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AUTOMATING VERTICAL IONOGRAM COLLECTION, PROCESSING AND INTERPRETATION

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Introduction

As a result of global scale and regional modelling of the Earth's ionosphere, international data exchange of the ionospheric data in the frame of international projects such as SUNDIAL or PRIME, creating of different data bases and data banks, there arises a need for fast data processing and recording in a standard format. One such format was elaborated by the URSI Working Group on the Ionospheric Informatics [1]. During the last years a lot of algorithms and computer programs appeared concerning the automatic scaling of vertical ionograms. At the same time we should keep in mind that the global network of ionospheric stations (especially in the previous Soviet Union) was created in the 50-60 years when the International Geophysical Year projects were carried out and a lot of stations continue their work with photo film or paper output. So the problem should be looked at more widely: not only from the point of view of modern hardware and digital ionosondes, but also how to include in the digital international data exchange these old stations and how to master the old data banks on photo films for the previous tens of years of regular observations.

This paper is an attempt to combine both the modern developments and modernisation of the old stations with the following description of the works carried out in the former Soviet Union (FSU).

The Short History

From the very beginning of vertical sounding activity in the Soviet Union IZMIRAN (Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of the Russian Academy of Sciences) was responsible. The present network of ionospheric stations was created mainly during the International Geophysical Year and the basic ionospheric station for the network was the station AIS (Automatic Ionospheric Station, see Fig.1) developed in IZMIRAN. Some of the central institutions like IZMIRAN, Moscow, were equipped by a more powerful station SP-3 made in Eastern Germany. All of them were tube stations with photo film output and manual processing of the ionograms. The majority of the stations still exist and are working within the network.

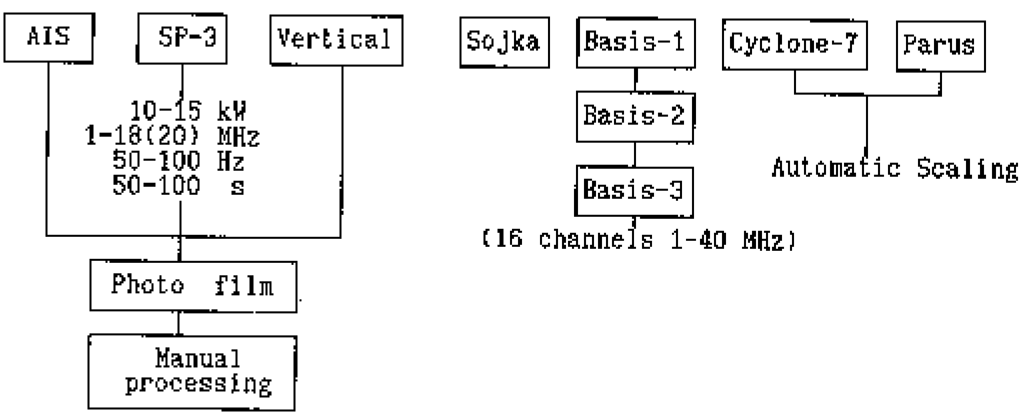

Fig.1 The hystory of Russian ionospheric stations

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When, after several transformations, IZMIRAN was included in the Academy of Sciences, the duty of ionospheric service and forecast was given to the Committee of Hydrometeorological Service where the special institutes were created such as the Institute of Applied Geophysics (Moscow), Institute of Arctic and Antarctic Research (St Petersburg), Institute of Polar Geophysics (Murmansk) etc. After this time coordination of ionospheric sounding was spread out and every institution tried to create its own ionosondes: "Vertical" station for service by Institute of Applied Geophysics, "Sojka" and "Basis" for scientific research by IZMIRAN (see Fig.1). If it is taken into account that some Universities which were subject to the Ministry of High Education (now Ministry of Science) had their own stations, the very complex system of ionospheric research in FSU can be understood. The centres which united the different institutions were the National Geophysical Committee and World Data Center B where the ionospheric data were accumulated (see Fig.2).

