SHORT-TERM FORECAST OF SOLAR ACTIVITY

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ABSTRACT. The works (1981-1985) of the KAPG member countries are considered in this review.

КОРОТКОСРОЧНЫЕ ПРОГНОЗЫ СОЛНЕЧНОЙ АКТИВНОСТИ: В обзоре оцениваются работы членских стран КАПГ за годы 1981-1985.

KRÁTKODOBÉ PROGNÓZY AKTIVITY SLNKA. V prehľade sú uvažované práce z krajín zúčastnených na mnohostrannej spolupráci KAPG za roky 1981-1985.

As a rule, solar activity forecast is important not by itself but in relation to predicting geophysical phenomena and the conditions in the near-Earth space. Since the development and improvement of forecasting methods depend on particular users, and the objective of prediction lies in minimizing the user's detriment, first and foremost, it is feasible to determine the list of users and their requirements. Services of:

- the ionosphere and radio wave propagation;
- the magnetosphere and geomagnetic field;
- radiative conditions in the near-Earth space;
- the upper atmosphere and planning of integrated experiments,

are the main users of solar forecast. To compile their own forecasts each of the above services needs both current characteristics of solar radiation and prediction of solar activity. Fig. 1 presents the information on solar radiation which is required to each of the users. Let us consider the scheme in detail.

Ionospheric state and the conditions for radio wave propagation are guided by variations in X-rays and UV solar radiation (G.S. Ivanov-Kholodny and G.M. Nikolsky, 1969). UV-radiation is the major ionizing reagent (in the ab-

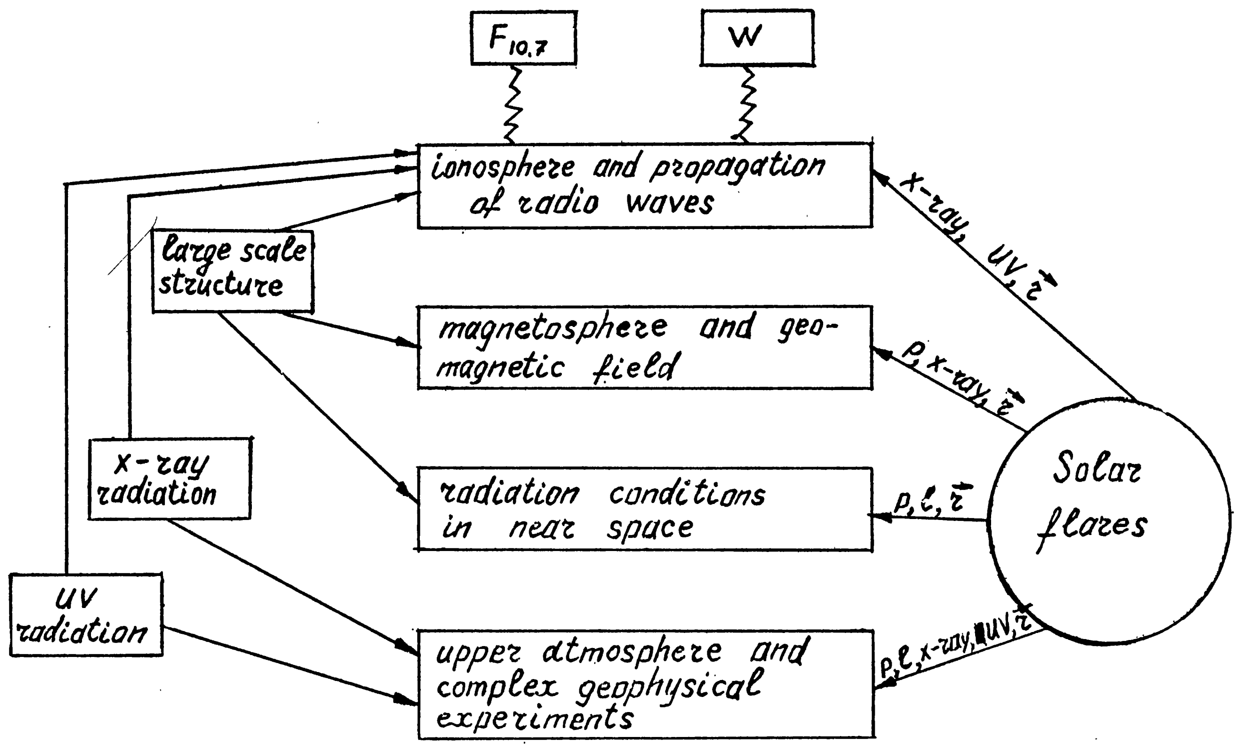

Fig. 1: Scheme of solar radiation and its responses in Earth's atmosphere.

