Bull. Spec. Astrophys. Obs., 2000, 49, 45-52

An algorithm for cleaning extended interferences in radio astronomical records

O.V. Verkhodanov, D.A. Pavlov

Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 369167, Russia

Received February 17, 2000; accepted March 9, 2000.

Abstract. An algorithm is described for removing extended interferences, for instance from a radar, which are shorter than the time of passage of a radio source across the beam of the radio telescope. The algorithm is developed on the basis of robust procedures with the application of extreme statistics. A procedure of removing "jumps" in observational records is also described. The results of performance of the algorithms are illustrated in the figures. The cleaning procedures are included in the standard data reduction system of RATAN-600.

Key words: methods: data analysis – astronomical archive – methods: numerical

1. Introduction

In the course of astrophysical observations one often encounters interferences that corrupt the arriving useful signal or the statistical noise estimates in observation records. This is especially pronounced in records of radio astronomical observations. In the processing of data, a number of noises are recorded that require special cleaning, which is frequently done manually, for instance, in the standard reduction system FADPS at RATAN-600 (Verkhodanov et al., 1993).

To perform the tasks of record cleaning from discontinuous jamming, extensive use is made of technical means at the detector level (see Berlin et al., 1995). However, when working with the archival data, one has to come across different kinds of noises that disturb the initial record. Such noises may be ordinary discontinuous jamming, radar signals, and also various jumps caused by the instability of ADC in data recording.

Recent work concerned with the development of the archive ODA (Kononov et al., 1998; Kononov, Pavlov, 1999; Kononov et al., 1999) of RATAN-600 observational data coming from the broad-band radiometers made it possible to solve the problems which demand the use of old data. Among such problems one may isolate, for instance, investigation of the background radiation (Parijskij, Korol'kov, 1986) and search for variability of radio astronomical objects. The processing of these data has naturally called for automatic search and removal of interferences that corrupt the signal. Some work over control of noises by programme means based on nonparametric evaluation of the mean was done at RATAN-600 several years ago (Erukhimov et al., 1990; Chernenkov, 1996; Shergin et al., 1997). One should also mention the programme development based on a gradient approach of removing discontinuous jamming which was initiated by Bursov (1987). The work over the creation of the cleaning procedure described below was started by Pavlov in 1997 (Pavlov, 1998) under the supervision of the former of the authors of this paper, when the problem of search and removal of solitary interference from the radar was resolved.

It is proposed in this paper to develop an algorithm capable of removing non-single interferences on a record. The algorithm employs both the robust (immune to influence) estimates of the mean on the basis of non-parametric rank algorithms (Huber, 1981) and the procedures based on extreme statistics, namely, minimax approach (Verkhodanov, Gorokhov, 1995), which enable fast evaluation of statistics changes in a given interval.

Below is presented a detailed description of removal of two classes of interferences: 1) radar and discontinuous jamming; 2) jumps in records.

2. Algorithm of radar interference cleaning

The problems presented by the signal from a radar (Fig. 1) are that it is not a δ-function, that is, it cannot be detected with the aid of the "gradient" approach without confusion with a real source, and it is quasiperiodic, i.e. it is "fuzzed up" in the region of spatial frequencies, which hampers its removal on the Fourier plane. Besides, because the signal is extended, the clipping (namely, removal of all points exceeding a specified level with subsequent replacement by pix-

