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DIURNAL DEPENDENCE OF THE FREQUENCY OF OCCURRENCE OF TRAVELING IONOSPHERIC DISTURBANCES OVER ALMATY

Abstract. We studied the diurnal dependence of the frequency of occurrence of large-scale traveling ionospheric disturbances (LSTID's) at mid-latitudes, which are a manifestation of atmospheric gravitaty waves (AGWs) generated in polar regions during geomagnetic disturbances. A significant amount of vertical sounding data of the ionosphere obtained at the Institute of the Ionosphere (Almaty 76 ° 55'E, 43 ° 15'N) in 2000-2007 was analyzed on a digital PARUS ionosonde connected to a computer designed to collect, store and process ionograms in digital form.

Further processing included the calculation of the altitude distributions of electron density

(N (h) profiles) by the Titeridge method and deriving from them variations of a number of F-region parameters (electron density at fixed heights $N_h(t)$; density at the maximum of the layer N_mF (t) ; the heights of the maximum of the layer $N_mF(t)$, etc.). The ionozonde provided a readout accuracy of

h '(t) ~ 2.5 km and a readout accuracy of f_oF ~ 0.05 MHz. It was shown that from session to session the number of waves observed during the night changed. In constructing the duirnal dependence of the frequency of occurrence of traveling ionospheric disturbances, all waves were taken into account.

A diurnal dependence of the frequency of occurrence of traveling ionospheric disturbances over Almaty was constructed from the measurement data. For this, a visual control of the behavior of a number of parameters of the F-region was carried out, identification of the LSTID's, determination of the time of their onset and duration.

It is shown that the predominant beginning of the development of the LSTID's is close to the moment of local midnight. 87% of traveling ionospheric disturbances were observed in the interval 20:00-04:00 LT. The distribution of the frequency of occurrence of the LSTID's in the time of day coincides with the dependence of the substorm frequency on world time, explained on the basis of diurnal variations in the angle of inclination of the Earth's magnetic axis to the Sun-Earth line. Ion drag and the dependence of the level of auroral activity, and, consequently, the intensity of the generation of LSTID's, on world time determines that the most favorable conditions for the distribution of LSTID's are created over Almaty at night.

Key words: ionosphere, vertical sounding, diurnal dependence of the frequency of occurrence of large-scale traveling ionospheric disturbances.

Introduction

Large-scale traveling ionospheric disturbances (LSTIDs) are caused by atmospheric gravity waves (AGWs), generated in the polar regions during geomagnetic storms [1], when the fast enhancement of auroral electrojects leads to the heating of the atmosphere. The process of rapid expansion and further compression of the atmosphere generates AGWs that propagates towards the equator and originates an LSTIDs on the way of their propagation. For many years, the propagation of AGWs in the neutral atmosphere and their ionospheric manifestation have been studied both experimentally and theoretically. The results of these studies are presented in the review works [1, 2]. The typical parameters of LSTIDs in the F region of the ionosphere are represented by the following values: the periods lie within the range from 40 min to 3 h; the horizontal wave lengths are 1000–3000 km; and the phase velocities are 400–1000 m/s. It is believed that generation and propagation of AGWs play an important role in the transfer of energy from the magnetosphere to the low latitude ionosphere. Although the LSTIDs have been studied for several decades, some fundamental problems remain little studied. Such problems include the question of the diurnal dependence of the frequency of their appearance at mid-latitudes.

Description of the equipment, and observation results

Nighttime observations of LSTIDs in the F region of the ionosphere are carried out at the Institute of Ionosphere (Almaty 76°55′ E, 43°15′ N) with a PARUS digital ionosonde connected to a computer for the collection, storage, and processing of ionograms in digital form. The information required for calculating various parameters of LSTIDs is read from ionograms using the semiautomatic method. Ionospheric sounding is conducted every 5 min. Nighttime measurement sessions last ~8–12 *h*, depending on the season. Ionograms provide the values of virtual heights of radio signal reflection h'(t) at several fixed operating frequencies of sounding and the values of critical frequencies foF. The further processing involves the estimation of the height distributions of electron densities ($N(h)$ profiles) by the Titheridge method [3] and obtaining the variations in several parameters of the F region based on them (the electron density at fixed heights $N_h(t)$; the density at layer maximum $N_mF(t)$; the heights of layer maximum $h_mF(t)$, etc.).