sence of flares). X-ray effects gain significance only at high level of solar activity. Variations in the fluxes of X-rays, UV-radiation and radio emission result from the generation and evolution of active regions and from changes in the parameters of large-scale structures (G.S. Ivanov-Kholodny, 1982; G.S. Ivanov-Kholodny and A.A. Nusinov, 1979). Partly the radiation (major fraction of the UV-range) is caused by quiet solar radiation which can be assumed constant within the considered range ($t \lessapprox 3$ days). Large-scale structure variations within such time intervals are related to the emerging of magnetic fluxes at the solar surface, and (to a less extent) to the general movement of structure boundaries (N.N. Stepanyan, 1983).

Data on radiation flux on a dozen of spectral wavelengths ($5 \div 10$ Å each) in the X-ray range and on $20 \div 30$ wavelengths (15-50 Å each) in the UV-range are required to evaluate the ionospheric state (G.S. Ivanov-Kholodny and A.V. Mikhailov, 1980). Unfortunately, a reliable real-time service for UV-radiation control is unavailable at present, and information on X-ray characteristics is obtained in a limited form. That is why, while forecasting we use the value of radio flux on $\lambda = 10.7$ cm correlated with the short-wave radiation rather than short-wave emission characteristics. Therefore, methods for predicting radio flux and indirect methods for forecasting UV-and X-ray fluxes developed on the above basis are of a certain interest. Routine inertion forecast of radio flux on $\lambda = 10.7$ cm yields an error of $6 \div 10$ %. Ostrovsky in his paper (G.I. Ostrovsky, 1981) suggests a quasi-invertion technique which takes into account flux variations during the previous two days. Mean square error for such a prediction does not exceed 6 %. The paper (N. Yu. Bocharova and A.A. Nusinov, 1983) presents a forecasting method based on plage area measurements and one-dimensional solar radio scanning during first several days of the active region existence. According to epignosis, on days when only one solar active region occurred, mean error is estimated as 20 % (quasi-inertion prediction yielding here about 3 %).

The paper (S.S. Fomin, 1984) presents a technique for forecasting solar UV-radiation using a fixed wavelelength $\lambda = 304$ Å. Using stochastic approximation, a solving rule is derived to obtain 1-, 2- and 3-day forecast with the accuracy of 5 - 6 % from radio data only (i.e., from $\lambda = 10.7$ cm flux) and 2 - 4 % from borth radio data and UV-flux. One should note the paper (A.A. Nusinov, 1984) which suggests a two-component model for UV-radiation variations which allows to calculate UV flux as a function of radio flux with the accuracy of about 5 %.

$$F_\lambda = B_o + B_1 (F_b - A)^{2/3} + B_2 (F_{10.7} - F_b)^{2/3} ,$$

where: B_o, B_1 and B_2 are λ -dependent constants;
F_b is the background radio flux on $\lambda = 10.7$ cm;
$F_{10.7}$ is the total radio flux on $\lambda = 10.7$ cm.

Thus, with radio flux prediction being available, one can forecast short-wave radiation flux. At present it is difficul to judge whether it can improve at least the inertion forecast from very short-wave radiation. Fig. 2 pre-

