

# DECISION SUPPORT SYSTEM FOR SOLVING PROBLEMS IN ATMOSPHERIC OPTICS

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*A methodology for constructing a decision support system for atmospheric optics and the basic components of the system — hardware, data base, and software — is proposed.*

## INTRODUCTION

The present stage of development of research in atmospheric optics is characterized by explosive accumulation of data and knowledge about the object of research. The existing and new information flows already require ever more powerful methods and means for processing data, which, naturally, in turn makes necessary extensive use and improvement of the means of the new information technology. The computer is now the main tool of this technology. The storage of information in machines, which enables processing on a computer, involves a radical restructuring of data representation and the methods for using the data. The main requirement that the new information technology must meet is that it must be tailored to the final user. Thus it is necessary to organize a technology for representing data and knowledge in languages that are as close as possible to the subject at hand — the optics of the atmosphere.

The extensive use of computers in research in atmospheric optics imposes one other requirement on information processing systems: the data base on all computers participating in the data processing must be integrated. It is obvious that this integration scheme must include not only the data (the passive part of the knowledge) but also the means for processing the data — programs, data base, and expert systems.

A characteristic feature of the optics of the atmosphere as a subject is that in addition to high information capacity, its active part, i.e., the processing programs, because of the extreme complexity of the mathematical models employed to describe the media under study, contains virtually the entire spectrum of processing means: information — retrieval, computational-logical, expert systems, as well as hybrid logical-linguistic and mathematical models.

These characteristics of the subject naturally impose characteristic restrictions on the configuration of the hardware, the information base, and the software. This collection, oriented toward the solution of specific problems in this field, is now customarily termed a decision support system (DSS).<sup>1</sup>

In this paper questions regarding the organization of the DSS for problems in atmospheric optics that has been realized at the Institute of Optics of the At-

mosphere of the Siberian Branch of the Academy of Sciences of the USSR, are examined.

## II. HARDWARE

The first and most important component of the DSS for the solution of problems in atmospheric optics is the hardware. In research on atmospheric optics the experimental methods, primarily methods of remote laser sounding, based on the use of various types of interaction of laser radiation with the atmosphere, are of primary importance. Obviously, because of the complexity and high rates of interaction it is impossible to interpret such measurements without the use of automatic meters, based on different elements of computer technology.

Every subfield in atmospheric optics — spectroscopy of the atmosphere, optics of atmospheric aerosol, optics of the turbulent atmosphere, and other subfields — engenders, together with lidar meters, its own collection of meters, primarily computerized meters.<sup>2</sup> Theoretical investigations in this field, because of the great complexity of the physical phenomena under study and their high information content, in their turn also cannot be performed without the use of computers.

Based on what we have said above and the fact that the DSS must be tailored to the final user, the main problem in constructing the hardware is to allocate effectively the functions among all means of the computer technology employed in the investigations as well as to provide reliable exchange of information between these means.

The technical means employed, in the process of acquiring and processing optical and meteorological information are, on the whole, quite diverse universal 32-, 48-, and 64-bit computers; minicomputers with 16- and 32-bit architecture; automated work stations (AWSs) for theoreticians and experimenters based on micro-, mini-, and personal computers. The composition and configuration of the hardware are determined by the specific functional applications of its elements. At the same time, it is obvious that an efficient structure of the hardware of the DSS can be realized only with maximum unification of its component parts.

**The automated work station for an experimenter (AWSE)** is a professionally oriented computer system. Depending on the conditions under which the experiments are performed, such a system can be stationary or mobile. The concrete implementation of an AWSE can have a diverse structure, depending on the form of the experiment. This structure must nonetheless have four basic component parts:

1. Processor (personal or microcomputer).
2. Standard interfaces (MPI, CAMAC, etc.).
3. General systems modules (network adaptors, auxiliary-memory controllers, electronic disks, bus-to-bus adaptors, etc.).
4. The professional modules (processors for mass data processing, videoprocessors, display processors, a series of ADC, a series of photon counters, and special processors for solving specific problems).

It follows from this that the collection of modules of AWSE is quite limited and is unified by several types of buses. The fact that network adaptors and controllers with different auxiliary memory are necessarily present makes it possible, on the one hand, to employ the AWSE as an autonomous system and, on the other hand it ensures that the general resources of the entire computer network are accessible.