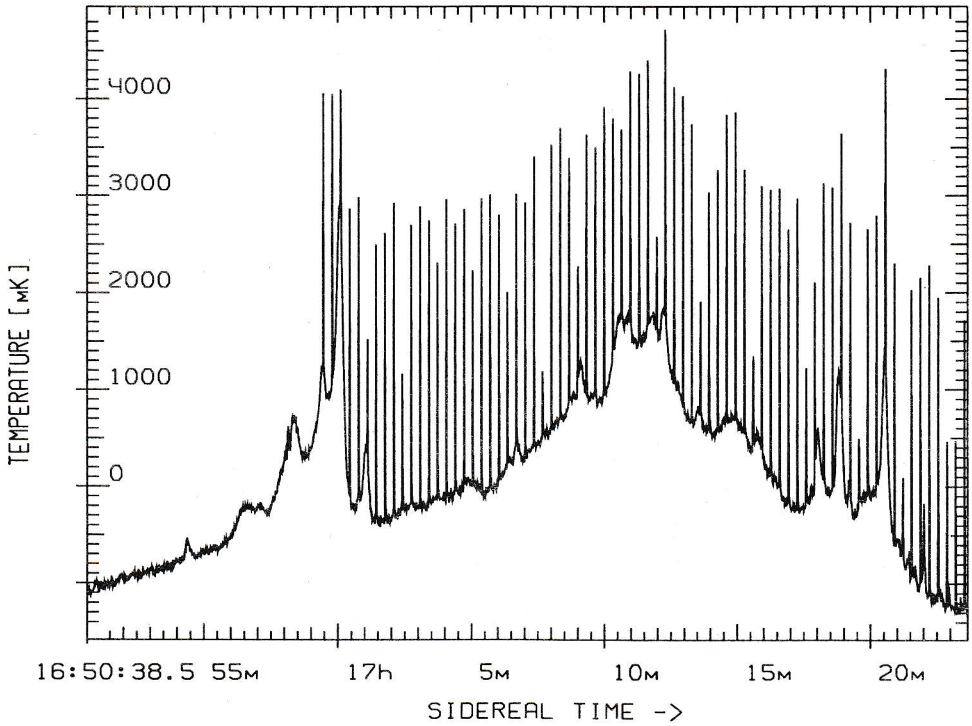

Figure 1: *Example of RATAN-600 observations at 13 cm on 28/08/1994 with the locator operated. The record of the Galactic Plane is covered with the "forest" of interferences (courtesy of S.A.Trushkin).*

els according to given rules) of its spatial spectrum will result in corruption of the signal. For this reason the authors decided to use statistical techniques to detect and remove interferences produced by the radar. The developed procedure permitted getting rid of simple discontinuous jamming. In principle, within the frame of FADPS one can establish a procedure of removing interferences from radars on the basis of the already available modules (Verkhodanov et al., 1992). For instance, such an algorithm can be synthesized from the modules of low noise subtraction, subtraction of the signal of Gaussian shape with a size larger than the specified one, clipping the record at a given level, and taking the sum of the record made with the subtracted low-frequency noises and detected sources. However, because of the multiplicity of Gaussians being computed and also the repetition of vector operations of addition/subtraction increasing the calculation time of the script operation, and due to the ambiguities arising in superposition of a useful signal and a radar signal, the authors made a decision to abandon this approach.

Prior to describing of the developed algorithm we will explain some terms being employed in this paper. By the window is meant the interval on the abscissa axis (for our data this is a time interval measured in seconds) inside of which a signal search is made. By sliding the window along the record we mean the sequential filling of the array of pixels in the appropriate interval when the window is shifted by 1 pixel along the record. By the robust evaluation of the mean is implied a simple median of distribution of pixel values in the given interval, while the robust dispersion is the dispersion estimate made via the median absolute deviation (MAD) under the assumption of Gaussian noises (in this case if μ is MAD, then $\sigma=\mu/0.674$ in accordance with the definition of second-order moments for the normal distribution).

When developing the algorithm, we used the archival data (Kononov et al., 1999) written in the form of the FITS-like F format (Verkhodanov et al., 1993) of the data processing system FADPS at RATAN-600.

The algorithm eliminating interferences from the radar comprises several steps:

1. Copying of data from the F file to the working array and evaluation of the robust dispersion σ of the total record.

2. Search for minimum and maximum values in the window sliding along the one-dimensional array. The window size is chosen equal to the beam of the radio telescope. As the window is sliding, an array of maximum peak-to-peak difference is filled in the current interval. The maximum scatter is computed as the difference of the maximum and minimum

values of the pixels (*max–min*) in the current limits along the axis of shift.

