An Alternative Approach to Measuring Solar Velocities on the Solar Dynamics Observatory (SDO)

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Abstract

Aboard the Solar Dynamics Observatory (SDO), the Helioseismic and Magnetic Imager (HMI)[1] measures the velocity of the Sun's magnetic fields. However, there is a calibration issue causing an artificial 24h periodicity. The SDO spacecraft's velocity leaks into the solar velocities data.

The spacecraft's velocity is much greater than the solar velocities and causes inaccurate data. I compared the current HMI Method results[3] with a Gaussian Fit Method, that could bypass the calibration error and avoid the leak of spacecraft velocity on the solar data. By plotting the Sun's spectra at six different wavelengths, I could use a Gaussian fit to calculate the distribution at each pixel.

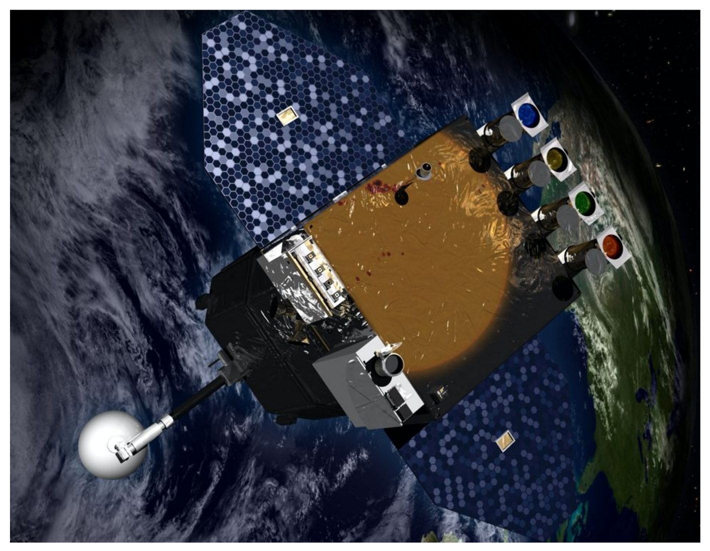

Fig 1. SDO Spacecraft. Image credit: NASA/Goddard Space Flight Center Conceptual Image Lab, 2007

After noticing trends in the two methods, I can claim the Gaussian Method works better at calculating solar velocities. However, it can be sensitive at identifying the wavelengths at Sunspot locations, varying only slightly from the original HMI data. This would give the most accurate results for solar velocities and limit the need for calibration.

Introduction

- From the Earth's line of sight, the Sun rotates on an axis in the approaching and receding motion.
- Due to the Sun rotating faster around the equator and slower around it's poles, the Sun's magnetic fields get tangled.
- Sunspots are regions where the magnetic fields lines have become so tangled the field lines pierce through the sun surface.
- The HMI instrument measures solar rotation and magnetic field velocity at all regions of the Sun.
- The current HMI Method uses ratios of 6 wavelengths to find a weighted velocity and requires a calibration via a sensitivity curve that assumes how the spectral line looks at each pixel[3]
- The current HMI method is causing a leak of the spacecraft velocity on the solar data

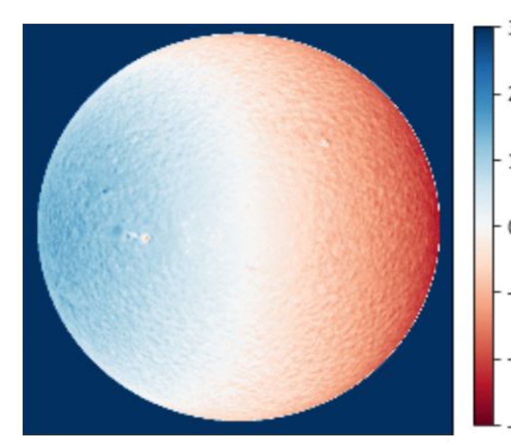

Fig 2. This dopplergram shows the velocity of the sun's rotation in a two-dimensional representation.

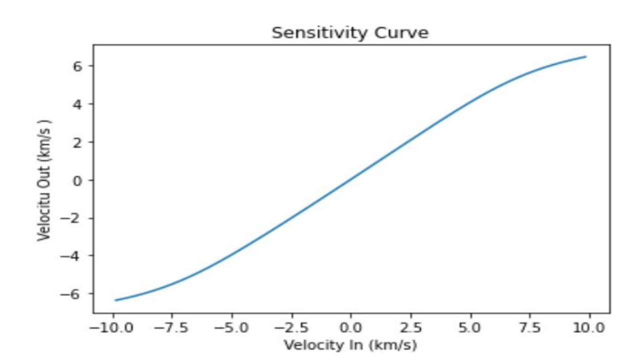

Fig 3. The Sensitivity Curve The HMI Method uses to calibrate the Data

Gaussian Method

- Plotting the Sun's spectra at six wavelengths, a non-linear algorithm was used to fit a Gaussian.
- The Gaussian plotted the wavelengths distribution and identified the Gaussian Center
- Strict estimations were used to determine the center of the Gaussian Center.
- the Doppler equation, $v = c\frac{\Delta\lambda}{\lambda_0}$ calculates the combined spacecraft and solar velocity.
- The solar velocity could be isolated by subtracting the spacecraft's velocity from the data.
- The Gaussian Method calculates solar velocities at very pixel of the sun