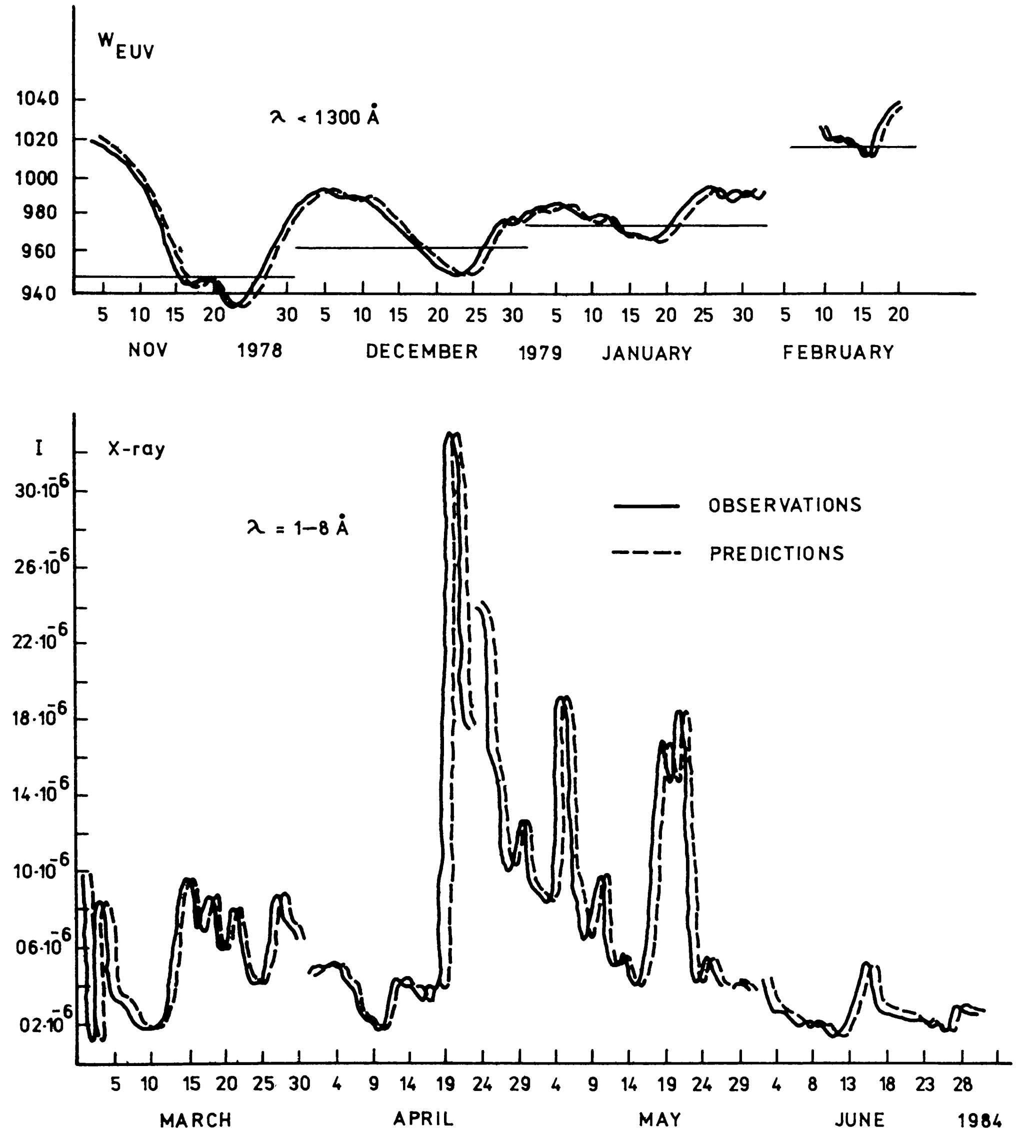

Fig. 2: Recors of the UV and X-ray solar variations.

sents characteristic examples of records of the UV- and X-ray variations (G.S. Ivanov-Kholodny and T.V. Kazachevskaya, 1981; Solar Geophys. Data, 1984) in the absence of flares. It also shows the inertion forecast, i.e. predicting presentday level of radiation for the next day. The error for UV-radiation is seen to be practically absent (less than 1 %), while that for X-rays is rather large (≈50 %). In case of ionospheric prediction a 5 %-accuracy for UV-

-radiation, and 20 % one for X-rays is sufficient.

