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# ИСПОЛЬЗОВАНИЕ ДАННЫХ ДВУХ БЛИЗКО РАСПОЛОЖЕННЫХ ИОНОЗОНДОВ ПРИ ДИАГНОСТИКЕ ПЕРЕМЕЩАЮЩИХСЯ ИОНОСФЕРНЫХ ВОЗМУЩЕНИЙ

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# USING DATA FROM TWO CLOSELY SPACED IONOSONDES FOR DIAGNOSTICS OF TRAVELLING IONOSPHERIC DISTURBANCES

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Для определения полного вектора скорости перемещающихся ионосферных возмущений (ПИВ) одного радиофизического инструмента может быть недостаточно, поскольку в этом случае определить азимутальный угол прихода радиоволны не всегда можно даже косвенными методами (предполагаются эксперименты, где прямое измерение углов прихода радиосигнала недоступно). Более эффективным и информативным оказывается совместное использование нескольких ионозондов.

В работе представлена методика исследования характеристик ПИВ по данным двух ионозондов вертикального (ВЗ) и слабонаклонного зондирования (СНЗ) в условиях, когда ионозонд ВЗ расположен на одном из концов радиотрассы ионозонда СНЗ (длина трассы составляет 120 км). Скважность получения ионограмм на каждом ионозонде составляла 1 мин. В рамках данного эксперимента типичной была ситуация, когда последовательность ионограмм с характерными короткоживущими серпообразными особенностями (которые не являются следами отражения от регулярных ионосферных слоев, а связаны с прохождением ПИВ), получаемая на одном из ионозондов, повторяется с определенной задержкой по времени (несколько минут) на втором ионозонде. Это дает основание полагать, что данные особенности связаны с одним и тем же возмущением. Наличие двух независимых пространственно-разнесенных инструментов позволяет восстановить дополнительные детали пространственно-временной структуры ПИВ.

To determine the full vector of TID velocity, we usually need more than one radiophysical instrument, otherwise it is not always possible to determine an azimuth angle of arrival even through the use of indirect methods (experiments are planned in which angles of arrival cannot be measured directly). The use of several ionosondes at a time proves to be more effective and informative.

This paper presents a method for examining characteristics of traveling ionospheric disturbances (TID) based on data from ionosondes of vertical ionospheric sounding (VIS) and oblique ionospheric sounding over short paths (OIS) with the VIS ionosonde being at one of the ends of the OIS path 120 km long. Ionograms were obtained by the ionosondes at 1-minute intervals. It was typical in the experiment that a sequence of ionograms with characteristic cusp-like features (due to the passage of TID) obtained by one of the ionosondes was obtained by the second ionosonde with a certain time delay (several minutes). The two independent instruments in use minimize ambiguity in reconstructing the space-time TID structure.

## Introduction

The possibility of TID diagnostics from VIS ionograms has been discussed in a number of papers (see, for example, [Krasheninnikov, Lyannoi, 1991a, b]). However, to determine, say, the full vector of TID velocity, we usually need more than one radiophysical instrument [Medvedev, Ratovsky et al., 2009], otherwise it is not always possible to determine an azimuth angle of arrival even through the use of indirect methods (experiments are planned in which angles of arrival cannot be measured directly). The use of several ionosondes at a time proves to be more effective and informative.

Figure 1 is the map of the experiment: the length of the Usolye–Tory path is 120 km. Geographical coordinates of the points of emanation and reception are 52°53′ N, 103°16′ E and 51°48′ N, 103°5′ E respectively. In addition to oblique ionospheric sounding over short paths (OIS), we took vertical sounding (VIS) at the Tory end of the path.

Winter day-time VIS and OIS ionograms often contain an additional cusp-shaped trace (Fig. 2, 3). The cusp usually moves down turning with time into a bend of the main trace in the ionogram [Drobjev, Yakovets, 1977; Krasheninnikov, Lyannoi, 1991]. The cusps in the ionograms have been found to be caused by traveling ionospheric disturbances the front of which is inclined to the horizon [Danilkin et al., 1987; Krasheninnikov, Lyannoi, 1991].

