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Post-Launch Calibration and Data Processing for the *Helioseismic and Magnetic Imager* (HMI) Instrument on the *Solar Dynamics Observatory* (SDO)

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Abstract The *Helioseismic and Magnetic Imager* (HMI) instrument was launched with the *Solar Dynamics Observatory* (SDO) on 11 February 2010. Details of the ground-based calibrations of HMI were detailed in a series of previous articles. Since launch we have been able to improve significantly on some of these calibrations, as well as complete some calibration tasks that were deliberately deferred. Here we present the results of these various calibrations and describe how the various observables are generated.

Keywords: Solar Dynamics Observatory; Helioseismology, Observations; Instrumentation and Data Management; Magnetic fields, Photosphere

1. Introduction

The *Helioseismic and Magnetic Imager* (HMI) instrument (Schou *et al.*, 2012a) was built as part of the HMI investigation (Scherrer *et al.*, 2012) and is designed to measure the Doppler shift, line-of-sight magnetic field, intensity, and vector magnetic field at the solar photosphere by observing the 6173 Å Fe I line.

The details of design have been given in Schou *et al.* (2012a) and will, in general, not be repeated here.

The ground based calibrations were described in detail in a separate set of articles Wachter *et al.* (2012) describe the image quality and CCD performance, Couvidat *et al.* (2012) the filter performance, and Schou *et al.* (2012b) the polarization properties.

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Figure 1. Updated/better quality version here. Got it from Phil. Schematic of the HMI optical layout with various elements annotated. The calibration LED behind the BDS beamsplitter is not shown. (Couvidat *et al.*, 2012).

The present paper updates the calibration results given in those papers and presents the results of the calibration that were deferred in those papers.

We also describe how the various observables (Doppler velocity, continuum intensity, LOS field strength and IQUV) are constructed. The procedures used for inverting for the full vector field is described elsewhere (**?**) **Centeno et al., 2014**.

The intent of the present paper is not to replace those earlier papers. Most details of the instrument design and most of the calibration details are described there and they continue to be the primary source. Rather the intend is to provide additional information that may in some case improve the usefulness of the HMI data.

2. Instrument Description

3. Calibration

The ground based calibration was described in separate articles for image quality and CCD performance (Wachter *et al.*, 2012**), for filter performance (**Couvidat *et al.*, 2012**), and for polarization properties (**Schou *et al.*, 2012b**).**

Finally, it should be noted that some of the calibrations have been deferred to on-orbit for practical reasons.

Try estimating errors. Effects on observables. List outstanding issues. Trends seen so far. Data capture stats. CALVERNN.

3.1. Image Quality

Details of the ground-based calibration procedures and results are given by Wachter *et al.* (2012).

Discuss actual distortion used, estimated accuracy, attempt to improve? PSF/MTF. Phase diversity, Venus, Moon. Strehl ratio. Scattered light. Limb, Moon, Venus. Time dependence. Norton vs. Yeo. Flat field. Actual processing. Rotational? Bad pixels. Cosmic rays, transient and permanent. Throughput degradation. Exposure time changes. Linearity and saturation. Describe different versions. Temperature dependence of gain. Roll angle and image scale. Errors. Venus. Others? Really need to look at Moon stuff. Limb finding. Height of formation changes.

3.2. Wavelength Dependence

The ground based efforts are described by Couvidat *et al.* (2012). **How are maps constructed. Drift. Tuning changes. Camera difference. Provide maps in electronic form. Actual veolcity algorithm used. Line profile tweaking. Polynomial correction. Fringe removal. I-ripple.**

Table 1. Framelist taking LOS data on the front and full IQUV on the side camera. See text for details. **Show actual framelist.**

FID	RelTime	Img	PL	WL	CF	Exp	ObsPath
10098	0	DEFAULT	258	469	DEFAULT	DEFAULT	FRONT2_IMAGE
10113	88125	DEFAULT	253	471	DEFAULT	DEFAULT	SIDE1_IMAGE

3.3. Polarization

The ground-based calibration efforts are described by Schou *et al.* (2012b).

Actual calibration used. Temperature dependence model. Polarization dependent PSF. Find origin? Telescope polarization. Really is not. Depolarization. Stress birefringence. Try to determine idea setting?

3.4. Pipeline Processing

Perhaps have a section describing the pipeline. Overall flow. Interpolation in space and time. Gap filling. NRT vs. definitive.

4. Conclusion

Instrument works well. Performance is good. Quantify?

Updated documentation about the instrument will be available from the project website http://hmi.stanford.edu and the observables from the instrument will be available from http://jsoc.stanford.edu shortly after the observations are taken.

Appendix

A. Sequencer and Framelist Examples

Table 1 shows an example of a framelist. In order the columns are the following:

Note that most of the settings use an index into another table. That table then details the settings of the individual mechanisms. In many cases a default value is specified. The corresponding values are kept separately in registers in the FSW. This allows for changing parameters such as the focus position and exposure time without remaking framelists.

Similarly PL positions 258 and 259 correspond to LCP and RCP while 250 through 253 are 4 positions allowing for the determination of I, Q, U, and V.

In the example shown in Table 1, WL positions 465, 467, 469, 471, 473, and 475 correspond, in order to I5, I4, I3, I2, I1, and I0, which in turn correspond to increasing wavelength.

As can be seen, the framelist loops twice through the wavelengths in a particular non-sequential order I3, I4, I0, I5, I1, I2. Combined with choosing the starting point such that the center wavelengths (I2 and I3) are centered on the target

times (0 seconds and 45 seconds), this minimizes the errors in the inferred Doppler velocities.

In both halves of the framelist, the front camera does LCP and RCP at each wavelength, thereby allowing for the Doppler and LOS field to be obtained. The side camera, on the other hand, does two of the four polarizations in the first half and the other in the second half, thereby allowing for a 90 second cadence using data from that camera only.

Many other framelists with various tradeoffs are, of course, possible. Apart from ones with different details in the regular observing sequences, they include ones taking detunes, focus sweeps, linearity data, and so forth.

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