Let us go back to Fig. 1. It follows from the Figure that the information on large-scale structures is an important element of geophysical prediction. Here we mean coronal holes and large-scale magnetic fields. Note that while electromagnetic radiation reaches the Earth practically immediately ($t < 10$ min), the information on magnetic field reconstructions that propagate with the solar wind velocity reaches the near-Earth space in 3-6 days. Therefore, even current information on large-scale structure distribution to a great extent provides short-term geophysical prediction. Forecast of coronal holes and large-scale magnetic field distribution is not actually available, though it is required by both the services studying the disturbance propagation from the Sun to the Earth, and heliophysical services. Here one can also expect satisfactory prediction of the boundary locations of the large-scale structures, since such structures are normally rather stable, and their characteristic lifetime considerably exceeds forecast period. At the same time, drastic reconstructions in the large-scale field can be observed within a single day (V. Bumba, 1983). It is usually related to the emergence of an oppositely polarized flux and/or appearance of an active region. Such fluctuations are removed from the synoptic chart for a single Carrington rotation but on a given day they can affect the considered processes and destroy our prediction. Perhaps, it is also expedient to consider the problem of predicting the index in helium line λ = 10830 Å (G.B. Gelfreikh et al., 1984). However, studies in this direction have been just initiated. As to the location of structural boundaries, one should start with correlating diurnal charts, establishing an archive and testing forecasting procedures (at leat trivial ones) on the basis of real-time data.

To sum up the abovementioned, the major impediment in solving the problems related to short-term prediction of non-flare radiation is the lack of patrol observations. What kinds of observations are required first and foremost?

X-rays:

Continuous regular measurements within several spectral ranges (1-100 Å) are desirable. It is also possible to calculate soft X-ray fluxes on the basis of reference spectrum technique (A.A. Nusinov, 1985) from the data on the flux in the range of 8-20 Å and 1-10 Å with the accuracy about 20 %. At present organization of such continuous measurements is not complicated in principal, though a closer cooperation with INTERKOZMOS is required (B. Valnichek, 1984).

Ultraviolet radiation:

Absolute measurements of spectral characteristics with the accuracy about 10% are also required here. However, absolute measurements with the above accuracy are not carried out at present. It is associated with the complicated calibration of UV-radiation receivers. Calculations in reference spectrum from radiation data in the line λ = 584 Å also yield the accuracy under 20 % (E.A. Bruyevich and A.A. Nusinov, 1984).

Large-scale magnetic fields:

Until present the services in socialist countries have failed to carry out similar magnetographic observations. However, the telescope STOP (Solar Telescope for Operational Prediction) developed in the USSR (V.M. Grigoryev et al., 1984) can solve the above problem, and within current fine years we hope for the organisation of such a service.

As far as determination of the filed structure from filament observations in H_α is concerned, such observations are carried out but their regularity and real-time characteristics fail to provide for the tasks of operational prediction. Let us add the following: to solve the problems on the distribution of matter, it is advisable to obtain large-scale magnetic field distribution not only in the photosphere but also in the transition zone and corona, since the obtained charts not always concide, though correlate with each other. Therefore, it is worth noting the possibility to obtain data on large-scale field structure at high altitudes from radio polarization measurements (S.I. Avdyushin et al., 1983). However, large antennas and highly stable equipment are required for the above measurements.

Coronal holes:
Possibilities to predict coronal holes from optical data are available nowadays (V. Rushin and M. Rybansky, 1984). But this is insufficient. Observations in the helium line λ = 10830 Å and X-ray charts are needed. To measure coronal hole parameters indirectly it is necessary to obtain X-ray images at least once in two days.

In our opinion, establishing such types of patrol will enable to solve the problem related to short-term forecast of non-flare solar radiation.

Let us return to Fig. 1 once more. The most common and complicated element of prediction is the solar flare forecast. Though the problem has received and still receives the greatest attention and has been considered in various papers (A.F. Altyntsev et al., 1982; S.I. Avdyushin et al., 1984; L.I. Miroshnichenko, 1985), let us also touch upon this aspect.

A remark should be made here. Forecast should include information on the forthcoming flares with the period which could allow the user to take necessary measures for diminishing possible damage. Prediction of qualitative character ("flares possible") allow for the before.hand preparation of these or those modes of operations; quantitative prediction ("maximum flux is to amount to 10^n erg/cm^{2}s") enables to carry out activities in accordance with the expected radiation level. Since the minimum period "Δ t" between the obtaining of information for the prediction and the taking of relevant measures by the user is hardly likely to be less than an hour, forecast for a shorter period have no practical importance or, at least, should be of qualitative character.

During past five years we made no progress in forecasting flares with the help of the models for physical processes in the flares. We still have not achieved clear understanding of the pre-flare energy storage and the way of the energy release. At least, we have neither numerical criteria not the list of actually controlled parameters, nor even the description of the process on the basis of the observed characteristics during concerned time intervals.