The ionosonde ensures the reading accuracies $h'(t)$ ~2.5 km and f_oF ~ 0.05 MHz. Nighttime was chosen for observations because LSTIDs with big amplitudes of variations in ionospheric parameters at midlatitudes are usually observed at night [4]. For the period 2000-2007 we carried out 1166 night observations, while 581 nights were characterized by wave activity [5]. The variations in $N_h(t)$ at a series of heights made it possible to determine the form of a height profile of amplitudes $A(h)$ with the A_m maximum absolute amplitude. For analysis, we selected observation sessions that recorded LSTIDs with a relative amplitude (δh) exceeding 25% at a height corresponding to A_m. Here, $\delta h = A(h)/N(h)$, where $A(h)$ is the absolute amplitude of a wave at height h and $N(h)$ is the value of the undisturbed electron density at a given height.

Figure 1 shows a typical time behavior of a number of parameters after the onset of large magnetic disturbances. From the figure it follows that the beginning of the LSTIDs falls on the time interval 20:00-22:00, and the end on the interval 02: 00-04: 00. The lower curve corresponds to the height of the base of the layer (h = 150 km). The upper (bold) curve corresponds to the variations of N_mF (t) at the maximum of the h_mF layer. Variations in the electron density shown in the figures demonstrate a feature characteristic of most of the sessions in which LSTIDs were observed. The peculiarity lies in the fact that the LSTIDs in the N_mF (t) variations are manifested much weaker than in the N_h (t) variations at fixed heights located below the height of the layer maximum. The reasons for this altitudinal dependence of the ionosphere response to AGW passage were considered in [6].

It should be noted that the number of waves observed during the night changed from session to session. In the example shown in figure 1, four waves are present. In constructing the diurnal dependence of the frequency of occurrence of traveling ionospheric disturbances, we took into account all the waves.

Earlier [7], a good correlation of LS TIDs with auroral substorms was proved; therefore, good similarity of their diurnal dependences should be expected. The long-term component in auroral disturbances, representing the dependence of the intensity and number of substorms on world time, was noted in [8, 9]. It became obvious that the beginning of the auroral substorms, as follows from the behavior of the auroral electrode jet index (*AL*-index), was the most frequent between 13:00 and 19:00 UT. More than 30% of the reported peaks in the *AL*-index accounted for a relatively narrow time domain of 13: 00–16: 00 UT [9]. The dependence of the substorm frequency on world time was explained on the basis of diurnal variations in the angle of inclination of the Earth's magnetic axis to the Sun-Earth line.

We analyzed the diurnal dependence of the frequency of occurrence of traveling ionospheric disturbances over Almaty according to measurements for 2000-2007. For this, a visual control of the behavior of a number of parameters of the *F*-region was carried out, identification of the LS TIDs, determination of their start time and duration. It is nessesary to notice that high probabilities of the formation of nighttime enhancements in NmF2 and the passage of LS TIDs mean a high probability of their simultaneous presence over the observation point, leading to a necessity to distinguish these two events. We performed selection LS TIDs as made it in our work [10].

