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THE DYNAMICS OF IONOSPHERIC D-REGION OVER EAST SIBERIA

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ABSTRACT

Some main results of experimental investigations of the dynamical regime of the ionospheric D-region over East Siberia are presented. Regular measurements of horizontal ionospheric drifts by the radio method of closely spaced receivers, using a long wavelength transmitter operating at a frequency of 200 kHz, have been carried out near Irkutsk, USSR, since 1975. The seasonal and inter-annual variations of prevailing wind (zonal and meridional), and amplitudes and phases of semi-diurnal tides are investigated. Evidence is presented to show the response of D-region dynamics to stratospheric warmings. Planetary and gravity waves are found in the wind field. Comparison with results of analogous measurements in Central Europe (Collm, GDR) reveals a longitudinal effect on the dynamical regime of the mid-latitude lower thermosphere.

The structure, composition and radiative properties of the middle atmosphere cannot be completely understood without full consideration of the role of atmospheric motions on all scales. Relatively little is known about the large-scale circulations in the 60 to 100 km region, their interaction with ionospheric phenomena, and their role in vertical transport of trace species.

There is observational evidence for the broad spectrum of motions in the D-region. These include zonal and meridional mean motions, planetary waves, tides, gravity waves, synoptic scale motions, turbulence. The most important results of measurements (structure and composition) include the finding that the lower ionosphere exhibits not only a solar but also a strong non-solar control which is partly of meteorological nature.

The Middle Atmosphere Program (MAP) involves the investigation of the global wind field in the height range 15-120 km and, in particular, in the upper mesopause region. This region (85-95 km) has until presently been comparatively poorly understood, while its dynamics and structure determine the manner of interaction between lower-atmospheric meteorological phenomena and ionospheric processes. We believe that continuous monitoring of the dynamical regime of the ionospheric D-region is one of the most urgent tasks of the upper atmosphere physics.

There are some significant difficulties with undertaking of such monitoring. Most of the experimental data have been obtained from rocket experiments, meteor trail radars, spaced-receivers (D1) using vertical pulse radar (including partial reflections) and a modification of the D1 method which includes the use of broadcasting longwave transmitter signals, reflected by the lower ionosphere during the nighttime. The last method offers some advantages (comparatively simple equipment, no additional radio noise sources) and in principle measures the horizontal drift velocity of ionospheric irregularities. But there are good reasons for interpreting these measurements as an information on the neutral meteorological wind in the reflection region (85-95 km). This method has been calibrated by independent radar meteor and rocket wind measurements and its physical efficiency is proven.

The available regular experimental information about the midlatitude ionospheric wind has until recently been confined solely to the American (GREGORY and MANSON, 1975) and European (PORTNYAGIN and SPRENGER, 1978) continents. There were no data on the dynamical regime of the lower thermosphere for the Asian continent. For the investigation of the general atmosphere circulation at ionospheric heights and of local behavior of the dynamical regime over East Siberia, regular wind measurements have been made by the D1 method (200 kHz) near Irkutsk (USSR) since 1975. The method we apply yields the wind velocity averaged over 30 minutes. The volume of data (~13x10^3 half-hourly values) permits to assess with great confidence the average characteristics of prevailing winds, of amplitudes and phases of the semidiurnal tide, and the spectrum of planetary and internal gravity waves.

Observations are possible only at night (the data interval, depending on season, is 8-16 hours long). The instrumentation and processing techniques have been described by KAZIMIROVSKY and KOKOUROV (1979).

It is evident that the wind velocity modulus in the region under investigation is quite stable. Most of the values are within the range of 20-60 m/s so that a wind velocity of 40 m/s can be considered typical for this region. It should be noted that this value is in good agreement with wind measurements at similar heights made in Canada (GREGORY and MANSON, 1975) and Australia (STUBBS and VINCENT, 1973).

Both during summer and winter, the eastward wind prevails, but during equinoxes the westward wind. The seasonal variation of the velocity is not very large, maximum values of the zonal velocity being observed during solstices. The spring reversal of circulation is as a rule longer than the autumn reversal (KAZIMIROVSKY and KOKOUROV, 1979; KAZIMIROVSKY et al., 1979; KAZIMIROVSKY, 1981).

