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IONOSPHERIC INFORMATICS - PART II

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IONOSPHERIC INFORMATICS. 2. PROBLEMS OF EXPERT SYSTEM

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"If one knows what is it to search -
then what for to seek?
But if one is not aware of it -
how one finds out a way? "
Ancient wisdom.

ABSTRACT

Characteristic features of expert systems in the field of artificial intelligence are briefly discussed. Review of principal techniques for gathering information on the ionosphere and the parameters obtained is presented. Two main parts in the expert system on ionospheric informatics are pointed out: a background or regular model description of structure of the quiet ionosphere and inhomogeneities specific for variability of the ionosphere. Examples of interrelated variations of the ionospheric parameters in the conjugate zones of the opposite Earth's hemispheres, related ionospheric and magnetic disturbances at the different global regions and times, during epoch of minimum solar activity, diurnal, monthly, annual and the cycle of solar activity are given.

INTRODUCTION

While in the subject area of the ionospheric research the computerized methods and systems for diagnostics, modelling and prediction of the state of the ionosphere have been developed, in the field of artificial intelligence there appeared a set of other fields expert systems on medical diagnostics, chemistry, symbolic mathematics, operational systems for computer management, and so forth /1/. Principal features of such systems is the knowledge-base. One of the most urgent need there is to transform available human's knowledge into computer-accessible form /2/. In so doing the knowledge is included into the systems copying and further implementing automatically the human's knowledge.

Accumulation, coding and interchange of such knowledge allows in due course to pose problems for the knowledge-based systems to extract new knowledge from the experience a posteriori. For example, currently personal tasks on approbation, testing

and comparison with other data, updating the modelling and forecasting systems and their implementation in the more involved radio-technique systems fulfilled by a man, could be gradually made by an expert system on the ionospheric informatics. Some elements of realisable artificial intelligence have been employed in the diagnostic ionospheric systems for control of operation of digital ionosondes using programmable choice of the optimum times of the sounding based on results of current observations /3,4/.

Implementation of expert systems faces the problems of managing the great volumes of information while the most urgent need for their employing refers to the fields such as the ionospheric informatics where the role of heuristic rules and knowledge is predominant since therein it is not feasible to formulate exactly a problem or the way to its solution or when the problem posed cannot be solved by pure formal approaches. We shall look at the specific tasks which could be encountered by a special expert system on ionospheric informatics but first of all we will point out some general features of different expert systems.

FEATURES OF AVAILABLE EXPERT SYSTEMS

The formalised knowledge implyes (1) a declarative part, (2) procedures, and reasoning. The first knowledge involve descriptions as well as relations between these subjects. An example of such information is empirical ionospheric models such as IRI /5/. In developing and using of expert systems the heuristic knowledge can be encountered at the following stages:

(1) options provided by an expert system
(2) option made by a user
(3) knowledge acquisition from an expert
(4) interaction of engineer-interpretator with expert in the field.

Block-diagram of interaction of an expert system with outer world is given in Figure 1 /6/. Here are presented: 1 - expert system involving three sub-systems: procedures, declarations and reasoning knowledge as well as control program-monitor; 2 - users of expert system; 3 - field of implementation of expert system; 4 - engineer-interpretator for knowledge acquisition - programmer familiar with language of knowledge presentation; 5 - expert-specialist in the present scientific field wh could ignore details of expert system building and its language in computer; 6 - data base used by the expert system; 7 - program-verificat for improvement, modifications, updating the knowledge base responding to errors in the expert system and reacting backward with the expert-person.

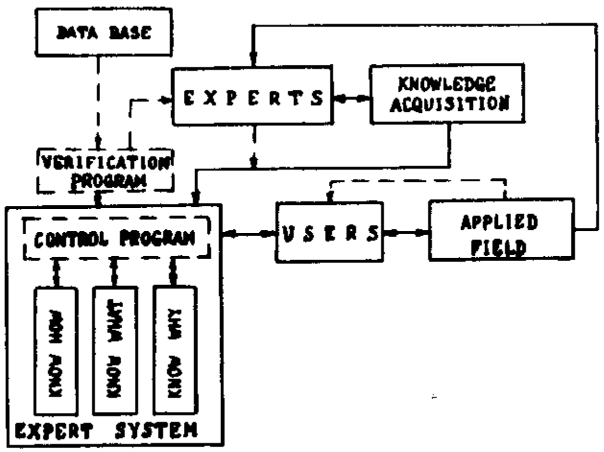

Fig. 1 . Block-diagram of Expert System

T a b l e 1 . Principal classes of application of Knowledge Engineering.