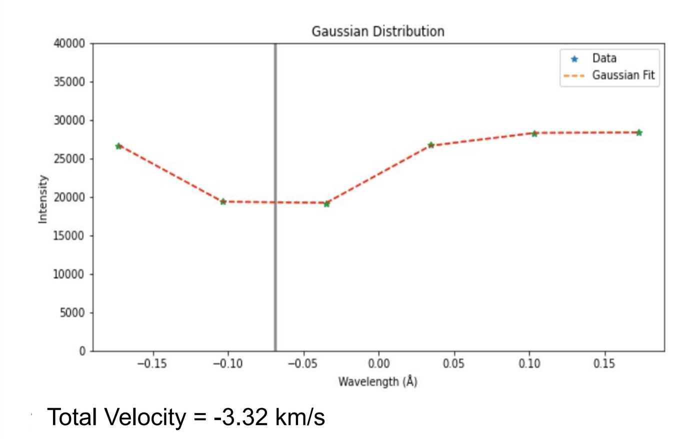

Fig 4. A Gaussian fit of the data at the center of the Sun The Gray line identifies, Δλ, the center of the peak.

Results

- The figures show the results of the solar velocity plotted over 24 hours using the Gaussian fit, robust HMI method before calibration and after calibration, at different locations on the Sun.
- The HMI method incorporated a calibration in attempt to calculate accurate data. However, The use of calibration on the HMI data is unneeded when calculating the solar velocity in quiet inactive regions and caused the spacecraft's velocity to leak into the solar velocities.
- The HMI Method after calibration may produces accurate results in active region of the sun.
- The Gaussian method produced accurate solar velocity results at both active and inactive regions without the need for calibration.
- The lack of data with sunspots given, makes it difficult to determine what is happening in Fig 8.

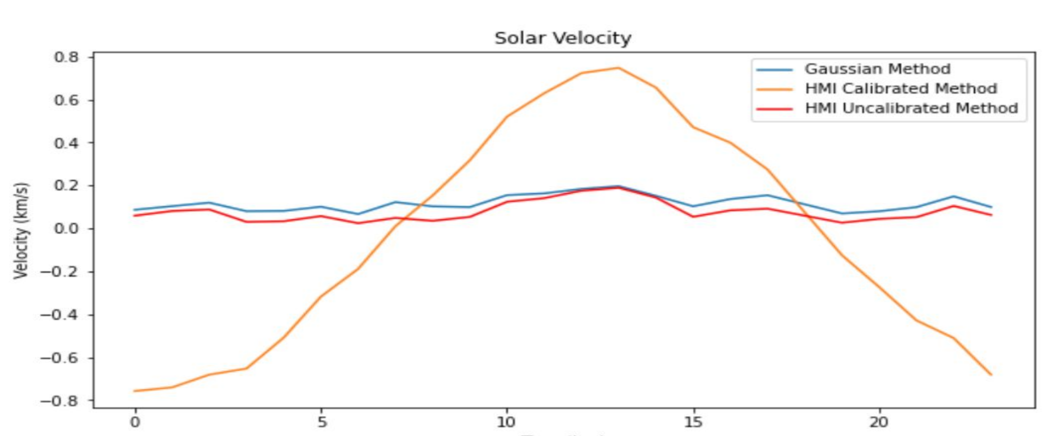

Fig 5. The solar velocity at the center of the sun. The velocity should be close to zero due to the spacecraft line of sight.

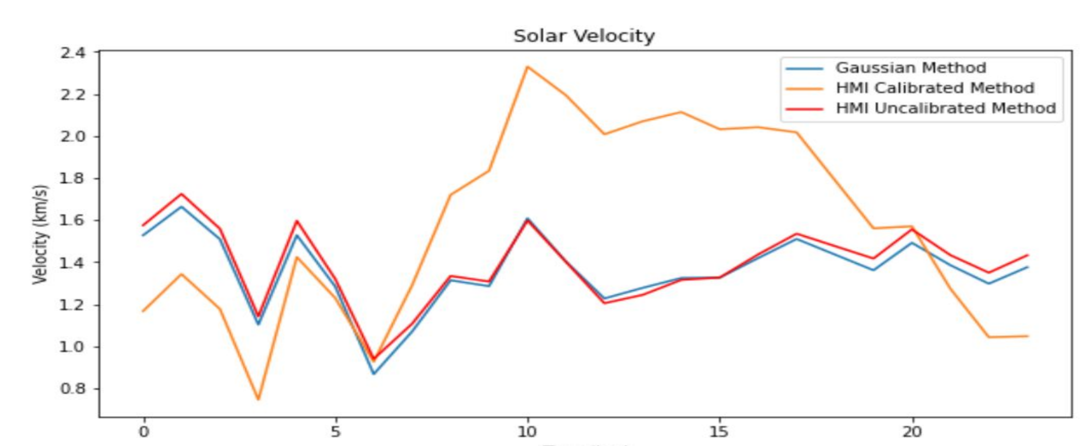

Fig 7. The solar velocity on the left limb of the sun along it's equator. The positive value identify that the sun is rotating away from the Earth.

