Michelson Doppler Imager Recalibration Effort

The method of measuring Doppler shifts with SOHO/MDI is described in Scherrer et al. 1995. Only the details related to the present study are described here. The SOHO/MDI is tuned to 5 wavelengths with 4 equally spaced in wavelength spanning the FeI 617.8 nm line and the 5th tuned to the best available continuum position. The Michelsons are tuned by rotating half-wave plates about the optical axis. The Michelsons are not perfect with the center of the passband varying across the field. This variation across the field can be measured by taking a set of 9 images made with tuning the narrow band (NB) Michelson to 0, 120, and 240 degrees for each of the same positions of the wide band (WB) Michelson. This is done with the MDI optics configured in “Cal Mode” which is accomplished by rotating two lenses into the system such that the entrance pupil of the telescope is imaged onto the CCD camera, instead of the Sun as in the “ObsMode” configuration. This sequence of tunings is referred to as a “detune” set. In CalMode each pixel receives a spectrum that is identical with the line shifted by the velocity of SOHO with respect to the average Sun. For each pixel a fit of phase error can be made by calculating the tuning profile of the instrument convolved with the modeled solar line. The phase error at each pixel is varied to find the best fit. The “phasemaps” are the resulting phase variations across the image.
The solar velocity is obtained at each pixel by tuning the pair of Michelsons such that they have the best average passband cotuned at the 4 tuning positions spanning the solar line. The onboard velocity is computed from the 4 intensities in each tuning set. The 4 values allow one to determine first Fourier components of spectrum in the passband. The net passband is about 2 line widths so the sine and cosine components can be easily computed then the phase of the solar line is determined from the arc tangent of the ratio of the two components. The calculation is then a ratio of two differences and is free of brightness and flat field to first order. But the resulting signal is not linear with solar velocity. To correct it a “lookup table” is used. This table is computed by convolving a model solar line with the instrument profile at the 4 tuning positions, then using the shift of the solar line as a true velocity and the computed “observed” velocity results from the same calculation as used onboard for the calibration velocities. This default table is uploaded to MDI so that the first order velocity can be computed onboard. Since the Michelson phase errors are slowly changing this allows onboard averaging to lower resolution Dopplergrams as required by the SOHO telemetry bandwidth limitations. These onboard Dopplergrams are the primary global helioseismology data products. To use them we must perform a second level of calibration on the ground. This is done by computing the more accurate lookup table for each pixel then calculating the on-ground correction to the onboard Dopplergrams. The more accurate lookup table is computed with the phasemaps.

During the SOHO/MDI operating years, from May 1996 through April 2011 detune sets were obtained each month. These sets consisted of several minutes dedicated to this calibration activity. Multiple detunes were made in each calibration interval, from 1 to more than 50 with the average near 10. The average phase of each Michelson drifted with time for still unknown reasons. This resulted in a changing velocity zero. The instrument was “retuned” each 6 months in order to account for the combination of SOHO-Sun annual variation in velocity and the drift. The average phase of each Michelson as measured from the average of a set of detunes and this average was used to set the offset angle of the tuning wave plates hollow-core motors.

The shape of the phasemaps change very little with time so only the average was updated each six months. Most of the mission the phasemaps pair made in April 1997 was used. Most analysis of the resulting Dopplergrams showed no degradation from not recomputing the whole phasemaps, not just the averages. This was true until it was found that the time-distance method of deep flow measurements for determining the deep meridional solar flows. It was found that different flow values were obtained for times when SOHO was in original orientation and the rolled orientation. This meant that half of the data from 2003 to the end could not be used. Further is is not clear what the correct values should be.

There is a second order effect of imperfections in the Michelsons, or rather in the way we can measure the phasemaps. This is due to the optical design and thickness of the Michelsons. When we go to CalMode we interchange the image and pupil planes in the filter section of MDI. This means that while we have a sun-as-a-star no-image at the CCD we have a real image in the entrance blocking filter in the tuning section. At different locations through the filter section we have a mixture of image and no-image which in most cases does not matter. The tuning errors are due to variations in thickness, very tiny variations, in multiple locations along the optical path. So the instrument profile is slightly different when we switch from ObsMode to CalMode because the Sun rotates with a 2000 m/s velocity at the equator. We referred to this as the "colored cone" problem during pre-launch ground calibrations. It mean that there were small variations in phasemaps obtained at different times of day. In the lab the Sun was imaged with a heliostat that produces an image that rotates once each day.

We were aware of this possible issue, but for reasons that none of the team can remember we did not make calibration phasemaps for the SOHO inverted times during the mission.

However we did make the regular detune sets.

In the present recalibration effort phasemaps have been computed for the 2507 detune sequences obtained over the years. These were divided into two sets, 159 with SOHO normal and 69 with SOHO inverted. Phasemap averages were made for each of the months with good data. The average maps for both NB and WB Michelsons and for SOHO normal and inverted are shown in Figure 1. Small but important difference can be seen, primarily in the left to right (East to West on Sun) phase change amplitude. These differences will result in a spatial variation in helioseismic amplitudes.

Unfortunately this effort was much more difficult to accomplish than had been anticipated. There were no serious block that would have caused the abandonment of the correct way in favor of the alternate recalibration method described in the proposal. It was not anticipated that the original phasemap code would not be available. One the average phase code was found in the original IDL library. However the phasemap code for SDO/HMI is in principal close enough to be used. That code was written be a team member no longer present. With more than anticipated effort the code was modified and MDI phasemaps were computed.