The professional modules include processors for mass data processing and especially processors for image processing.<sup>3,4</sup> Including them in the AWSE makes it possible to reduce substantially the information flows between the computer networks, to make the AWSE as autonomous as possible, and to increase the reliability of the DSS as a whole.

**The automated work station for a theoretician (AWST)** is structurally the same as the AWSE. Naturally, the composition of the professional modules for such systems is substantially restricted. However, because the DSS is tailored as much as possible to the final user, in the AWST the information-representation modules, primarily the display processors and image processing devices, which implement the computer graphics and make it much easier for the investigator to interpret the information, are the most important modules. The processors employed in mass data processing play just as large a role in AWST as in AWSE.

The fact that the automated work stations have large auxiliary memories makes it possible to create local data bases tailored to the specific investigations being performed, and this reduces to a minimum the information exchange along the DSS network.

Automated work stations are tailored primarily to specific technical or scientific applications and are individual instruments used by a single investigator (or group of investigators). The experimental data can be processed using complex mathematical models of the actual atmospheric and optical processors primarily, because of their algorithmic complexity and high information content, based on computer systems (large universal computers or work stations). It is obvious that for automated work stations the access to the base systems must be made as simple as possible.

For this reason, all means of computer technology must be combined into a distributed collective-use computer system (DCCS).

The DCCS makes it possible to provide to investigators an integrated collection of instrumental and program tools for processing, storing, transmitting, and displaying data, i.e., it makes it possible to create the medium in which the DSS for atmospheric optics functions as well as to improve the efficiency of the specialized devices employed for processing, storing, and displaying data for both the base computer systems and the automated work stations.

The main difficulty connected with implementing the DCCS is that different computer systems, which operate in an environment of operational systems of different types (i.e., the DCCS is heterogeneous), participate in the information processing occurring in the medium of the DSS. This is because different types of computer systems are tailored to specific types of work. Thus, for example, the El'brus computer system (BESM-6) is designed to perform primarily complicated computational and logical work. These systems are fast precisely for problems of this class. However their efficiency drops significantly if large arrays of data must be processed. Data arrays are processed more efficiently on the ES-series computers. Naturally, combining machines of the El'brus type with ES machines and separating their functions in a manner so that each machine works on problems best suited for its class makes it possible to increase the overall efficiency of the entire system above the simple sum of efficiencies of the separate systems. Analogously, the SM-series computers are incorporated into the DCCS according to the principle of functional separation.

The DCCS is constructed based on the concept of systems of virtual and real computers (SVRC). In this concept the virtual computers have the same access to the resources as do the real computers (AWSE and AWST). This makes it possible to treat all of the software and hardware in the DSS from a unified point of view.

The basic method used to combine computers into a distributed collective-use computer system is the network method of utilizing computer resources. **The local area network (LAN)** provides for all required data transfers over short distances (within the buildings of the scientific and technical complex). The protocols for data transmission and the interfaces are significantly simpler than those of large networks, because the problems of optimizing the transmission band of the communication channel and organizing the routes for LAN are simpler.

Transfer of information between the machines in LAN is strictly controlled by a system of standardized protocols.<sup>5</sup> The specific collection of protocols is determined by the topology and the transmission medium of the LAN. Of the currently most widely used local-network topologies (star, single-channel, ring, and tree) the topology of the single-channel type, in which the users are connected by one common high-speed channel, has been adopted as the base

topology in DSS for problems in atmospheric optics. This is because the reliability of information exchange is significantly higher for one transmission medium and such a configuration makes it possible to unify the network equipment and to connect new users in the simplest possible manner.

The characteristics of information transmission through a channel are determined by the logic of high-speed transmission of signals and by the method by which the channel is separated between stations in the network (access protocol). Single-channel networks have a number of advantages over other types of networks: Their reliability is high; the initialization procedure is simple; it is possible to develop a branched topology; and, different access protocols with a wide spectrum of characteristics can be implemented.