Type	Problems addressed
Interpretation	: Description inference, data directed
Prediction	: Expectation-driven reasoning, situations directed
Diagnostics	: Default procedures (in natural and artificial system), data directed
Projecting	: Configuration inference, objects limited
Planning	: Scheduling of actions
Monitoring	: Comparison of observations with plan's critical points
Refining	: Recommendations inference to overcome mischieves
Repair	: Execution of recommendation according to plan
Learning	: Diagnostics, refinement and correction of student's (user's) behaviour
Control	: Interpretation, repair, prediction and monitoring of system behaviour

The second type of knowledge - procedures - defines operations which have to be indertaken in the process of solving the problem or expectation-driven reasoning. Procedural or technological knowledge involve methods to solve the problems, procedures for information processing, inferential rules, i.e. succession of actions to be undertaken and goal-directed reasoning. The knowledge-based expert system processes solving the problem either by input data-directed reasoning or by expectation-reasoning. In particular, the diagnostic systems for solving the inverse problems of radio sounding the ionosphere and determinative (theoretical) models serves as procedural knowledge.

The third specific type of knowledge involved in expert systems is feasibility of explanation of its actions by indicating methods used by the program, interactive quaring of user to understand his intentions by computer, information on the errors. As a component of the large distributed networks of the data bases and the base of knowledge, an expert system is capable of mastering the great fluxes of information which cannot be afforded by a man-expert. As a result of such activity, at the output of an expert system such solutions and recommendations could appear which would be cumbersome or unacceptable to a men-user so one would need an explanatory information. The most appropriate form of conversation of a system with a user is "menu" proposed by the system as indication of options one of which should be pointed out by user as his response to the query of system. Learning of the system is based on broadening the base of knowledge as well as on keeping in the computer memory of the user's questions and of system's answers to these, classification of users by a level of complexity of their questions and promotion of users to a higher level according to their higher qualification (learning), etc. Operation of a system is supported by the real time providing all necessary information through the "blackboard" and its current updating.

The principal types of the expert systems are listed in Table 1 /1/ most of these being relevant as a specific expert system on ionospheric informatics. Optimum approaches to decision-making and lucky knowledge presentation could greatly enhance ability of an expert system to an effective and workable operation in solving the problems in this particular field.

SPECIFICATION OF PARAMETERS AND REGIONS IN THE IONOSPHERIC INFORMATICS

There have been many attempts in the ionospheric research to introduce a classification from a particular point of view for the principal techniques and goals of a development of this scientific field /7-10/. For instance, in Table 2 /7/ are presented classification of the electromagnetic techiques and observing parameters in the ionospheric research with those separated into two objectives: measurements for the scientific eventual studies and monitoring (routine) observations.

T a b l e 2. Primary classification of electromagnetic probes of the ionosphere.

Heights	Measure	Monitor
Below 70 km		Long waves
		Partial reflection
70 - 100 km	Ground-based sounder: Ne(h)	Riometer (absorption)
	Cross-modulation: Ne(h), νen(h)	Long waves
	Partial reflection: Ne(h), νen(h)	Bottomside vertical-incidence
	Rockets: Ne(h), Ni(h), Nn(h),	and oblique sounding
	Te(h), Ti(h), Tn(h)	
	Lidar	
Above 100 km	Bottomside sounder: Ne(h)	Bottomside vertical-incidence
	Topside sounder: Ne(h), Ne(h_s),	and oblique dounding
	Te(h_s), Ti(h_s), Ni(h_s), B (h_s)	Topside sounder
	Rockets: Ne(h), Ni(h), Nn(h),	Riometer (absorption)
	Te(h), Ti(h), Tn(h)	Atmospherics
	Incoherent scatter: Ne(h), Te(h), Ti(h),	Faraday (total electron
	ion composition, v, νin, νii, E_{ph}	content)
	In-situ satellite observations: Ne(h_s),	Scintillations
	Ni(h_s), Nn(h_s), Te(h_s), Ti(h_s), Tn(h_s), B(h_s)	