3. When looking for the maximum among the values of differences, which exceeds the level $n \cdot \sigma$, where n is the assigned level (by default 3), analysis is made to search for the maximum locations by way of simple comparing the array values.

4. In the region where the local maximum is found the behaviour of the statistics of the surrounding pixels is determined in case the signal does not fall fully within the window. With this aim in view, the current position of the interval with respect to the signal being detected is found: right and left of the maximum, by means of robust averaging of neighbouring points. Depending on the current vicinity (right or left) of the observed signal, the location of the interval in which the parameters will be estimated is chosen. The real maximum must always fall within the given interval.

5. Once the window position has been found, statistical estimate of principal characteristics of the detected signal is made. For this purpose the following formulae (Fomalont, 1989) are used:

$$I = \sum_t I_t$$

$$X = \frac{1}{I}\sum_t X_t I_t \qquad (6)$$

$$B = \sqrt{\frac{1}{I}(X_t - X)^2 I_t}, \qquad t = 1, r;$$

where I_t is the intensity value of the t-th point in the current interval, X_t is the location of this point in the record, X is the coordinate of the source centre of gravity, I is the integral intensity of a possible sought-for signal, B is the object size, r is the size of the surveyed interval in pixels.

6. Comparison of the found parameters with the specified ones to search for an interfering signal. If the determined amplitude is smaller than the specified one or the size (duration) of the signal exceeds the given one (i.e. a real source is detected), the window is then shifted by one pixel and a return to the point of calculation of (*max–min*) statistics is accomplished.

7. If the parameters correspond to the expected properties of an interference, the boundaries of the signal to be removed are defined.

8. In the procedure of replacement of the points of the record within the limits found, provision is made for variants of replacing the generated noise with characteristic properties (dispersion and mean) of the noise process of the present record or ordinary regression by two estimated means at the edges of the record bordering on the current interval. To generate a noise Gaussian process, the standard library function of the language "C" *rand()* is used, which outputs uniformly distributed values. For conversion to the Gaussian noise, we applied a simple procedure of averaging with a shifted mean and normalizing:

$$N_i = \sigma\sqrt{12m}\frac{2\sum_i^m R - m}{2m},$$

where R is the vector of random numbers of the uniform distribution of the function *rand()* returned by the generator, m is the number of the points involved in averaging of uniformly distributed numbers. The larger m, the better the distribution corresponds to normal. We employed m=32 in our procedure. The value of the current system time is used as the origin of the generator.

9. If there is one more maximum in a specified interval, then return to the point of search for the location of the maximum in the current window (see above) is performed.

10. If the end of the record is not reached, a shift is made by the size of the interval of cleaning along the axis.

11. When the record is finished the data are output to the F file.

The schematic of the radar interference removal algorithm described above is displayed in Fig.2.

The results of operation of the algorithm presented in Fig.3.

Fig.4 shows the power Fourier spectra of the two records displayed in Fig.3: prior to cleaning and after it. To highlight the difference, one and the same curve of the low-frequency background is subtracted from both records. The difference between the spectra is caused by elimination of the discontinuous jamming and quasiperiodic radar signal.

3. Algorithms of removing "jumps"

Apart from interferences treated by the described algorithm, there is a class of interferences not infrequently found in archival records: jumps of the mean or "steps" (Fig.6). We have developed a procedure of search for the jump on the basis of analysis of the mean over four neighbouring sliding intervals.

The algorithm is described as follows:

