The inhomogeneous response across the solar disc of unresolved Doppler velocity observations

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Abstract. Unresolved Doppler velocity measurements are not homogenous across the solar disc [Brookes et al. 1978]. We consider one cause of the inhomogeneity that originates from the BiSON instrumentation itself: the intensity of light observed from a region on the solar disc is dependent on the distance between that region on the image of the solar disc formed in the instrument and the detector. The non-uniform weighting affects the realization of the solar noise and the amplitudes of the solar oscillations observed by a detector. An ‘offset velocity’, which varies with time, is observed in BiSON data and has consequences for the long-term stability of observations. We have attempted to model, in terms of the inhomogeneous weighting, the average observed offset velocity.

1. Introduction

Birmingham Solar Oscillations Network (BiSON) instruments use resonant scattering spectrometers to make unresolved Doppler velocity observations of the Sun. This involves determining the difference between the intensity of light observed on the red and blue wings of a solar Fraunhofer line. Sun-as-a-star Doppler velocity measurements are not homogenous across the solar disc and so the observed data do not represent a uniform average over the entire surface. The inhomogeneity is influenced by the solar rotation and limb darkening [Brookes et al. 1978]. We have considered a further instrumental effect that occurs because the image is viewed through a vapour: the intensity of light observed from a particular region on the solar disc is dependent on the position of the detector with respect to the image of the Sun seen by the instrument. The majority of BiSON instruments have two detectors, positioned on opposite sides of the observed solar image. The observations made by each detector are weighted towards differing regions of the solar disc, which affects the observed mode amplitudes and granulation noise.

The layout of the rest of this paper is as follows. In Section 2, we model the bias across the solar disc that is seen by BiSON instruments by accounting for the position of the detector with respect to the observed image of the Sun. In Section 3 we measure and attempt to model an ‘offset velocity’ that is present in the BiSON data and the results are summarised in Section 4.
2. Modelling the bias across the disc

The port and starboard detectors of a BiSON instrument are positioned on either side of a potassium vapour cell (see Figure 1). The intensity observed by the detector from a given region on the Sun, \( I \), is determined by the optical depth of the vapour in the cell, \( \tau \), and is given by \( I = I_0 e^{-\tau} \), where \( I_0 \) is the intensity of light received from the Sun. The optical depth of a vapour can be described as \( \tau = Kz \), where \( K \) is the extinction coefficient and \( z \) is the optical path. Here, as a first-order approximation, we have only considered the perpendicular distance between the region of the image and the inside wall of the vapour cell (as shown in Figure 1). We assume that \( K \) is constant throughout the vapour cell. We now use this model to determine the observed bias across the solar disc.

We have combined the effects of the solar rotation and limb darkening with the weighting caused by the position of the detector to produce contour maps of the weighting of the solar disc (see Figure 2). The instrumental effect means that each combination of wing and detector is weighted towards differing regions of the solar disc and so the sensitivity to the observed modes of each combination is different. Each detector will observe at a different height in the solar atmosphere, affecting the amplitudes of the modes and the realisation of the granulation noise observed by the detector. The weighting pattern is dependent on the line-of-sight velocity between the Sun and the observing instrument (‘the station velocity’), which was set to 0 ms\(^{-1}\) for the shown contour maps. As the station velocity increases the weightings are shifted towards the approaching limb of the Sun.

We now use this image of the weighting of the Sun to try and model an offset velocity that is observed in BiSON data.

3. Velocity offset observed in BiSON data

The observed velocity can be extracted from the raw intensity measurements by determining the ratio, \( R \), which is given by \( R = (I_b - I_r)/(I_b + I_r) \), where \( I_b \) and \( I_r \) are the strengths of the resonantly scattered signal on the blue and red wings of the solar potassium absorption line respectively. The ratio varies with station velocity but a given value of the ratio should correspond to the same velocity.
Bias in Sun-as-a-star Doppler velocity observations

Figure 2. Contour maps showing the non-uniform weighting of the solar disc. The intensities have been scaled so that the region which contributes the most has been given a weight of 100, while the regions that contribute the least have been given a weight of 0 and contours in the range 10 to 90 have been plotted. In the contour maps the left limb is approaching an observer and the right limb is receding.

from day to day. We have determined, for many different days, the value of the observed velocity that corresponds to a ratio of $R = 0.15$ and we call this determined velocity the offset velocity (see Broomhall et al., in preparation, for further details). The observed offset velocity is different for the port and starboard observations and varies systematically with time (see Figure 3). The observed offset velocity is analogous for the different BiSON instruments.

We have used our model of the observed inhomogeneity to determine whether this effect can be recreated in artificial data and the results are shown in Figure 4. In the model we took the optical depth at 15mm to be $\tau = 1.1$. The average observed and model offset velocities are in reasonably good agreement, however, the observed offset velocity shows significantly more variation than the model offset. In the model we have varied the orientation of the rotation axis and the size of the observed image with time, which introduces some variation into the offset velocity. However, the range is still at least a factor of 10 too small and to date we have no satisfactory explanation for this.

4. Discussion

We have shown that the observed weighting across the solar disc is different for the red and blue wing observations and the port and starboard observations. The addition of the instrumental effect allows us to model the difference that exists between the port and starboard observations. The observations are biased
An offset velocity is observed, in BiSON data, to vary by of the order of 50 m s$^{-1}$ over the course of a year. The observed offset velocity introduces low-frequency noise into BiSON data and affects the long-term stability of the observations. Although the model of the observed weighting produced is able to make reasonably good predictions of the average offset velocities it is unable to explain the large observed variation with time.

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References

Brookes J., Isaak G., van der Raay H., 1978, MNRAS, 185, 19
Christensen-Dalsgaard J., 1989, MNRAS, 239, 977