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NUMERICAL MAPPING AND MODELLING AND THEIR APPLICATIONS TO PRIME

COST 238/PRIME Workshop

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OVERVIEW

The volume contains a selection of papers presented at the May 1994 COST 238 Workshop on 'Numerical mapping and modelling and their applications to PRIME'. It is a pleasure once again to be associated with a full PRIME Workshop - this time the sixth in a series extending over as many years. PRIME (Prediction and retrospective ionospheric modelling over Europe) was formally initiated as Project COST 238 in March 1991 as a four-year project aimed at developing improved models of the European ionosphere for telecommunications applications, but the work has its origins earlier arising from existing collaborations in the areas of vertical and oblique-incidence sounding. We now have active participation from groups within 18 Western and Eastern European countries and again all were represented at this latest Workshop.

COST (Cooperation in Scientific and Technological Research) was initially established for European Union Member States, with each country joining those projects in which it has interest on a case-by-case basis. However, over recent years the numbers of COST countries have grown and there is now provision for participation of individual institutes from non-COST countries. In our case we have three such institutes involved.

The Workshop gave prominence to progress in developing NEW empirical mapping techniques along lines first proposed at a limited Workshop held in Abingdon, UK in December 1993. Following tests by specially appointed computer experts who had been assessing the relative accuracies of various candidate approaches the previous week in Eindhoven, latest developments were considered. Discussions centred on what further improvements could be incorporated. Subsequent to a successful specialist Workshop on instantaneous mapping which took place in Warsaw in March 1994, this topic was also addressed at length and a number of optional approaches considered.

The work of PRIME as a whole covers the topics of vertical and oblique-incidence sounding, short-term and long-term ionosphere mapping and modelling and short-term forecasting of ionospheric characteristics. Some 30 presented papers addressed different aspects of these subjects. In addition there were 9 poster papers. As always, time constraints limited full review of every facet, but by restricting the numbers of presented papers to invited topics it became possible to identify the key points and to take important decisions on the way ahead. I am grateful to Dr Leon Kamp and to the Working Group Leaders for their help in formulating the Workshop programme.

Each Session Chairman and Working Group Leader has provided a summary covering the ensuing discussion. Thanks should be extended to all who contributed to the Workshop both in preparing presentations and in participating in the discussions. I believe that in a very full programme optimum use was made of the available time and that good and timely overall progress is being made towards our agreed goals.

We are all particularly grateful to Dr Kamp on behalf of the Eindhoven University of Technology for hosting us and for the painstaking way in which he made the local arrangements. We extend our sincere thanks to him and his colleagues for all they did to ensure the event was a success. We especially thank Professor F W Sluijter and the University for hosting an accompanying social excursion and dinner.

Thanks are accorded to the University, The Netherlands Foundation for Fundamental Research on Matter, Océ van der Grinten, Stichting Universiteitsfonds Eindhoven, PTT Research and to the European Commission for financial support in making the meeting possible. Finally too our thanks go to Dr Kamp for arranging this present publication.

Peter A Bradley
Chairman COST 238

COMPATIBLE ANALYSES OF VERTICAL AND OBLIQUE SOUNDING DATA ON DOURBES-ROQUETES PATH

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INTRODUCTION. Oblique sounding ionogram reflects the group delay dependence against a frequency change in definite region. This group delay function express the ionosphere structure in a much more complex way than it does in a vertical sounding ionogram. For instance, if critical frequencies of VS ionogram depend only from values of plasma frequencies in corresponding layers peaks then peculiar points of OS ionogram (MUF) are dependent not only from the characteristics but also on the form of height distribution of electron density and in considerable degree from horizontal inhomogeneity on a path. In this aspect it would be interesting to analyze VS and OS data on the same path simultaneously in order not only to clear up their mutual dependence but, what is more important, to find possible ways to increase an accuracy of real height profiles estimation. In this paper some results of such analyses on the path Dourbes - Roquetes (D=1129 km) is presented with an emphasis on an investigation of intervals between ionospheric layers.