The final steps are more straightforward and will be accomplished in the coming months. This final report was delayed as long as possible to allow further, unfunded, progress to be described. The effort will continue since we really want to have better measures of the solar meridional flows. But for this effort the final product is the phasemaps. The plan going forward is to use the averages shown in the figure to compute re-calibration tables then to see if that solves the problem.

A nice side effect of this study is that some deficiencies discovered and corrected in the HMI phasemap code will help with the solution of the HMI daily sensitivity issue that allows the SDO orbit velocity to “leak” into the HMI Dopplergrams (about a 1% error) and the Magnetograms (a larger error since the Zeeman effect causes line shifts larger than most solar Doppler shifts. Attention to the HMI problem had a noticeable effect on the present study.

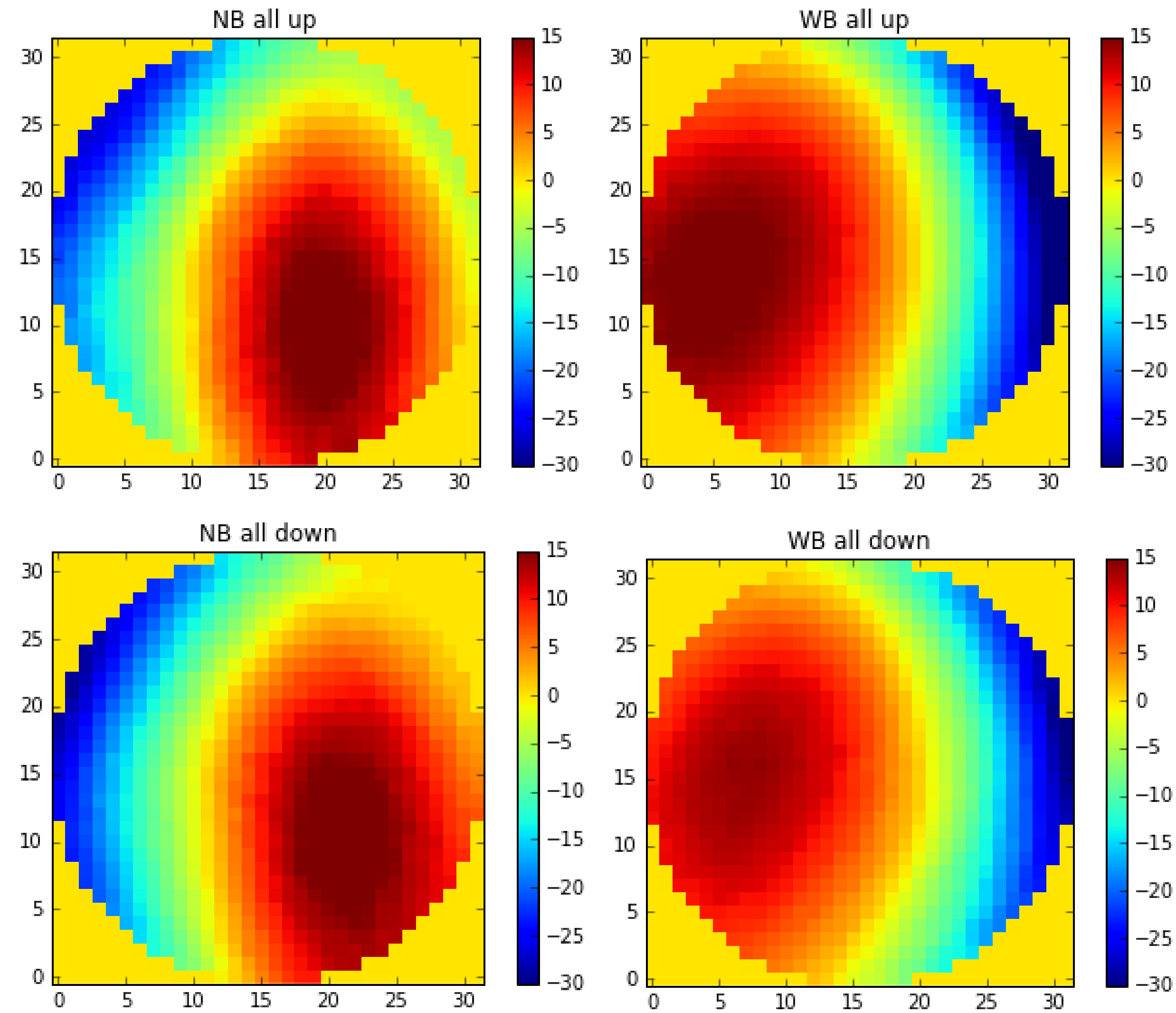

Figure 1. Average phasemaps for the two Michelson Interferometers that make up the final two filter stages in MDI. The narrow band element is in the left, and the wide band on the right. The scale is in degrees of phase. The top row is from the times when SOHO was in its original orientation with solar north at the top of the images. The lower row is for the times that SOHO is inverted with solar north at the bottom of the images.

Reference:

Scherrer et al., The Solar Oscillations Investigation - Michelson Doppler Imager, olar Physics, Volume 162, Issue 1-2, pp. 129-188.

Data:

The data and produced is available from the SDO JSOC at http://jsoc2.stanford.edu

Series: **mdi.detune** contains all of the MDI "detune" images

Series: **mdi.phasemaps** contains the phasemaps computed from the detunes.