

# User Manual for M8

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# 1. Introduction

Earthquake prediction is an uncertain profession. Following the Good Friday Alaskan earthquake, the U. S. president's science advisor called a panel which recommended a ten year program of research on earthquake prediction (1). Stimulated by this recommendation the U. S. Geological Survey began a major program of research in 1966. Japan, China and the Soviet Union also began, at about the same time, large research programs on earthquake prediction. After almost thirty years of serious research, however, a reliable method to predict strong earthquakes does not exist.

Many methods for earthquake prediction have been proposed and some of these methods may be reliable. The problem is that most of these methods cannot be tested and evaluated either in lieu of their precise definition or due to small sample statistics.

Mathematicians and geophysicists at the International Institute for Earthquake Prediction Theory and Mathematical Geophysics in Moscow have applied methods of pattern recognition to the problem of earthquake prediction (2). V. I. Keilis-Borok and V. G. Kossobokov developed the M8 algorithm which has successfully predicted several strong earthquakes (3). Earthquake predictions from this algorithm have been presented to the U. S. National Earthquake Prediction Evaluation Council, NEPEC (4), and NEPEC has recommended that the USGS undertake an evaluation of this algorithm. After successful prediction of the Loma Prieta 1989 earthquake J. H. Healy, V. G. Kossobokov, and J. W. Dewey (5) designed a rigid test to evaluate the M8 algorithm. Since 1991 each half-year the algorithm has been applied in a real time prediction mode to the seismicity of the entire Circum Pacific seismic belt. The experiment is set to predict magnitude 7.5+ earthquakes and we expect that in five years there will be more than ten of them in the territory considered.

This publication intends to facilitate communication and better understanding of the intermediate-term earthquake prediction method as it provides ultimate description of the algorithm, i.e. a program with a source code and a set of fixed parameters. M8 is a computer program written in Fortran 77 that allows for the intermediate-term prediction of earthquakes using the M8 algorithm, as well as the evaluation of a time series of several integral counts based on the transient seismicity in a region. These

counts might be useful for an independent analysis of seismicity.

The first version of M8 dates from 1986 when the algorithm was distributed among participants of the Workshop on Earthquake Prediction held in Lima (Peru). Its parent programs were in operation in 1984, when Keilis-Borok and Kossobokov presented the first results related to retroactive prediction of magnitude 8.0+ earthquakes worldwide (5). Here we provide the 1991 versions for IBM-compatible personal computers (PC, XT, AT, 286 PC, 386 PC, 486 PC, 586 PC, PS/1, and PS/2). A version for batch runs is used in updates of the test of the M8 algorithm (6). Another version permits interactive change. Both versions have the same computational core, and therefore give identical output for the same set of input parameters. In 1992 J.-B. Minster and N. P. Williams (7) reprogrammed M8 using the C language in a form, which might be more suitable for statistical evaluation. (Final results obtained from their program, M8C, and from M8 may differ due to different roundoffs in the evaluation of functions.)

The user should understand that catalog errors may impact all of the quantities determined by M8 since they may change the population of events which are counted, especially, when these errors have long term systematic nature (8). Therefore we strongly recommend the user to start his application with a thorough analysis of the input catalog for completeness and for presence of duplicates.

The authors emphasize that any specific prediction can be made only on experimental basis, and users are advised to disclaim any liability for consequences of actions based on their predictions. Accordingly the authors disclaim liability for any consequences of the use of this program. Let us remind also that each prediction of a large earthquake must be released by a qualified scientific body to proper local authorities.

It should be mentioned that the M8 program allows broad variation of parameters including a set of measures, two different shapes of an area of investigation, size of areas and other constants of the M8 algorithm. Therefore M8 program should be considered as an exploratory tool which permits, when set to default values, to run the M8 algorithm. In the next section (Section 2) we start with a description of the M8 algorithm along with definitions of the measures which are traditionally used and conclude it with a more general scheme which is employed in M8. The following two sections describe hardware requirements and software installation. Section 5 lists all input parameters of M8. In Section 6 we provide an example of

application of the M8 algorithm to predict the Great Guam August 8, 1993,  $M = 8.2$  earthquake. This section contains also the table with the description of the dialog, and an explanation of how to run the batch version of M8. Then we describe the output of M8 (Section 7) and possible error messages (Section 8).

## 2. The M8 Algorithm

### The circles of investigation, CI's

The M8 algorithm examines seismicity in circular regions. In early testing of the algorithm on magnitude 8+ earthquakes the best results were obtained using a radius of six degrees of the Earth meridian, i.e. 668 km. Previous work had established a rough scaling law between magnitude and source dimensions (9). After some testing the developers set the relationship between the radius of the CI and the magnitude of the predicted earthquake,  $M_0$ , as:  $R(M_0) = 55.5 \cdot (\exp(M_0 - 5.6) + 1)$ ; which gives, 668 km for magnitude 8.0, 427 km for 7.5, 281 km for 7.0 and 192 km for 6.5.

### Aftershocks

The strongest statistical effect in earthquake catalogs is aftershock phenomenon, the clustering of smaller earthquakes following the occurrence of a larger earthquake. Aftershocks can mask weaker phenomena unless something is done to suppress or remove them. In the M8 algorithm aftershocks are defined as all of the smaller earthquakes that follow a larger earthquake within a time and distance that are functions of the magnitude of the mainshock. For purposes of the algorithm the time and distance that define the aftershock zone are arbitrarily set to an exact value in a table from (10):

Magnitude, M	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0+
r(M), km	40	40	50	50	50	100	100	150	200
T(M), days	23	46	91	183	183	365	730	913	1096

All the earthquakes that occur in an "aftershock zone" are removed from the catalog to produce a catalog of "mainshocks". This definition of aftershocks and mainshocks oversimplifies a complicated issue, but seems rather adequate for our purposes.

## **Selecting a starting time and magnitude cutoff**

Following the methods of pattern recognition the data is transformed by a number of functions. The most important part of these transformations is the averaging over time and space. The spatial averaging is accomplished by selecting all of the earthquakes in a given CI. The time averaging is accomplished by summing the values over the preceding  $s$  years. To count earthquakes we must deal with two important questions: the time interval over which the earthquakes are to be counted and the magnitude of the earthquakes.