SYNTHESIS OF OS IONOGRAM. An important part of the analysis is a technique of OS ionogram synthesis on a bases of real height profiles derived from VS ionogram at the end points of the path.

Every point of oblique sounding ionogram is a solution of the boundary problem of radio wave propagation when in terms of geometric optics approach is necessary for selected frequencies to find ray trajectories connecting location places of two ionosondes. In the approximation, first proposed by (Haselgrove, 1955), the problem can be expressed in a form of ray equation technique for magnetoionic medium (Kravtsov and Orlov, 1990):

$$\frac{d\vec{r}}{dt} = \frac{\vec{k} - \frac{\omega^2}{2c^2}\frac{\partial\mu^2}{\partial\vec{k}}}{\frac{\omega\mu}{c^2}\frac{\partial(\omega\mu)}{\partial\omega}} \qquad \frac{d\vec{k}}{dt} = \frac{\frac{\omega}{2\mu}\frac{\partial\mu^2}{\partial\vec{r}}}{\frac{\partial(\omega\mu)}{\partial\omega}} \tag{1}$$

where $\vec{r}$ - radius and $\vec{k}$ - wave vectors, ω - radian frequency of a sounding wave, c - velocity of light in free space, t - time delay, ct - group delay in current point of the trajectory. Refractive index μ can be expressed in a form accepted in (Budden,1961) and (Devies, 1969), when in common Appleton-Hartree formula its imaginary part is much lower then real one

$$\mu^2(\vec{r},\vec{k},\omega,\theta) = 1 - \frac{2X(1-X)}{2(1-X)-Y^2\sin^2\theta \pm \sqrt{D_1}} \tag{2}$$

$$D_1 = Y^4\sin^4\theta + 4Y^2(1-X)^2\cos^2\theta, \quad Y = \omega_H/\omega, \quad X = \omega_N^2/\omega^2$$

where ω - radian gyrofrequency, ω - radian plasma frequency and θ - angle between wave's and Earth's magnetic vectors. Signs "+" and "-" correspond to ordinary and extraordinary components of the wave. Partial derivatives in the ray equation system (1) can be written in the following way:

$$\frac{\partial\mu^2}{\partial\vec{r}} = \frac{\partial\mu^2}{\partial X}\frac{\partial X}{\partial\vec{r}} + \frac{\partial\mu^2}{\partial Y}\frac{\partial Y}{\partial\vec{r}} \tag{3}$$

$$\frac{\partial\mu^2}{\partial X} = -\frac{(1-\mu^2)^2}{X(1-X)}\left\{1 \pm \frac{2}{\sqrt{D_1}}Y^2(1-X)\cos^2\theta + \frac{1-2X}{1-\mu^2}\right\} \tag{4}$$

$$\frac{\partial\mu^2}{\partial Y} = \frac{(1-\mu^2)^2}{X(1-X)}\left\{-Y\sin^2\theta \pm \frac{1}{\sqrt{D_1}}\left[Y^3\sin^4\theta + 2Y(1-X)^2\cos^2\theta\right]\right\} \tag{5}$$

$$\frac{\partial(\omega\mu)}{\partial\omega} = \mu + \frac{(1-\mu^2)^2}{\mu(1-\mu)}\left\{\frac{1}{X}\left[1 \pm \frac{Y^2(1-X^2)\cos^2\theta}{\sqrt{D_1}} - \frac{X}{1-\mu^2}\right]\right\} \tag{6}$$

$$\frac{\partial\mu^2}{\partial\vec{k}} = \frac{(1-\mu^2)^2}{X(1-X)}\left\{Y^2\cos\theta \pm \frac{1}{\sqrt{D_1}}\left[2Y^2(1-X)^2\cos\theta - Y^4\sin^2\theta\cos\theta\right]\right\} \times \frac{(\vec{h}-\vec{p}\cos\theta)}{|\vec{k}|} \tag{7}$$

where $\vec{h} = \vec{H}/|\vec{H}|$, $\vec{p} = \vec{k}/|\vec{k}|$. The system of equations (1)-(7) should be completed with formulas, connecting cartesian coordinates system where the ray equations is written with spherical one, where a presentation of the ionosphere is natural. In the calculations was used dipole approximation of geomagnetic field (Davies, 1969) which is accurate enough for middle latitudes. For not distant paths, as in our case, the second part of equation (3) is much more less then the first one and, as a rule, can be neglected. Horizontal inhomogeneity of the ionosphere was deter- mined by two real height profiles at the end points with linear interpolation inside the path. The boundary solution was found in a special procedure by changing the value of an impulse in the initial conditions (an angle of emission).