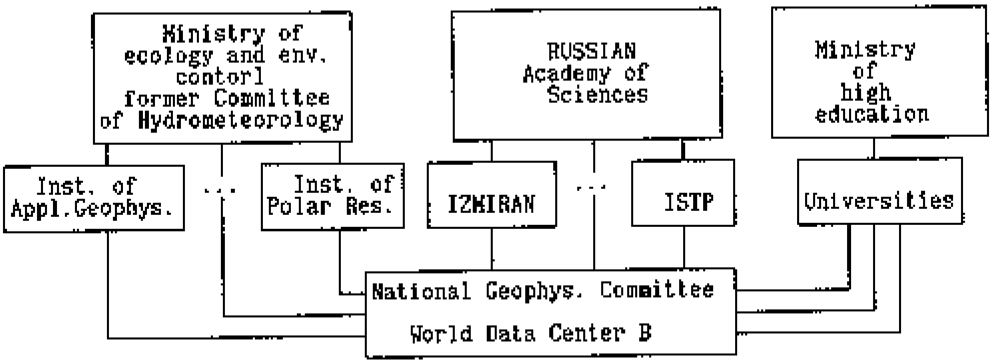

Fig.2 Schematic diagram of Ionospheric study management

The first station which used computer processing of ionograms was the "Sojka" station opened at IZMIRAN in the 70s. The first algorithms of ionogram "cleaning", extracting of traces and automatic scaling were created at this station.

The next family of ionosondes which should be mentioned are the "Basis" stations where for the first time multi-channel technology was used for the automatic extraction of O or X traces and Doppler measurements. Some of the ionospheric observatories in the FSU are equipped with Basis-1 or 2 stations. The latest version, the Basis-3 station, is a 16-channel station which could work within the frequency band 1-40 MHz in vertical or oblique sounding regimes and could be regarded as a HF Coherent radar station. The main deficiency of the station is the low degree of integrated electronic circuitry, which lowers its reliability.

The first stations where the fully automatic algorithms of ionogram processing were introduced are: Cyclon-7 station in Kazan' (Kazan State University, Tatarstan), Chirp station at Irkutsk (Institute of Solar-Terrestrial Physics) and Parus station at IZMIRAN (Troitsk, Moscow Region).

Automatic Scaling of Vertical Ionograms

First of all, in developing the principles for automatic scaling the input information for scaling algorithms needs to be taken into account. The most complex case is old ionograms stored on photographic film and currently working, old ionosondes with film output. In this case we have as input two dimensional frequency-time delay information (Fig.3a). The second step introduces the amplitude of the reflected signal into the processing procedure, which is possible if the output from the old ionosonde is taken before being photographed (for example with the help of a digitising card, taking the analogous electrical signal output).

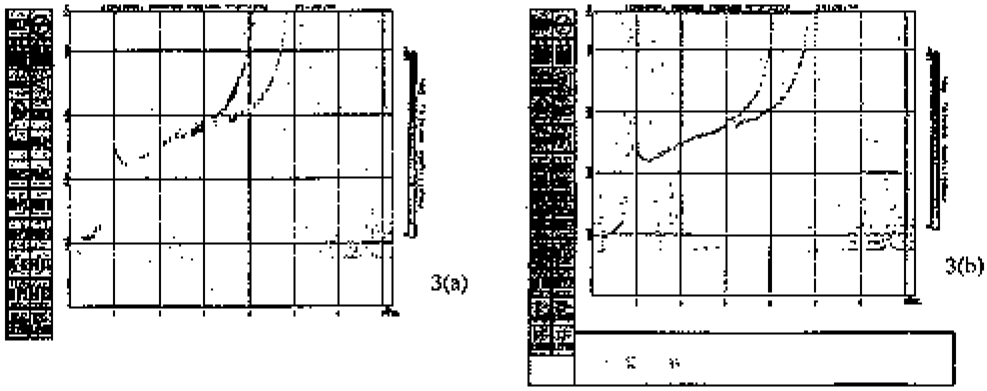

Figure 3: PARUS ionosonde ionogram before (a) and after (b) "cleaning" procedure.