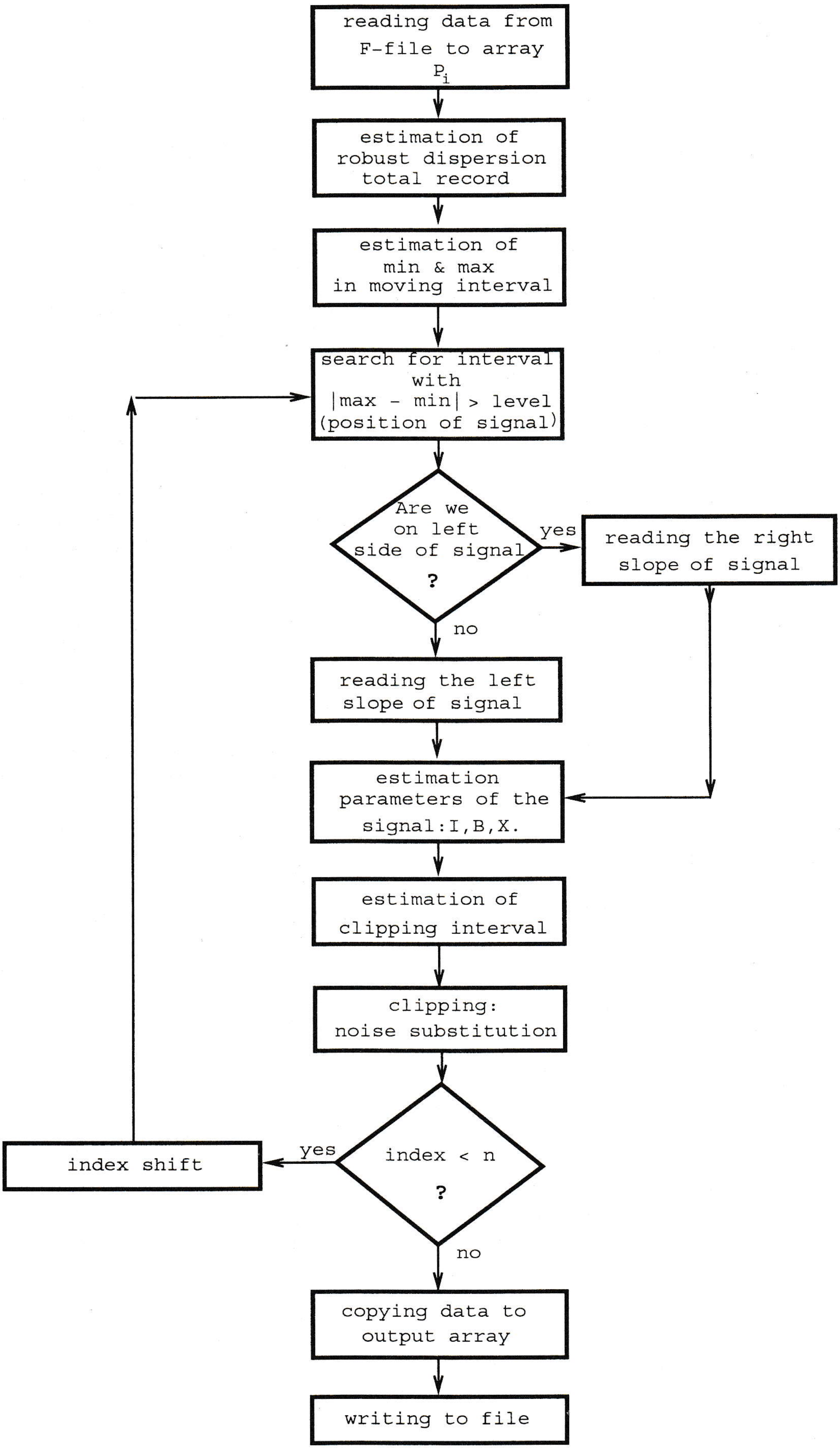

Figure 2: *Block-diagram of search for and clipping point-like and extended interferences.*