LAN users interact primarily by means of a transport subsystem, which is implemented in the form of transport stations.<sup>6</sup> Incorporating into the hardware of the DSS the work stations of experimenters imposes additional requirements on the medium used to transmit data in the LAN, since characteristics such as

the probability of exceeding a fixed delivery-time threshold and the guaranteed response time start to play an important role. This makes increasingly more problematic the use of the "old" version of the CSMA/CD protocol with binary exponential delay.<sup>7</sup> For this reason, in order to optimize data transmission the development of the most efficient protocols for LAN of DSS was investigated.<sup>8-3</sup> As a result, a new method for controlling multiple access of local-network stations in a single channel — a "pulsating ring" — has been proposed.<sup>11</sup>

The method is based on the idea of a cyclic arrangement of stations, in which the stations are group stations. Such a queue has a variable configuration that can be adapted to both the overall intensity of the traffic and to the individual transmission capacities of separate stations. The proposed method is an advantageous symbiosis of random and determinate accesses. The usual CSMA/DC apparatus is sufficient to implement this method. Investigations showed that this method has significant advantages over the most widely employed methods BRAM, CSMA/CD, HYBRID, Enet II, etc.<sup>13</sup>

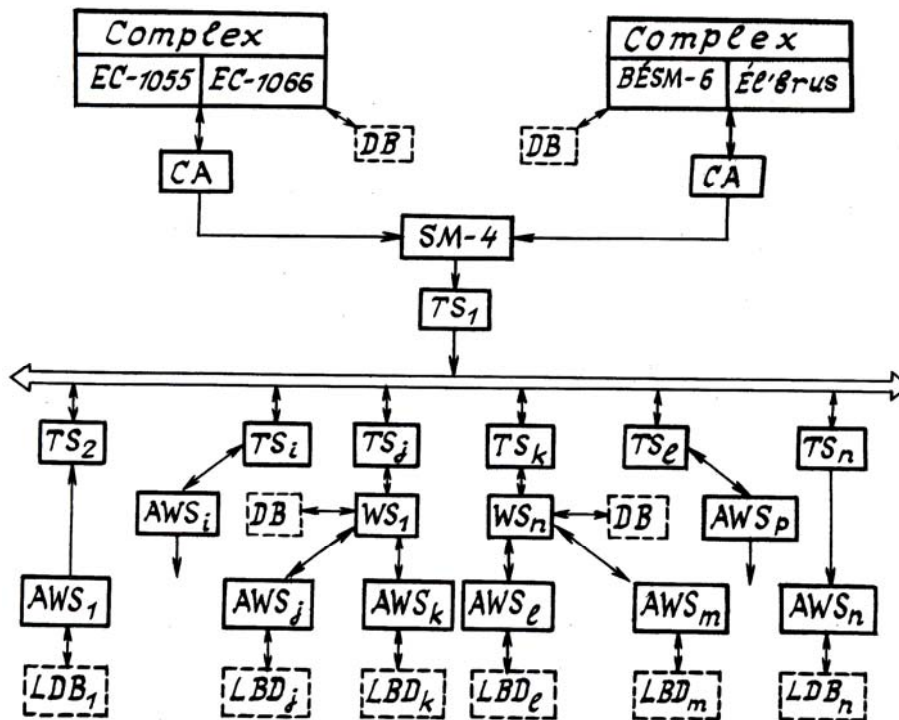


FIG. 1. Structure of the hardware of DSS for problems in atmospheric optics:  
 CA — communication adaptor; TS — transport station; DB — data base; LDB — local data base;  
 WS — work station.

The protocols of the "pulsating ring" solved the problem of the transport subsystem. The base elements of the extended means for memory-memory coupling of virtual machines IUSV are employed as the basic interface elements of the "session" level,<sup>14</sup> since these elements can be translated along the network with only insignificant modification. The essence of these

modifications consists of the following: the means specific to the system of virtual machines are excluded from the IUSV; to the monitor of the virtual machines there is associated a transport station; and, to the virtual machine there is associated an ARME (or ARMT). Expansion of the means of IUSV ensures that the interfaces are unified with the transport subsystem of the real and

virtual machines, and in the process the SVRC concept is preserved; in addition, it makes unnecessary the extremely laborious development of the network mathematical software for the ES-series computers.

