COMPENSATING INSTRUMENTAL LARGE-SCALE NONLINEARITIES IN SOLAR VELOCITY MAPS OBTAINED WITH MAGNETO-OPTICAL FILTER

L.V. DIDKOVSKY, O.A. ANDREEVA, P.I. BORZYAK, A.I. DOLGUSHIN
Crimean Astrophysical Observatory, Nauchny, Ukraine

E.J. RHODES, JR., N.M. JOHNSON, P.J. ROSE
University of Southern California, Los Angeles, CA, USA

S.G. KORZENNIK
Smithsonian Astrophysical Observatory, Cambridge, MA, USA

ABSTRACT  Standard techniques of calibration of solar Dopplergrams suffer from large-scale nonlinearities which introduce systematic errors and additional random noise in the corresponding solar velocity maps. We have developed a new algorithm for processing the observational data, which allows us to reduce the standard errors connected with the large-scale nonlinearities along the East-West direction and in the vicinity of the solar equator by a factor of approximately 1.5. We demonstrate the efficiency of the new technique by applying it to filtergrams taken with a two-cell sodium Magneto-Optical Filter (MOF) at the Mt.Wilson 60-Ft Solar Tower.

INTRODUCTION

A standard temporal method of calibration of solar Dopplergrams, which uses the Doppler signal integrated over the solar disk and takes into account the rotations of the Sun and the Earth, the orbital motion of the Earth, and the gravitational red shift, produces significant large-area nonlinearities in the resulting solar disk velocity maps, especially along the East-West direction. A separate spatial calibration method which assumes that the Doppler signal varies linearly parallel to the solar equator also results in similar large-scale nonlinearities. These nonlinearities add noise into the observed power spectra of solar oscillations. They may also result in erroneous values of modal amplitudes of low-degree and, to some extent, of intermediate-degree p modes. We present a new technique which significantly reduces the errors in the velocity maps. The algorithm has been included into a software package for a PC-486 computer, which is being developed at the Crimean Astrophysical Observatory for the joint CrAO-USC Project in Helioseismology (Rhodes et al., these proceedings).
Fig. 1  A non-compensated Doppler velocity field image.

DATA REDUCTION

Phase method for Ronchi angle determination
To determine the Ronchi angle, we use a phase method which has rather high stability and precision. It consists of several steps. First, every CCD column of Ronchi-image is processed by a Fourier transform, and the pattern frequency of the stripe repetition and phase for each frequency are calculated. The obtained phase function is then fitted by linear regression. The angle coefficient of the regression along with the value of the averaged frequency gives us the value of the Ronchi angle.

Determination of solar image shape
In order to determine how close the shape of a solar image is to a circle, we compute a standard deviation of the edge of the image from an averaged radius of the solar disk. If this value does not exceed one pixel then it is assumed that the shape of the image is a circle. We have applied an iterative algorithm to determine the coordinates of the center of the solar disk and its radius. In this algorithm, we first choose initial values for the central coordinates, and estimate the radius using a threshold method. Then, these values are iterated until the standard deviation value reaches a minimum.

Rotation and shift of the solar image
The solar images are rotated in order to orient the image of the solar rotation axis along the CCD columns. The corresponding algorithm has been checked
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Fig. 2 The comparison of two different methods of spatial calibration.

by calculating the Ronchi angle before and after rotation. We have found that the errors of this procedure do not exceed those of the initial Ronchi angle determination. A shift of the solar image is carried out after determining the central coordinates of the two consecutive filtergrams (red and blue) so that the centers coincide.

Calibration of Mt. Wilson Data

Traditional method for spatial calibration
To obtain the solar line-of-sight velocities from the observed Dopplergrams, we have applied a traditional method described by Howard & Harvey (1970) (see their formula [7]), which accounts for components of the motion of the Sun relative to the instrument and for the red shift. The velocity field obtained after the spatial calibration using this method is shown in Fig. 1. One can see some large-scale dark and bright areas which are due to the nonlinear distortions of the image, which cannot be corrected by adjusting the coefficients \(a, b, c\) and \(e\) in the formula [7].

Compensation of non-linearities in the velocity field
The typical profiles of lines in a filtergram contain three specific zones: a central zone where signals are changing almost linearly and two near-limb zones where signals rise or fall. These zones cause the Doppler profile to be significantly nonlinear, especially in the E-W direction. The size of the near-limb zones, which depends on the chosen spectral window and on the technique of registration of Doppler velocities, may reach 10-15% of the total profile length in the E-W direction (Rhodes et al., 1986, 1990). Figure 2 shows, for comparison, two profiles observed from the same CCD line near the solar equator: the upper profile was obtained using the traditional method of spatial calibration (Howard
Fig. 3 A compensated Doppler velocity field image.

& Harvey, 1970) (the profile was moved up to 1.0 for clarity), and the lower profile - using the present compensating algorithm. Some distinctive details of the upper signal are present in the lower plot but the standard deviation from a straight line is approximately 1.5 times less for the lower profile. The Doppler velocity field on the solar disk after the compensation of the large-area nonlinearities is shown in Fig. 3.

CONCLUSION

Our algorithms for primary data reduction provide rather high precision and stability. The new method of reducing large-scale nonlinearities in the Doppler velocity field allows us to get results which look very similar to those obtained by subtraction of two consecutive Doppler images 2.5 min apart. This method will significantly reduce noise in the power spectra of low-$l$ mode oscillations, obtained from observational data of high spatial resolution.

REFERENCES