In a presence of geomagnetic field there is no any analytical solutions for ray equation system (1) and it gives no a possibility of direct estimation of the group delay calculation accuracy. A comparison with the results of ray tracing technique application, provided by other authors (Rao, 1969 and Gething,1978) shows that an error in group delay does not exceed 0.05 km.

In this technique we did not touch a problem of power-frequency dependence although we understand its impotence in OS ionogram interpretation. Here will be used necessary estimations such as a power of different modes of propagation, received for the corresponding isotropic case (Krasheninnikov et all, 1993). This approach to OS ionogram synthesis, taking into account all these main peculiarities of sounding waves propagation, can give results which could be in most correct form be compared with experimental ones.

EXPERIMENTAL DATA AND THEIR ANALYSIS. As a rule a quality of OS data is lower then VS ones and the synthesis of OS ionograms is simply un- avoidable procedure to correctly understand its mode structure and, especially, accurately define absolute group delays of sounding signals. On fig.1,a and fig.1,b are presented the examples of vertical and on fig.1,c an example of oblique sounding of the ionosphere on the Durbes-Roquetes path in day time and in a presence of all three ionospheric layers.

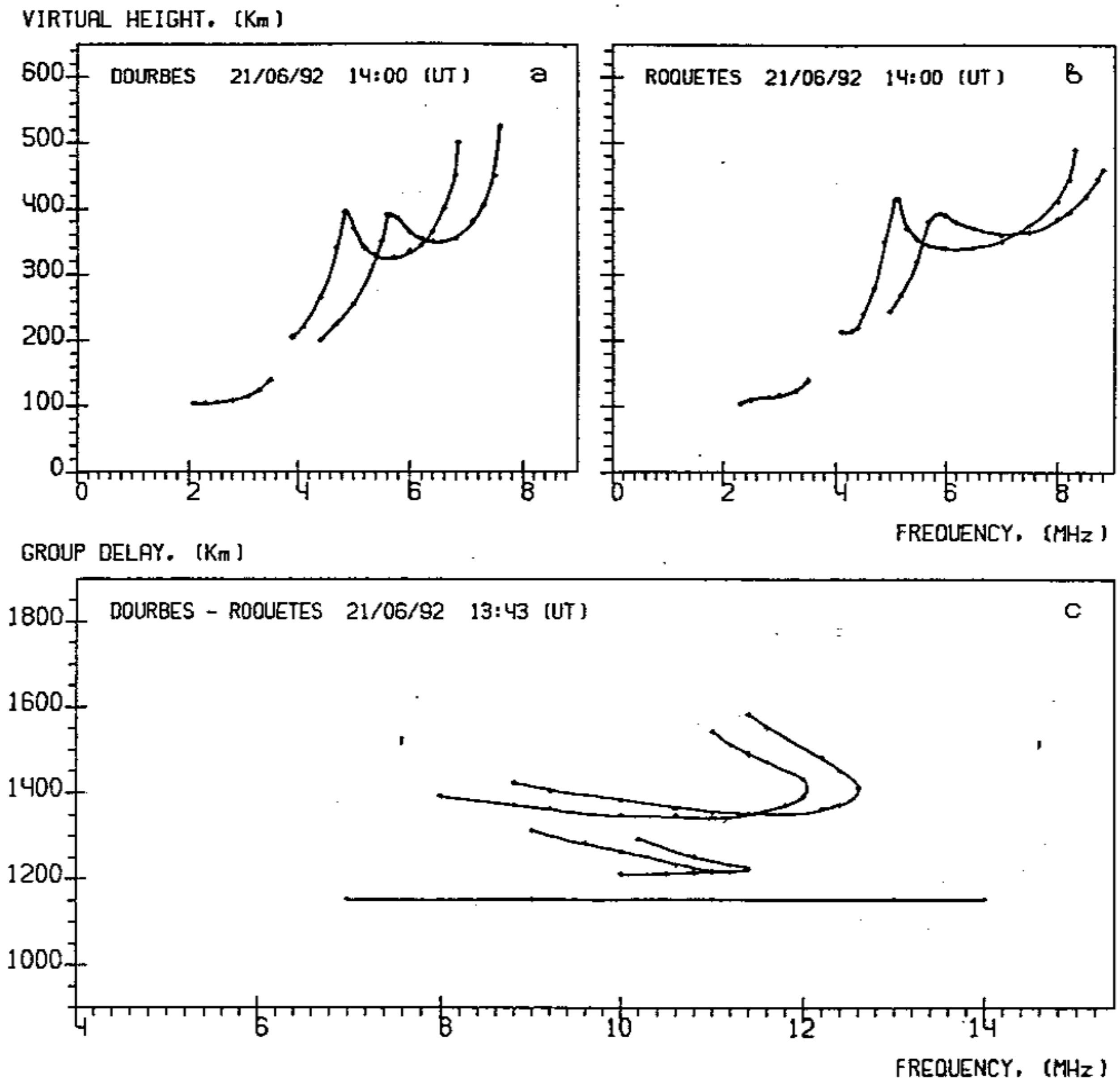

Fig. 1. Vertical (a,b) and oblique sounding (c) ionograms on Dourbes-Roquetes path.

One can see all peculiarities of a classical OS ionograms of the ionospheric layers E, F1 and F2, tracks of lower and upper rays and magnetoionic depletion of the tracks. Upper rays tracks of E-layer do not be observed (such situation takes place in overwhelming majority of cases) and that is why regular MUF of the layer can not be determined very accurately. Real height profiles from VS ionograms were calculated using POLAN program (Titheridge, 1975). On the fig.2 are depicted three cases of N(h)-pro-