The IUSV coupling means allow transmission of messages between the terminal stations of the network and provide the following possibilities for exchange of information:

- establishment of a logical link between two stations (users), which organize the interaction;
- the possibility of transferring messages without external interruptions together with the possibility of obtaining information about messages through external Interruptions; and,
- a set of options which make it possible to establish links between stations (users) and sending messages to them.

The data transmitted over the network are configured as messages, transmitted along predetermined communication paths. Several such communication paths can be established simultaneously, i.e., each user can be both a sender and a receiver. In order to provide a link between computers of different types the protocols allow for implementation of the level "data representation", whose function includes providing an appropriate representation of data of the types "integral", "real", and "symbol" for different coding systems.

The overall structure of the hardware of the DSS for problems in atmospheric optics is shown in Fig. 1.

### III. DATABASE

Hardware development is oriented primarily toward efficient use of the central part of the DSS data. Research in a field as complex as the physics of the atmosphere involves the processing of large and "superlarge" volumes of information. Thus, for example, data on the meteorological parameters of the atmosphere, which have now been accumulated, constitute  $\sim 1.3 \cdot 10^{11}$  bytes, and the data are accumulating at a rate of  $\sim 10^{10}$  bytes/yr.<sup>15</sup> In addition, the models describing real phenomena in the atmosphere are becoming increasingly more complicated, and therefore the volume of information that adequately characterizes the state of the phenomena is increasing. Investigation of different material phenomena in the atmosphere in interaction exacerbates even more the problem of the "information explosion" in atmospheric optics. Thus the data (information resources) are indeed becoming the central, most important part of the DSS.

Obviously, under these conditions the traditional approach to the solution of database problems, which is oriented toward organizing data in the form of separate files, rigidly linked with the processing programs, is no longer acceptable. The DSS for problems in atmospheric optics requires integrated storage, centralized control, and multiaspect collective use of the data. This ideology corresponds to the concept of databases, i. e., organization of blocks

of information in the form of a collection of inter-coupled data, employed in one or several applications and stored with minimum excess. An efficient method for implementing this concept is to develop models of the data, which adequately reflect the state of real objects of research in one or another information structure, and software that performs the input, actualization, storage, and display of data.

The diversity of phenomena in atmospheric optics engenders also a diversity of possible formal descriptions of the subject and the information structures corresponding to these descriptions. Thus the state of the subject is uniquely reflected in the model of the database. It is obvious that because of the complexity of atmospheric optics it is hardly possible to develop a universal data model.

The most efficient method for designing and developing the database for DSS for problems in atmospheric optics is to subdivide the entire collection of phenomena into subsystems with their own collection of interrelations and to associate with these subsystems their own specific data models. In this country and abroad a number of infological models are employed for diverse applications of optical-atmospheric research.<sup>15–22</sup> Analysis shows that these models include the entire spectrum of models – from two-dimensional to relational, i. e., the system of databases for DSS for problems in atmospheric optics is nonuniform.

Aside from nonuniformity of the databases, the DSS is characterized by decentralized use of information, because data input and preliminary processing of the data occur on the computers of ARME and ARMT. At the same time, the data must be accessible for use by any applied program implemented on any computer network. Thus the problem of developing an efficient database for the DSS reduces to developing an integrated system of distributed databases.<sup>22</sup> One of the most important problems remains the problem of optimizing the structure of local data bases in order to minimize the use of memory and navigation through the data.

The largest local database of the DSS is the database of meteorological parameters of the atmosphere.<sup>21</sup> Optimization of its logical structure gives the maximum increase in resources. The optimization is based on the method of unifying one-to-one particulars.<sup>21</sup> In relations with a large number of particulars studied, their subsets, which are unified along a small number of particulars, are separated and relations are established between the subsets. As a result an optimal matrix of relations  $M = \{a_{ij}\}$  is obtained. The logical structure of the database of meteorological parameters of the atmosphere, corresponding to the relational matrix  $M = \{a_{ij}\}$  is presented in Fig. 2. In Table I the external memory required in the case when the same volume of information is organized in the form of an SAS archive<sup>23</sup> and in the form of an archive of the system AISORI<sup>15</sup> are compared.