The time interval selected for analysis is largely determined by the quality and completeness of the seismic catalogs. In the 1960's the quality and completeness of the global catalogs were improved with installation of the Worldwide Seismic Network. Since 1963 all the earthquakes of magnitude five or greater are located and in many areas catalogs are complete to magnitude four. The beginning of the analysis is usually selected as January 1, 1963 although the time may be earlier or later depending on the quality of the local catalogs. It takes about 20 years of data for the algorithm to set the thresholds that define anomalous seismicity, so application of the algorithm is limited to a period of about 10 years in most regions when used to predict a large earthquake. Some of the functions in the algorithm may not scale with time and some changes in the method of selecting the starting time may be required for regions where there are longer periods of good data and in the future when more decades of good data are available.

In preparation of the data we recommend setting the initial cutoff depending on the completeness of the catalog. For example, in the global test of the M8 algorithm (6) we initially cut off the global catalog at magnitude 4.0, because the catalog is seriously incomplete below this threshold.

## **The Functions**

To count the number of earthquakes we must choose a magnitude cutoff. The M8 algorithm does not choose a fixed magnitude cutoff rather it chooses the number of earthquakes that are desired for the calculation. It selects in each CI two populations of mainshocks. The first one, CAT20, is defined by a magnitude cutoff that yields an average of 20 earthquakes per year. Thus, to analyze a 30 year interval the algorithm selects a magnitude cutoff that provides 600 earthquakes. Usually the selected cutoff

will yield somewhat more than 600 earthquakes. If there are less than 20 earthquakes per year in the CI we must make a decision to continue or to terminate the analysis. In the test of the M8 algorithm (6) the analysis is not performed in a CI that contains less than 16 earthquakes per year.

A second population, CAT10, is selected from the CI in the same way using the magnitude cutoff that produces 10 earthquakes per year.

These two populations of earthquakes are selected for each CI, so that the corresponding magnitude cutoffs may vary from one CI to another in response to varying levels of seismicity.

The algorithm is based on seven functions of the seismicity data -

$F_1(t)$  is the count of the number of earthquakes from the first population, CAT20, in the preceding six years;

$F_2(t)$  is the same count as  $F_1(t)$  for the second population, CAT10;

$F_3(t) = F_1(t) - F'_1(t)$ , where  $F'_1(t)$  is the average number of earthquakes per six years in the interval from the beginning of the analysis,  $t_0$ , to  $t - 6$  years. The measure is taken on CAT20;

$F_4(t)$  is the same as  $F_3(t)$  measured on CAT10.

$F_5(t)$  is a magnitude weighted sum of mainshocks divided by the number of these events to the  $2/3$  power,  $\sum 10^{0.46M_j} / (\sum 1)^{2/3}$ . The summations are taken over the preceding six years from a third population,  $CAT20a = CAT20 - \{\text{events with magnitudes } M_j \text{ above } M_0 - 0.5\}$ .

$F_6(t)$  is the same as  $F_5(t)$  calculated on a fourth population,  $CAT10a = CAT10 - \{\text{events with } M_j \text{ above } M_0 - 0.5\}$ .

$F_7(t)$  is based on a count of the number of aftershocks. To calculate the function we define a fifth population, CATMS, including mainshocks in the magnitude range ( $M_0 - 2.0, M_0 - 0.2$ ) within a given CI. The catalog of this population includes the count of aftershocks,  $B_j$ , in the first two weeks following each mainshock.  $F_7(t)$  is set

equal to the largest  $B_j$  in CATMS. in the preceding year.

The functions are evaluated every six months and it is convenient to describe them in terms of six months intervals ending at  $t_i = t_0 + (i \text{ half-years})$ . Let  $X_i$  be the number of earthquakes in the six months interval ending at  $t_i$ , and  $S_i$  be  $\sum 10^{0.46M_{ij}}$ , where  $\{M_{ij}\}$  are magnitudes of all mainshocks from the  $i$ -th half-year interval. In this notation the functions are:

$$\begin{aligned}
 F_1(t_i) &= X_{i-11} + X_{i-10} + \dots + X_i && \text{[CAT20]} \\
 F_2(t_i) &= X_{i-11} + X_{i-10} + \dots + X_i && \text{[CAT10]} \\
 F_3(t_i) &= F_1(t_i) - (X_1+X_2+\dots+X_{i-12}) \cdot 12/(i-12) && \text{[CAT20]} \\
 F_4(t_i) &= F_2(t_i) - (X_1+X_2+\dots+X_{i-12}) \cdot 12/(i-12) && \text{[CAT10]} \\
 F_5(t_i) &= (S_{i-11} + S_{i-10} + \dots + S_i)/(X_{i-11} + X_{i-10} + \dots + X_i)^{2/3} && \text{[CAT20a]} \\
 F_6(t_i) &= (S_{i-11} + S_{i-10} + \dots + S_i)/(X_{i-11} + X_{i-10} + \dots + X_i)^{2/3} && \text{[CAT10a]} \\
 F_7(t_i) &= \max B_j \text{ in the preceding year.} && \text{[CATMS]}
 \end{aligned}$$

(In [ ] we indicate the catalog used to calculate the function.)

## Votes

The functions vote for declaring of a warning or *time of increased probability*, TIP, for an earthquake with magnitude  $\geq M_0$  in the CI. The first six functions cast their vote for a TIP when they are in the top ten percent of their historic range. The seventh function votes for a TIP when it is in the top 25% of its historic range.

## TIP's

A time of increased probability is declared for the CI when five of the first six functions and the seventh function have voted sometime in the preceding three years, and when this condition is met in two successive six-month evaluations. Once a TIP is declared it lasts for five years. As new data is added to the catalog the thresholds which cause the functions to vote may change so a TIP may be terminated early or extended for more than five years.



## The M8 program

The ultimate description of the M8 algorithm is the M8 program with a set of fixed values of parameters. These are provided as default values in the program. However, the program permits one to define and run on seismic catalogs other algorithms based on the general concept of activation. According to this concept predicted phenomena are likely to occur in a system during, or following without much delay, a period of "activation" when the majority of integral measures rise above their normal values. A prediction strategy in this case could be to declare an alarm or *time of increased probability*, TIP, each time when such an "activation" is identified. In addition to the M8 algorithm the M8 program may consider square areas of investigation and up to 6 types of functions described below.

M8 computes several integral measures on a sequence of earthquakes from an area of investigation and identifies TIP's.

The user must have a catalog of mainshocks in appropriate binary format (see Input for M8).