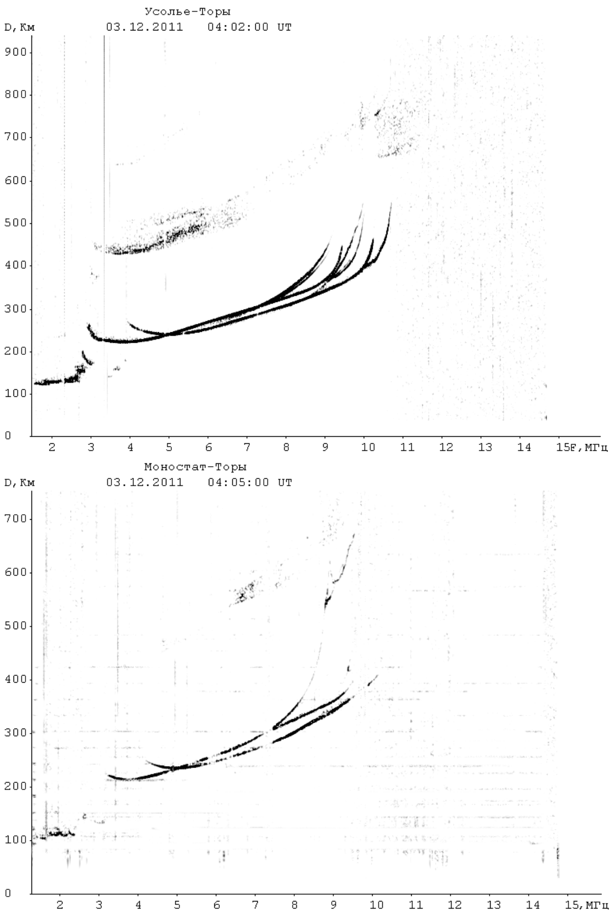
Figure 2 illustrates a situation where a pattern observed in ionograms from one of the ionosondes can be observed several minutes later in ionograms from the second ionosonde. The closest fit between the cusps in the ionograms (in this example, with a 3-minute delay: from 10:57 to 11:04 LT for OIS and, correspondingly, from 11:00 to 11:07 for VIS) suggests that the TID was moving from north to south. Notice that in most cases the cusp appeared initially in Usolye–Tory ionograms, and several minutes later, in VIS ionograms. This implies that the said TID direction prevailed during this experiment.

Let us consider a series of ionograms with typical cusps obtained at 1-minute intervals (Fig. 3). The ionograms in Fig. 3, *a*, *b* were obtained by OIS over the Usolye–Tory path; the ionograms in Fig. 3 *c*, *d*, by VIS in Tory.

## Recovery of TID parameters

Note first that the availability of the VIS station along with the close OIS radio path in this experiment (which in diagnostic possibilities is equivalent to the availability of two VIS stations provided that one of them is at a midpoint of an OIS path) allows a rough estimate of the TID horizontal drift velocity from ionograms without modeling. To do this would require selecting two ionograms, OIS and VIS cusp-shaped parts of which are most closely matched (a cusp minimum from a group delay is suggested as a proximity criterion).


*Fig. 1*. The layout of the experiment.