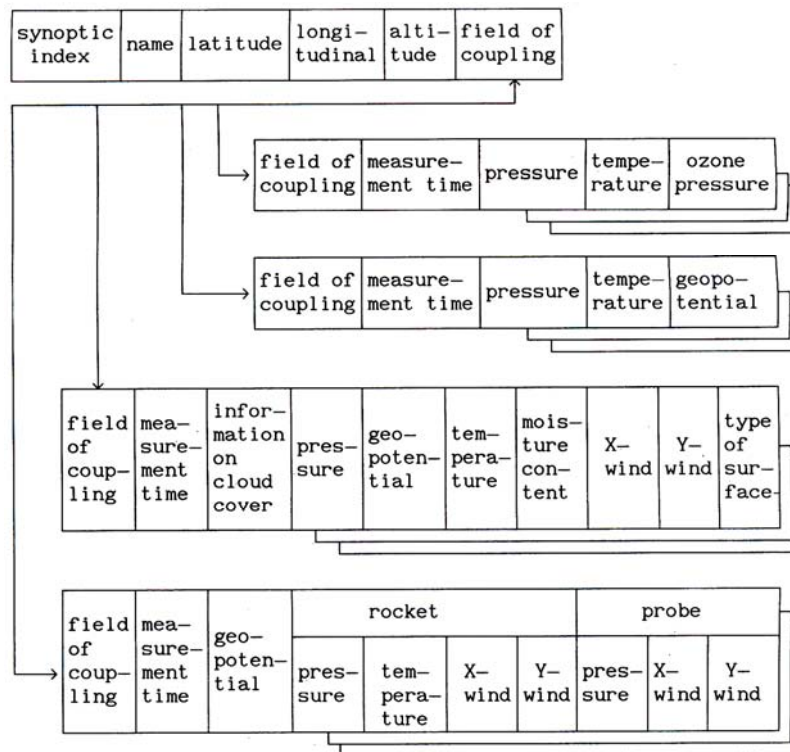


FIG. 2. Logical scheme of the database for the meteorological parameters of the atmosphere.

TABLE I. Estimate of the external-memory requirements

File	Number of records	Length of records (information)	Length of record (information)	Increase in length (%)	Number of descriptors	Data (Kb)	ASSO (Kb)	Outlay (%)
BD probe	14600	361	367	1.5	5	5360	263	6
SAS	345000	-	-	-	-	21000	0	300
AISORI	58400	-	-	-	-	11350	0	114

A comparison shows that the proposed optimization scheme makes it possible to reduce the required volume of the memory by at least a factor of four. This shows that the logical structure constructed is highly efficient.

Video data represent a special class of data. Because of the extensive use of synoptic measurements, video data are now starting to play an increasing role in the problems of the optics of the atmosphere.<sup>24,25</sup> The use of results obtained by sounding from satellites makes it possible to transfer from measurements at points to analysis of three-dimensional fields. Naturally, the methods for organizing "traditional" databases are of little use when working with video information.<sup>26</sup> In video databases, in the general case three components must be stored: half-tone video images; structured data on the characteristics of the object and the associated information; and, unstructured description of the relation between the image

and the real object.

Specialized image-processing devices (IPDs) play a very important role in choosing a method for storing video data. Transferring to the IPD some of the functions of manipulating the video data (selection of the fragment, search and manipulation of elements of the video data, etc.) makes it possible to simplify substantially the storage technology. In DSS for problems in atmospheric optics, thanks to the existence of efficient IPDs,<sup>4</sup> the system of video databases is implemented precisely in this manner. The image is regarded as a simple type of data, access to which is realized through an identifier (or a collection of indicators), and all functions of manipulation with elements of the image, including navigation, are performed with the help of special IPD software.<sup>27,28</sup>

As we have already mentioned, the entire existing collection of optical and meteorological data stored in the computer network must be processed in accordance

with the general interests of the users. There thus arises the problem of developing a strategy for optimal distribution of files over the network in order to minimize the data call times.

Access to a distributed database is usually organized by means of a system of directories, containing a list of user-accessible files. The systems of directories are divided into a system of centralized directories, a system of local directories, and a system of distributed directories.