These winds exhibit both seasonal and interannual variability. Interannual variability is most pronounced during equinox periods and is associated with the circulation reversal in the upper mesospheric region. The winter regime (November-December) is most stable, although some interannual variability in winter is also indicated. These variations, we believe, should be interpreted as a consequence of the effect of stratospheric warmings (the number and intensity of which are different for the same months of different years) and as a possible effect of variations of solar and geomagnetic activity.

In fact the dependence on solar cycle of both prevailing and tidal wind in the height region between 90 and 100 km during winter, as found at first by SPRENGER and SCHMINDER (1969) from ionospheric drift measurements in the LF range, has been confirmed by PORTNYAGIN et al. (1977) by similar results from radar meteor wind measurements. GREGORY et al. (1980) has revealed a complex pattern of trends in zonal and meridional flow. The 11-year cycle response of seasonal zonal flow was shown to vary with altitude. Speeds increase from solar minimum to maximum by factors of 2-4. Response in the upper mesosphere and lower thermosphere was present in summer as well as winter.

We have found also from our drift measurements that zonal prevailing wind increased from 1975 to 1981, but not so fast as in Canada and Europe. This may be connected with the lower geomagnetic latitude of our observatories.

In addition we found a strong coupling between the dynamical regime of the region under investigation and stratospheric temperature. We can track stratospheric warming effects upon the ionospheric dynamics up to E-region winds (KAZIMIROVSKY et al., 1982).

We have investigated stratosphere-ionosphere coupling both for the winter solstice and for the spring circulation reversal. During the periods of sudden stratospheric warmings there are effects in the ionospheric D-region dynamics

1-2 days after the time of maximum temperature at the 30-mb level. The velocity modulus increases, the southward transport gets stronger, the amplitude of the semidiurnal tide for the meridional wind increases too, and the zonal wind decrease and even changes its sign. In winter the meridional wind is more sensitive to stratospheric temperature variations but during spring reversal the zonal wind is. Statistical analysis allows us to find out that for the most prevailing wind directions at the 85-95 km level we have almost always the same regime of stratospheric pressure and temperature. We found that the most favorable conditions for coupling from below occur in winter, when stratospheric zonal winds get weaker and the meridional extent of disturbing processes increases. The character of coupling varies not only from year to year but also from one warming to the other and is determined by the height and location of anticyclones generation.

Simultaneously with our measurements, a coordinated study of upper atmospheric winds has been carried on by the same method in Central Europe (Geophysical Observatory Collm, GDR). Cooperative analysis of the data (SCHMINDER et al., 1978a, 1978b, 1979, 1980) shows a difference in the wind field despite the fact that geographical latitudes of both stations are nearly equal and the procedure of data treatment is practically the same. We can find longitudinal effects manifested in a distinct character of histograms for the wind direction, a systematic excess of the prevailing zonal wind in East Siberia in comparison with Central Europe, a weaker semidiurnal tide during winter months over East Siberia, and different periods of equinoctial reversal of the circulation (spring reversal is observed respectively later and autumn reversal earlier over Siberia than those over Europe), etc. Thus, we have obtained the experimental evidence for a change of the midlatitude general atmospheric circulation at ionospheric D-region heights not only with season but also with region. We may interpret this as an effect of the dependence of the lower ionospheric dynamics on the climatic characteristics of the region under investigation and on the state of the lower atmosphere.

The reasons for real geophysical variations of the monthly mean values have been discussed by PORTNYAGIN et al. (1978) and attributed to synoptic fluctuations of wind velocities having periods of several days. Such synoptic fluctuations are associated with strato-mesospheric warmings and planetary wave propagation. In addition to these processes we believe that variations of the reflection height, which are associated with variations of the character of the vertical distribution of ionization, may also be significant. Regrettably, we lack information about the three-dimensional global distribution of D region ionization. We lack even a complete two-dimensional picture for any height. Evidence for the electron density in the D region is deduced from rocket profiles and data obtained by the method of partial reflection. Large seasonal differences and variation from year to year are observed. Longitudinal gradients in the distribution of electron density in the D region are also possible (in the ionospheric F region these effects are well documented). This will lead to variations of the radio wave reflection height in the long wavelength range at different radio frequencies and at different locations and even at one frequency and one location during different years. We also know that in the mesosphere region, the dynamical regime can vary rapidly with altitude.