The key problem while developing short-term flare prediction is that of energy storage and release. Along with traditional mechanisms based on the concept of Syrovatsky (B.V. Somov, 1985, 1986), alternative models are stu concept of Syrovatsky (B.V. Somov, 1985, 1986), alternative models are studied. Thus Mogilevsky (E.I. Mogilevsky, 1983, 1984) has been developing a model for active processes on the basis of synergetic description. Possible energy transfer from larger structures to smaller ones during the active region evolution is considered self-waves and spiral waves in flare-active regions are analyzed, possible energy storage resulted from non-linear MHD-waves (solitons) is discussed. However, the above theory at present has suggested no specific observed parameters to be used in operational prediction. The paper (A.D. Chertkov et al., 1984) presents a model of the flare with the under-photospheric energy source, based on similar concepts. Unfortunately, as the authors indicate that it is difficult to test the model theoretically or experimentally. Critical parameter of the flare is the dome structure of the magnetic field which results from the interaction between the large-scale field and active region field. I.E., measurements of the transverse magnetic field are required. One can note that the flare occurrence in such a structure is also highly probable according to traditional schemes. During recent five years calculations of the active region magnetic field have been considerably developed. The paper (S.I. Gopasyuk et al., 1983) shows that, as a rule, flare activity is observed when the measured magnetic field sufficiently differs from the potential one. Powerful (up to 2000 A/km^2) vertical currents should be observed in such regions. Similar behaviour of the magnetic field allows to reveal relevant prognostic criterium. The papers (V.I. Dolgopolov, 1985a, b, c) presents computer model for the field distribution constructed from active region observations in the moment t_o, and the field distribution forecast for $t_o + \Delta t$. When Δt = 6 hr, the observed field rather well (r 0.8) correlates with the predicted one.

Certain hopes are associated with proper motions of spots. In recent years the interest has grown due to the "popularity" of shear movements. The papers by Dezso et al. (1984) and Kálmán et al. (1984) considered spot movements and variations in magnetic field structure in relation to flares. The occurrence of "shear" was shown to be a precursor of solar flares. The papers (R.N. Ikhsanov, 1985; R.N. Ikhsanov and G.P. Shchegoleva, 1985) show that the occurrence of a new magnetic flux is followed by solar flares in the nearest day or two. The paper (A.A. Golovko et al., 1985) suggests a general pattern of large-scale structure (magnetic field and velocity field) impact on the active region structure in the vicinity of polarity boundary. Observations of the above impact can provide the information on the region transition to a flare-active phase.

Practical application of the above results in flare forecast requires continuous observations by vector magnetograph, measurements in H and white light, the obtaining of beam velocity charts.

Let us consider the papers on revealing informative parameters of active regions. Studies on the effect of pre-flare increase in solar radio pulsations as a possible prognostic parameter have been continuied. The paper (M.M. Kobrin et al., 1984a) studied long-term $T \approx 20$ min pulsations of 3 cm radio emission in several periods of 1970-1983 which covered 15 proton events. There is evidence for the amplitude increase in 1-3 days before the proton event. However, the problems related to the possible observation of similar enhancements in the absence of strong flares have been studied poorly. The paper (M.M. Kobrin, 1984b) analyzed the fluctuations of H-component of the geomagnetic field before strong flares. Pulsations with $T \approx 20$ min are also observed here, which can be associated with solar radiation pulsations. The paper (A.A. Zhdanov and Yu. E. Charikov, 1985) presents frequency analysis of the pre-flare soft solar X-rays from Prognoz satellite. Significant periods of 2; 10; 40 and 90 min are revealed. It is shown in (G.M. Blokh and B.M. Kuzhevsky, 1984) that a day before solar cosmic ray flare the enhancement of low-energy proton flux is observed. Such an increase was observed in 28 cases from 33 ones (i.e., in 85 % of cases). Similarly to papers by M.M. Kobrin et al., the problem of possible enhancements of such fluxes without following flares is uncertain.