The problem of optimizing the arrangement of the local databases so as to minimize the average call time can be reduced to a problem in nonlinear programming of the following form:<sup>29</sup> minimize the average system response time

$$\min R(\{n_{ij}\}), \quad (1)$$

under the constraints

$$\sum_{i=1}^L n_{ij} f_i < u_j; \quad n_{ij} \geq 0; \quad \sum_{j=1}^M n_{ij} = N_i, \quad (2)$$

where  $L$  is the total number of files;  $n_{ij}$  is the number of blocks in the  $i$ th stored in the  $j$ th memory device;  $u_j$  is the service intensity on the memory device  $j$ ;  $M$  is the total number of storage devices;  $N_i$  is the length of  $i$ th file in blocks;  $R(\{n_{ij}\})$  is the average response time of the system; and,  $f_i$  is the frequency of block calls.

The response time of the system is defined by the following relations, depending on the type of directory.

1) System of centralized directories

$$t_{1,d} = \frac{\sum_{i=1}^n q_i (1 + P_i)}{2\mu_1 \left[ \mu_1 - \sum_{i=1}^n q_i (1 + P_i) \right]} + \frac{l q_1}{2R [R/l - q_1]} + \frac{2l}{R}, \quad (3)$$

where  $t_{i,d} = t_1(i) + t_2(i) + t_3(i)$ ;  $t_1$  is the latency for entry into a directory;  $t_2$  is the latency for exiting from a directory;  $t_3$  is the call and response transmission time;  $1/\mu$  is the service time for queries;  $q_i$  is the intensity of the flux of queries generated in the  $i$ th computer to the directory;  $P_i$  is the directory refresh factor;  $R$  is the rate of transmission along the communication line;  $l$  is the number of symbols in the query; and,  $n$  is the total number of computers in the network.

2) For a system of local directories the query time of the  $i$ th computer for the  $k$ th directory is

$$t_{1,k} = \frac{\sum_{i=1}^n q_i}{4\mu_1 \left[ \mu_1 - 0.5 \sum_{i=1}^n q_i \right]} + \frac{l q_1}{2R [R/l - q_1]} + \frac{2l}{R}. \quad (4)$$

3) In a system of distributed directories  $t_2 = t_3 = 0$ , so that

$$t_{1,d} = t_1(i) = \frac{q_1 \left( 1 + \sum_{k=1}^n q_k \right)}{\left\{ 2\mu_1 \left[ \mu_1 - q_1 \left( 1 + \sum_{k=1}^n P_k \right) \right] \right\}} \quad (5)$$

By solving the problem (1)–(5) simultaneously and comparing the results it is possible to optimize the structure of the distributed database. If the cost of storage of the directories on external memory devices is neglected, then for a local computer network a system of distributed directories is optimal. Precisely such a system was adopted for the DSS for atmospheric optics. The basic elements used in organizing access to the local databases consist of the IUSV means. The link between the IUSV means is organized between the information user and the local database. This link is made by transferring data from the main memory of the computer – where the local database is stored – to the main memory of the user. The data are configured in the form of messages, which are transmitted along predetermined links.

Since the system of distributed databases of the DSS is different, for purposes of integrating the data the question of data conversion becomes important. It is useless to develop a system of converters for each data model employed in research on atmospheric optics because of the diversity of the possible variants. The system of converters proposed in Ref. 21 is employed in the DSS. This program permits using a wide class of input and output record fields, tailored to one or another model. The input fields and the records themselves are monitored at the same time; this significantly increases the reliability and correctness of the information exchanges along the network.

Thus an integrated system of distributed non-uniform databases in the DSS for atmospheric optics is implemented by using data directories. The basic elements of the lower level of the information exchange are the IUSV means. The conversion system guarantees the reliability of the data and makes possible data control.

#### IV. SOFTWARE

The information base of the DSS and its main element – the databases – describe, in the general case, the static state of the subject "atmospheric optics." However new knowledge about the objects and phenomena being studied is obtained in the process of analysis and processing of the data. The software (SW) is the active part of the DSS that makes it possible to obtain such knowledge and data.

The software of the DSS for problems in atmospheric optics is characterized by a number of peculiarities, which are connected primarily with the functional properties of the subject "atmospheric optics."

First, it should be noted that the traditional loop of software development "model – algorithm – program" is not always strictly formalized. Knowledge about the object can be represented in both structured and un-

structured forms, i.e., the logical-linguistic model—algorithm—program” (expert system) is correct.