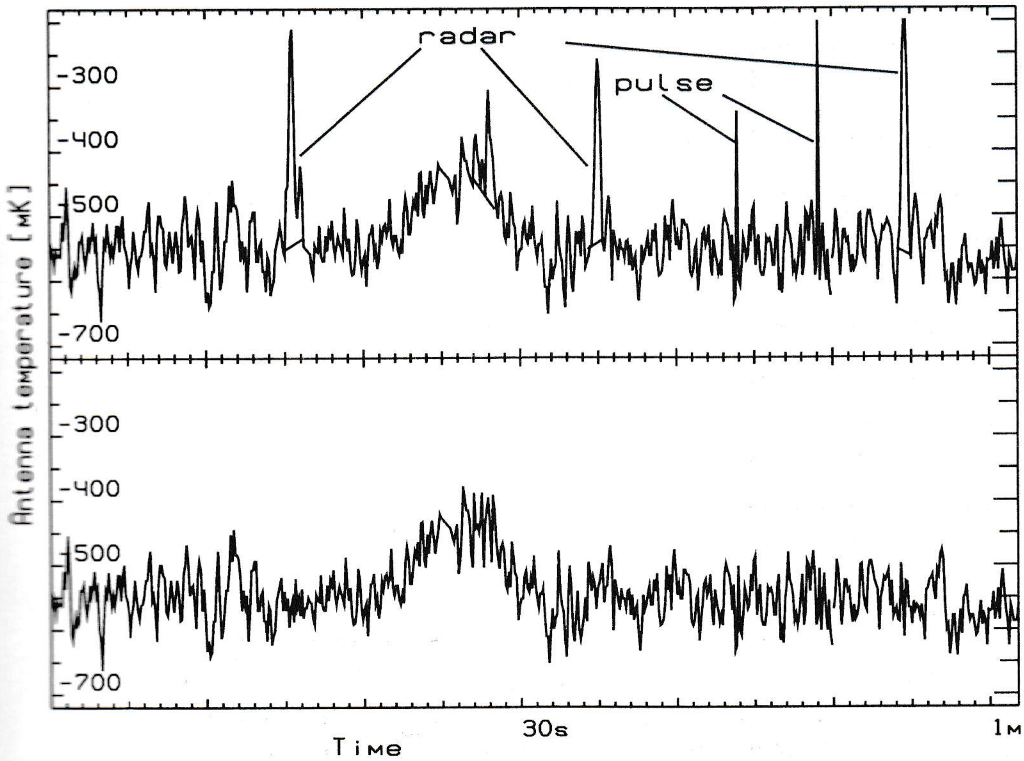

Figure 3: Results of clipping interferences in a record of wide-band radiometers. The upper panel shows a record with a source and impulse, and locator interferences. The lower panel shows a record cleaned with the algorithm of extended interference clipping with noise addition.

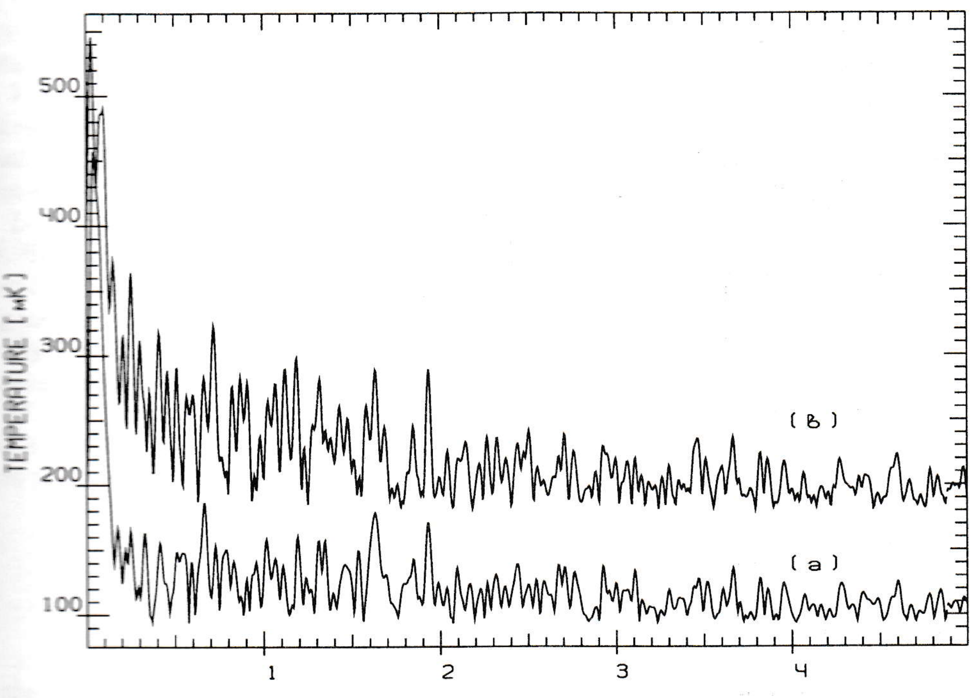

Figure 4: Power Fourier spectrum of records before (a) and after (b) cleaning (see Fig. 3). The difference is due to cleaning of two impulse interferences and a quasiperiodic signal of the locator.