In one run of M8 the user has a choice to consider up to 18 areas either of circular or of square shape.

The dimension of areas (i.e. radius or half-side) can be set to a constant value. The user has a choice to use an arbitrary constant or to compute it using the above mentioned equation for  $R(M_0)$ . The formula values are used as default values.

The user can consider up to 9 integral measures of the following types -

(n) count of the number of mainshocks with magnitude  $M \geq m$  in the preceding  $s$  years,

$$n(t|m,s);$$

(l) deviation of count  $n$  from a longer-term average,

$$l(t|m,s,t_0) = n(t|m,s) - n(t|m,t-s-t_0) \cdot s / (t-s-t_0),$$

where  $t_0$  is the beginning of the analysis;

(k) difference between two consecutive independent determinations of count  $n$ ,

$$k(t|m,s) = n(t|m,s) - n(t-s|m,s);$$

(v) variation of count  $n$  in preceding  $u$  years,

$$v(t|m,s,u) = \sum |n(\zeta|m,s) - n(\zeta-dt|m,s)|,$$

where  $\zeta$  belongs to  $[t,t-u]$ , and  $dt$  is a uniform step between consecutive determinations;

(s) magnitude weighted sum of mainshocks divided by the number of these events to the  $\gamma$  power,

$$s(t|m,M',s,\beta,\gamma) = \sum 10^{\beta M_j} / (\sum 1)^\gamma,$$

here the summations are taken over the preceding  $s$  years on a population of mainshocks  $\{j\}$  with magnitudes  $M_j$  from the interval  $m \leq M_j < M'$ . (Note:  $n$ -type is formally embedded into  $s$ -type for  $\beta = \gamma = 0$ .)

(b) maximal number of aftershocks in the preceding  $s$  years,

$$b(t|m,M',M_a,s,e) = \max B_j,$$

here  $B_j$  is the number of aftershocks with magnitudes above the threshold  $M_a$  in the first  $e$  days following each mainshock  $j$ , and the maximum is determined over the preceding  $s$  years on a population of mainshocks  $\{j\}$  with magnitudes  $M_j$  from the interval  $m \leq M_j < M'$ . (Note: M8 does not calculate  $B_j$  but uses the counts of aftershocks provided in the catalog of mainshocks. Therefore, the user has to rebuild the catalog of mainshocks to make changes to  $M_a$  and/or to  $e$ .)

For each measure, the user can select either of the two magnitude thresholds,  $m$  or  $M'$ , 1) as an arbitrarily chosen constant (con), 2) as a value shifted by constant from  $M_0$  (shf), and 3) as a magnitude cutoff that provides, on average in an area of investigation, constant annual number of events (act).

The user also defines the percentile to be used in determining whether a value of a measure is abnormally high or not. The program permits different percentile levels for B-type and other measures. For determination of percentiles (and, if any, magnitude cutoffs defined by constant annual numbers of events) in areas of investigation there is a choice between the interval  $(T_b, T_e)$  or  $(T_b, T_*)$ , where  $T_b$  is the beginning of the analysis,  $T_e$  is the end of the analysis, and  $T_*$  is a specific time in a given area of investigation. For example, during the M8 algorithm real-time test in Circum Pacific (6) we chose intervals  $(T_b, T_*)$ , with  $T_*$  set to the date six months before of the update or the origin time of the magnitude M7.5+ earthquake predicted in the circle of investigation.

To declare times of increased probability, TIP's, M8 computes two additional numbers,  $h(t)$  and  $g(t)$ .  $h(t)$  counts how many measures were above their normal values sometime in the preceding  $\tau_{ex}$  years, while  $g(t)$  counts how many different types of measures give positive contribution into  $h(t)$ . When  $h(t) \geq H$  and  $g(t) \geq G$  at two successive determinations ( $t - dt$ ) and  $t$ , the program reports of a TIP from  $t$  to  $(t + \tau)$ . (Here  $\tau$ ,  $\tau_{ex}$ ,  $H$  and  $G$  are given constants specified by the user.)

M8 classifies a TIP as

e.c., an "earthquake caused" activation, when an earthquake of magnitude  $M_0$  or above occurred in the same area of investigation during the time from  $(t - 2dt)$  to  $t$ , i.e. just before a TIP. The program considers such a case as no alarm;

STIP, a "successful alarm", when an earthquake of magnitude  $M_0$  or above occurred in its spatial and temporal limits;

FTIP, a "false alarm", when the alarm expired before the end of analysis,  $T_e$ , and no earthquakes of magnitude  $M_0$  or above occurred in its spatio-temporal limits;

CTIP, a "current alarm", when it is not expired before  $T_e$ , and no earthquakes of magnitude  $M_0$  or above occurred in its spatial and temporal limits.

In sum, M8 allows the user to investigate the seismicity of a region in a multidimensional space of integral measures. In such an investigation the user may get far away from the original M8 algorithm, which passed through a number of tests (at least in retroactive applications in numerous regions worldwide), and thus loose much of its reliability. The user is advised to supplement earthquake prediction results with a number of stability tests described earlier (e.g. retroactive simulation of forward prediction, etc).

To apply the M8 algorithm the user must use the default values of the program, i.e. to consider circular areas of investigation with radius  $R(M_0)$ , the seven functions ( $F_1$  and  $F_2$  of type n,  $F_3$  and  $F_4$  of type l,  $F_5(t_i)$  and  $F_6$  of type s, and  $F_7$  of type B), etc. (see above).

### 3. Hardware Requirements

To run M8 you need:

(1) An IBM-compatible personal computer (PC, XT, AT, 286 PC, 386 PC, 486 PC, 586 PC, PS/1, and PS/2) running the IBM PC-DOS or MircroSoft DOS operating system (version 3.1 or later).

(2) At least 250 kilobytes of free RAM memory.

(3) A floppy or CD disk drive.

(4) A hard disk is optional but necessary for any serious work. Floppy disk drives are just too slow and limited in storage capacity. For complete installation of the programs, auxiliary files and data for the M8 algorithm test in Circum Pacific you should have at least three megabytes of free space. At run time, you must have free room to hold output files generated by M8.

(5) A math coprocessor (compatible with your PC's CPU) is desirable, but not necessary. Without it floating points calculations will be emulated by software and will slower execution.

(6) A printer if you need to print the results.

