Ionogram sequence observed by satellite radio sounding from below of the *F*-layer maximum

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Abstract.

New ionograms were recorded from an ionospheric sounder operated on the MIR manned space station, situated below of the F-layer maximum. These ionograms have new features, which (as far as the authors know) have not been detected in previous topside sounding experiments. A typical feature of the above-mentioned ionograms is the bend on 180 degrees and continuation of a reflection from the Earth trace with large group delays. As discussed earlier [1], this unusual topside sounding return - the Retarded Lower Trace (RLT) – is probably formed by the refraction of signals of different frequencies that return to the satellite after oblique reflection from the Earth and a deviation of the signals by ionospheric irregularities. These new features encouraged us to provide a more complete description of the properties of the medium studied by topside sounding. It is possible that the properties of the environment, in which there is refraction and propagation of ionosonde signals on many frequencies, will be described better if a sequence ionograms is considered. The present paper is devoted to the description of two ionogram sequences and their preliminary analysis.

Introduction

New satellite sounding ionograms recorded below the F2 layer maximum were shown in [1]. Figure 1 shows a portion of one ionogram from [1]. The top part of figure shows the MIR ionogram received from a position below the F2 peak. The bottom part of figure is a rough sketch, which shows the ionogram details that the author considers essential to the subsequent analysis. To reveal the 'ionospheric signal' in Figure 1 the ionogram is accompanied by a sketch where the main details are shown (noise and interference being ignored here). The lower frequency part of the ionogram, where no ionospheric reflections were observed is excluded.

As discussed earlier [1], the unusual returns - Retarded Lower Trace (RLT) - are probably formed by the refraction of signals of different frequencies at sharp, lateral electron concentration gradients due to ionospheric irregularities. This refraction precedes, or follows, the oblique reflection of the signals from the ground, returning to MIR on all frequencies. This qualitative explanation of the observed effect raises many questions. First of all: what horizontal gradients should exist to make possible a realization of the above-mentioned oblique rays. The authors know of no experimental data in which such trajectories have been recorded or calculated. Therefore the existence at many frequencies of returning trajectories with very peculiar group delays detected in our experiments needs to be proved by numerical simulation methods. Danilkin and Kotonaeva [2] quantitatively checked the above-mentioned hypothesis of horizontal gradients causing RLT tracks. Figure 2 shows the result of one their calculations.

An ionogram with a characteristic retarded lower trace in the high frequency range (on the right below and sketch at the left below) has been deliberately chosen. The first obligatory part of a numerical simulation is a preliminary calculation of an N(h) profile. It was calculated by the transionospheric method [3] using directly the ordinary traces of the signals reflected from the Earth surface (really it was signals of the double transionospheric propagation). To do this, calculations were performed assuming vertical propagation of the signal to find a Nh-profile, requiring that the calculated virtual depth (or height) for the propagation from the surface would coincide (for all the frequencies of both magneto-ionic components considered) with the experimental virtual depth or height derived from the traces of the signals reflected from the surface and from the ionosphere.

The results are shown in Fig. 2. The Nh-profile derived from the bottom of the ionosphere up to the F-region maximum was used to calculate signal trajectories from the satellite to the Earth's surface.

In the second stage of the numerical simulation, the irregularity parameters were found. The frequency was fixed and was the one at which the returning trace was observed. Introduction of the irregularity should have led not only to a turn of the trajectory but also to its return exactly into the satellite location point. This procedure gave the result of the irregularity parameters presented in Fig. 2.

The location and sizes of the irregularity cannot be obtained from a quantitative analysis of a single ionogram. However, it is possible that by examining a sequence of the ionograms it will be possible increase the information on the sizes and site of irregularity.

First Ionogram sequence. The next step in understanding the nature of the fixed irregularity should be the analysis of an ionogram sequence. It is possible to anticipate what the ionogram sequence will show about the size of the irregularity. The earlier report [1] showed that there is a wide spectrum of lengths (or time intervals) of ionogram sequences with RLT. An ionogram sequence, received above the Indian Ocean, is shown on a figure 3. Its geographical situation is shown on a figure 4a, b and the attributes of ionograms are given in the table 1.