Therefore, it is clear that although the morphological study of the space-time variations of the dynamical regime on the basis of coordinated programs using the radiophysical methods is of great value, these measurements alone cannot reveal unambiguously the cause of the variations observed without simultaneous careful control of the reflection height with an accuracy of the order of a few kilometers. There is a need to organize complex experiments combining remote sensing and in situ rocket methods of measurements of all parameters of the plasma in the height range under investigation.

Essential part of the dynamical regime of the ionosphere with the exception of the prevailing wind and tides are the planetary waves and internal gravity waves. We studied the spectrum of these waves on the basis of our wind measurements in the upper mesopause region (KAZIMIROVSKY and CHERNOBROVKINA, 1979; KAZIMIROVSKY et al., 1980) and found waves with prevailing periods from 20 to 80 minutes in zonal and meridional wind variations. From the daily values of the prevailing velocity and amplitude of semidiurnal tide, we determine with high statistical reliability the presence of maxima in the spectrum corresponding to periods 50-60, 32-34, 27-30, 22, 16-19, 10-13, and 4-8 days. The wide range of prevailing periods may be explained by the nonstationarity of the processes being studied. Actually, a special kind of dynamical spectral analysis confirmed the change of the wind field spectrum with the time.

In conclusion, we may say that we have obtained some new information about the dynamical regime of the ionospheric D-region over East Siberia. This information can be used to improve atmosphere models, such as CIRA-72, which have neglected longitude differences above 60 km. For the Middle Atmosphere Program, morphological study of space and time variations of the dynamics, based on coordinated observations by a network of stations using the radar-meteor and spaced receiver methods, is invaluable.

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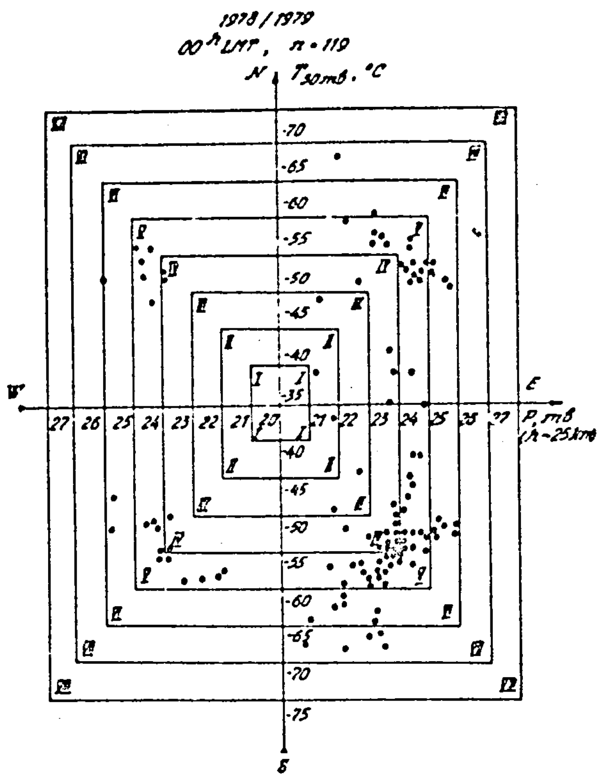

Figure 1. Map of the midnight wind direction distribution in the ionospheric D region for different thermobaric zones. Winter, 1978/1979.