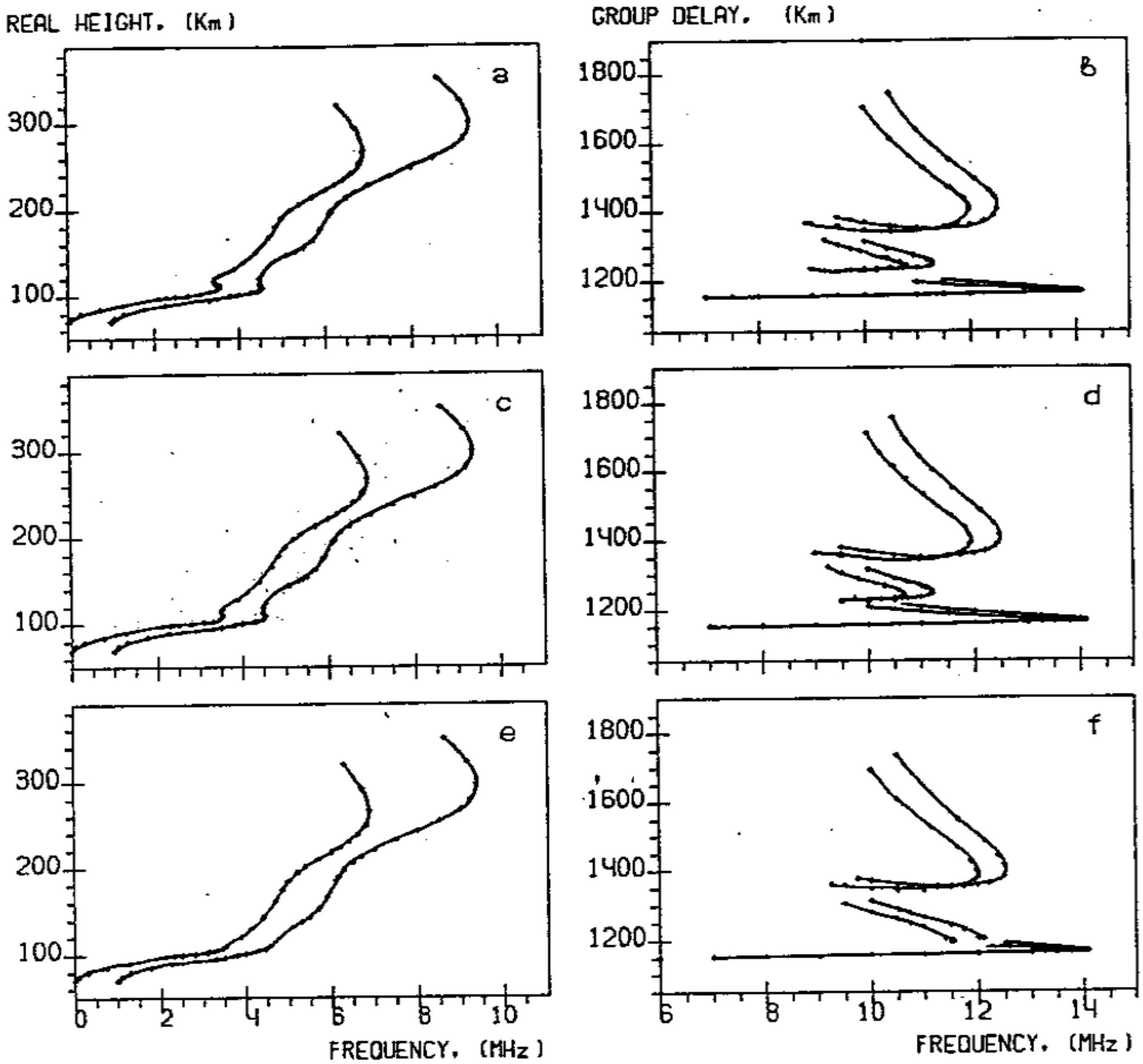

Fig. 2. A sequences of N(h)-profiles (a,c,e), derived from VS ionograms, and corresponding synthesized OS ionograms (b,d,f).

files: first (fig.2,a) with the valley, determined from both ordinary and extraordinary components, second (fig.2,c) with the valley, determined only on ordinary component in so called "default" regime and the third (fig.2,e) without a valley at all (monotonic equivalent). The valley parameters are decreasing from the first case to the third and the structure of the corresponding synthesized OS ionograms reflects these changes. If compare MUF F2 for synthesized and the experimental ionogram one can say that notwithstanding on strong horizontal gradient of electron concentration along the path their values are very