Tet us also note the paper (E.A. Bryuevich and A.A. Nusinov, 1985) which presents the method of predicting major optical flares on the basis of calculating the ratio between X-ray intensities within the range of 8 - 20 Å and UV-radiation intensity in the line 584 Å. The obtained results carry no evidence for obtaining a satisfactory prognostic rule, since here we are not dealing with a prediction, but the suggested parameter along with the other ones, can possibly yield useful information. Similar approach is used in the paper (L. P. Morozova and V.N. Obridko, 1984) which reports on solving the problem of X-ray flare prediction from calculating variations in radio flux on $\lambda = 3.2$ cm. Here, the authors were not enough correct while introducing the estimates of prognostic rule efficiency. The analysis of the obtained results (carried out together with one of the co-authors) has shown the obtained rule to be unsatisfactory. Below we shall consider the aspect of qualitative assessment of the predicting rule.

All operational methods of flare prediction are based on revealing empirical and statistical relationships. The major guideline in developing and improving the methods is related to computer application and derivation of formalized solving rules. The papers (E. Paszkiewics, 1985; V.A. Burov, 1985, 1986) can serve as an example of the above direction. The paper by Paszkiewics presents the results of X-ray flare prediction for the coming day on the basis of multi-variat discriminative analysis (MVDA). 20 characteristics of active regions are used as input ones. Prognostic rule was derived on the basis of the following periods: 01.07.83 - 10.08.83 (first variant) and 08.03.84 - 01.05.84 (second variant). Testing was carried out from observations during 11.08.83 - 14.04-84. Table 1 presents the results of the rule application.

Table 1

Observations / Forecast	No flares	C	M	X	Total number of forecasts
No flares	10	15	0	0	25
C	3	7	1	0	11
M	1	7	0	0	3
X	0	0	2	1	3
Total number of events	14	24	3	1	42

On the basis of the given data it is difficult to speak about obtaining a satisfactory solving rule for 4 classes both due to limited statistics (42 cases) and due to poor probability of correct predictions according to the classes. In case of dividing into two classes: "flare/no flare" - reliability amouts to 55 %. In contrast to the papers cited above, here we mean actual prediction, and the achieved quality of the rule can be evidently improved in future.

Similar approach was used in the paper which continuied the work (V.A. Burov et al., 1980). The problem of forecasting X-ray flares (algorithm "Topol" pol") was solved using observations of 20 active region parameters in 1978 (1366 vectors). Table 2 presents the results for 3 classes.

Table 2

Forecast Observations	0	C	M+X	A	P(A/H)
0	1220	31(35)	6(2)	1260	97 %
C	47	36(37)	3(2)	86	42 % (43)
M+X	1	1(11)	21(11)	23	88 % (48)
H	1268	68(83)	30(15)	1366	
P(H/A)	96 %	53 %(45)	70 %(73)		

Here, unlike the previous paper, the procedure of rule derivation was not entirely automated, the search being carried out through several stages. The numbers given in brackets are obtained in case 38 vectors that were not provided with sufficient information are referred to class "C", the most probable flare class. Algorithm "Vetka" (V.A. Burov, 1984) was developed on the basis of pattern recognition technique to provide a more automated procedure for rule derivation. Operational capacity of the algorithm was tested by the data of 1981 - 1982 (V.A. Burov et al., 1984). Reliability of optical flare prediction for a day in two classes amounted to 85 %.

The major part of known flare prediction methods are based on optical classification. At the same time, X-ray event forecast is more important for practice. It seems useful to consider relations between the above classifications to evaluate possible application of the earlier obtained flare predictions in predicting X-ray events. Such an attempt is made in (V.A. Burov, 1986). Fig. 3 presents arbitrary probabilities of X-ray flares in the presence of optical flares. In particular, it follows that the relationship between X-ray flares and small (≤ 1) optical flares is rather weak.