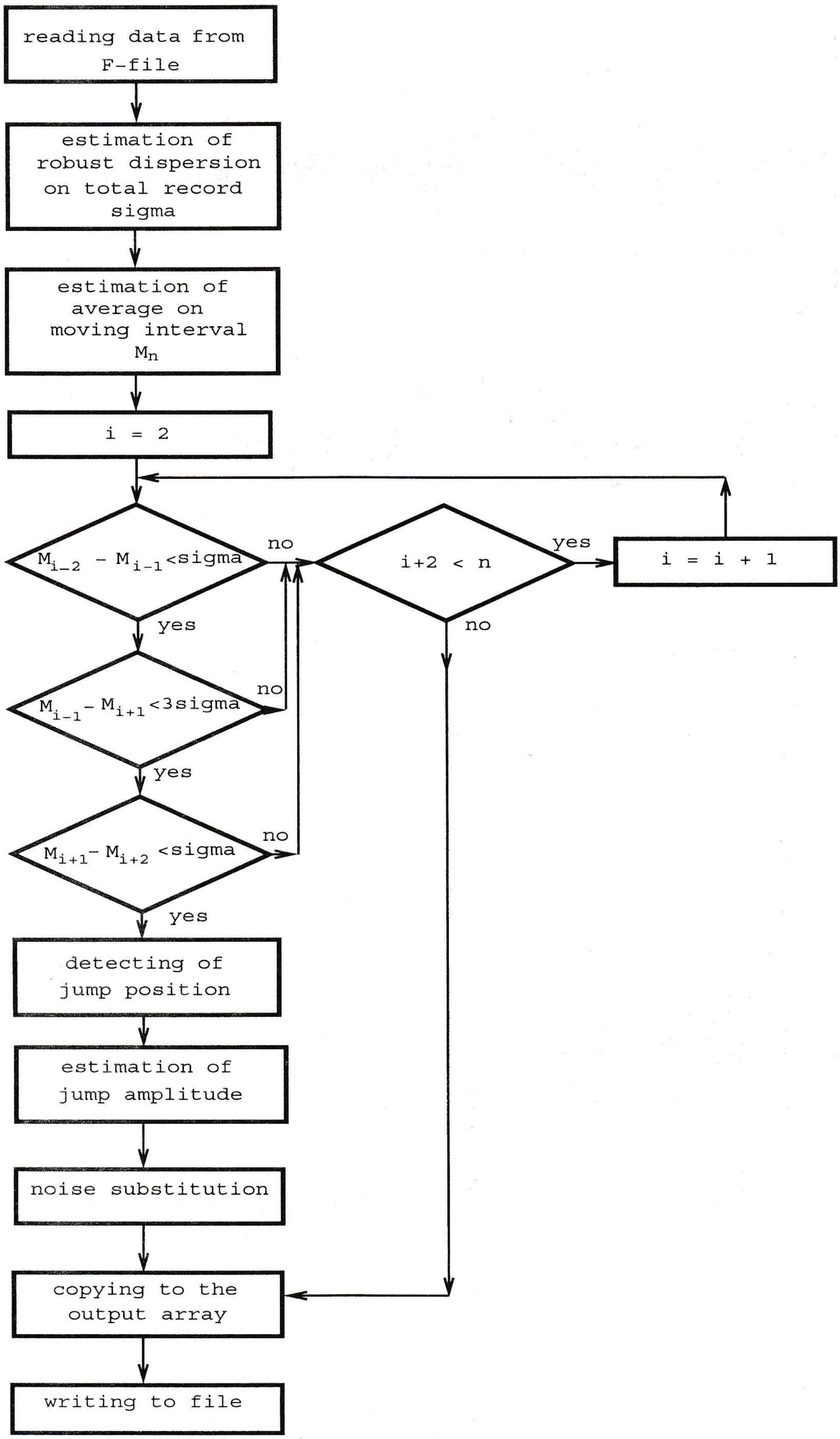

Figure 5: *Block-diagram of search for and clipping record jumps.*

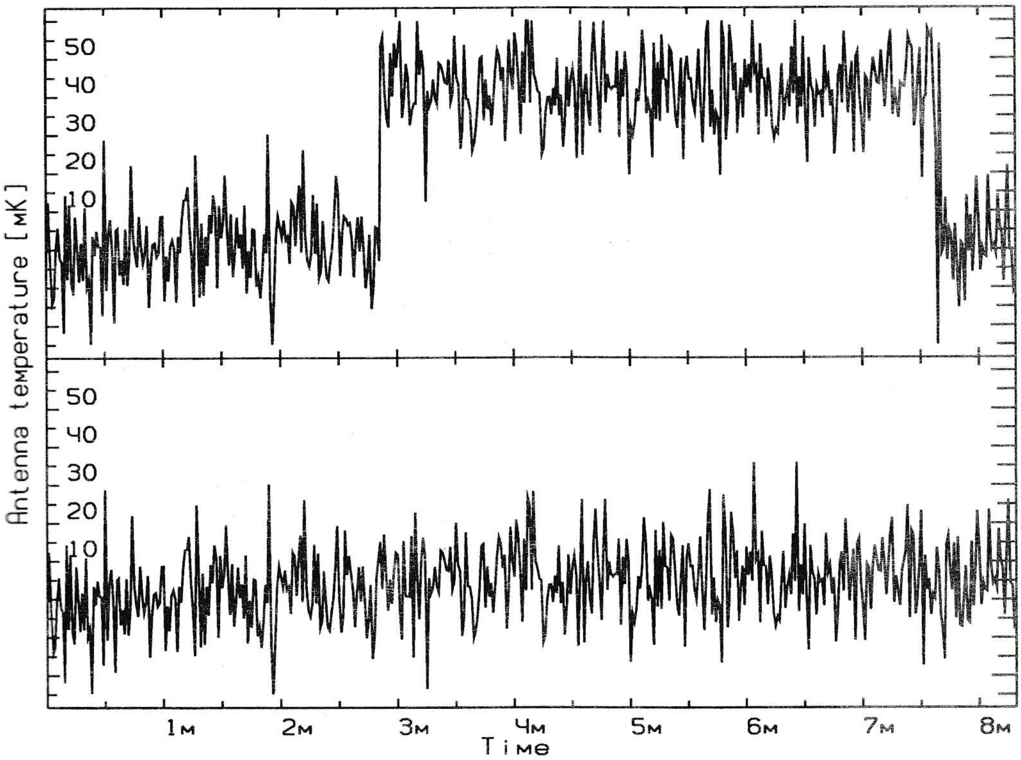

Figure 6: *Results of removing jumps in a record. The upper panel shows a record with a jump. The lower panel shows a cleaned record.*

1. Reading data from the F file to the working array and estimation of the robust dispersion σ of the total record.

2. Filling the array M_n, where every element is an estimate of the mean in the sliding window of a specified size. It is desirable that the size of the window should be chosen not shorter than 5 pixels.

3. Location of the interval in which a jump occurred. Here we analyse the array of the mean values estimated by a robust technique with the aim of revealing the position of the abrupt increase of the mean ($> n\sigma$, by default n=3) value (gradient approach) by way of comparing the values of four elements of the array M. The jump is considered to be detected in the i-th interval provided the following conditions are satisfied at the same time:

$$|_{i-2} - M_{i-1}| < \sigma,$$

$$|M_{i-1} - M_{i+1}| < n\sigma,$$

$$|M_{i+1} - M_{i+2}| < \sigma.$$

Thus the scheme of coincidence of the mean in two neighbouring intervals at the edges and of uneven transition in the central window is realized.