Here N is the density, T - temperature, ν - collision frequency, h - height above the Earth, h_s - the satellite height, E_{ph} - energy of photoelectrons, v - the drift velocity, B - the geomagnetic field; subscipts e, i, n represent electrons, ions and neutrals; e.g. νen(h) is the electron-neutral collision frequency as a function of height, and Te(h_s) is the electron temperature at the satellite height.

The results of the different measuring techniques prove to be dependent on many factors. Thus, the long wave measurements on rockets, atmospherics and Faraday observations depend on the wave propagation through the media. Riometer's results - integrated absorption, partial reflection, cross-modulation depend on radio waves absorption. Natural resonances produce a sophisticated pattern at the topside and bottomside sounding. Scattering properties of the medium affect the incoherent scatter results (ionised medium) and lidar (neutral medium). Interactions of in situ probe and the medium affect the results obtained with rockets and satellites.

Specific for the ionospheric research is that the object of study - the ionosphere - and the agent to study - the radio techniques - are mutually affected one upon another. The relative percentage distribution of radio frequencies used in the ionospheric research during six years selected since International Geophysical Year (1 - 1957, 2 - 1964, 3 - 1971, 4 - 1978, 5 - 1985, 6 - 1986) according to the review of publications /11/ is presented in Figure 2. One can see that priorities during this 30-years period have been given to studies using HF radio frequencies of 3 to 30 MHz which however gradually decrease in due course as compared with other frequencies used during the years 1 - 6 above, the same is valid concerning optical observations at $3\cdot10^8$ to $6\cdot10^8$ MHz range. Contribution of the low frequency band of 0 to 1 MHz and that above the main F region peak at 30 to $3\cdot10^4$ MHz is gradually increasing owing to progress in power radio frequencies techniques and optical ground based and satellite-borne studies.

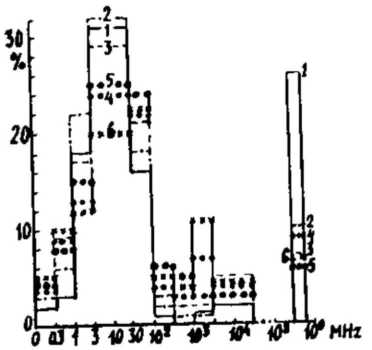

Fig. 2. Percentage distribution of the annual studies at different ranges of frequencies used in the ionospheric informatics with radio techniques and optical observations: 1 - 1957, 2 - 1964, 3 - 1971, 4 - 1978, 5 - 1985, 6 - 1986.

Detailed specification of methods, parameters and goals in the ionospheric informatics including 60-grids scale of the ramifications in the ionosphere and its interrelations with other components of solar-terrestrial physics is given in /10/. As an example the spatial characteristics of the ionosphere are shown in Figure 3 where three latitudinal zones with different physical properties are indicated: equatorial, mid-latitudinal and polar regions as well as the natural bounds between these - an equatorial anomaly and the main ionospheric trough. A lot of attention has been given in the literature both to development of these zonal models and to their boundary regions, and a certain amount of success has been reached in their synthesis into global ionospheric models /5/. One more important feature of the global ionosphere structure and particularly of its dynamics is due to the belt of the solar terminator inducing many disturbances at the night/day boundary.

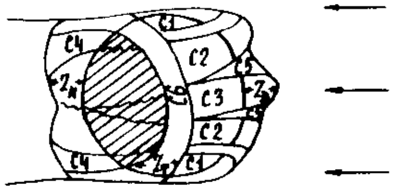

Fig. 3. The F region peak height in the Sun-oriented system of coordinates (night area hatched). C1 - polar zone, C2 - middle latitudes, C3 - low latitudes and equator, C4 - main ionospheric trough, C5 - equatorial anomaly, C6 - solar terminator. Heights: Z_D - dayside, Z_N - nightside, Z_T - the solar terminator.