### 4. Software Installation

Although it is possible to run M8 from a floppy, we will describe the software installation for a hard disk only.

Software installation for M8 simply consists of copying the M8 program and its associated files from NLDEP Disk. To proceed, first find the NLDEP Disk, and then follow the steps specified below. If you are **not** an experienced PC user, please consult you DOS Manual.

We assume here that (1) you have the required hardware specified in Section 3, and (2) your PC boots up on a hard disk (C:), and has a floppy and/or CD disk drive (A:).

**Step 1.** Turn on your PC. After the DOS prompt appears on the monitor, go to the root directory by issuing the DOS **cd \** command.

**Step 2.** Check once again for a free space on your hard disk by issuing the DOS **dir** command.

**Step 3.** Insert IASPEI Disk # X in the A: drive and type

**a:M8\_inst**

If your floppy disk drive is B: device in your PC, then substitute b: for a: in the above command.

After installation your PC should have C:\M8 directory with subdirectories M8\_EXE, M8\_CODE, M8\_TEST.

C:\M8\M8\_EXE directory should have the following files:

- (1) M8.EXE -- Executable program with interactive interface for making counts on sequences of mainshocks and for identification of TIP's in areas of investigation.
- (2) M8\_BAT.EXE -- Executable program to be run from command line for making counts on sequences of mainshocks and for identification of TIP's in areas of investigation.
- (3) ASC2B20.EXE -- Executable program to convert a catalog of mainshocks in an ASCII format to the 20 bytes binary format used by M8 program.
- (4) CAT\_M8.EXE -- Executable program to select subcatalog of events from specified ranges of latitudes and longitudes out of a given catalog in the 20 bytes binary format.

C:\M8\M8\_CODE directory should have the following files:

- (1) M8.FOR -- Fortran source code of M8 main program with interactive interface for making counts on sequences of mainshocks and for identification of TIP's in areas of investigation.
- (2) M8\_BAT.FOR -- Fortran source code of M8 main program to be run from command line for making counts on sequences of mainshocks and for identification of TIP's in areas of investigation.
- (3) M8\_SUBR.FOR -- Fortran source codes of subroutines for M8 program.
- (4) ASC2B20.FOR -- Fortran source code of (3) ASC2B20 program.

(5) CAT\_M8.FOR -- Fortran source code of CAT\_M8 program.

C:\M8\M8\_TEST directory should contain

(1) MS4\_NEIC.DAT -- the catalog of mainshocks prepared by P.Shebalin UPDATE program from the National Earthquake Information Center Global Hypocenters Data Base System in 20 bytes binary format, and

(2-14) 13 subdirectories with regional "profiles" to run the M8 algorithm test in Circum Pacific as on January 1, 1994 and the results of such a run.

(15) Subdirectory TIMES with the files of dates of the M8 algorithm test updates.

(16) RUN\_REG.BAT -- the batch file to run the M8 algorithm test update in a region.

(17) RUN\_TEST.BAT -- the batch file to run the M8 algorithm test update in all regions of Circum Pacific.

Each of the 13 subdirectories with regional "profiles" should have a file of regional boundaries with extension \*.CAT, an input profile with extension \*.REM (see next Section), and output files from the January 1, 1994 update with extensions \*.PRI, \*.ERS, \*.RES, \*.TIP, and \*.STR. Following is the list of the geographical names for the 13 regions: TO - Tonga-Kermadec; GU - New Guinea; JV - Java Trench; PH - Philippines; TJ - Taiwan and Ryukyu; JB - Japan-Idzu-Bonin Trenches; BM - Mariana Trench; KK - Kurils and Kamchatka; AA - Aleutians and Alaska; WA - Western United States; CA - Central America; SA - South America; SS - South Sandwich Islands.

The complete contents of these directories are given in the INDEX file of C:\M8 directory.

**Step 4.** Check the presence of the above files on the hard disk. If these files exist, remove the NLDEP Disk from the A: drive and return it to the binder.

## 5. Input for M8

To run M8 the user must specify the following parameters -

(1) Catalog file name. You must have a catalog of events in the 20 bytes binary format (a standard for earthquake data analysis used in the International Institute for Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences). (Remark: The catalog file name should not exceed 14 bytes.)

(2) Magnitude cutoff  $M_0$ . This parameter defines events to be predicted as those with magnitude  $M \geq M_0$ .

(3) Interval of analysis ( $T_b, T_e$ ). The dates (year, month, day) of the beginning and ending of determinations of measures, e.g. 1975,1,1,1994,1,1.

(4) Choice of interval for determination of percentiles. Two choices to consider values either: (1) from interval ( $T_b, T_e$ ) or (2) from ( $T_b, T_*$ ), where  $T_*$  is a specific time in a given area of investigation (e.g. the origin time of a large earthquake).

(5) Increment of determinations  $dt$ . Interval in years, e.g. 0.5.

(6) Number of functions. Total number of counts in one determination, i.e. dimension of description.

(7) Number of areas of investigation. Total number of areas to be considered in a run of the program.

(8) Shape of areas. Two options: circular or squared shape.

(9) Dimension of areas  $R$ . Radius of circle or half-side of square in kilometers. If the value of this parameter is set to 0, the program calculates  $R = R(M_0) = 55.5 \cdot (\exp(M_0 - 5.6) + 1)$ .

For each area of investigation the user has to define:

(10) Center of the area. The latitude and the longitude of the center for each area (positive values for N and E, and negative - for S and W).

(11) Time  $T_*$ . The date which is specific for the area.

For each function the user have to define:

(12) Type of measure. One of {n, l, k, v, s, b}.

(13) Type of lower magnitude cutoff. This parameter can be either an arbitrarily chosen constant (con), or a value shifted by constant from  $M_0$  (shf), or a magnitude cutoff that provides, on average, constant annual number of events (act). It is used to specify the lowest limit of magnitude range for the count.

(14) Type of upper magnitude cutoff. This parameter can be either an arbitrarily chosen constant (con), or a value shifted by constant from  $M_0$  (shf), or a magnitude cutoff that provides, on average, constant annual number of events (act). It is used to specify the highest limit of magnitude range for the count.

(15) Value of the lower magnitude cutoff. A value consistent with the type of magnitude cutoff.

(16) Value of the upper magnitude cutoff. A value consistent with the type of magnitude cutoff.

