Astronomical Data Analysis Software and Systems VIII
ASP Conference Series, Vol. 172, 1999
D. M. Mehringer, R. L. Plante, and D. A. Roberts, eds.

Joint Processing of Radio Data Produced by the SSRT Together With Data of Other Spectral Ranges

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Abstract. Some techniques and a set of IDL programs and routines were developed to process data obtained by the Siberian Solar Radio Telescope (SSRT) together with data of other spectral ranges.

1. Introduction

The emergence of abyssal magnetic fields from the Sun induces various physical processes in the solar corona. Radio observations allow one to study the solar corona against the background of the solar disk and augment the measurements of soft and hard X-rays. Radio observations are sensitive to both thermal and non-thermal components of plasma in quiet and perturbed conditions in the corona up to coronal mass ejections. They provide the only method for measuring the coronal magnetic fields because the calculations using photospheric data are not reliable under perturbed conditions. They also provide diagnostics for parameters of high-energy electrons. Radio observations give the only way to study the processes of particle acceleration and energy release in the outer corona.

The variety of emission mechanisms and their dependence on parameters of the emitting electrons make it extremely difficult to study solar processes without information provided by other spectral ranges. Namely, the magnetic configuration given by magnetograms along with the temperature and density distributions given by X-ray observations contribute to the correct interpretation of radio data. Thus, the study of the solar activity based on the radio observations suggests the involvement of multi-spectral data. Thanks to the development of the Internet, astronomers can now, in fact, use data of all ground-based and orbital observatories. On the other hand, the use of the heterogeneous material requires various methods of data processing, coordination (overlay) of solar images in different formats, etc.

Experience shows that data processing is usually done in a few stages. In the first stage, routine procedures are performed (rejecting of records, building and calibrating maps, bringing them to a standard form, etc.). Subsequent steps include previewing, selecting foremost records, correlating them with data obtained by other instruments, measuring the parameters of radio sources, and calculating estimates of the physical conditions and the model.

As a rule, the first level of data reduction is executed by routine instrument-specific software. Subsequent data processing is often carried out under conditions when not only techniques but also the approach to the solution of a particular physical task is not clear. These conditions suggest interactive work when various techniques of data processing can be tested.

An effective tool to solve such tasks is Interactive Data Language (IDL[1]) which has been used by many observatories and institutions for some years. Taking into account its advantages, we have chosen it as the base in solving of our tasks. We present a set of IDL programs and routines which process data obtained by the Siberian Solar Radio Telescope (SSRT) (Smolkov et al. 1986; Altyntsev et al. 1994; Uralov et al. 1998) together with data of other spectral ranges: Nobeyama Radioheliograph (NRH), Yohkoh, BATSE, Kitt Peak, Big Bear, etc. Besides well-known methods, these programs realize some specific techniques developed by us. Some of the programs which perform tasks that are particularly demanding of computer time and resources were written in C++.

2. Conventional Procedures

2.1. Calibrations of the Intensity and the Spatial Position

We usually apply both intensity and spatial self-calibration to the observational data. In complicated cases, solar images obtained by other instruments are also used.

Radio maps are produced by the SSRT using frequency scanning. Hence non-uniformities of frequency characteristics of both the feed and receiver systems result in appearance of "geometric" noise whose spectrum overlaps the signal's spectrum. We cannot employ an external signal for the calibration, so we apply self-calibration for both the feed and receiver characteristics. For this purpose, mean and standard deviation are calculated for each channel within some time interval (usually $\sim$ 1 hour) from which zero values and gains are obtained.

For the intensity calibration, we use the technique developed by Dr. Y. Hanaoka (Hanaoka et al. 1994) which is based on statistical analysis of the image. As two values dominate in solar radio maps (the levels of the sky and the "quiet" Sun), the histogram of any map must contain two prominent peaks. The distance between those peaks is the level of the quiet Sun expressed in corresponding units. Since the SSRT is an equidistant antenna array, there exists a possibility to use not only clean, but also dirty maps because of good coverage of the $(u,v)-$plane. The use of dirty maps for the intensity calibration results in some systematic errors in brightness temperature of compact sources. This error depends on the angular size of radio sources and can reach as high as 20%. In complicated cases, when the SSRT beam is essentially distorted, the calibration can be made in the interactive mode. In this method, two regions are selected in images: the first region corresponding to the sky, and the second to the quiet Sun.