4. Revision of the jump location (for instance, on the i-th pixel) by means of comparison.

5. Decrease of the values of all pixels following the i-th pixel by the value of the jump amplitude.

6. Decrease of all values in the array of the means in the sliding window, which follow the current value of the mean.

7. If there is no limitation on the length of the record, a shift along the record and jump to the condition of the check point are performed. In other words, the cycle is completed.

8. Recording to the F file.

In Fig.5 is shown a schematic diagram of the above-described algorithm of searching for and removing the jump in the records. The results of performance of the algorithm are demonstrated in Fig.6.

4. Conclusions

Through analysing statistical properties in the current interval of the record the developed algorithms find and remove interferences of different kinds quickly and effectively.

The procedure is involved as a command "clip" and included in the standard data processing system FADPS at RATAN-600.

Provision is made for possible extension of the algorithm to two-dimensional data and its application to removal of cosmic particle signals on CCD images.

Acknowledgements. The authors owe debts of gratitude to N.F. Vojkhanskaya for valuable comments in the

course of preparing the manuscript.

References

Berlin A.B., Nizhelskij N.A., Tsybulev P.G., & Pilipenko A.M., 1995, in: Thesis book of XXVI Radio Astron. conf., St.Petersburg. Inst. of Applied Astronomy. 339

Bursov N.N., 1987, private communication

Chernenkov V.N., 1996, Bull. Spec. Astrophys. Obs., **41**, 150

Erukhimov B.L., Vitkovskij V.V., & Shergin V.S., 1990, Preprint SAO RAS, **50**, Nizhnij Arkhyz

Fomalont E.B., 1989, in: Perly R.A, Schwab F.R., Bridle A.H. (eds.) A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School, Astronomical Society of Pacific, 213

Huber P.J., 1981, Robust Statistics. N.-Y. Wiley

Ivanov L.N., 1979, Astrofiz. Issled. (Izv. SAO), **11**, 213

Kononov V.K., Pavlov S.V., Mingaliev M.G., Verkhodanov O.V., 1998, Preprint SAO RAS, **128T**, Nizhnij Arkhyz

Kononov V.K., Pavlov S.V., Mingaliev M.G., Verkhodanov O.V., 1999, Preprint SAO RAS, **131T**, Nizhnij Arkhyz

Kononov V.K., Pavlov S.V., 1999, Preprint SAO RAS, **130T**, Nizhnij Arhkyz

Pavlov D.A., 1998, Bachelor Diploma, Rostovskij University

Parijskij Yu.N., Korolkov D.V., 1986, in: Syunyaev R.A. (ed.), Sov.Sci.Rev.E. Astrophys. Space Phys., Harwood Academic Publishers GmbH, Switzerland, **5**, 39

Shergin V.S., Verkhodanov O.V., Chernenkov V.N., Erukhimov B.L., Gorokhov V.L., 1997, in: G. Hunt & H.E. Payne (eds.) Astronomical Data Analysis Software and Systems VI, ASP Conference Series, **125**, 182 http://www.cv.nrao.edu/adass/adassVI/verkhodanov2.html

Verkhodanov O.V., Vitkovskij V.V., Erukhimov B.L., Zhelenkova O.P., Likhvan O.P., Monosov M.L., Chernenkov V.N., Shergin V.S., 1993, Preprint SAO RAS **89SPb** (in Russian), St.Petersburg branch

Verkhodanov O.V., Gorokhov V.L., 1995, Bull. Spec. Astrophys. Obs., **39**, 155

Verkhodanov O.V., Erukhimov B.L., Monosov M.L. Chernenkov V.N., Shergin V.S., 1992, Report of SAO RAS, **205**, Nizhnij Arkhyz

Verkhodanov O.V., Erukhimov B.L., Monosov M.L. Chernenkov V.N., Shergin V.S., 1993, Bull. Spec. Astrophys. Obs., **36**, 132