The next step which increases the probability of automatic scaling is the use of polarisation measurements. In this case one can exclude from the processing algorithm one of the most complex procedures of the ionogram scaling: separation of O and X traces.

The last improvement which has now been made in most modern ionosondes is the Doppler measurements and measurements of the angles of the wave arrival. This is a very important feature, especially in high latitudes and during disturbed periods when non-vertical propagation traces could be registered.

Various possibilities are as follows:

Semi-manual scaling and digitising of vertical ionograms.

As the input for processing we have a two dimensional (frequency-virtual height) picture. The sources for such processing could be: digitised ionograms from photo films or from paper, a digitised ionogram directly from the analog output of an old ionosonde or a computer recorded ionogram without amplitude as in the Polish, KOS type, ionosonde. In the first two cases we need to introduce the procedure of screen scaling. It is implied that all ionograms under processing have the same scale and the procedure of screen calibrating is done once before processing any ionograms. The software, for ionogram scaling, was created at IZMIRAN by V. Zarubanov and S. Pulinets and includes the following procedures:

· Screen scaling

· Ionogram scaling and interpretation with recording of standard ionospheric parameters and their URSI codes

· Ionogram scaling and N(h) profile calculation based on algorithm of Gulyaeva [2]

· Formation of hourly tables of standard ionospheric parameters in URSI IIWG format

Ionogram processing could be done with the help of a mouse or keyboard. For good quality ionograms the procedure of automatic tracing could be introduced as it was produced for topside ionograms. In this case it is necessary to indicate by hand the O and X traces.

Further utilisation of the data base in URSI IIWG format is possible using the IDIM (Ionospheric Data Illustrator) program developed at IZMIRAN [3]. This program makes the visualisation of any standard ionospheric parameter (monthly variations, daily variations or any selected period within one month) possible. The User can construct, with the help of this software, their own output format plot for any of the ionospheric parameters or several of them together. One can edit the ionospheric data files in the form of hourly tables. It is possible to use the external programs using the ionospheric parameters and results will be presented on the screen in graphical form. The hard copy of every plot could be done.

Semi-automatic scaling using the amplitude information

Amplitude information is used for ionogram processing in ionosonde systems "Parus" [4] and "Cyclon-7" [5]. In both systems a correlation analysis and adaptive filtration procedure is used to clean the ionograms before their interpretation. Wide-band noise, spread signals and non-trace points are removed from the ionogram with the help of a "cleaning" procedure and the maximum weighted amplitude points are kept as a trace. One can see on Fig.3a the example of an ionogram before and after the "cleaning" procedure. The automatic tracing procedure is then used. The role of the operator is to "show" the O and X traces to the tracing program. Such an algorithm is realised in the "Parus" system. The more advanced procedure of full automatic scaling of vertical incidence ionograms using only amplitude information, was developed at Irkutsk Institute of Solar-Terrestrial Physics [6] and is described in the next paragraph. The procedure is described in more detail because it does not demand advanced hardware and could easily be introduced into any ordinary ionospheric station.

Automatic scaling of vertical incidence ionograms

The program PACIFIC (Program for Autoscaling of Conventional Ionograms with Flexible Interpretation Control) was designed for a FMCW sounder but the algorithm could be used for any ionogram because the linguistic image analysis procedure was chosen for ionogram processing and is based on the final appearance of the ionogram pattern. The main processing steps are as follows:

· Separating Overlapped Echoes (adaptive separation based on significance of valley between peaks);

· Segment Fit (line tracing by fitting, combining and chaining trace segments);

· "E-Es-F2-F1" Interpretation Procedure (search for the fxF2 cusp after E-layer data has been identified);

· Inclination Check (interpretation of the traces with proper inclination).