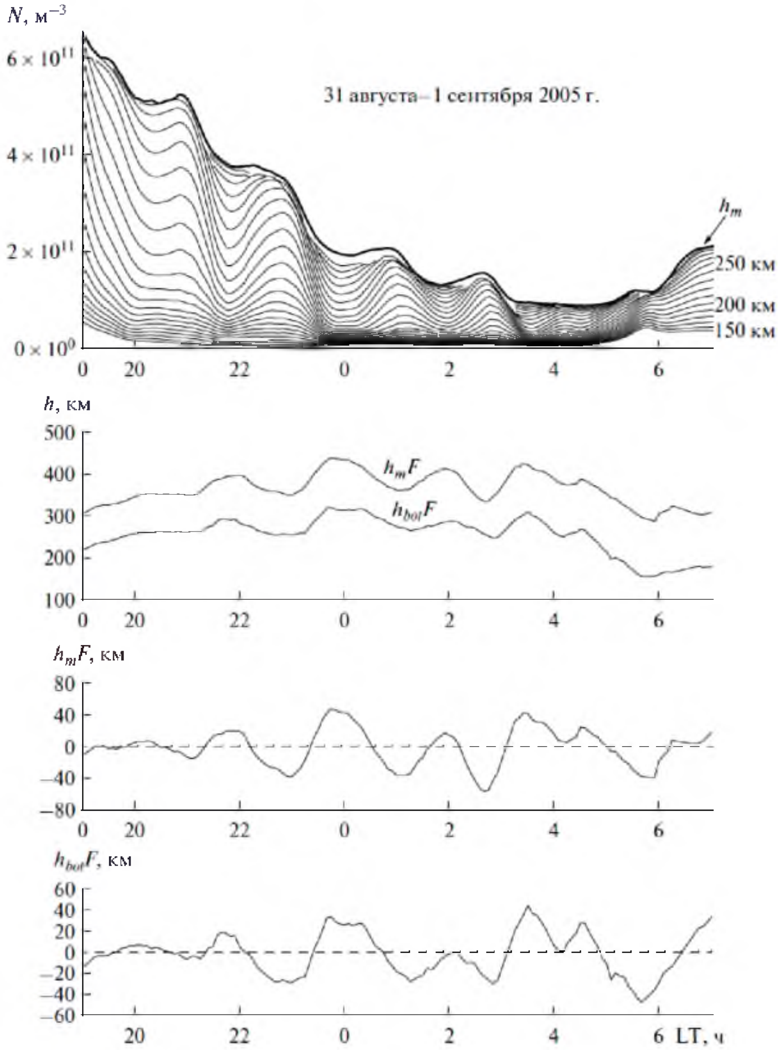

Figure 1 - Variations of the *F*-region parameters during the night with high magnetic activity (August 31 – September 1, 2005): top panel — electron density *N*(*t*) at a series of heights with a distance between adjacent heights of 10 km; the second panel - the heights of the maximum of the F-region h_mF and its base $h_{bot}F$; the third and fourth from the top of the panel are h_mF and $h_{bot}F$ with an exclusive trend

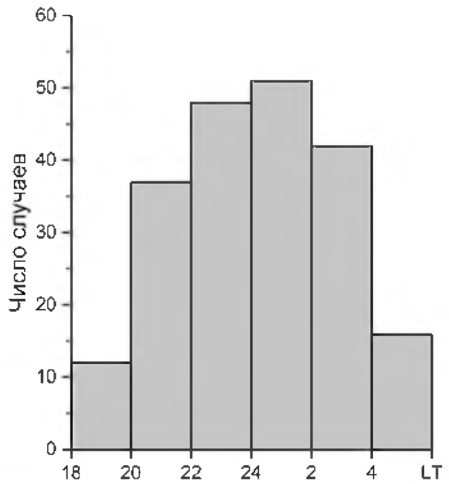

Figure 2 - diurnal dependence of the frequency of occurrence of large-scale traveling ionospheric disturbances over Almaty

According to measurements for 2000-2007. we have constructed a diurnal dependence of the frequency of occurrence of traveling ionospheric disturbances (figure 2). From the figure it follows that the predominant beginning of the development of the LS TIDs is close to the moment of local midnight. 87% of the traveling ionospheric disturbances were observed in the interval 20:00-04:00 LT. Taking into account the difference between world time and local Almaty time is 5 hours, we find that the overwhelming majority of the LS TIDs was observed in the interval 15:00-23:00 UT.

Let us consider why the LS TIDs are local in time near the midnight. In [11], the response of the ionosphere to a large magnetic storm was studied using data from the global network of vertical sounding stations and the Cosmos-900 satellite. It has been shown that the ionospheric response, which is the LS TIDs with a quasiperiod of ~ 3-4 hours, is observed throughout the globe, while the amplitudes of the LS TIDs in the night observation sector are several times higher than the amplitudes observed in the illuminated half of the Earth.