Determining the goals of an expert system on ionospheric informatics to provide a convenient numerical description of the ionospheric conditions based on available observations /10, 12/, we will separate this description on a regular background model representation such as /5/ - the International Reference Ionosphere, and variance of the ionospheric parameters of different time-scales /13/.

To facilitate an efficiency of such a system it is important to take account of interrelations of the ionosphere with neighbouring adjacent aeronomical regions some aspects of which will be considered below.

INTERRELATIONS OF SPATIAL CHARACTERISTICS OF THE IONOSPHERE

Structure of the ionosphere is "frozen" into orientation of the Earth's magnetic field. With due account of the neutral atmosphere structure and illuminating the upper atmosphere by sunlight schedule of an expert system on ionospheric informatics must be ready to respond to requests of users on the whole set of the ionospheric and outer controlling parameters, to distinguish between a quiet and disturbed conditions and to provide diagnostics of a source of occuring or predictable disturbance.

Regular re-structure of the ionosphere occurs twice a day with passing the solar terminator. In the region of the solar night/day terminator a large temperature gradient is created at the Earth's surface which due to the heat exchange between the ground and the atmosphere induces an inhomogeneity in the latter. With the planet rotation the inhomogeneity moves with great speed exceeding the supersonic velocity at the latitudes from the equator to ± 40°. As a result, atmospheric gravity waves are produced those being a source of mixing the atmosphere during their upward propagation. /14/. Some features of the ionospheric characteristics at sunrise depending on condi-

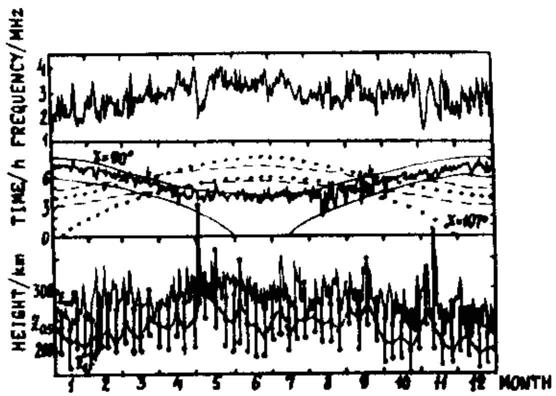

Fig. 4. Daily variations of the dawn minimum of the F2 layer critical frequency foF2 (top section), the time of its occurrence LT and the true height parameters ZmF2, $Z_{0.5}$ and Z_1F (bottom section) derived from the ionograms at Karaganda during 1986 at solar minimum.

tions of illumination at conjugate ionosphere is illustrated in Figure 4. Here the annual variation of the dawn minimum of the F2 layer critical frequency, times of its occurrence at Karaganda (see coordinates in Table 3) and the F2 layer peak height and sub-peak two characteristic heights above the valley are given. Sunrise at the ground (solar zenith angle χ=90°) and at the atmosphere altitude of 300 km (χ=107°) are shown at the point of observation at Karaganda (solid lines), at magnetically-conjugate point of geographic coordinates 32.3°S, 81.4°E (dotted lines) and the geographically opposite location Kerguelen - see Table 3 (dashed lines). The observed dawn foF2 minimum and its times are seen to be affected by annual illumination both at the point of observation and at the conjugate points according to greater illuminating in summer at different months at the opposite hemispheres. Daily variability of the ionospheric parameters typical for the dawn transitional conditions are also evident /14, 15/.

Effects of interrelated phenomena of the ionospheric scintillations and F-spread accompanying by small-scale inhomogeneities in the magnetically-conjugate zones of the Western hemisphere are studied in /15/. Similar effects of the vertical motions of the large-scale inhomogeneities in the magnetically-conjugate zones (of Northern hemisphere) during the total solar edlipses and chemical artificial modifications of the ionosphere at the Southern hemisphere are discussed in /16/. These results and other studies of the same conjugate effects indicate a possibility to use in an expert system of a strategy of the remote sensing of the state of ionosphere at one hemisphere using observations at opposite hemisphere. Such results help also to improve parameters of basic ionospheric models at the zones where network of the ionosondes is sparse (such as the oceans aquatories) using synoptic models of opposite hemisphere /17/. Another option in a case of missed measurements in some regions of the global ionosphere can be implementation of theoretical models /12/.