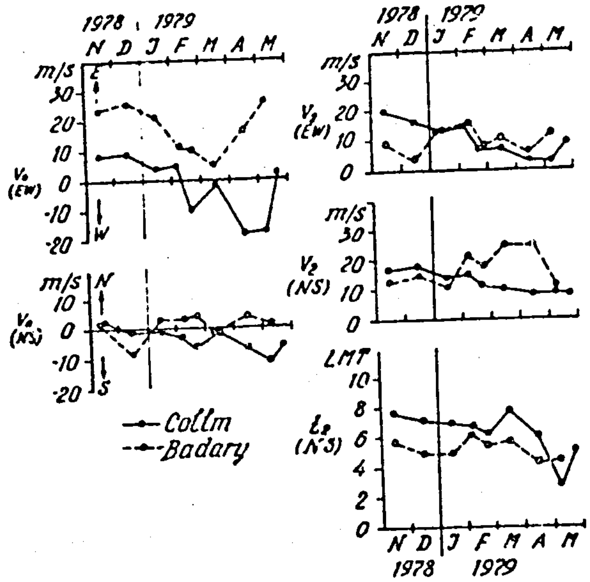

Figure 2. Longitudinal effects in the results of upper atmospheric wind measurements (D1, 85-95 km) obtained over Central Europe and East Siberia: seasonal variations (November 1978 - May 1979) of the wind field parameter in the upper mesopause region. V_0 m/s - prevailing wind, positive towards E and N, respectively; V_2 m/s - amplitude of the semidiurnal tide; t_2 (LMT) - phase of the meridional semidiurnal tidal wind component defined as the local mean time of the occurrence of the northward maximum.

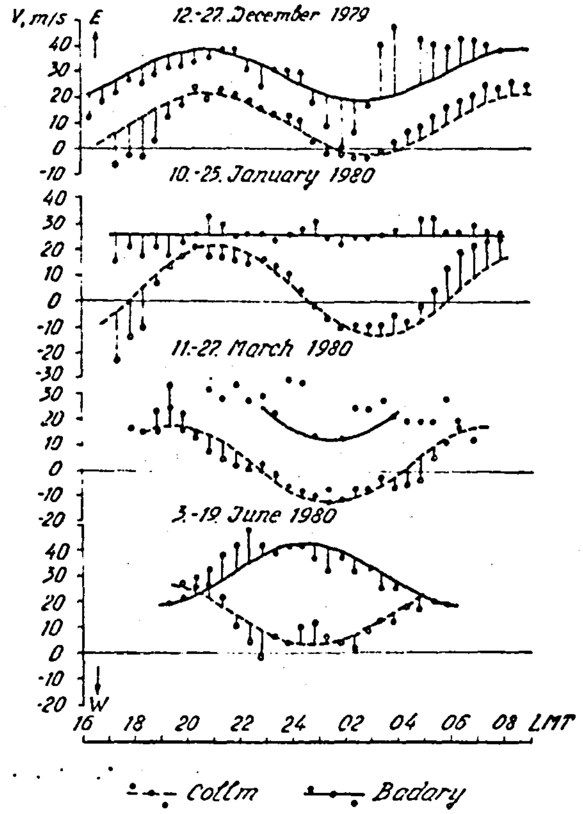

Figure 3. Longitudinal effects in the results of upper-atmospheric wind measurements (D1, 85-95 km) obtained over Central Europe and East Siberia: mean nighttime variations of the measured wind, zonal component.

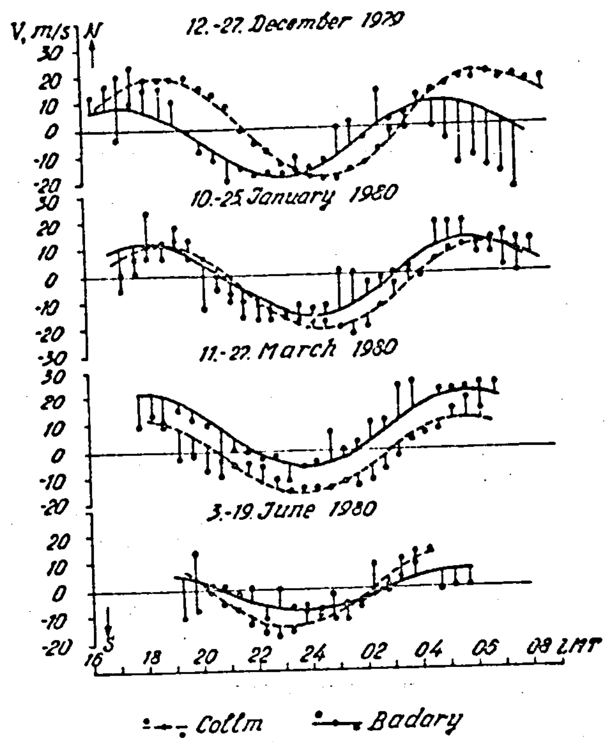

Figure 4. Mean nighttime variations of the measured wind (D1, 85-95 km), meridional component.