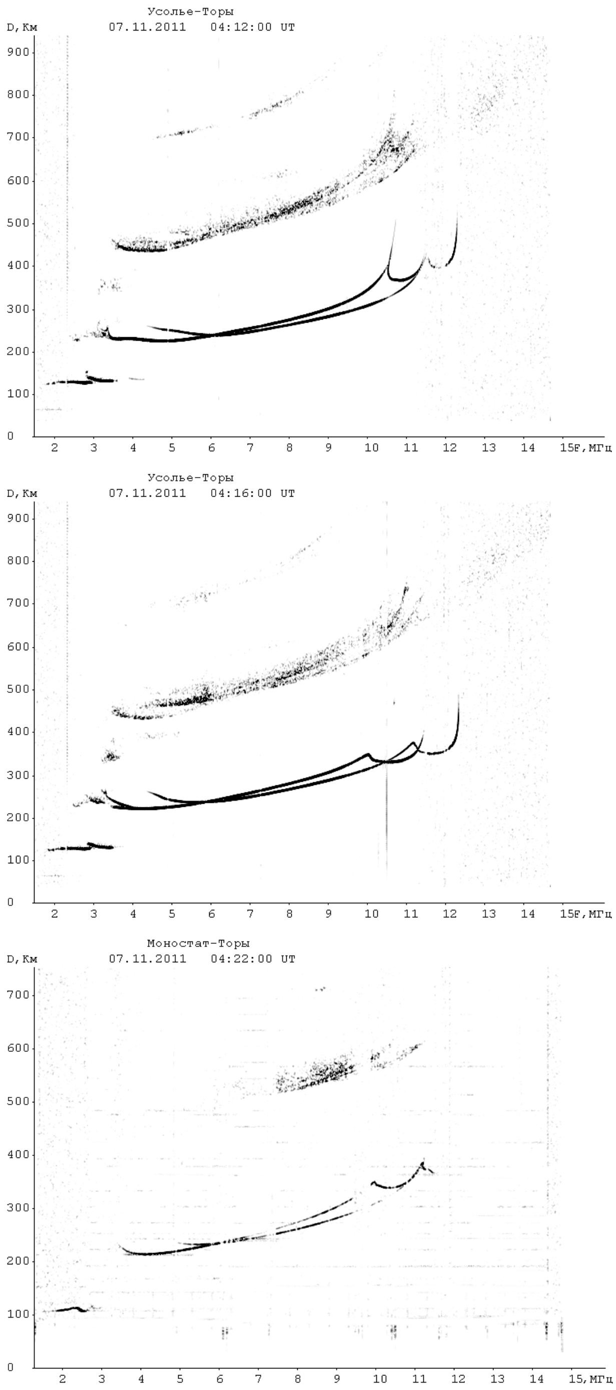




*Fig. 2*. The succession of the TID features in the ionograms.

In this case, these are ionograms obtained by OIS at 11:14 and VIS at 11:22 whose group delay is 687 and 681 km respectively. The identity of the cusps in these two ionograms indicates that they were caused by similar disturbances; therefore the time difference between the ionograms (8 min) is the time taken by the TID to pass from one path midpoint to another (60 km in this case). Thus, the horizontal projection of the TID velocity

$$V_X \approx \frac{60\,\text{km}}{8\,\text{min}} = 7.5\,\text{km/min} = 125\,\text{m/s}.$$

This approach can also be applied to Figure 2 where the shape of the cusp repeats itself every 3 min.

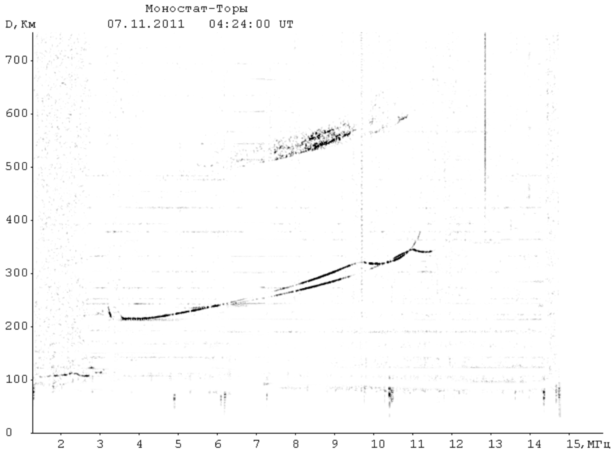



*Fig. 3*. The evolution of the cusp in the ionograms.

**Conclusion**

As an example, for the selected series of OIS and VIS ionograms we determined such TID parameter as drift velocity.

The method of determination of intensity, angle of incidence, spatial scale from a series of experimental ionograms with cusp-like features obtained independently by two closely-spaced ionosondes based on a trajectory synthesis with subsequent fitting is supposed to be published in the following papers.

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