Semester Report

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PhD Program: Astronomy and Space Physics
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Research Topic: Investigating the Magnetic Field in the Lower Solar Atmosphere: Relevance to Space Weather Studies
Semester: 2nd Semester (2025/2026)

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1 Introduction

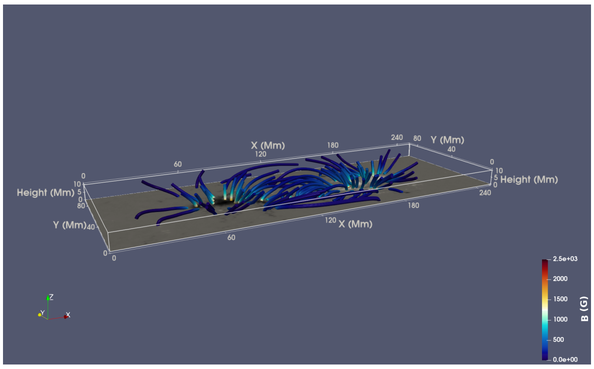
During the first semester of my doctoral studies, I developed and validated a computational framework for three-dimensional magnetic field extrapolation in the lower solar atmosphere using the linear force-free field (LFFF) approximation [1, 4]. This provided the numerical basis for the present stage of the project.

During the current semester, the framework was applied to compare extrapolations obtained from photospheric observations by the *Helioseismic and Magnetic Imager* (HMI) aboard the *Solar Dynamics Observatory* (SDO) and lower-atmospheric observations from the *Synoptic Optical Long-term Investigations of the Sun / Vector Spectromagnetograph* (SOLIS/VSM). The extrapolated magnetic fields were analysed using the R-value, magnetic polarity inversion line (MPIL) properties, and the weighted horizontal magnetic gradient (WG_S) to examine how these diagnostics evolve with height. The main objective was to investigate how the choice of observational boundary influences the reconstructed magnetic field and flare-related magnetic complexity diagnostics.

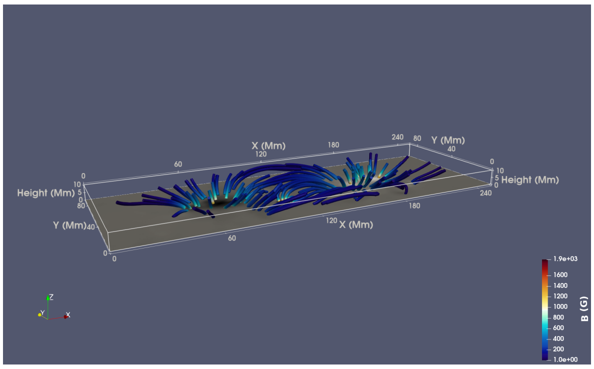
2 Research

The primary objective of this semester was to apply the numerical framework developed during the first semester to investigate the influence of different observational boundary conditions on magnetic field extrapolations in the lower solar atmosphere. A comparative study was carried out using photospheric observations from the HMI aboard the SDO and lower-atmospheric observations from the SOLIS/VSM. After preprocessing and co-aligning the magnetograms onto a common computational grid, three-dimensional extrapolations were performed using the LFFF approximation [1, 4].

The reconstructed fields were visualised in ParaView to examine the overall magnetic connectivity of the active region. Figure 1 shows the extrapolated field lines obtained using the HMI (left) and SOLIS/VSM (right) boundary conditions. Both extrapolations reproduce the large-scale magnetic structure, while differences are evident near the lower boundary, where the HMI extrapolation preserves stronger, more compact structures and the SOLIS/VSM extrapolation appears comparatively smoother.



(a) HMI



(b) SOLIS/VSM

Figure 1: Three-dimensional LFFF extrapolations for the HMI (left) and SOLIS/VSM (right) boundary conditions. Field lines are coloured by magnetic field strength.