VARIABILITY OF THE IONOSPHERE OF DIFFERENT TIME SCALES

Association of the equatorial ionosphere with the solar wind and magnetosphere interactions is tracked through auroral latitudes /18/. These are illustrated by relevant disturbances of the magnetic field registered at magnetograms of meridional chain of the stations. Characteristic disturbances could be traced also with the data of chain of the ionospheric stations. Thus for the magnetic-ionospheric storm on 8-9 February 1986 amplitude of the diurnal variations of the F2 layer critical frequency is shown in Figure 5 for seven ionospheric stations listed in Table 3. Except for one station located at the magnetic equator (Manila) synchronous decreasing of the amplitude parameter has been observed at all other stations.

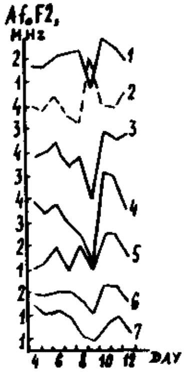

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Fig. 5. Variations of the diurnal amplitude of the F2 layer critical frequencies during the magnetic-ionospheric storm on 8-9 February 1986 from the data of chain of the ionospheric stations.

Table 3. Ionospheric stations denoted in the Figures.

	Station	Latitude	Longitude
		geographic	
(1)	Manchouli	49.6	117.4
(2)	Manila	14.7	121.I
(3)	Vanimo	- 2.7	141.3
(4)	Townsville	-19.6	146.8
(5)	Canberra	-35.3	149.0
(6)	Hobart	-42.9	147.7
(7)	Kerguelen	-49.3	70.5
(8)	Moscow	55.5	37.3
(9)	Kiev	50.5	30.5
(10)	Karaganda	49.8	73.1
(11)	Bekescsaba	46.7	21.2
(12)	Alma-Ata	43.2	76.9

Amplitude of the diurnal variations is energetic characteristic of the ionosphere. The parameters of solar activity such as the sunspot number and the radio emission flux (Covington index) are given only once a day so the diurnal amplitude of the ionospheric parameters appears to be a convenient index of the ionospheric activity /19/ along with other available indeces /20/. For instance, diurnal amplitude of the total electron content variations during minimum solar activity at Alma-Ata revealed semi-annual variation as well as a period of 27-days variability from Faraday rotation observations /19/.

The similar approach has been applied to an averaged by 27-days sliding median of the amplitude of the diurnal variation of the F2 layer critical frequency, AfoF2, observed at a set of the ionospheric stations in the bottom part of Table 3 for the same years of solar minimum 1985-1987. The results given in Figure 6 testify that an annual variation of this parameter differs with latitude while semi-annual variation is evident only at Alma-Ata alike the total electron content results /19/. For a comparison the dashed lines are given to illustrate relevant variation of AfoF2 during previous minimum of solar activity 1963-1965 which basically is similar to the variations at the recent years. The epoch of solar minima of a small ionising solar emission produces the minimum values of electron concentration in the ionosphere so the drop of the diurnal amplitude of the critical frequency from winter to summer is about 1 MHz.

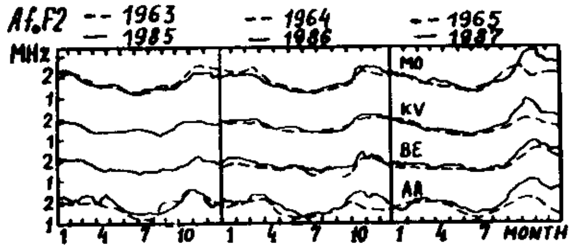

Fig. 6. Smoothed annual variation of the diurnal amplitudes of the F2 layer critical frequencies after 27-days running averaging during two epochs of the solar activity minimum. MO -Moscow, KV - Kiev, BE- Bekescsaba, AA - Alma-Ata.