The problem of proton event prediction remains unsolved. Diagnosis of such flares and proton flux development prediction are not considered here, since it is beyond the limits of the present report. Relevant data can be found in (L.I. Miroshnichenko, 1985; S.I. Avdyushin et al., 1983). As to the methods of predicting such events for several days, relevant papers are not numerous. Efimenko (V.M. Efimenko, 1983) has considered the problem related to

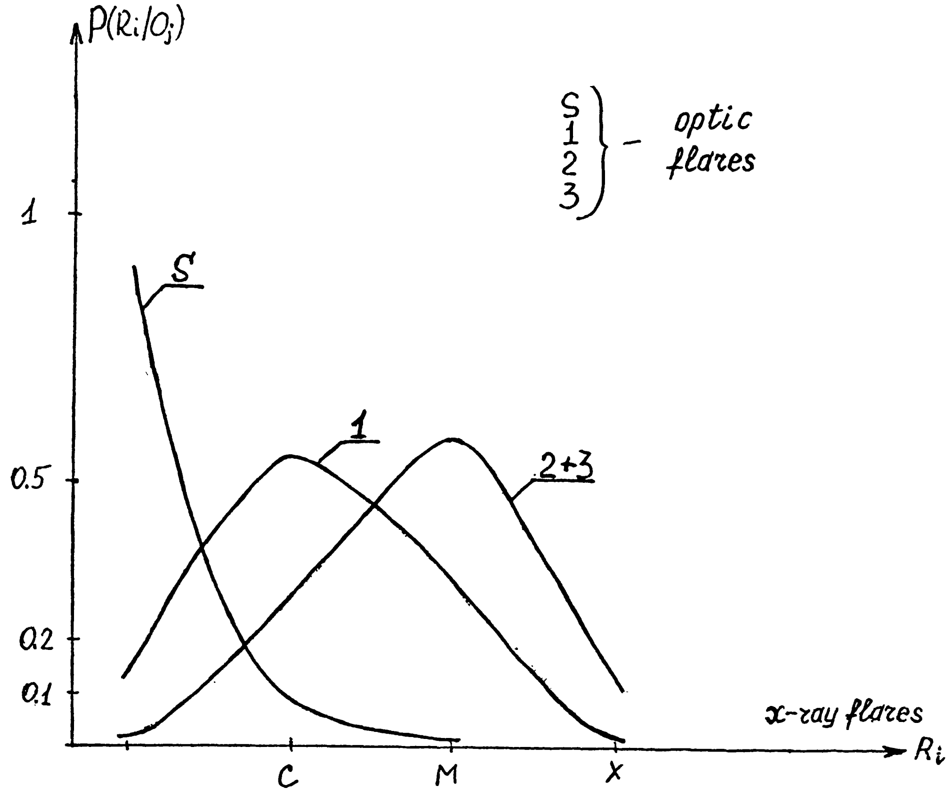

Fig. 3: The arbitrary probabilities of X-ray flares in the presence of optical flares. The relationship between X-ray flares and small optical flares is rather weak.

proton flare prediction for three and five days (with no reference for a particular day of flare occurrence). The problem was solved using the method of false disturbances on the basis of observational data on 15 active region parameters during three previous days. 91 % reliability is obtained for a three-day forecast, and 87 % for a five-day one for 1968-1969 (180 sunspot groups).

The paper (V.M. Efimenko and V.V. Telnyuk-Adamchuk, 1984) considered the problem of predicting one of the classes with high probability. By means of successive exclusion of parameters impeding the recognition of the concerned class, the authors achieved 100 % recognition in the considered class, while preserving 20-40 % of correct predictions in a competitive class. To our mind, such a problem is of practival significance but in a general case it is solved by introducing error costs and searching minimum losses.

Summarizing the above papers, it can be noted that reliability of alternative flare forecasts (for the accepted prediction texts) amounts to 85-90 % for archive data. All prediction techniques indicate the moment of flare with the time period no more than a day. Indication of time interval up to 4-6 hr would allow for a considerable improvement of short-term geophysical predictions. However, method designers can only use observational data on one measurement of active region parameters or total events for a day. The major part of information is obtained once a day. It is natural that prediction period specification is only possible in case the data are obtained more frequently (in real-time as an ideal case). This will lead to the organization of relevant communication channels and complete transition to computer processing and transmission.