(17) Size of the time interval  $s$ . The integer multiple of the increment of determinations  $dt$  (e.g.  $s = 12$ , for time interval of 6 years and  $dt = 0.5$  year).

(18) Size of the time interval  $u$  (for v type counts only). The integer multiple of the increment of determinations  $dt$  (e.g. it equals 18, for  $u = 9$  and  $dt = 0.5$  years).

(19) Time  $t_0$ . The start point for the data used in analysis should be chosen with regard to the completeness for the magnitudes. For example, the NEIC Global Data Base System has records of events at the beginning of the century and earlier, however, in the M8 algorithm test we set  $t_0$  to be January 1, 1963 since the analysis



requires completeness of magnitude 5 events.

(20) Percentages  $p$  and  $p_B$ . The percentile levels to define what values of a function are abnormally high. By M8 program definition, the highest  $p$  (or  $p_B$ ) percent of values only vote for a TIP.

(21) Interval This parameter defines time span for counting votes for a TIP.

(22) Voting thresholds  $H$  and  $G$ . When the two measures of voting pass these thresholds, i.e.  $h(t) \geq H$  and  $g(t) \geq G$ , at two successive determinations  $(t - dt)$  and  $t$ , the program reports of a TIP starting at  $t$ .

(23) Interval  $\tau$ . This parameter sets the duration of a TIP.

(24) Choice of printout file. This parameter allows the user to chose between full-size output and short one (default). In the later, tables of function counts are omitted.

(25) Choice to save the "profile". It is convenient to store in a file all the parameters for one run of M8. Such "profiles" permit the user to reproduce the results achieved in the past. They are very helpful when the user makes numerous runs with few changes of parameters. If needed, the program can output all the parameters into a profile of special format, with the name specified by the user.

Because of the limited number of typeface characters used in the M8 program there is a need in the following table which clarifies equivalence of the constants.

Constant	Name in Dialog	Description
$M_0$	Mo	Magnitude cutoff which defines large events
m	M	Lower magnitude cutoff for the count
$M'$	MM	Upper magnitude cutoff for the count
$M_a$	Ma	Magnitude cutoff for the count of aftershocks
$t_0$	To	The start point of the analysis
$T_b$	Tb	The beginning of determinations of measures
$T_e$	Te	The ending of determinations of measures
$T^*$	$T^*$	A specific time in a given area
dt	dt	The step between determinations of measures
$s, u, e$	s, u, e	Intervals of time for determination of measures
$\tau$	Tau	The duration of a TIP
$\tau_{ex}$	Tex	The time span for counting votes
$\beta$	beta	The constant for exponential weights in $s(t)$
$\gamma$	d	The power for denominator in $s(t)$
H, G	H, G	The voting thresholds

## 6. Running M8

The M8 program can be run either in interactive mode or in batch mode. In interactive mode the parameters are entered through an interactive dialogue with the program. In batch mode the parameters are entered through a special-format "profile" prepared by the M8 program or with the aid of any DOS text editor. We

recommend first running M8 program in interactive mode and create some profiles (e.g. with the default values of the parameters). Our experience in distributing the program at Workshops on earthquake prediction (Lima-Peru, 1986; Trieste, 1988, 1991 and 1993; Caracas, 1991) shows that it might be very useful to start with an example. The participants of these Workshops performed "postdictions" of the Mexican (1985), Spitak (Armenia, 1988), Loma Prieta (California, 1989), Limon (Costa Rica, 1991), and Landers (California, 1992) earthquakes. We suggest the user to begin with one example of the application of the M8 algorithm using the available global catalog of mainshocks MS4\_NEIC.DAT.

## An Example.

Check that C:\M8\M8\_EXE directory with M8.EXE is in your PATH and that your working directory has the catalog of mainshocks MS4\_NEIC.DAT from the IASPEI Disk # X, then execute **M8**. Opening information will appear on your monitor with the question **Some profile (y-n-name) ? =>** at the bottom.

By convention the program gives in brackets possible answers with a suggestion. You can agree with the suggestion by answering **/**, if not you should type in your own answer. Let us start with the default parameters by answering **n** to the opening question.

The program will show the default parameters of the M8 algorithm which were used for the prediction of the Loma Prieta 1989 earthquake as a magnitude 7.0+ event in circle centered at 36°N, 120°W, and will ask for **Any changes?(n-y) =>**

In the first run we recommend to go for changes (answer **y**) and correct the file name of the catalog and some other parameters. As an example, let us consider that we want to know whether or not the Great Guam August 8, 1993 magnitude 8.2 earthquake occurred within a TIP diagnosed by the M8 algorithm. After answering **y** the program will ask the user to specify **Number of block to be corrected?(1-5) =>**

The M8 program parameters are arranged into 5 blocks specifying - (1) catalog of mainshocks and magnitude  $M_0$  that defines earthquakes to be predicted; (2) temporal constants of analysis; (3) areas of investigation; (4) functions; and (5) constants of

a TIP diagnostics. In our example we should not change anything but the catalog name, the constant  $M_0$ , the ending of analysis, and location and specific time of the CI. Thus, we have to make corrections of blocks **1- 3**. Let us start with **1**.

(Note: For a larger set of areas of investigation the list of all parameters may not fit one screen. In such a case the user can go for changes in a block he wants to check.)

The program displays parameters of the first block and asks **Is it correct?(y,n,1-5)** => No, we want to change the catalog name and set  $M_0 = 8.0$ . After **n**, the program will ask for **Name of file with main shocks?(mWestUS.dat )** => Let us type in **ms4\_neic.dat** (we assume that this file is in your working directory). For request **Mo = 7.00 ?** => type **8.0**. The program will display the first block with your corrections and will ask again **Is it correct?(y,n,1-5)** => If the corrections are right, type **2** to change  $T_e$ .

The program displays parameters of the second block and asks **Is it correct?(y,n,1-5)** => Here we have to change  $T_e = 1990/01/01$  for  $1994/01/01$ , i.e. the end of the NEIC catalog available. After **n**, the program brings on the screen **(Tb, Te) = (1975, 1, 1, 1990, 1, 1) ?** => Answer **1975,1,1,1994,1,1**. (It is possible to give shorter answer **,,,1994/** because of convention of numeric input.) Answer to the further requests in this block with **/**'s. After the program displays the second block with your corrections and the message **Is it correct?(y,n,1-5)** => , check if the corrections are OK, and type **3** to change the settings of areas of investigation.