The sequence comprises 12 ionograms. Ionogram 1 is the ionogram for which there are no characteristic reflections from irregularities. It is shown to help define the initial situation in the ionosphere before an irregularity is encountered. Magneto-ionic components of signals (z-pink, o-red, x-green) reflected from ionosphere are clearly visible. The trace reflected from the Earth is not seen. The satellite location with respect to the height of maximum ionisation cannot be specified.

Ionogram 2 shows a reflection from the irregularity. The parameters of the vertically reflected signals are complicated by inclined reflecting surfaces. As the plasma frequency near MIR is very close to the critical frequency of the F2 layer peak, it is possible to conjecture that the irregularity is very close to the layer F2 maximum.

Starting with ionogram 5, all ionograms have practically the same details, as were shown in the previous paper [1] - the reflections from the ionosphere with three (or are less) components, vertical and inclined reflections from the Earth. It is evident for all ionograms that the greatest frequency for inclined reflection from the Earth is much more than the critical frequencies for both magneto-ionic components.

The figure 1 inspires optimism, as it is apparent from it that the internal structure of the irregularity can be determined. Radio frequencies, shown in an ionogram, penetrate various regions of electron density change and return as the satellite and can be sufficient for drawing up of system of equations to describe this feature or parts of this feature, as shown in Figure 2. In many cases, the ionosonde continuously records this feature over many hundreds of kilometers. So it is possible to conclude that it is the same feature, but every ionogram displays the passage of many beams through various areas of it. Hopefully, the synthesis of various sites of the feature received both on one ionogram, and on many ionograms, will allow a better to understanding of its internal structure. It is possible to describe this feature analytically.

For example, the greatest frequency of inclined reflection from the Earth on ionograms 7 and 8 exceeds 3 MHz, more than the critical frequencies of both magneto-ionic components. So we have 20 group delays on one megahertz determined in our experiment and 60 on 3 MHz.

The second ionogram sequence. In rare cases the ionosonde, having made a circle around of the Earth, returned to approximately in the same area of the Earth, and once again recorded the feature. The second ionogram sequence, from above the Indian Ocean, is shown in figure 5. Its geographical location is shown on a figure 4a and the ionogram attributes are given in the table. It is highly likely that this was the same feature. The impression is that the feature is amplified in the ionogram's appearance and are more diffuse than in the first case.

The first and second ionograms from the second orbit show the station orientation with respect to the feature although they do not show its presence. On the third, the trace of feature has a curved base. The fourth and the fifth ionograms show RLT, with reflections on frequencies considerably greater than the critical frequencies of all magneto-ionic components. It is possible to confidently show only two vertical reflections on the fourth ionogram and it likely that the first is the z-component, and the second is ?-component. Other ionograms of this series show presence of the feature and vertical reflections from the ionosphere outside it in those or other combinations. Separate details of traces on ionograms are not visible. It is possible to imagine it occurs due to selective absorption, or is connected to rotation of the MIR station plus effects of the antenna. The RLT trace is hardly visible on ionogram 13 and 14 ionogram it is not visible.

Summary. We publish this paper in INAG Bulletin, which – we believe - is read by ionospheric researchers who understand radio sounding ionograms. We hope, that they will be interested in our results, and can not only offer an alternative interpretation for them, but also can offer a quantitative explanation of the data. For this purpose ionograms sequences are accompanied by all data necessary to tabulate these calculations.

References.

1. N.P.Danilkin, 2003, New ionograms observed by satellite radio sounding from below of the F-layer maximum. Bulletin INAG, 2003, www.ips.gov.au/IPSHosted/INAG/web-inag/index.html.
2. N. Danilkin, N.Kotonaeva, 2002, The features of ionospheric radio sounding performed using the “Mir” space station; Radiophysics and Quantum Electronics, Vol. 45, No. 6, pp 431-439.
3. Danilkin, N. P., Transionospheric sounding, *J. Atm. Sol. Terr. Phys., 56* (11), 1423, 1994.