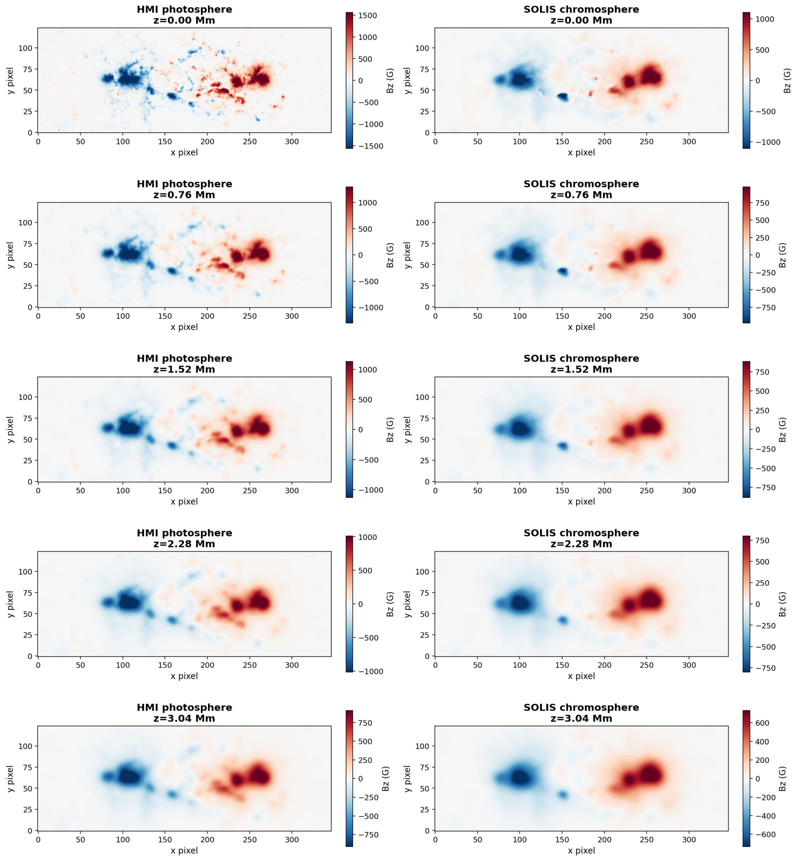


Figure 2: Horizontal slices of the extrapolated magnetic field at selected heights. Left: HMI. Right: SOLIS/VSM. Heights increase from top to bottom.

Figure 2 illustrates how the reconstructed magnetic field changes with increasing extrapolation height. Near the lower boundary, the HMI extrapolation retains stronger fine-scale magnetic structures, whereas the SOLIS/VSM extrapolation appears comparatively smoother. As the extrapolation height increases, the small-scale magnetic features gradually disappear and both extrapolations converge towards similar large-scale magnetic structures.

To quantify the magnetic complexity of the extrapolated fields, three commonly used flare-related diagnostics were evaluated. The R-value measures the unsigned magnetic flux surrounding strong-gradient polarity inversion lines and is widely used as an indicator of magnetic complexity [2]. The total MPIL length characterises the spatial extent of polarity inversion lines within the active region [2], while the WG_S quantifies the magnetic gradient between opposite-polarity regions and has been proposed as a useful parameter for flare prediction [3].

Figure 3 summarises the variation of these magnetic complexity diagnostics with extrapolation height. The top row (from left to right) presents the R-value, total MPIL length, and unsigned magnetic flux around the MPIL, while the bottom row shows the WG_S, the separation parameter, and the longest MPIL segment. All six quantities decrease with increasing height, reflecting the gradual simplification of the extrapolated magnetic field. Compared with the SOLIS/VSM extrapolation, the HMI boundary generally produces larger R-values and stronger WG_S values, whereas the SOLIS/VSM extrapolation exhibits longer MPIL structures close to the lower boundary.