Second, together with the schemes indicated above, in which the possibility of constructing a mathematical model by separating the important factors from the set of factors affecting the process is realized, in problems in atmospheric optics phenomena in which an a priori separation of a large number of variables into important and unimportant variables is not always possible are investigated. Understandably, in these problems it is very difficult to use the traditional mechanism of abstraction “model—algorithm—program” so that the software must contain means for automatic formalization of the professional knowledge, i.e., it must allow motion along the loop “program—algorithm—model.”

Third, because of the complexity of models in atmospheric optics one processor often cannot perform within an acceptable time all required computational functions. It is thus desirable to separate the software into modules so that the functions are distributed among different processors in the computer network. The DSS software must include the interfaces of the modules and a convention for data exchange between computers. In addition, the large volume of information accumulated in the form of developed and modified packages of applied programs (PAP) cannot be ignored and must be incorporated in the DSS software.

Finally, the technical implementation of DSS in the form of a distributed collective-use system with possibilities for parallel computations and data storage requires that the software be adapted to the given conditions.

Thus in developing the software for the DSS for problems in atmospheric optics the following problems must be solved.

1. For the systems software (SSW) means for free connection of the elements of the software, that would enable transferring from a single-processor to a multiprocessor configuration with minimal changes in the software itself (software bus<sup>30</sup>) must be developed.

2. For the functional software (FSW) a program-oriented instrumental complex for development (synthesis) of programs based on the methods of logical programming must be developed.

The SSW of any computer system is based on the operating system (OS). It combines into one entity all components of the program complexes and implements the necessary service functions. The modern trend to use the OS for the DSS is characterized by maximum possible application of multicomputer operating systems (MOS)<sup>31</sup>, which facilitate as much as possible the transfer of programs from one computer to another. (The Unix operating system is regarded as one of the best MOS.<sup>32</sup>) At the same time, since the ideology of tailoring each computer in the network to the problems to which it is specifically adapted specific class has been adopted in the DSS for problems in atmospheric optics, the problem of on-line transfer of the program product is not the main problem. Under these conditions the transfer of text files (initial modules)

ensures intercomputer program exchange. The possibilities of the local information-computer network of the DSS satisfies these requirements.

Thus the problem of choosing an optimal operating system for the DSS, on the whole, reduces to the problem of selecting the optimal operating system for a specific type of computer. Each operating system employed must satisfy a definite set of requirements: it must permit efficient organization of the computing process on the computer; it must implement the maximum number of service functions; and, it must provide the same possibilities to users of different types of computers.

The most important service functions are as follows:<sup>31,33</sup> the interactive regime; convenient means for controlling the data; possibility of organizing a rapidly changeable menu, on the display screen; graphical display of data; large-format electronic tables (LET); and, others. In addition, all software must be upgraded as improved versions of the operating system appear.

It should be noted that modern operating systems perform most of the functions enumerated above. For this reason, the operating system should be chosen so as to preserve as many of the programs as possible. In the DSS for problems in atmospheric optics collection of operating systems is employed precisely based on this principle.

There are different opinions regarding programming languages. The choice of programming language is determined not only by the functional field (optics of the atmosphere), but also by the operating characteristics of the computers in the computer network of the DSS. For this reason, the main problem in using the language support consists of software integration, which must ensure the following:

- compatibility of data from different programs;
- simultaneous use or rapid switching between two and more programs; and,
- development of a single input/output method for all programs.<sup>34</sup>

Thus the paramount problem is to standardize the programming languages and software as a whole. However such standardization involves hardware conversion and requires significant time and resources.<sup>34–37</sup> Nevertheless it is now already necessary to develop software that meets as many of the above requirements as possible. This approach is implemented in the DSS for problems in atmospheric optics, i.e., the software is constructed according to a hierarchical principle in the form of a system of monitors, which function with all types of interfaces (external and intrasystems) and perform the required service functions.<sup>33</sup>

The basic elements of the software in the DSS are the libraries. There are two types of libraries:

- standard libraries, maintained by a monitor of the system libraries;
- nonstandard libraries, each of which has its own service monitor.

The catalog of any library contains an indicator of the type of library and the “driver” of the corresponding monitor.