Table to Ionogram sequence N1 (Fig. 3 and Fig. 4a)

Ionogram number	Day	Time	Satellite coordinates		
			Height	Latitude	Longitude
1(26)	05.05.99	18.01.37	377.01	-48.27	45.33
2(41)	05.05.99	18.03.37	375.94	-44.89	55.08
3(43)	05.05.99	18.03.53	375.66	-44.37	56.29
4(44)	05.05.99	18.04.01	375.52	-44.11	56.88
5(45)	05.05.99	18.04.09	375.37	-43.84	57.47
6(46)	05.05.99	18.04.17	375.22	-43.57	58.05
7(47)	05.05.99	18.04.25	375.07	-43.30	58.63
8(48)	05.05.99	18.04.33	374.92	-43.02	59.20
9(50)	05.05.99	18.04.49	374.61	-42.46	60.33
10(55)	05.05.99	18.05.29	373.82	-41.00	63.05
11(58)	05.05.99	18.05.53	373.33	-40.09	64.63
12(64)	05.05.99	18.06.41	372.30	-38.19	67.64
13(66)	05.05.99	18.06.57	371.95	-37.54	68.61

Table to Ionogram sequence N2 (Fig. 5 and 4b)

Ionogram number	Day	Time	Satellite coordinates		
			Height	Latitude	Longitude
1(110)	05.05.99	19.35.19	375.88	-44.74	32.14
2(114)	05.05.99	19.35.51	375.31	-43.69	34.51
3(116)	05.05.99	19.36.07	375.01	-43.14	35.66
4(121)	05.05.99	19.36.47	374.23	-41.72	38.45
5(123)	05.05.99	19.37.03	373.91	-41.12	39.53
6(126)	05.05.99	19.37.27	373.42	-40.22	41.11
7(129)	05.05.99	19.37.51	372.92	-39.290	42.65
8(133)	05.05.99	19.38.23	372.23	-38.01	44.63
9(135)	05.05.99	19.38.39	371.88	-37.36	45.59
10(136)	05.05.99	19.38.47	371.70	-37.03	46.07
11(138)	05.05.99	19.39.03	371.35	-36.36	47.00
12(140)	05.05.99	19.39.19	370.99	-35.69	47.92
13(142)	05.05.99	19.39.35	370.63	-35.01	49.83
14(147)	05.05.99	19.40.15	369.71	-33.27	51.02

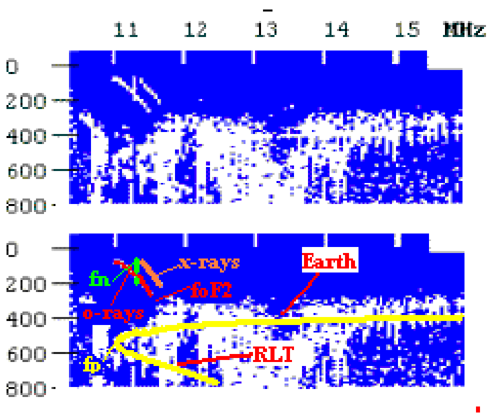

Figure 1.

The top part of figure shows the MIR ionogram recorded from a position below F2 peak. The lower frequency part of the ionogram, where no ionospheric reflections were observed, is excluded. The bottom part of figure is a rough sketch that shows the ionogram details the authors consider essential to the subsequent analysis. The reflections of ordinary and extraordinary rays from the ionosphere are clearly visible. The value of the plasma frequency near to the satellite, and F2 critical frequency, can be measured with insignificant errors. The RLT also is clearly seen.

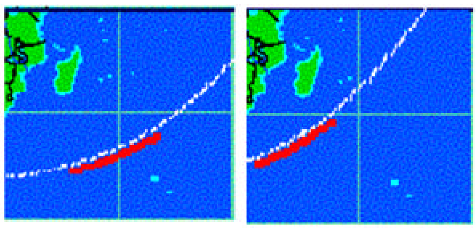

Figure 4.

Projection to a surface of the Indian ocean of MIR trajectory. Ionograms with RLT are received there, where is highlighted red.