The planetary nature of the propagation of large-scale LS TIDs was also studied in [7] for a period of high solar activity, where it was shown that the probability of observing LS TIDs in the Australian-Asian longitude sector is significantly higher than the probability for the European and American sectors. This longitudinal effect is explained on the basis of the mechanism of ion drag of AGW, which takes maximum values at the illuminated time of day, and the diurnal dependence of auroral activity with a maximum of 13–19 UT. While neutral particles move freely across the line of the geomagnetic field, ions rotate around the field line and have difficulty crossing the field lines. This difference between the mobility of neutral particles and the mobility of ions limits the movement of neutral particles in the AGW in the collision of neutral particles and ions, leading to the attenuation of the AGW. This mechanism is called the ion drag effect. The magnitude of ion drag depends on the frequency of collisions of neutrals with ions, which is linearly related to the densities of neutrals and ions. Since the density of ions in the daytime is much higher than the nighttime density, the AGW attenuation on the daytime side of the Earth noticeably exceeds the attenuation on the nighttime side.

Ion drag and the dependence of the level of auroral activity, and, consequently, on the intensity of the generation of LS TIDs, on world time determines that the most favorable conditions for the distribution of LS TIDs are created over Almaty at night.

Conclusion

On the basis of a graphical representation of the reaction of the parameters of the F2 layer in the 23rd cycle of solar activity to the passage of large-scale traveling ionospheric disturbances (LS TIDs), the diurnal dependence of the frequency of the appearance of LS TIDs over Almaty was studied. It is shown that the frequency has pronounced maxima in the interval 20: 00-04: 00 local time. The distribution of the frequency of occurrence of the LS TIDs in time of day coincides with the dependence of the substorm frequency on world time, which is explained on the basis of diurnal variations in the angle of inclination of the Earth's magnetic axis to the Sun-Earth line.

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АЛМАТЫ ҚАЛАСЫНЫҢ ҮСТІНЕН ҚОЗҒАЛАТЫН ИОНОСФЕРАЛЫҚ АУЫТҚУЛАРДЫҢ ПАЙДА БОЛУ ЖИІЛІГІНІҢ ТӘУЛІКТІК ТӘУЕЛДІЛІГІ

Аннотация. Орташа ендіктегі ірі масштабты қозғалатын ионосфералық ұйтқулардың (ІМҚИҰ) пайда болу жиілігінің, геомагниттік ауытқулар кезінде полярлық аудандарда генерацияланатын атмосфералық гравитациялық толқындардың (АГТ) көріністері болып табылатын тәуліктік тәуелділігі зерттелді.

Ионосфераны тік зондтау деректерінің 2000-2007 жылдары алынган елеулі көлемі талданды. Ионосфера институтында (Алматы 76°55' E , 43°15' N) сандық ионозонд "ПАРУС" компьютермен ұштасқан, ионограммаларды сандық түрде жинауга, сақтауга және өңдеуге арналган. ІМҚИҰ әр түрлі параметрлерін есептеу үшін қажетті ақпарат ионограмммен жартылай автоматты әдіспен есептелді. Ионосфераны зондтау әрбір 5 мин. жүргізілді. Түнгі өлшеу сеанстарының ұзындыгы маусымга байланысты өзгерді және ~ 8-12 сағ құрады. Ионограммалардан маңызы бар қаланың қолданыстагы биіктерге көрсету *h'(t)* радиосигналды бірқатар белгіленген жұмыс жиілік зондтау және маңызы бар сыни жиілік f_oF есептелінді. Одан әрі өңдеу Титеридж әдісімен электронды тыгыздықтың $N(h)$ -профильдердің) биіктік таралуын есептеуді және олардың негізінде F-аймақтың бірқатар параметрлерінің вариацияларын алуды ($N_h(t)$ тіркелген биіктіктердегі электрондық тыгыздықты; $N_mF(t)$ қабатының максимумындағы тығыздықты; $N_mF(t)$ қабатының максимум биіктігін және т.б.) қамтиды. Ионозонд *h'(t)* ~ 2.5 км оқу дәлдігін және f_oF ~ 0.05 МГц оқу дәлдігін қамтамасыз етті.

Сеанстан сеансқа түнгі уақытта байқалатын толқындардың саны өзгергені көрсетілген.