Now the program displays parameters of the third block and the message **Is it correct?(y,n,1-5)** => Note that one change in the block was already made when we set  $M_0 = 8.0$ . The value of  $R$  now is 668 km, but not 281 km as it was for  $M_0 = 7.0$ . After **n**, the program brings on the screen **Shape of area?(1 - squares or 2 - circles) : (2)** => The 2 in brackets indicate that the current choice is "circles". Answer with a **/** or type **2** to accept this shape. For **R = R(Mo) km? (punch 0 for R=R(Mo))** => answer with a **/** or type **0** to accept this choice. Next the program displays the area specific info listed in table and asks **Correction, deletion or addition?(c-d-a-n)** =>. Answer **c** for correction and then follow the table below:

Question	Answer
<b>Area No.? =&gt;</b>	<b>1</b>

Latitude?(36.00) =>	13
Longitude?(-120.00) =>	145
T*: year, month, day?(1989,01,01) =>	1993,7,1
Correction, deletion or addition?(c-d-a-n) =>	n

The program displays the second block with your corrections and the message **Is it correct?(y,n,1-5) =>** , check if the corrections correspond to location at 13°N, 145°E in Marianas and to July 1, 1993, i.e. near the epicenter and about one month before the Guam 1993 earthquake (by convention positive values are given to °N and °E, and negative - to °S and °W). Then type **y** to finish changes of the settings.

The program will show the parameters of the M8 algorithm as if we are using it to predict the Guam 1993 earthquake as a magnitude 8.0+ event in the circle centered at 13°N, 145°E, and will ask for **Any changes?(n-y) =>** Answer **n**.

For **Do you want to print functions?(y-n) =>** , answer **y**. For **Do you want to save a profile?(y-n) =>** , answer **y**. For **Name the profile, please =>** , type some file name, e.g. **guam.rem**. The program then starts the calculations.

At the end of a run the program reminds that ----- **Outputs are in files m8.\*** -----.  
(The contents of these files are described below.) By inspection of the M8.PRI file you can check that the Guam 1993 earthquake did occur in a STIP.

If you do not want to lose results during the next run, rename output files using the MS DOS **ren** command, e.g. execute **ren m8.\* guam.\*** (we assume that M8.EXE is not in the same working directory).

## Changing the algorithm.

The program permits variation of all parameters including the list of functions, so that the user may create his own algorithm which has nothing to do with the M8 algorithm. The M8 algorithm is neither optimal nor unique algorithm for the intermediate-term prediction of earthquakes. The fact that several large earthquakes were predicted and more than fifty retroactive case-histories of successful predictions are established speaks in its favor. However, after almost ten years of study of premonitory activation we are still in the field of small sample statistics.

Thus, there is the need for additional testing and control experiments in each particular case.

## Description of the dialog.

Following is the table of questions of the M8 program dialog and possible answers together with the program responses:

Question	Answer and response of the program
1. Some profile?	y - goes to Q. 2; n - the default is used, goes to Q. 3; the name of profile - goes to Q. 3.
2. Name of profile, please	the name of profile - goes to Q. 3.
3. Any changes?	y - goes to Q. 4; n - goes to Q. 43. Comment: Before this question the table with all parameters considered is displayed.
4. Number of block to be corrected?	1 - goes to Q. 5; 2 - goes to Q. 8; 3 - goes to Q. 12; 4 - goes to Q. 20; 5 - goes to Q. 38.
5. Is it correct?	y - goes to Q. 3; n - goes to Q. 6; an integer from 1 to 5 - see answers to Q. 4. Comment: Before this question block No. 1 concerning the catalog is displayed.
6. Name of file with main shocks?	/ - the file with the displayed name will be used; the name of the file with main shocks which will be used.
7. Mo= *** ?	/ - the displayed value ( *** ) of Mo will be used; the value of Mo which will be used.

8. Is it correct?	y - goes to Q. 3; n - goes to Q. 9; an integer from 1 to 5 - see answers to Q. 4. Comment: Before this question the block No. 2 concerning common time constants is displayed.
9. (Tb,Te)=(***,***)?	/ - the displayed values (***,***) of Tb and Te will be used; the values of Tb and Te which will be used.
10. dt= *** ?	/ - the displayed value (***) of dt will be used; The value of dt which will be used.
11. Time interval for activity estimation?	1 - magnitude thresholds will be defined for time interval ( Tb, T* ); 2 - magnitude thresholds will be defined for time interval ( Tb, Te ).
12. Is it correct?	y - goes to Q. 3; n - goes to Q. 13; an integer from 1 to 5 - see answers to Q. 4. Comment: Before this question the block No. 3 concerning the space vicinities is displayed.
13. Shape of area?	1 - the areas will be squares; 2 - the areas will be circles.
14. R = *** km?	y - the displayed value (***) of R will be used; / - the displayed value (***) of R will be used. The value of R which will be used. If the answer is 0, the value of R is calculated by formula from comments to the description of the algorithm.
15. Correction, deletion or addition?	c - goes to Q. 16; d - goes to Q. 16; a - goes to Q. 17; n - goes to Q. 12. Comment: Before this question the table of the areas considered is displayed. For each area the coordinates of the center and the date of T* are given.

16. Area No.?	The number of the area to be corrected or deleted ( according to the answer in Q. 15 ).
17. Latitude?	The value of latitude of the center; / - the displayed value will be used.
18. Longitude?	The value of longitude of the center; / - the displayed value will be used.
19. T*: year, month, day?	Values of year, month and day for the date of T* for the area; / - the displayed value of T* will be used.
20. Is it correct?	y - goes to Q. 3; n - goes to Q. 21; An integer from 1 to 5 - see answers to Q. 4. Comment: Before this question the block No. 4 concerning functions of diagnosis is displayed.
21. Correction, deletion or addition?	c - goes to 22; d - goes to 22; a - goes to 23; n - goes to 20. Comment: Before this question the table of functions of diagnosis is displayed.
22. Function No.?	The number of function to be corrected or deleted ( according to the answer in Q. 15 ).
23. Function x?	y - the displayed type (x) of function remains; / - the displayed type (x) of function remains; the type of function to be used. Comment: Before this question the list of general notations of functions which can be used in diagnosis is displayed.
24. Value of ns ( $s=ns*dt$ )?	The value of the number (ns) of steps dt in s; / - the displayed value of ns will be used.
25. Value of nu ( $u=nu*dt$ )?	The value of the number (nu) of steps dt in u; / - the displayed value of nu will be used.
26. Beginning of the catalog, To = ?	The year to start estimation of long range trend of seismic activity; / - the displayed year will be used.