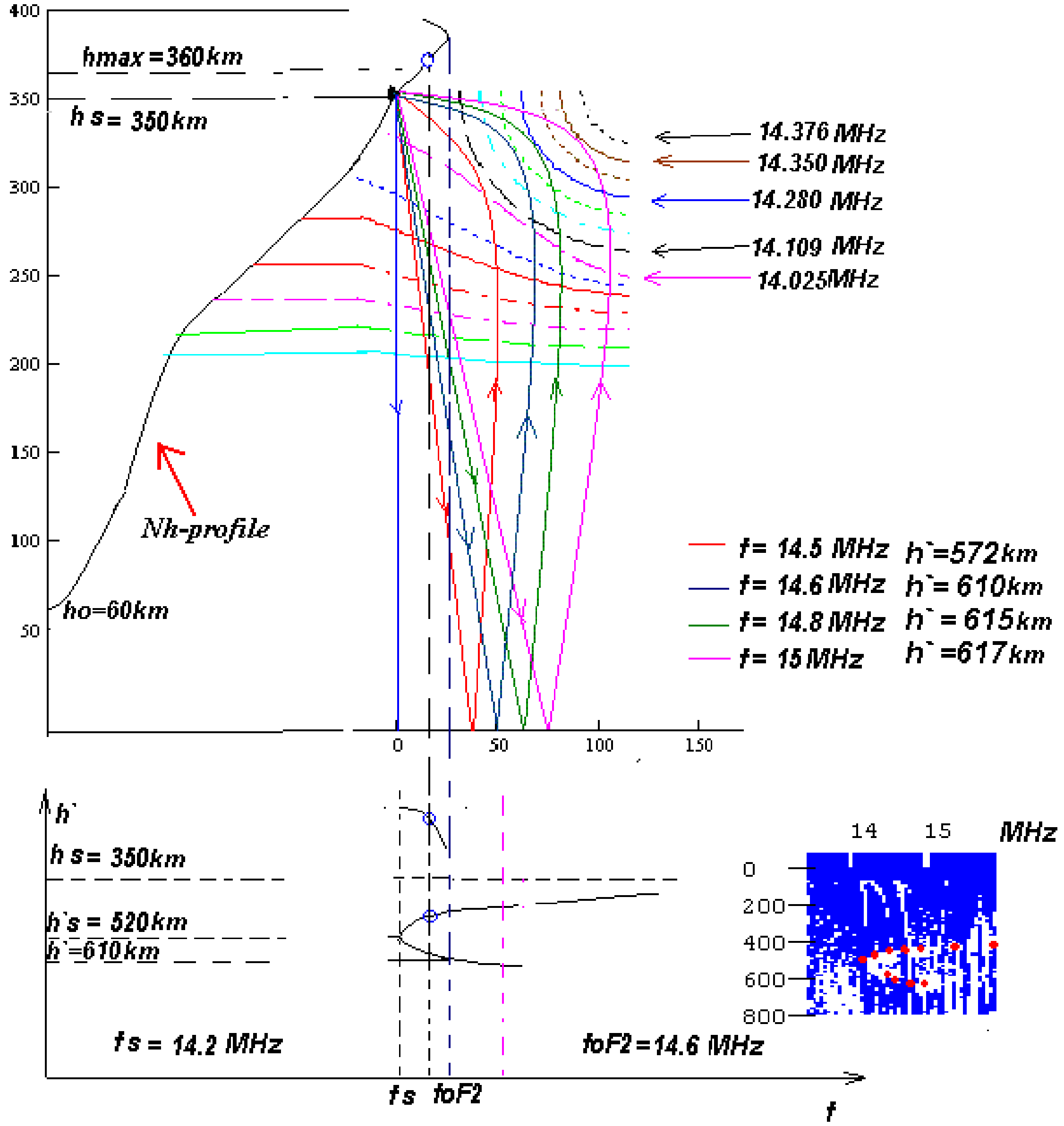

Figure 2.

This shows the N(h)-profile and ray trajectories returning as satellites in the left-hand top of picture. The resulting plasma frequencies of the layers of the feature are given at the upper right. The ionogram and its sketch are shown below.