Қозгалатын ионосфералық ауытқулардың пайда болу жиілігінің тәуліктік тәуелділігін құру кезінде барлық толқындар ескерілді. Өлшеу деректері бойынша Алматы үстінен қозгалатын ионосфералық ұйтқулардың пайда болу жиілігінің тәуліктік тәуелділігі салынды. Ол үшін F-облыстың бірқатар параметрлерінің мінез-құлқына визуалды бақылау, ІМҚИҰ сәйкестендіру, олардың басталу уақыты мен ұзақтыгын анықтау жүзеге асырылды. ІМҚИҰ дамуының басым бастауы жергілікті түн жаруга жақын екендігі көрсетілген. 87% қозгалатын ионосфералық 20:00-04:00 LT аралыгында қалыптан байқалды. ІМҚИҰ пайда болу жиілігінің тәулік уақытында таралуы жер магниттік осінің Күн-Жер сызыгына көлбеу бұрышының тәуліктік вариациясы негізінде түсіндірілетін қосалқы агын жиілігінің әлемдік уақыттан тәуелділігіне сәйкес келеді. Иондық тежелу және авроральді белсенділік деңгейінің тәуелділігі, демек, ІМҚИҰ генерациясының қарқындылыгы әлемдік уақыттан бастап ІМҚИҰ тарату үшін аса қолайлы жагдайлар Алматының үстінен түнгі уақытта құрылатынын анықтайды.

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СУТОЧНАЯ ЗАВИСИМОСТЬ ЧАСТОТЫ ПОЯВЛЕНИЯ ПЕРЕМЕЩАЮЩИХСЯ ИОНОСФЕРНЫХ ВОЗМУЩЕНИЙ НАД АЛМАТЫ

Аннотация. Изучена суточная зависимость частоты появления крупномасштабных перемещающихся ионосферных возмущений (КМ ПИВ) на средних широтах, являющихся проявлением атмосферных гравитационных волн (АГВ), генерируемых в полярных районах во время геомагнитных возмущений. Проанализирован значительный объем данных вертикального зондирования ионосферы, полученных в 2000-2007 гг. в Институте ионосферы (Алматы 76°55'E, 43°15'N) на цифровом ионозонде «ПАРУС», сопряженным с компьютером, предназначенным для сбора, хранения и обработки ионограмм в цифровом виде. Информация, необходимая для расчетов разнообразных параметров КМ ПИВ, считывалась с ионограмм полуавтоматическим методом. Зондирование ионосферы проводилась каждые 5 мин. Длина ночных сеансов измерений изменялась в зависимости от сезона и составляла ~ 8–12 ч. С ионограмм считывались значения действующих высот отражения $h'(t)$ радиосигнала на ряде фиксированных рабочих частот зондирования и значения критических частот f_oF. Дальнейшая обработка включала в себя расчет высотных распределений электронной плотности ($N(h)$-профилей) методом Титериджа и получение на их основе вариаций ряда параметров F-области (электронной плотности на фиксированных высотах $N_h(t)$; плотности в максимуме слоя $N_mF(t)$; высоты максимума слоя $N_mF(t)$ и др.). Ионозонд обеспечивал точность считывания $h'(t)$ ~ 2.5 км и точность считывания f_oF ~ 0.05 МГц. Показано, что от сеанса к сеансу менялось количество волн, наблюдаемых в течение ночи. При построении суточной зависимости частоты появления перемещающихся ионосферных возмущений учитывались все волны.

Была построена суточная зависимость частоты появления перемещающихся ионосферных возмущений над Алматы по данным измерений. Для этого осуществлялся визуальный контроль поведения ряда параметров F-области, идентификация КМПИВ, определение времени их начала и продолжительности.

Показано, что преобладающее начало развития КМПИВ близко к моменту местной полуночи. 87% перемещающихся ионосферных возмущений наблюдалось в интервале 20:00-04:00 LT. Распределение частоты появления КМПИВ во времени суток совпадает с зависимостью частоты суббурь от мирового времени, объясняемой на основе суточных вариаций угла наклона земной магнитной оси к линии Солнце-

Земля. Ионное торможение и зависимость уровня авроральной активности, а, следовательно, и интенсивности генерации КМ ПИВ, от мирового времени определяет то, что наиболее благоприятные условия для распространения КМ ПИВ создаются над Алматы в ночные часы.

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