ALIGNING THE GONG NETWORK

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ABSTRACT

We describe the method recently adopted by the Global Oscillation Network Group (GONG) for determining the proper alignment of thier images. The method provides an internally consistent set of equations that describe the temporal variation of the direction of solar north for each GONG instrument. Internal errors are estimated to be ~ 0.02 degrees, however, systematic errors resulting from uncertainties in Carrington's rotation elements used for ephemeris calculations could be as large as ~ 0.1 degrees.

1. INTRODUCTION

GONG has deployed a network of six ground based telescopes around the globe in an effort to obtain $\sim 24^h$ of continuous coverage of the Sun. The data being collected by these instruments consists of a full-disk dopplergram every minute during the daylight hours at each site. These data are subsequently processed to study the global modes of the solar oscillations.

Ideally, the data should be recorded in "exactly" the same way at all sites (i.e., the same sampling, size, orientation, etc...). Unfortunately, the ideal is seldom achieved. Orientation errors are especially troublesome because they can lead to misidentification of the modes when the images are registered and decomposed into spherical harmonic transform (SHT) coefficients. A small orientation error can cause poor agreement between the SHT coefficients from simultaneous data obtained at different sites, especially at higher ℓ-values.

Things are complicated by the fact that the GONG detector has rectangular pixels. This means that the images need to be aligned in the same way relative to the pixels at all sites, otherwise the modes will be sampled differently. Add to that the fact that the telescope design is such that the solar image rotates during the day, and the fact that the solar p-angle varies seasonally, requires that the instrument must rotate the detector to compensate. Hence the need for a camera rotator.

In principle, both the diurnal and seasonal changes can be calculated and the camera rotator can be programmed to track the rotation of the solar image, keeping solar N-S aligned with the long axis of the pixels. In practice, misalignments of the telescope structures and optical elements lead to a residual rotation that is not accounted for in the calculations. It was decided that at deployment (and again whenever a site is visited by a maintenance team) a day of "drift scans" would be recorded. During this procedure the solar image is allowed to drift across the detector every few minutes throughout the day. This then allows one to calculate the residual error in the camera rotation angle as a function of time. Using the drift scan results a polynomial in hour angle is computed so that the residual rotation errors can be allowed for during the data processing.

Originally it was hoped that this polynomial could be used until it could be remeasured during the next site visit. Unfortunately, the rotation errors are not constant in time – they vary seasonally with the solar declination. Since each site is visited only infrequently (every 6-9 months) there can be substantial change in the residual rotation errors between visits.

Since it is not feasible to visit each site with the frequency needed to maintain an accurate measure of the camera rotation errors, it was decided to develop a software method that could, in effect, do the same thing. The method, described below, determines an optimal set of equations that makes the entire network internally consistent in terms of orientation. When a site is visited and drift scans are obtained, these results can be used to "nudge" the other sites so that they are all aligned with "true" solar north. In this way, the orientation of the entire network is checked whenever any one of the sites is visited ($\sim$ every 4 to 6 weeks).

2. THE METHOD

The relative orientation of simultaneous image pairs is determined by performing an angular cross-correlation. This is shown schematically in figure 1. The procedure is to select a pair of simulateous images from two different sites (top panel), then take data from a narrow annulus in each image and divide it into equally spaced angular bins (second panel), next high-pass filter to remove solar rotation (third panel), and finally perform a one dimensional cross-correlation to obtain the relative angular shift (bottom panel). The process is repeated for several annuli and the mean and standard deviation is computed. The formal errors on individual cross-correlations are $\sim 0.^\circ 02$.

Initially, one selects a time when a set of drift scans has just been obtained at one site. For the other sites use the latest estimates for the rotation errors (from either the most recent [earlier] drift scans, or from the software) as initial guesses. Compute the

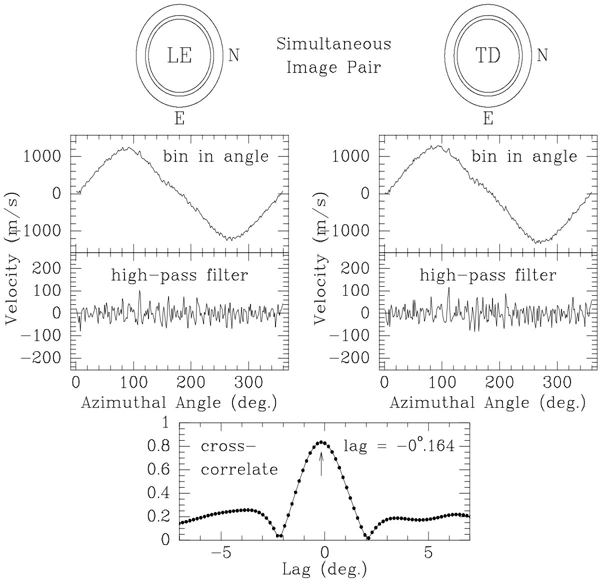


Figure 1: Schematic of the angular cross-correlation procedure.