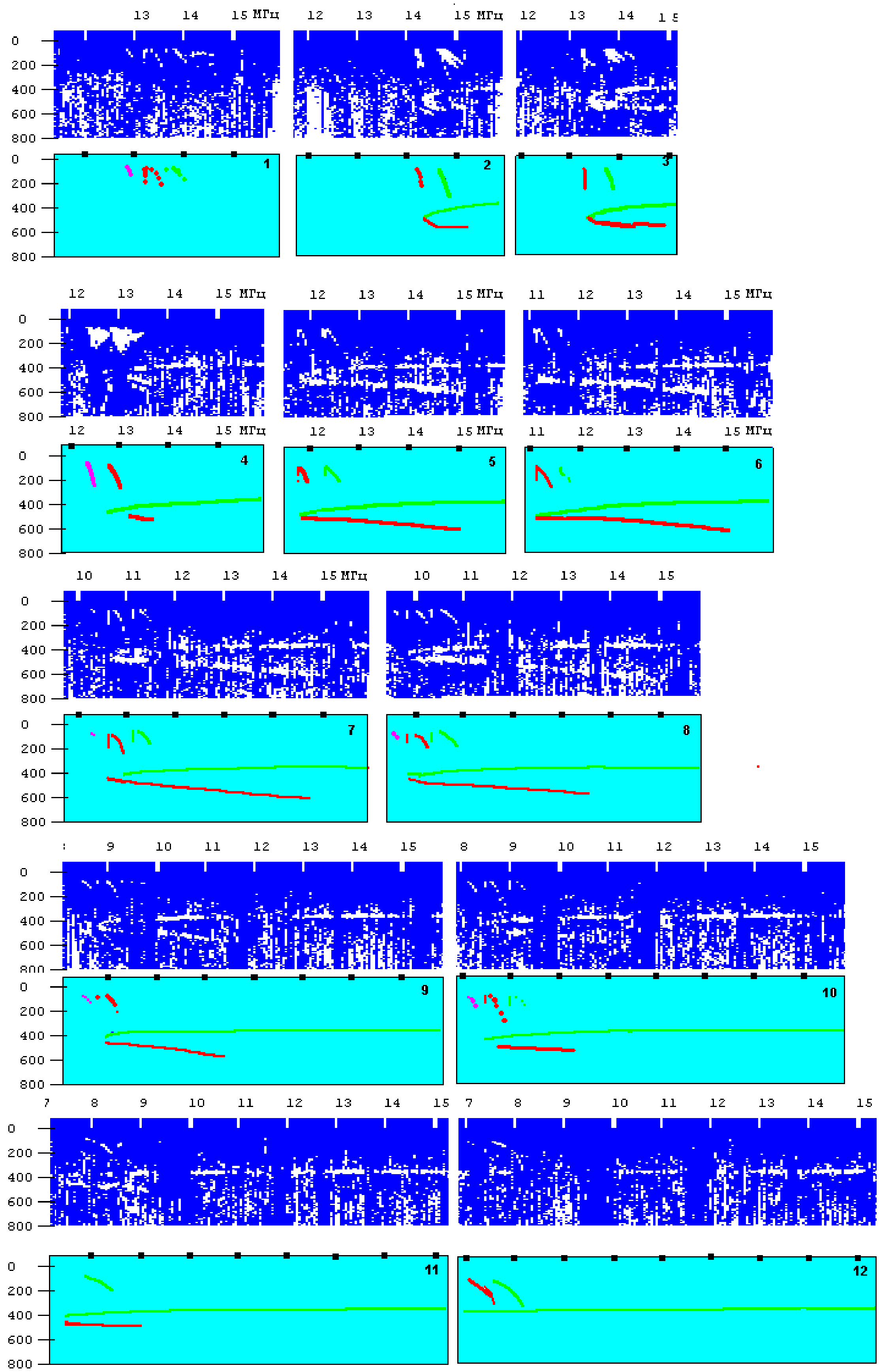

Figure 3. Ionogram sequence (ionograms and sketches) with RLT received above the Indian Ocean.