The more so during the epoch of solar minimum the more pronounced become any variations of the ionospheric parameters as compared with their background values which allows us to illustrate a degree of variability of the ionosphere. To this end difference between daily amplitude of the diurnal variation AfoF2 and the 27-days running average of those values has been calculated. Then the most active periods have been defined as the days with the above difference more than 20% and 40% /21/.

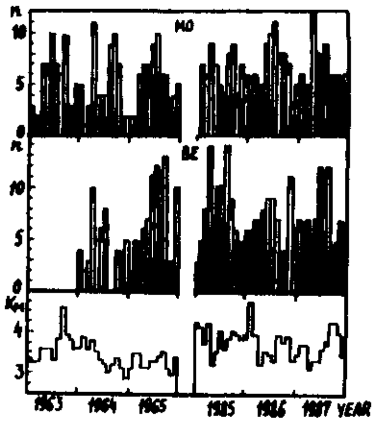

Fig. 7. Diagram of the ionospheric and geomagnetic activities during epoch of solar minimum. The day number during each month when amplitude of daily F2 layer critical frequency exceeds by 20% or by 40% (black) the smoothed values at Moscow (MO) and Bekescsaba (BE). Bottom section - monthly-mean index K_M from the magnetigrams at Moscow.

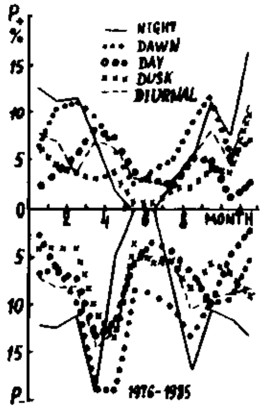

Fig. 8. Percentage deviations of positive and negative variability of the F2 layer critical frequency at Moscow averaged for 1976-1985. Dawn and dusk times correspond to the solar zenith angle within 90° to 108°.

Total monthly number of such days for two epochs of the solar minimum from the ionograms at Moscow and Bekescsaba is shown in the diagram of Figure 7. Also monthly-mean characteristic of the magnetic activity evaluated from the magnetograms at Moscow using maximum dayly K-index averaged for a month is given in the bottom of Figure 7. One can see the character of variability of the magnetic and ionospheric data to be the same /22/ for the epochs selected. Rather large magnetic and ionospheric disturbance is observed during the latest minimum of solar activity which may be attributed either to long-term secular variations of the above parameters or reflect global change of those /23-25/. Note that about one third days of every month undergoes deviations from the background values more than by 20% of the dayly amplitude of the F2 layer critical frequency which testifies that such disturbances should be accounted for by an expert system on ionospheric informatics.

Percentage values of the positive (P_+) and negative (P_-) disturbances of the F2 layer critical frequency at Moscow averaged for every month of the latest cycle of solar activity 1976-1985 is presented in Figure 8 /26/, for the times of dawn, day, dusk, night and dayly-averaged. Variability of the ionosphere is dominant during nighttime and dawn, the less - for the summer when the F region heights are illuminated during 24 hours.

All the above factors with a certain measure of probability should be foreseen in the algorithm of an expert system on ionospheric informatics.

CONCLUSION

Ability of an expert system to goal-directing, adaptation, self-improvement and shaping new features of an object is determined by availability inside the system of information model of media and a description on its own account - i.e. reflection and self-reflection /27/. In this respect an expert system should involve not only data (data base) and the ionosphere model but also the knowledge-base on the ionosphere capable of intelligent activity in assistance to experts-specialists on the ionospheric informatics. Using experience gained in development of the real-time systems of analysis of experimental data the ionospheric informatics could gradually move to obtaining knowledge on the ionosphere in real time as it is already pointed out in some aspects with development of the ionospheric models of second generation where part of creative modelling efforts is proposed to introduce as sub-programs into the very model system /28/. As well as development of the ionospheric models proved to be helpful for building up requirements to the data bases and promotion of new experiments and upgrading techniques of data analysis, so the development of an expert system on the ionospheric informatics would stimulate progress in systems on diagnostics, modelling and prediction of state of the ionosphere.

It would be no wonder that different specific expert system could arise in the ionosphere research as it have happen in other branches of this subject of study. There have already appeared reports on a first experience of the kind /12/. In due course of development of expert system one could expect their predominant role in the ionospheric informatics.

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