The main elements of the library are the modules. The modules contain, together with the functional programs, the library catalog, which services the monitor and the ports (address of another library with a section of memory for information exchange), which are intended for exchanging information with libraries which are updated or were updated by the given library.

The software constructed based on this principle provides for opening of the library, creation of a copy of the library, initialization of the corresponding ports, and linkage of the required monitors. During operation the content of the library can be refreshed (without changing the information about the library in the catalog) or a new library can be created. These functions are performed by the monitor at the end of the session. Information exchanges are determined by the protocols of the distributed collective-use computer system of the DSS for problems in atmospheric optics.

The loop "model—algorithm—program" is implemented at the procedural level by constructing a computational model from the constituent functional programs of the software (libraries). These computational models, taken as a whole, form the semantic model of the subject area — the knowledge base. In the DSS the knowledge base, like the database, is distributed over the computers of the local information-computer network.

The expert part of the DSS, which implements the loop "logical-linguistic model—algorithm—program," is organized as a hierarchical collection of expert systems (ESs). The concrete expert systems for problems in atmospheric optics include, together with the traditional components — expert knowledge (facts), rules for logical output, and components of explanations — the procedural knowledge (in the form of functional program modules) and mathematical (computational—logical) models of the processes investigated. Thus the expert systems for problems in atmospheric optics are hybrid expert modeling systems (HEMS).<sup>38,39</sup>

The structure of the hierarchical tree of expert systems is constructed so as to reflect the traditional separation of the subject area "optics of the atmosphere" into the directions of research adopted in it. In addition, the organization of the expert systems in the form of a hierarchical system is also efficient based on the following considerations.

1. The collection of rules for logical output and the functional modeling programs is specific to each direction of research and can differ significantly from other collections. The efficiency of the expert systems, however, is significantly higher for the "narrow" problems, which do not require references to allied fields.

2. The proposed structure can be modified at any level of the hierarchy without changing the operation of the system as a whole.

3. The hierarchical structure makes it possible to adapt easily the conceptual knowledge about the subject area to the changing ideas of the investigators. Thus new knowledge can be introduced very simply.

Such a system can be used at any level as an independent expert system, with its own knowledge

base and collection of rules for logical output. At the same time, moving along the branches of the tree could make it possible either to specify more precisely the ideas about the process under study (motion downwards) or to formulate the problem more accurately (motion upwards), thereby realizing the synthesis—analysis principle.<sup>40</sup>

The problem of automatic formalization of the knowledge presumes that the functional programs created by the user according to the direction of his research (often incomplete) is integrated into a functionally complete operating system of programs. Thus there arises the problem of synthesizing reliable program systems.

For these purposes an approach based on the formalism of structural C-computing models<sup>33,41</sup> is used for the DSS software for problems in atmospheric optics. This formalism is distinguished from the traditional approaches by the fact that the computational model can be synthesized not only based on elements that are external to the given model, but also by using elements of the model itself (i.e., recursion can be realized).

Thus the above-formulated problem of constructing a program system for investigating (modeling) a physical process is solved by synthesizing from procedural knowledge (programs) practically any level of the hierarchy of DSS software. The program so constructed is not necessarily linear; it may contain branches and recursions.

The software constructed based on the technology described above satisfies, with respect to most parameters, the requirements which the DSS software for problems in atmospheric optics must meet. Since the system is open, the updating of the software at the same time as a new generation of computers is introduced is more of an applied character. Nonetheless many questions regarding the development of DSS software for atmospheric optics are still open and are of great scientific and practical interest.

## V. CONCLUSIONS

The problem of efficient organization of calculations and utilization of computers for solving specific physical problems remains urgent. Together with the development of decision support systems, there also exists an alternative direction — development of specialized operational systems. From our viewpoint, this direction is less adapted to the dynamically changing ideas of researchers about the applied functional area and is less flexible with regard to the realization of complicated modeling systems.

It is obvious that for narrow applied fields specialized operating systems can give a fundamental advantage in resources. However the proposed structure of the DSS makes it possible to incorporate in the system, without making any significant conversions, computer systems that operate under control by such operating systems; this once again demonstrates the importance of research on the development of DSS.



The openness of the DSS gives wide possibilities for improving and updating both separate elements of the system and the structure of the main constituent components.

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