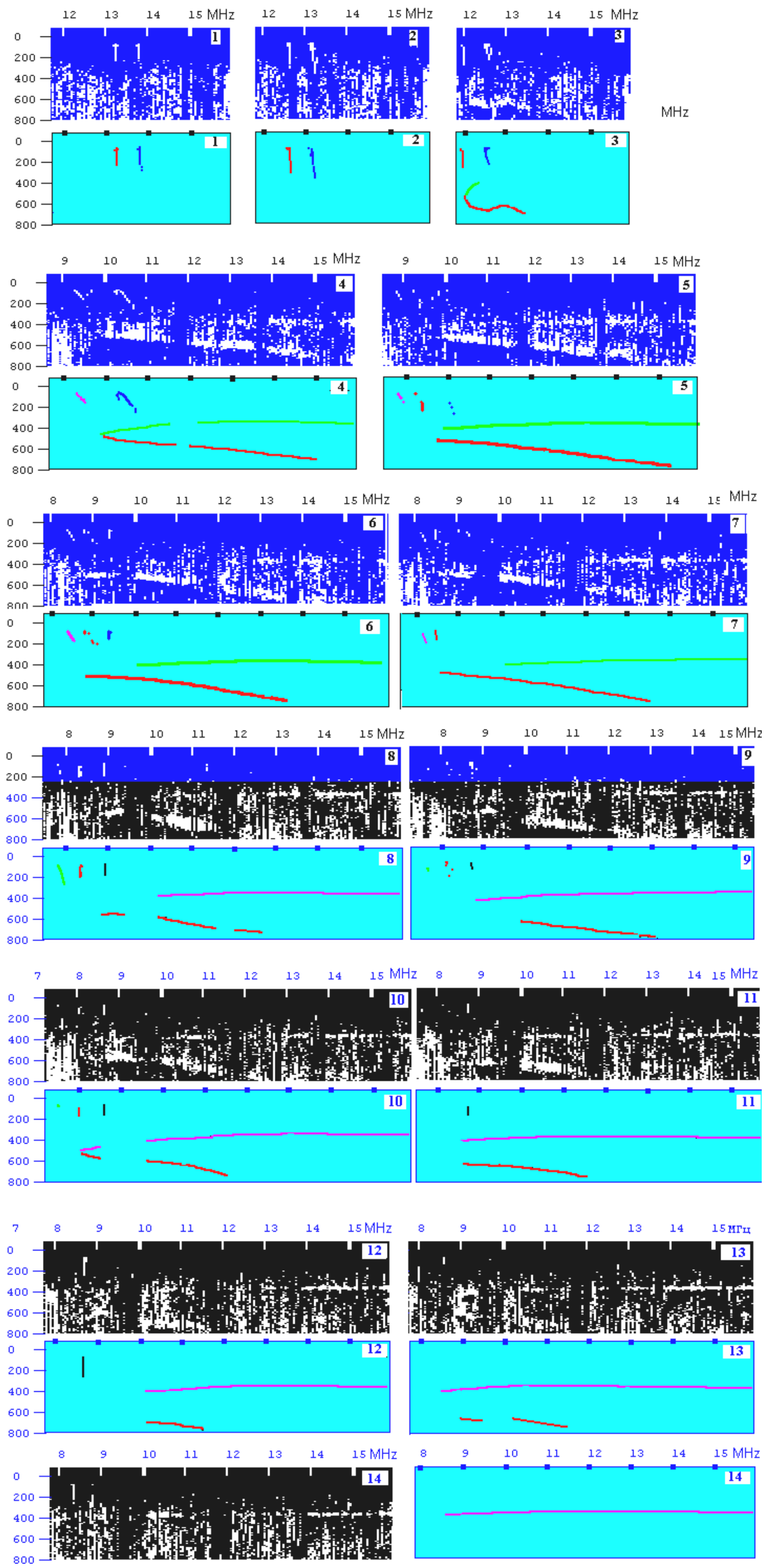

Figure 5. Second Ionogram sequence with RLT received after one circle above approximately the same region of the Indian Ocean.