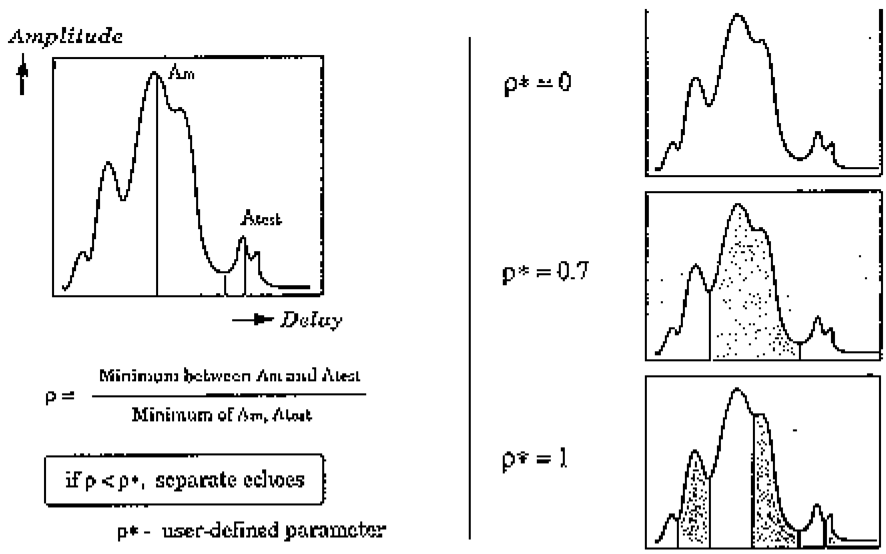

Figure 4: Illustration of the Separating Overlapping Echo procedure within the PACIFIC algorithm.

The first step is illustrated in Fig.4. The special criterion developed is based on which signal of complex form is recognised as consisting of two or more overlapping signals. The control parameter p makes it possible to control the dividing threshold. One can see on the presented figure that, depending on the parameter value, the same signal could be recognised as one, three or six different signals.

The Segment Fit procedure is illustrated by Fig.5. It is based on the fitting mask algorithm. The left side of the mask is fixed on the processed point and different inclination angles are probed, and the best variants of mask orientation are stored. Then the selection and combining of stored masks is done to provide chaining of the ionogram elements. During the fitting procedure, information on the 9 neighbour frequencies is analysed to determine what makes the algorithm more stable.

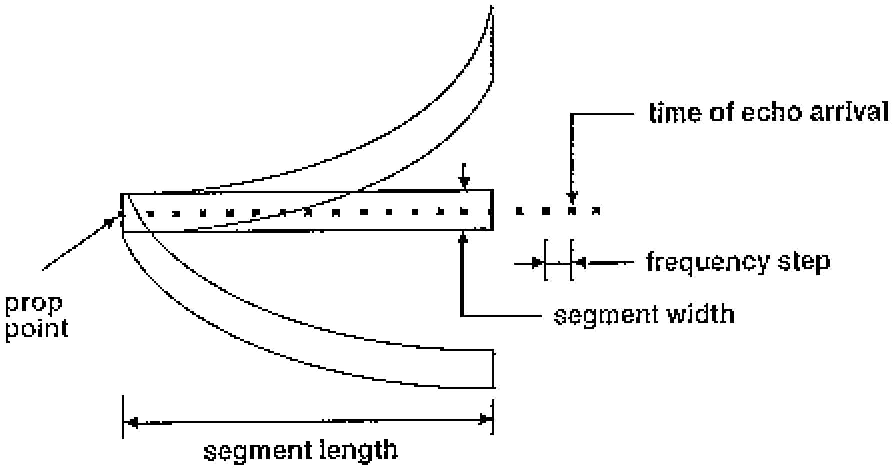

Figure 5: The Single Segment Fit procedure within the PACIFIC algorithm.