27. Type of M ?	c - the magnitude threshold will be constant $M = a$ , goes to Q. 28; s - the magnitude threshold will be counted using $M_0$ : $M = M_0 - a$ , goes to Q. 29; a - the magnitude threshold will be counted from the activity, goes to Q. 30; y - the displayed type will be used; / - the displayed type will be used.
28. $M = a = ***$ ?	The value of the constant magnitude threshold $M = a$ ; / - the displayed value (***) of $M$ will be used.
29. $a = M_0 - M = ***$ ?	The value of the difference $a$ between $M_0$ and $M$ ; / - the displayed value (***) of $a$ will be used.
30. $M = M(a)$ , where $a$ is the average number of shocks per year: $a = ***$ ?	The value of $a$ ; / - the displayed value (***) of $a$ will be used.
32. Type of MM?	c - the magnitude threshold will be constant $MM = aa$ , goes to Q. 33; s - the magnitude threshold will be counted from $M_0$ : $MM = M_0 - aa$ , goes to Q. 34; a - the magnitude threshold will be counted from the activity, goes to Q. 35; y - the displayed type will be used; / - the displayed type will be used.
33. $MM = aa = ***$ ?	The value of the constant magnitude threshold $MM = aa$ ; / - the displayed value (***) of $mm$ will be used.
34. $aa = M_0 - MM = ***$ ?	The value of the difference $aa$ between $M_0$ and $MM$ ; / - the displayed value (***) of $aa$ will be used.
35. $MM = M(aa)$ , where $aa$ is the average number of shocks per year: $aa = ***$ ?	The value of $aa$ ; / - the displayed value (***) of $aa$ will be used.
36. $\beta = ***$ ?	The value of the coefficient for the main

	shock weights in function s; / - the displayed value (***) of the coefficient will be used.
37. d = *** ?	The value of the power for the number of main shocks summarized in function s; / - the displayed value (***) of the power will be used.
38. Is it correct?	y - goes to Q. 3; n - goes to Q. 39; an integer from 1 to 5 - see answers to Q. 4. Comment: Before this question the block No. 5 concerning the constants for diagnosis of TIP is displayed.
39. Values of percentile p for b (pb) and other functions(p)?	The values of pb and p. / - the displayed values will be used. Comment: pb and p are used in definition of extremely large values of functions.
40. Value of Nex (Tex=Nex*dt)?	The value of the number (Nex) of steps dt in a time window for the definition of "simultaneous" extrema; / - the displayed value of Nex will be used.
41. Values of G and H?	The values of the thresholds for the number of groups of functions with "extremely large" values (G) and the number of such functions (H); / - the displayed values of G and H will be used.
42. Value of Nau (Tau=Nau*dt)?	The value of the number (Nau) of steps dt in the duration of a TIP; / - the displayed value of Nau will be used.
43. Do you want to print functions?	y - the table of values of the functions considered will be written in the file for printing (m8.pri); n - the table will not be written in the file.
44. Do you want to save data in a profile?	y - goes to Q. 45; n - the program starts calculations.
45. Name the profile, please	The name of profile in which the data will be written.

	The program starts calculations.
--	----------------------------------

## Running the batch version of M8

In some cases it might be more convenient not to go through interactive dialog but run M8 from the command line. For this purpose we provide the user with M8\_BAT.EXE. To run it, execute **M8\_BAT *filename.REM time*** , where ***filename.REM*** is the profile created in a standard of M8 (see Appendix 1) and ***time*** is the file with the date of  $T_e$  in free format. This program is used to speed up the update of the M8 algorithm test in Circum Pacific. You can find corresponding batch files RUN\_REG.BAT and RUN\_TEST.BAT in the M8\_TEST subdirectory. To run the January 1, 1994 update in region BM (Bonin-Mariana Trench), go to the M8\_TEST subdirectory and execute **RUN\_REG BM 940**. To run the July 1, 1993 update in entire Circum Pacific go to the M8\_TEST subdirectory and execute **RUN\_TEST 935** .

## Two auxiliary programs

The user is provided with the two supplementary programs, CAT\_M8 and ASC2B20. The first one selects a subcatalog from a catalog in the 20 byte binary format. This program permits the specification of ranges of latitudes and longitudes, i.e.  $lat\_min \leq latitude \leq lat\_max$  and  $lon\_min \leq longitude \leq lon\_max$  (this area may cross the  $180^\circ$  longitude but its longitudinal size should not exceed 180 degrees). To run CAT\_M8 type **CAT\_M8 *limits input\_catalog output\_catalog*** , where ***limits*** is a file with (lat\_min, lat\_max, lon\_min, lon\_max) in free format, ***input\_catalog*** and ***output\_catalog*** are the file names the input catalog and the output subcatalog. The program is useful when the catalog available covers significantly larger territory than an area of investigation, e.g. we use it to speed up execution of updates of the M8 algorithm test in Circum Pacific.

The other program converts an ASCII catalog of mainshocks to the 20 bytes binary format which is used by M8. Each line of an ASCII catalog should contain the following as numbers separated by commas - year (AD), month, day, hour, minute, latitude, longitude (both in degrees), depth (in km), magnitude, number of

aftershocks, e.g.: 1993,8,8,8,34,12.96,144.78,60,8.2,75 . By convention positive values of coordinates are °N and °E, and negative - °S and °W. To convert an ASCII catalog named *ASCII* to binary catalog named *BINARY* execute: **ASC2B20 ASCII BINARY** .

## 7. Output of M8

The M8 program outputs several files: M8.PRI, M8.ERS, M8.TIP, M8.STR, M8.RES (and, optional, profile \*.REM). M8.PRI is an easy to read output with the results of the M8 program run. Its heading lists all the values of input parameters. For each area of investigation, i.e. Region, the program reports the annual average rate of all the events from the catalog, including records for the first and the last quakes used in this calculation, and for every function the magnitude range of the count. Next, for each Region, the program compares the annual average rate of all events to the maximal requested rate from the definitions of functions. If the later is greater, the program will give a warning. The program will not perform computations for the region if the rate of activity in it is less than 80% of the requested. If the rate is sufficient for calculations the program reports, if any, the TIP's and "strong quakes", mainshocks with magnitude greater or equal to  $M_0$ , in the region. Each TIP is specified by its identification, Region number, coordinates of center and time span.