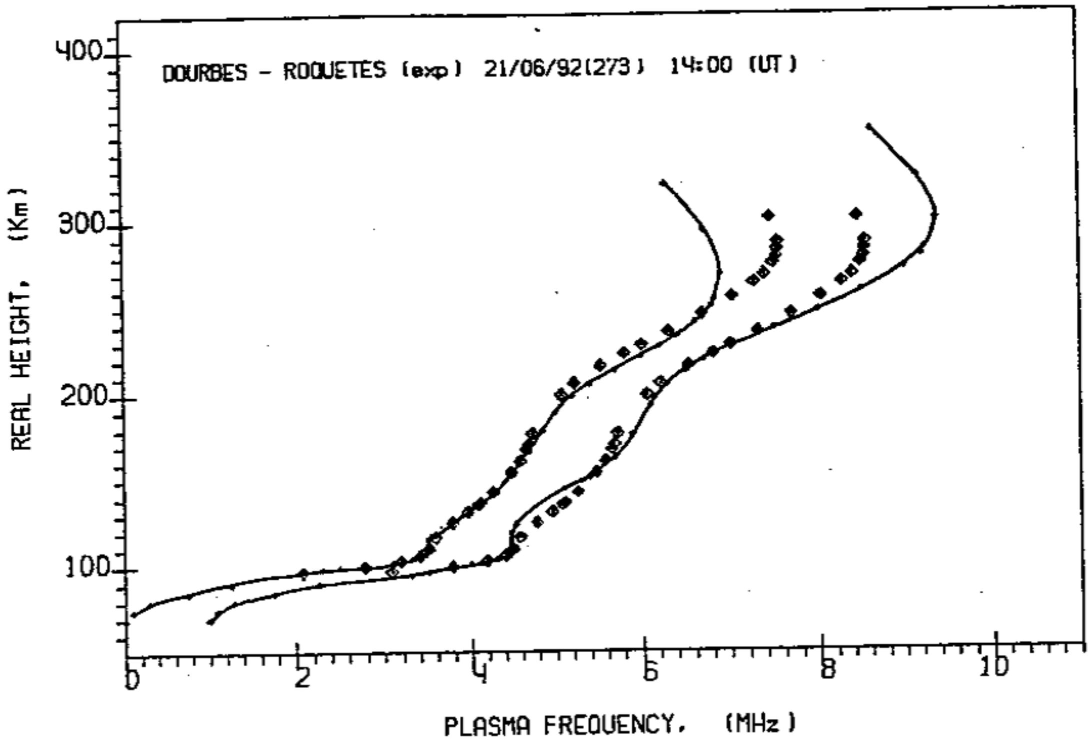

Fig. 3. Results of a comparisons of N(h)-profiles on Dourbes - Roquetes path, derived from VS and OS data.

close (the difference less then 0.1 MHz). MUF of E-layer doesn't change in all three cases because a height dependence of an electron concentration in the layer and below it changes very insignificantly in all three cases. But a structure of F1 layer tracks in considerable degree depends on a form of height electron concentration distribution in the interval between E and F1 layers. If the experimental value of MUF F1 is equal 11.4 MHz then the calculated values range from 11.2 to 12.0 MHz from case to case. There is also definitely expressed dependence of a beginning of the lower ray tracks and the values of their group delays from the valley structure. The more deep and wide the valley is the more low frequency the tracks start from and in monotonous case they are practically absent at all.

DISCUSSION OF RESULTS. All that means that, at the first, in common fitures VS and OS ionograms are in good concord each other and our representation of sounding waves propagation in both cases as vertical so oblique, seems, corresponds to a reality. Secondly, a structure of synthesized OS ionograms are sensitive to a form of N(h)-profiles derived from VS data and this informationcould be used for selection of more appropriate solution in a problem of an estimation of height distribution of electron concentration of the ionosphere. In the analyzed case one can definitely say that a valley really exists but its deepness and widens are very small because even for the smallest parameters automatically determined by POLAN program, we can not reach complete coincidence of synthesized and experimental OS ionograms (fig.2,c,d). It should be also marked that even an estimation of a valley parameters from both ordinary and extraordi- nary components do not give complete guarantee of their correctness. Similar situation takes place in the interval between F1 and F2 layers. If look at the tracks of F2 layer on synthesized and experi- mental OS ionogram one can notice than there is a difference in its starting points (about 1.0 MHz) and in a character of the tracks behavior near the points. Taking into account the results presented above one can say that a peak of F1 layer should be expressed more distinctly and in an interval between F1 and F2 layers can even exist a small valley. It is interesting that in VS ionograms there is no any discontinuity in the region. Results of OS data inversion, using a technique (Krasheninnikov and Liannoy, 1991), support the statement (fig.3). Although the technique can give an estimation of N(h)-profile only in a form of monotonous equivalent one can see that a passing from F1 to F2 layer have another character then one received from VS data. The results are correspond to ones (Chen C.F. et all, 1991) received from a comparisons of N(h)-profiles calculated from VS and incoherent scatter radar data.

CONCLUSIONS. From the results presented and discussed above one can conclude:

a) the technique of OS ionogram synthesis can help in correct interpretation of experimental data and can reveal relations between VS and OS ionogram structure;

b) compatible analyses of VS and OS data can give, seems, a more accurate and reliable estimation of height distribution of electron concentration of the ionosphere and reduce an uncertainty in intervals between ionospheric layers.

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