angular cross-correlations as outlined above between all simultaneous images to determine the relative rotation (i.e., compute rotation of image A relative to image B assuming some angle for image B). Do the cross-correlations in both directions (A$\odot$B and B$\odot$A). Use non-linear least squares techniques to optimize the set of equations: i.e., minimize the following function:

$$\mathcal{E} = \sum_{i} \sum_{j(j \neq i)} \frac{\left[\mathcal{M}_i - (CC_{ij} - \mathcal{M}_j^0 + \mathcal{M}_j)\ W_i\ W_j\right]^2}{\sigma^2}$$

where:

i is the "test" site index

j is the "reference" site index

CC_{ij} is the cross-correlation angle of site i relative to site j

$\mathcal{M}_i$ is the optimized rotation equation for site i

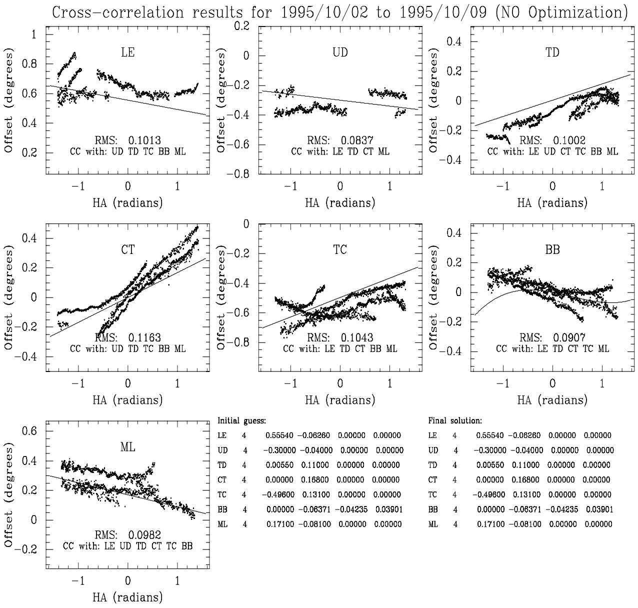
$\mathcal{M}_j$ is the optimized rotation equation for site j

$\mathcal{M}_j^0$ is the initial guess for the reference site

W_i & W_j are the observing windows for sites i and j

σ is the estimated error on the cross-correlations

An example of the cross-correlation results before and after optimization is shown in figures 2 and 3. One can see from the figures that the scatter has been dramatically reduced by the optimization procedure. The rms between the cross-correlation results and the polynomial fits has been reduced from ~ 0.°1 before the optimization to ~ 0.°02 after the optimization. One must keep in mind, however, that there could be systematic errors as large as ~ 0.°1 due to uncertainties in Carrington's rotation elements.



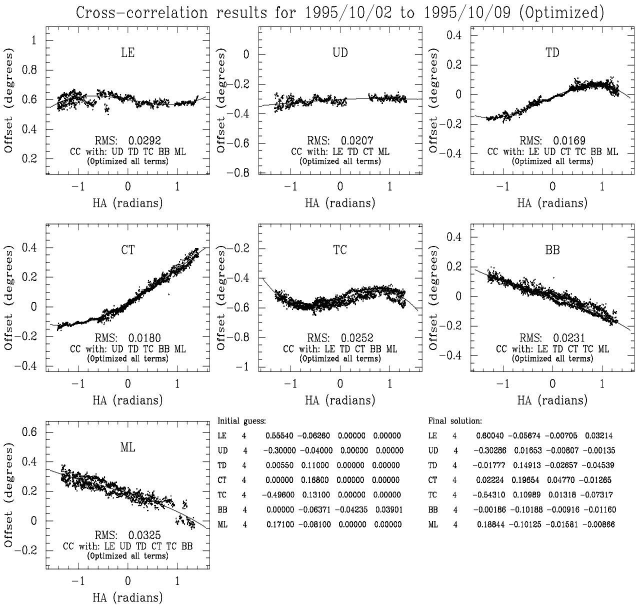
Initial guess:

LE	4	0.55540	−0.06260	0.00000	0.00000
UD	4	−0.30000	−0.04000	0.00000	0.00000
TD	4	0.00550	0.11000	0.00000	0.00000
CT	4	0.00000	0.16800	0.00000	0.00000
TC	4	−0.49600	0.13100	0.00000	0.00000
BB	4	0.00000	−0.06371	−0.04235	0.03901
ML	4	0.17100	−0.08100	0.00000	0.00000

Final solution:

LE	4	0.55540	−0.06260	0.00000	0.00000
UD	4	−0.30000	−0.04000	0.00000	0.00000
TD	4	0.00550	0.11000	0.00000	0.00000
CT	4	0.00000	0.16800	0.00000	0.00000
TC	4	−0.49600	0.13100	0.00000	0.00000
BB	4	0.00000	−0.06371	−0.04235	0.03901
ML	4	0.17100	−0.08100	0.00000	0.00000

Figure 2: Cross-correlation results - No optimization. The solid lines are the fits from the most recent drift-scans.



Initial guess:

LE	4	0.55540	−0.06260	0.00000	0.00000
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BB	4	0.00000	−0.06371	−0.04235	0.03901
ML	4	0.17100	−0.08100	0.00000	0.00000

Final solution:

LE	4	0.60040	−0.05674	−0.00705	0.03214
UD	4	−0.30286	0.01653	−0.00807	−0.00135
TD	4	−0.01777	0.14913	−0.02657	−0.04539
CT	4	0.02224	0.19654	0.04770	−0.01265
TC	4	−0.54310	0.10989	0.01318	−0.07317
BB	4	−0.00186	−0.10188	−0.00916	−0.01160
ML	4	0.18844	−0.10125	−0.01581	−0.00866

Figure 3: Cross-correlation results - Optimized. Here the solid lines are determined from the optimization.