Precise centering of solar images based upon the calculated orientation of the SSRT beam cannot be ensured because of many displacing instrumental factors. We use the well-known cross-correlation technique on the solar map

[1]IDL is the trademark of Research Systems, Inc.

and the model disk. The presence of patterns across images are sometimes due to distortions of the beam. To reduce their influence, the linear decline is subtracted from the image. Here, pixel values in the maps are limited to exclude the influence of bright sources.

The accurate centering of the response of an interferometer operated in the 1-dimensional (1-D) mode ("scans") is hardly possible without use of 2-D images. The centering of SSRT scans can be made, for example, using radio maps of the NRH. In such a case, a 1-D scan is computed from the 2-D image along the proper direction. The contribution of the quiet Sun is suppressed in both images, and then the centering is made referring to compact quasi-stable sources using the cross-correlation technique.

2.2. Overlay of Data Obtained by Different Instruments

To compare images obtained in different spectral ranges (and, of course, by different astronomical instruments), their correlation is needed. It is convenient to do this using an overlaid contour image.

Images to be compared must be projected onto the same grid. In some cases, all needed values are already contained in the data files (e.g., FITS files of NRH, Kitt Peak Vacuum Telescope, etc.). In other cases, both the solar radius and the coordinates of the solar center are found in the interactive mode. Then the images are regridded and brought into coincidence.

It is possible to correlate both SSRT 1-D scans and 2-D images with any 2-D solar images obtained by other instruments.

Of course, if the interval between observations of the solar images to be correlated was ≥ 1 hour, the sources on the solar surface will be displaced. This displacement must be corrected.

2.3. Compensation for the Rotation of the Sun

A rather simple but efficient routine was developed to "rotate" solar images around its polar axis. This transformation is used in solving such tasks:

- "synchronizing" images obtained at different instances,
- creating high-sensitivity images by averaging of frames obtained within a long interval (some hours),
- monitoring the development of active regions. Here, this transformation allows to correct images for the projection distortions.

2.4. Measurements of Radio Source Characteristics and Their Variations

The programs and routines perform measurements of coordinates, sizes, areas, brightness temperatures, and fluxes of radio sources (Konovalov et al. 1997a, 1997b). They also build time profiles of variations for these characteristics. Some programs have widget-based graphical user interfaces which allow one to perform standard measurements easily and efficiently.

3. Special Techniques

Astronomical instruments can create many images during an event which contain large amounts of information. Integral characteristics help to reveal essential features. Along with the total flux measurement, we also use the effective height of sources which can be measured either as a weighted center, or as coordinates where the second derivative has its minima. However, structural variations are masked in this case. Additional features can be detected by means of another integral characteristic: the effective area of an emitting region computed as its flux divided by maximum of the brightness temperature over the image.

4. Conclusion

The programs and routines have been checked under MS Windows 95 and UNIX with IDL versions 3.0.1 through 5.1. They are used extensively in data processing for the SSRT and the NRH. This software was used in a comprehensive investigation of a range of solar events since 1992. We plan to put our IDL programs onto our Web site, `http://ssrt.iszf.irk.ru`.

Acknowledgments. We are indebted to Dr. D. Stern (Research systems, Inc.) for his assistance in updating the programs to IDL 5.0. We are grateful to the ADASS'98 conference organizing committee for the financial aid which has made possible the attendance of the presenter (V. Grechnev) at the conference. We wish to thank the editors of these proceedings for their help with this paper. This work was supported by the Russian projects of RFFI No. 96-02-16648, No. 97-02-16906, and Astronomia.

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