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# Variations in Global Mode Analysis

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**Abstract.** As with any data analysis, the standard MDI medium-$l$ analysis pipeline is based on approximations and somewhat arbitrary choices in the processing. It is furthermore known that the results of the standard analysis contain systematic errors, most notably a bump in the normalized residuals of the $a$-coefficients around 3.4 mHz, an annual variation in $f$-mode frequencies, and possibly a polar jet in the rotation inversions. Our previous work has explored how these errors are affected by making various corrections to the analysis. In this article we extend our study to include a comparison of the results of full disk data to those of the binned data we have previously used. We go on to explore how several choices made in the analysis, such as the amount of zero padding and the width of the fitting interval, affect the mode parameters and the magnitude of the systematic errors.

## 1. Data and Analysis

The MDI instrument is capable of producing images of the Sun with a resolution of $1024^2$ at a cadence of one minute. However, due to telemetry constraints, these images are usually smoothed by a Gaussian, cropped at 90% of the solar radius, and sampled every 5x5 pixels. Dopplergrams obtained in this way are the usual input for the MDI medium-$l$ program. Every year for some months, however, there is telemetry available to send down the full disk images in addition to the lower resolution ones. These are the dynamics runs. The full disk images can be run through the pipeline in almost exactly the same way, but not only is the spatial resolution higher, the data goes closer to the limb. Specifically, vector weighted images are usually apodized with a cosine curve from a fractional image radius of 0.83 to 0.87, while the full disk images are usually apodized in the same way from 0.90 to 0.95.

For this work, the remapping for the spherical harmonic decomposition uses updated values for the $P$-angle and Carrington inclination and makes corrections for the plate scale of the instrument, cubic distortion and CCD tilt. The resulting timeseries are then detrended and gapfilled, and the subsequent peakbagging takes into account horizontal displacement and distortion of eigenfunctions by differential rotation.

In addition, we try several variations of our peakbagging method. The first is zero padding, that is, appending a chunk of zeros to the end of the timeseries before performing the Fourier transform. We extend the length of the timeseries in this way by factors of 2, 3 and 4, which increases the frequency resolution of the Fourier transform by the same factor. We also try using different fitting intervals. The standard pipeline uses an interval of 5 linewidths, and we try using 7.5, 10, and 15 linewidths. This is partly motivated by discrepancies with the GONG project, which uses a much wider fitting interval.

## 2. Results

For each variation of the peakbagging, we reanalyzed two years of data. To summarize the effect of each variation, we took the average over the two years by taking the modes that were fit at least 70% of the time and fitting a second-order polynomial to each parameter. We then took the average of the fit. Figure 1 shows the difference between two variations divided by the error in the fit, for the modes that they had in common (fit in 70% of both). That is, each y-axis is in units of standard deviation. None of the variations made significant changes to mode frequencies. As we increased the fitting interval, our algorithm fit fewer modes. Also, due to technical problems with the codes, we were unable to fit above $l = 280$ for the highest factor of zero padding. Both issues require further investigation.

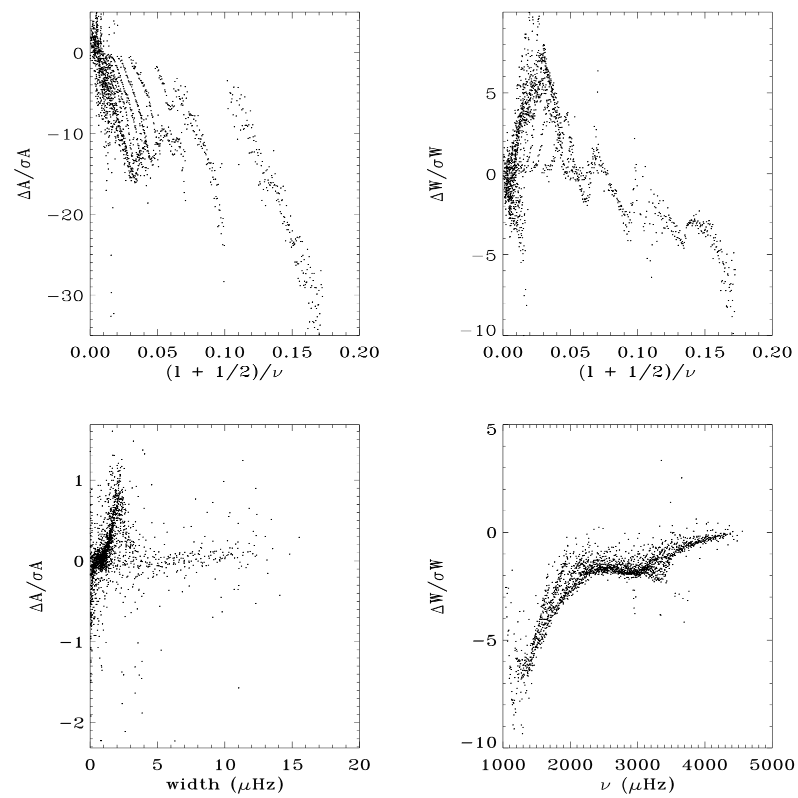


Figure 1. Differences in amplitude and linewidth between two analyses and the default. Top panels show results using a 10 linewidth fitting interval. Bottom panels show results after zero padding by a factor of 4.

## 3. Effect on Systematic Errors

Our analysis always shows a marked annual component in the average fractional change in $f$-mode frequency. We measure the magnitude of this error by fitting the sum of a linear function and a sinusoid with a one year period to the data. The only variation that had a noticeable effect was doubling the fitting interval (we were unable to fit any $f$-modes when we tripled the fitting interval). The magnitude of the sinusoidal component decreased and the residual from the fit increased, but this could be for reasons discussed below.