Since all flare prediction schemes are based on empirical and statistical approach, criteria for evaluating the quality of solving rules play the crucial role in estimating the results. In fact, while physical models can be accepted or rejected depending on their correspondence to physical laws and correctness of mathematical calculations recommendations on the applicability of statistical prediction designs can only be made on the basis of experimental testing. The main argument is the following: whether the forecast is "good" or not. Incorrect selection of an estimation criterion can not only result in a false image of the operational capacity of the method but also lead to a worse result as compared to the one expected while using the considered method. Recommendations on selecting the criteria are available in (A.T. Altyntsev et al., 1982; V.A. Burov, 1981). The main source of errors in statistical forecasts is non-representativity of the sample from which the solving rule is obtained in relation to general complex, as well as changed (non-stationary) distribution within the alarm interval. A practically faultless rule (e.g., a complicated curve dividing two groups of points on a small surface area) can be obtained from a sample of finite length; however, this does not mean equally good division throughout the whole data. I.e., distinguishing the objects which formed the basis for the rule ("learning") does not guarantee similar division while forecasting ("examination"). In other words, the quality of the rule should be tested using independent statistical material. The obtained results (reliability) should be compared with the known or trivial (inertion, climatological, etc.) forecasts made using the same data. One should be especially careful while estimating climatological probability of events considered in the problem. The increase in reliability should be statistically significant, which results in requirements to the length of the testing sample. In a general case, the decision on the forecast usefulness should be made on the basis of calculating the losses (or benefits) of the user, and the_solving rule is optimized using risk function calcilations. To this end, it is necessary to determine (together with the user) comparative costs of false alarms and skipping of events.

So, what problems should be solved to improve short-term prediction?

Forecast of non-flare component:

- Organizing patrol observations of X-ray and UV-radiation within several spectral ranges.
- Patrol of the large-scale magnetic field, and coronal holes.

Flare prediction:

- Development of dynamical models for the active region and flare processes. The significance of the problem is evident.
- Development of prognostic techniques from radio data. At present optical observations only form the basis of prediction. If we secceed in obtaining reliable criteria within the radio range, it is possible to reduce the number of observational sites (since radio observations are practically independent of weather), and to lower the costs of communication channels, computer facilities, personnel, etc.
- Development of methods for predicting flare particle fluxes prior to the moment of flare. The problem is far from being solved, and there are no available information concerning the ways of its solution.
- Development of methods for flare predicting with the indication of a more precise (4-6 hr) period of its appearance. In our opinion, the problem could be solved using the data on physical processes within the active region and applying known flare predictors observed in a short (hour) period before its appearance.
- Organization of a data bank on active region characteristics ready to be directly used with the help of computers. This is especially important for those who work with large data samples. Similar data bank is being established at WDC-Moscow (B.V. Danilichev, 1985).
- Observations. Any forecasts are based on observational data. The truth is common knowledge and requires no proof. What observations are lacking at present to improve the techniques (to increase reliability, specify the texts, and transfer to quantitative prediction)? Measuring the vector of the active region magnetic field, obtaining the charts of mass velocities, measuring the characteristics of large-scale structures, obtaining high-resolution tion solar radio charts (intensity, polarization) on a number of frequencies obtaining X-ray images.

Nowadays the above observations are carried out episodically, and the instruments to provide for them are small in number. In addition to developing the equipment, joint observations in the framework of KAPG should be conducted according to observational programmes coordinated in advance. In this case the efficiency of observational facility application considerably increases.

In conclusion, the authors hope that during current five years KAPG member-countries would succeed in solving some of the abovementioned problems and thus obtaining significant effect of our scientific recearch.

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DISCUSSION

Yu.I. Vitinsky

Хотя это и не относится к научным вопросам изложенным в докладе, было бы очень важно организовать устойчивую связь с прогностическими центрами для передачи полной информации, включая карт. Без этого вряд ли можно ожидать эффективного прогнозирования солнечной активности с малыми интервалами заблаговременности.

V.A. Burov

Да. Это очень важно при практическом прогнозировании. В данем докладе идет речь о разработке и проверке методик прогноза.

V. Bumba

Разрешите добавить к тому что было сказано в дискуссии:

а/ для прогнозирования вспышек в активных областях не нужны карты крупномасштабного поля. Достаточно если у Вас нормальные магнитные карты данной области с нормальным разрешением (порядка от 2" до 10").

б/ протонные области опытный наблюдатель узнает сразу после их появления из-за лимба или даже во время их формирования. Но предсказать когда появится протонная вспышка, через несколько дней, это иногда бывает трудно.

в/ Вспышек много типов, в зависимости от их места рождения относительно магнитного поля, от типа области, высоты и других параметров. Но до сих пор вся беда в том, что для прогнозирования этот факт не учитывается.