Towards near real time high-resolution Dopplergrams from GONG

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Abstract. The GONG network, consisting of six sites around the globe, provides continuous observations of the Sun. The processing and merging of Dopplergrams from various sites usually takes several months before these are made available to the community for analysis. In this paper, we discuss our recent attempts to reduce the delay between observations and the availability of merged Dopplergrams. Our analysis indicates that the modified approach does not influence mode parameters and inferred helioseismic flows. However, the duty cycle plays a significant role in inferring the sub-surface flows and a low duty cycle, if less stations contribute, may lead to qualitatively different results.

1. Introduction
The Global Oscillation Network Group (GONG) upgraded its cameras in 2001 to provide high-resolution Dopplergrams for studying solar interior using various local-helioseismology techniques. The reliability of these techniques depends upon the availability of non-interrupted observations of the Sun. The processing and merging of Dopplergrams from various sites usually takes several months before merged Dopplergrams are available for analysis. This time delay is primarily caused by the arrival of data tapes at the Data Management and Analysis Center (DMAC) in Tucson (USA), and various calibration procedures applied to the site images. Recently, DMAC has started receiving high-resolution Dopplergrams via Internet on a daily basis from five of its sites. We use these images to reduce the gap between observations and availability of merged Dopplergrams. In this paper, we describe how the quality of the “Quick Reduce” data affects the local helioseismology products, mainly on the results obtained from ring-diagram analysis [3]. We study the effect of angle determination and the duty cycle on various mode parameters and subsurface flows with depth.

2. Data and Procedure
We use sample Dopplergrams obtained via Internet for 8–10 May 2008 from five sites, namely Mauna Loa (ML), Big Bear (BB), Cerro Tololo (CT), El Teide (TD) and Udaipur (UD). Figure 1 shows the availability of Dopplergrams from individual sites for these sample days. Note that the Dopplergrams from the sixth site, i.e. Learmonth (LE), are not available due to poor bandwidth. The large gaps in observations, as shown in Figure 1, are due to the few images from UD and non-
availability of images from LE. Following the standard procedure, before merging Dopplergrams from different sites, the site images were calibrated and the image rotation was calculated.

One of the important steps in combining images is the precise determination of Solar North in each site image. For our analysis, we calculate the image orientation using two different sets of images:

- **Standard**: Calibrated Dopplergrams with existing method to determine optimized angle equations that include noon drifts and ±7 days of fully calibrated images,
- **Quick Reduce (QR)**: Calibrated Dopplergrams with optimized angle equations determined from noon drifts and ±7 days of near-real-time QR images.

Figure 2 shows the difference between the image P-angle obtained from the standard and the QR individual site images for three sample days. Both methods provide comparable orientation more than 50% of the time. The maximum difference is about 0.03 degrees. The relative offset between the merged images for these two sets is given in Figure 3. As seen in individual site images, the difference is again less than 0.05 degrees. It clearly indicates that the QR images can be reliably used to determine the image alignment. However, we notice an increase in offset angle or a drop in correlation coefficient when images from particular sites are used. Since seeing conditions at individual sites are different, and the QR and the standard images also pass through different calibration processes, this appears to affect the calculated angles. We need to investigate it in detail before using QR images for any scientific purpose.

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**Figure 1.** Coverage of GONG sites used in the QR data.

**Figure 2.** Histogram showing differences between the image rotation angles of individual site images obtained from the standard and the QR procedures for three sample days.

**Figure 3.** (Top) Relative offset between the merged images obtained with standard and QR angle determination procedures. The errors in these angles are of the order of $10^{-4}$ degrees. (Bottom) Cross-correlation coefficient between standard and QR images.
3. Influence on local helioseismic inferences

In order to understand the influence of near real time Dopplergrams on the helioseismic inferences, we processed three different sets of images through the GONG ring diagram pipeline [4] using 1440 minutes of merged data. These sets are (i) 5-site Standard, (ii) 5-site QR, and (iii) 6-site Standard Dopplergrams. The obtained power spectra are fitted to a Lorentzian profile model to estimate various mode parameters. The obtained velocity components are inverted to infer depth dependence of the horizontal flow.

3.1. 5-site standard vs. 5-site QR

In Figure 4, we plot the difference in mode frequencies at disk center obtained from the 5-site QR and the 5-site standard Dopplergrams. In all cases, the agreement is good at low frequencies while it starts to deviate at \( \nu > 4.5 \text{ mHz} \). Similar results are obtained for other mode parameters, e.g. amplitude and width. The variation of x- and y-components of the flow with depth at three locations on the disk is shown in Figure 5. The center of the maximum latitude/longitude patch is +52.5 degree from the disk center. The inferred flow profiles obtained for both data sets are identical and the values are in good agreement within errors in all cases. While work is in progress, our analysis demonstrates that the QR images provide comparable results to those obtained with a set of standard images.

3.2. 5-site standard vs. 6-site standard

To test the utility of using the merged images from a 5-site network, we have compared horizontal flows of a “Dense Pack” for standard images in Figure 6. The reduction in number of sites contributing to the merged images may also reduce the duty cycle. Since fewer images are available from UD for 9–10 May, and those from LE are completely absent, the duty cycles for...
these two days have substantially decreased. The maximum decrease is found on 9 May (22%) while it is marginal for 8 May (3%). The effect of duty cycle is clearly visible on flow vectors as both their magnitude and direction have changed significantly. These differences increase with larger changes in the duty cycle.

4. Summary
The modified method of determining the position of Solar North does influence mode parameters and inferred helioseismic flows, although all deviations are within the estimated errors. However, the duty cycle plays a significant role in inferring the sub-surface flows and a low duty cycle may lead to much different results. In order to increase the duty cycle for near real time Dopplergrams, it is crucial to get images from Learmonth via the Internet and we hope that the upcoming improvements in bandwidth at Learmonth will make this faster transfer possible in the near future. Furthermore, the rotation angle determination algorithm needs to be reviewed in order to shorten the number of trailing days needed.

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