If requested, these are followed by the values of counts assembled in a table. The title of the table specifies the Region with its number,  $T^*$ , and coordinates of the center. Each row lists the voting score  $g(t):h(t)$ , the maximal magnitude of events observed since the previous determination, the date of determination, and the values of functions (if the function can not be evaluated, the program will mark it with "-"). If the value of a function is "abnormally large" it is accompanied with "\*". The voting resulting in a TIP declaration is followed by "\*\*\*:\*" in the next four rows (the program excludes from consideration these four determinations of voting). In addition, each table is preceded by the first record and is followed by the last record of quakes considered for these counts.

The last lines of M8.PRI summarize the number of STIP's, FTIP's, CTIP's and "e.c."s, and reports statistics of the occurrence of quakes with magnitudes ranging

from  $M_0 - 0.5$  to  $M_0$  in the TIP's.

Four supplementary files might be useful for analysis and presentation of the results. M8.ERS contains the coordinates of centers of areas used in the run of M8. M8.STR provides all the "strong quakes" in the catalog during the period of investigation in a special ASCII format (see Appendix 2). M8.TIP lists in a short format all the TIP's determined. Each TIP is specified by its Region number, time span and by the number of "strong quake" in M8.STR that confirmed this alarm (0 for none). M8.RES shows the current state of alarm in all the areas of investigation at  $T_e$  (1 for an alarm, 0 for no alarm, -1 for insufficient data).

## 8. Error Messages and Trouble-Shooting

M8 returns the error messages when it can not find a file of mainshocks or a profile specified by the user. In these cases the program displays input parameters and asks the user to correct them (the batch version of M8 program will terminate the run).

As mentioned above, the program gives warnings when the catalog might be or is insufficient for the analysis. The author apologizes for not protecting most of the numerical input from mistyping and range inconsistency.

The author strongly recommends the book by R.S. Olson (*11*) for the user who does not want to get into trouble issuing earthquake predictions.

## Acknowledgements

The author of the M8 program is indebted to his coauthor of the M8 algorithm, Prof. Vladimir Isaacovich Keilis-Borok. The author is grateful to Profs. L. Knopoff, I.M. Rotwain, G.M. Molchan, A.V. Gabrielov, M.G. Shnirman, J.H. Healy, J.W. Dewey and J.B. Minster for criticism and fruitful discussions at different stages of design and testing of the M8 algorithm. The comments of Drs. I.V. Kusntsov, I.M. Primakov, and A.A. Soloviev related to the program per se are gratefully appreciated. The author thanks Profs. J.H.Healy and W.H.K.Lee for the opportunity of this publication, and Profs. D. Vere-Jones, Ma Li and R.E.Habermann for the reviewing of the program and its Manual.

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## Appendix 1. Format of the "profile" for M8 (\*.REM).

The first line contains -

- (1-14) - the name of the catalog of events (a14);
- (15-17) - the magnitude  $M_0$  multiplied by 100 (i3).

The second line contains -

- (1-8) - the value of  $dt$  (F8.5);
- (9-12) - the year of  $T_b$  (i4);
- (13-16) - the year of  $T_e$  (i4);
- (17-18) - the number of functions (i2);
- (19-20) - the number of areas of investigation (i2);
- (21-22) - the index which defines the shape of areas of investigation: 1 - square shape, and 2 - for circular shape (i2);
- (23-26) - the value of  $R(M_0)$  in km, 0 - for the default formula (i4);
- (27-28) - the index which defines the interval of analysis: 1 - for  $(T_b, T^*)$ , and 2 - for  $(T_b, T_e)$  (i2).

Each of the following lines (their number must be equal to the number of areas of investigation defined in the second line) contains -

- (1-6) - the latitude of the center of an area of investigation (F6.2);
- (7-13) - the longitude of the center of an area of investigation (F7.2);
- (14-21) - the date of  $T^*$  : year, month, day (i4,i2,i2).

Each of the following lines (their number must be equal to the number of functions defined in the second line) contains -

- (1) - the type of measure (a1);
- (3-5) - the type of lower magnitude cutoff (a3);
- (8-10) - the type of upper magnitude cutoff (a3);
- (13-16) - the value consistent with the type of lower magnitude cutoff (F4.2);
- (18-21) - the value consistent with the type of upper magnitude cutoff (F4.2);
- (22-24) - the number of steps  $dt$  in the interval  $s$  (i3);
- (25-26) - the number of steps  $dt$  in the interval  $u$  (i2);
- (27-30) - the year of  $T_0$  (i4);
- (31-35) - the value of  $\beta$  (F5.2);
- (36-40) - the value of  $d$  (F5.2).

The following line contains -

- (1-8) - the value of percentiles  $p$  and  $p_b$  (f4.2,f4.2);
- (9-11) - the number of steps  $dt$  in  $\tau$  (i3);
- (12-14) - the number of steps  $dt$  in  $T_{ex}$  (i3);
- (15-16) - the value of  $H$  (i2);
- (17-18) - the value of  $G$  (i2);



- (19) - the index which defines whether to print tables of functions or not:  
1 - for "yes" and 0 - for "no"(i1);
- (20) - reserved (i1);
- (21-34) - reserved (a14).

The following (last) line contains -

- (1-8) - the date of Tb: year, month, day (i4,i2,i2);
- (9-16) - the date of Te: year, month, day (i4,i2,i2).

## **Appendix 2. The format of an ASCII output file \*.STR.**

Each record of such a file contains -

- (1-4) - the year of the origin time of an event (i4);
- (5-6) - the month of the origin time of an event (i2);
- (7-8) - the day of the origin time of an event (i2);
- (9-10) - the hour of the origin time of an event (i2);
- (11-12) - the minute of the origin time of an event (i2);
- (13-14) - reserved (i2);
- (15-19) - the latitude of epicenter of an event multiplied by 100 (i5);
- (20-25) - the longitude of epicenter of an event multiplied by 100 (i6);
- (26-28) - the depth in km (i3);
- (29-31) - the magnitude of an event multiplied by 100 (i3);
- (32-34) - the count of aftershocks of an event multiplied by 100 (i3);
- (36-41) - reserved (i3,i3,i1).