After real trace selection, the interpretation procedure begins, which is shown in Fig.6. After separation of the E-layers, a search and identification of signals near the critical frequencies of both components is done making the algorithm more stable in relation to multiple layers and spread-F effects. The next step is the construction of the O-trace line between fmin and the O-X trace intersection point (6). This consists of the points of maximal amplitude. After its extraction, a search for kinks and fractures is made, which gives the F1 critical frequency.

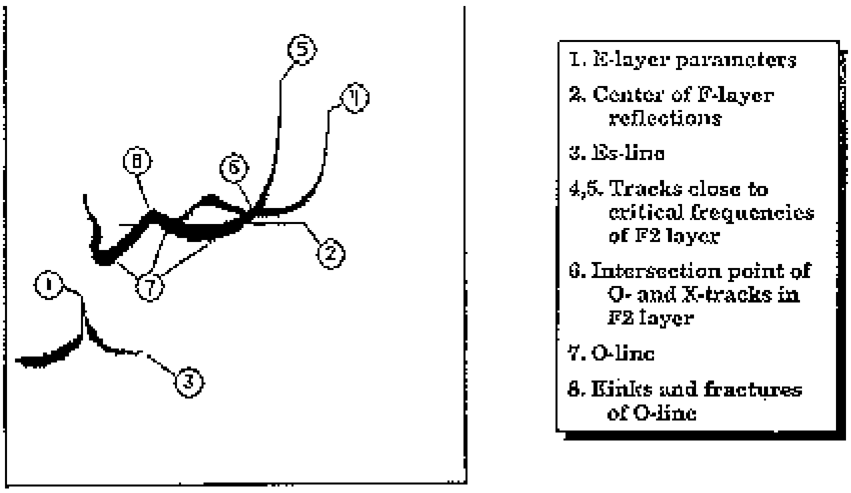

Figure 6: Schematic representation of the PACIFIC ionogram interpretation algorithm.

Testing of this software gave the following results in comparison with the manual scaling of March 1987:

Total 162	**ionograms**	**percentage**
113	processed without errors	70.0%
22	F1 interpretation errors	13.5%
11	O-line problems	6.7%
6	Errors due to F-spread	3.7%

5	F2 critical frequencies errors > 0.2 MHz	3.1%
5	h'F1 incorrect estimation	3.1%
5	foE errors	3.1%
4	Erroneous identification of Es	2.5%
3	Loss of steep tracks	1.9%
1	General scheme failure	0.6%

This is a very promising result. It should be mentioned that correcting mistakes when scaling automatically is much easier than manual processing of the ionogram from the very beginning.

Advanced Processing and Perspectives

The outlook on the automatic scaling of ionograms is now more optimistic than a few years ago mainly due to progress in signal and image processing. Modern ionosondes such as D-256, IPS-71 or "Parus" have options such as O/X separation, Doppler, Angle and Direction of Arrival information that can be measured routinely. For such stations the main task now is to improve existing algorithms, especially for high latitudes and during strongly disturbed periods. Experts in the field of artificial intelligence should be encouraged to introduce into algorithms more sophisticated methods of pattern recognition. One can attribute a lot of complex cases for ionogram interpretation but there are still a finite number of cases and they could be stored as samples in computer memory.

More complex is the situation with old film based ionosondes and utilising old ionospheric data stored on photographic film. The solution to the problem is seen in supplying old ionosondes with a digitising card connected to a computer. Digitising devices based on CCDs or TV cameras could process photographic films. Both types of ionograms, from the old ionosondes and those digitised from films, could be processed then by software like PACIFIC or ISC.

Taking into account the very great importance of real time processing of ionospheric information in the light of new ideas of global ecology monitoring, the possibility of earthquake predictions and the necessity for old data utilisation from the point of view of Global Change, a common international effort should be undertaken to make automatic ionogram scaling a common feature of modern ionospheric science.

Acknowledgments

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