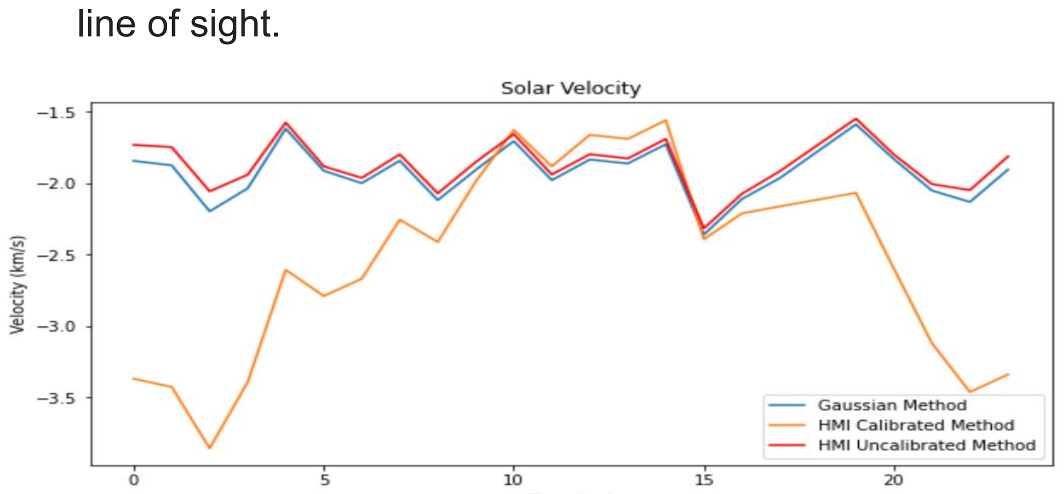

Fig 6. The solar velocity on the right limb of the sun along it's equator. The negative values identify that the sun is rotating towards the Earth.

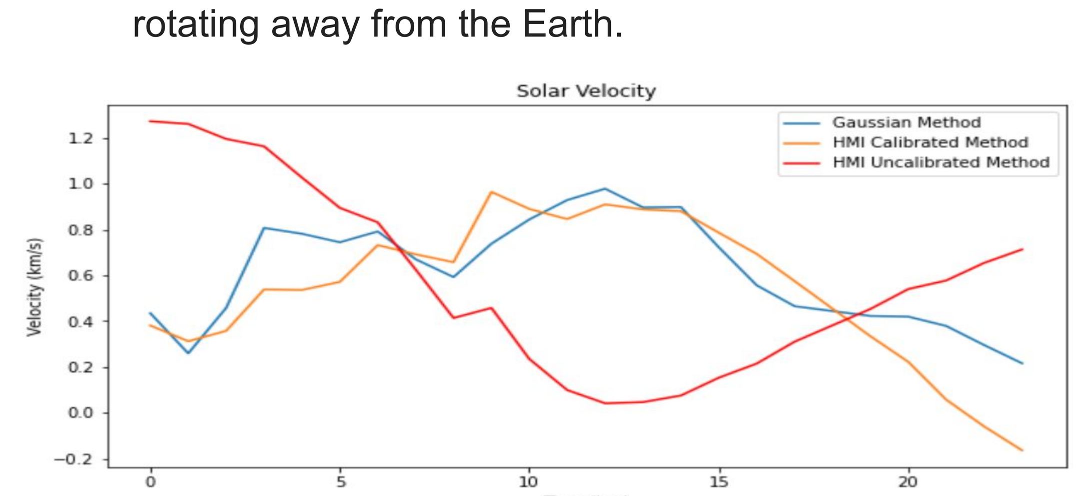

Fig 8.The solar velocity of the darkest point inside the Sunspot over 24 hours.

Conclusions

- The Gaussian Method produces more accurate results among both active and inactive regions.
- The HMI's calibration error in inactive regions indicate the leak of the spacecraft velocity in active regions as well.
- To produce accurate results the HMI method would need to correctly identify when calibration is need, if it is needed at all.
- Further research is needed to determine consistency in each of the methods.
- Future work would entail calculating the magnetic- field strength, Fe I line width, line depth, and continuum intensity using the Gaussian Method.

References

(1) Couvidat, Sébastien, et al., 2011, pp. 285–325.
(2) Couvidat, Sébastien, et al., 2012, pp. 217–240.
(3) Couvidat, S., et al., 2016, pp. 1887–1938.

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