Another systematic error in the analysis can be seen in the bump in the normalized residuals of the odd $a$-coefficients (see bottom left panel, figure 3). Zero padding had negligible effect on the bump. Changing the fitting interval, however, altered the behavior of the normalized residuals so drastically that a single bump wasn't easily discernible. This would seem to indicate that our model is not a perfect fit to the data.

Finally, we examine the actual rotation profile that results from a full two dimensional RLS inversion of each analysis. Again, zero padding did not make significant changes to the profile, and the results using the larger fitting intervals may be skewed by their lack of modes. The feature that is believed to be spurious is the jet at high latitudes (see bottom right panel, figure 3).

## 4. Dynamics Runs

For this work we analyzed the first ten dynamics runs. To examine the effect of using the full disk data versus the lower resolution data, we reanalyzed these ten periods in two different ways. First, we used the same full disk data but with the tighter apodization. Second, we performed our regular analysis on the same time periods. In both cases we used a common window function as input to the gap-filling. This is necessary because the full disk data has a lower duty cycle, and we wanted to eliminate this variable from our comparison. (We did, however, use the native window function for the regular full disk analysis. This results in at most a few hours of extra data.)

Using full disk data had only a small affect on mode frequencies, but the amplitudes and linewidths changed significantly. The form of this change varies from year to year, but in all cases the effect of the apodization was greater than that of the greater spatial resolution (see figure 2). We also observed a decrease in the magnitude of the systematic errors (see figure 3).

## 5. Conclusions

It would seem that we have a good lead on the cause of the bump in the $a$-coefficients and the potentially spurious jet in the inversions. It is possible that the apodization may not have been accounted for correctly in the leakage matrix; this warrants further investigation. If that is the problem with our model, it would also explain why changing the fitting interval had such an effect on the mode parameters. This hypothesis is also supported by the fact that using full disk data results in better fits.

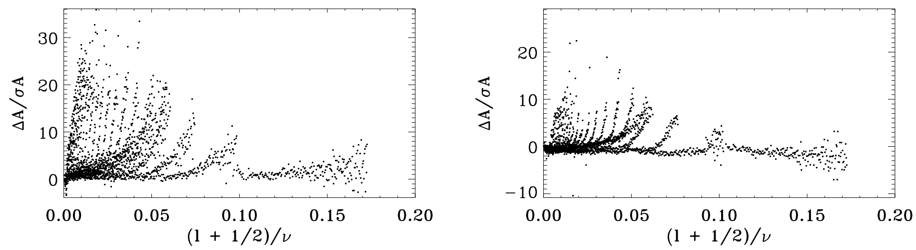


Figure 2. The 2001 dynamics run. Left panel shows effect of apodization, right shows effect of spatial resolution.

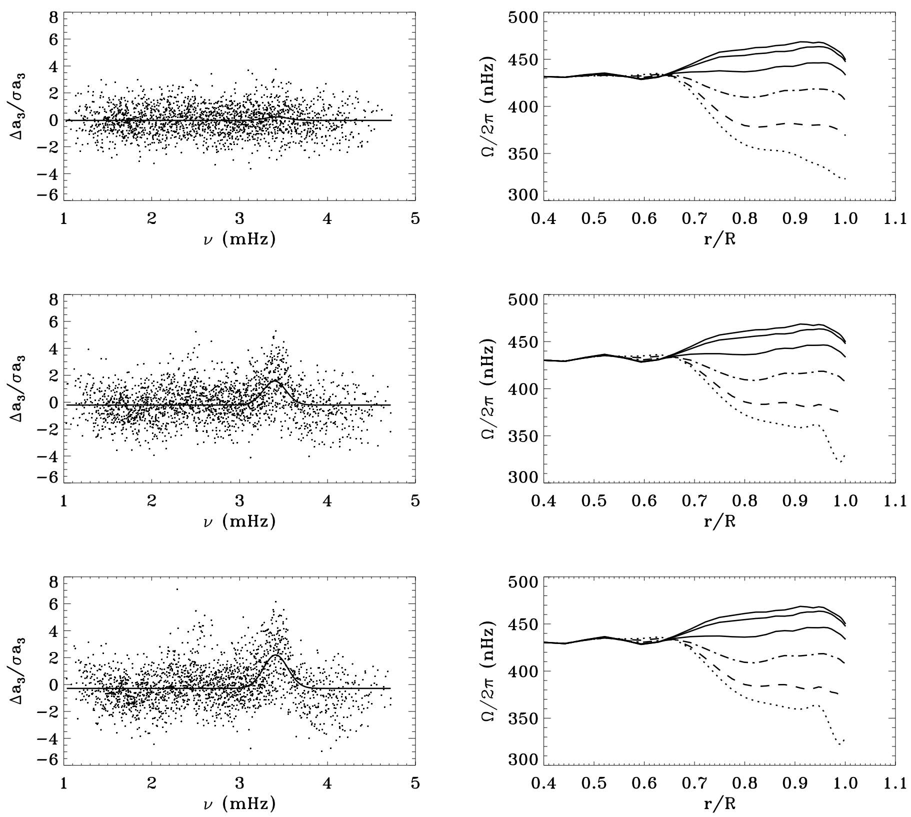


Figure 3. The bump and jet for the 2001 dynamics run. Top panels show the regular full disk analysis, middle panels show full disk data with the tighter apodization, bottom panels show the regular analysis.

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