component, 0÷–50 m/s.

7. The lower ionosphere is characterized by high variability of drift velocities. At the same time, statistical analysis makes it possible to clearly identify seasonal variations in the magnitude and direction of the ionization velocity in the lower ionosphere. There is a great

variability of directions, especially in winter and during the equinoxes, which is likely associated with seasonal changes in the nature of atmospheric circulation of neutral gas in the lower ionosphere. In the E-region, the southwesterly direction of ionization irregularities prevails in winter. In summer, the direction of the zonal horizontal ionization drift velocity component V_x changes to easterly (the northeasterly, less often southeasterly, direction prevails).

In the upper ionosphere, a more regular dynamic regime is observed. The westerly zonal direction of ionization irregularities steadily prevails for all seasons (above 230 km). The meridional horizontal drift velocity component is largely southward.

8. Velocities in winter are generally higher than in summer. This is most pronounced in the upper ionosphere for both zonal (V_x is directed to the west in winter) and meridional (V_y is directed to the south in winter) horizontal ionization drift velocity components. In the lower ionosphere, this regularity holds for the meridional component (V_y is southward in winter). Amplitudes of interseasonal variations in the zonal component V_x in the E-region (westward in winter; eastward in summer) are roughly comparable.

Let us focus on the conclusions made earlier in the monograph by Kazimirovsky and Kokourov [1979] and references therein to numerous scientific articles that the spaced-receiver method with a small base gives a quantitative estimate of the neutral wind in the lower ionosphere (to ~130 km) and the drift of medium-scale (~100 km) ionization irregularities in the upper ionosphere.

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