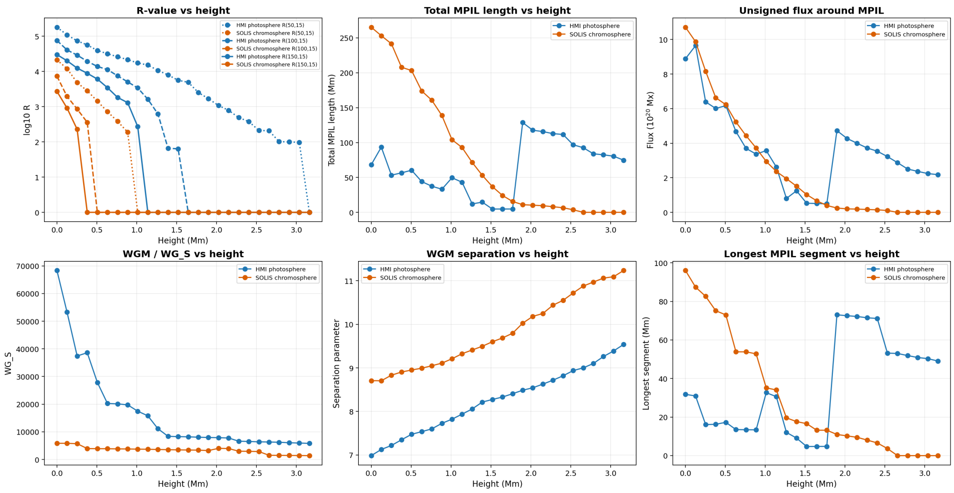


Figure 3: Variation of the magnetic complexity diagnostics with extrapolation height for the HMI (blue) and SOLIS/VSM (orange) extrapolations. Top row: R-value, MPIL length and unsigned MPIL flux. Bottom row: WG_S, separation parameter and longest MPIL segment.

To compare the two extrapolations directly, the relative differences between the magnetic complexity diagnostics were also evaluated. Since the R-value is expressed on a logarithmic scale, the difference between the HMI and SOLIS/VSM values was analysed directly, whereas the MPIL length and WG_S were compared using diagnostic ratios. Figure 4 shows that the SOLIS/VSM boundary does not simply reproduce the HMI magnetic field at a lower amplitude. Instead, it produces broader polarity inversion line structures while exhibiting weaker magnetic gradients and lower R-values. These differences demonstrate that the choice of observational boundary condition influences both the geometry and magnetic complexity of the reconstructed magnetic field.

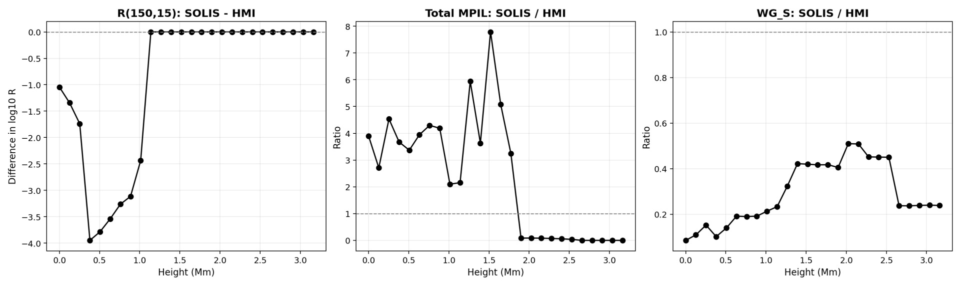


Figure 4: Comparison of the HMI- and SOLIS/VSM-derived diagnostics. Left: R-value difference. Centre: MPIL ratio. Right: WG_S ratio.

3 Publications

No publications were produced during this semester.

4 Studies in the Current Semester

During the current semester, I completed the following courses:

- **FIZ/5/010 – Radio Astronomy II** (5 credits) – Excellent
- **FIZ/5/057 – Solar Physics** (3 credits) – Satisfactory
- **FIZ/2/073 – Linear and non-linear MHD waves** (5 credits) – Excellent

5 Conferences in the Current Semester

During the current semester, I regularly attended the weekly Solar Physics Group meetings held every Friday. Attended ESPD Summer School(Online). No conference presentations or workshop participation were undertaken during this semester.

Outlook

The work carried out during this semester provides a solid foundation for the next stage of my research. Future work will focus on performing the extrapolations using consistent values of the force-free parameter α for all boundary conditions, allowing the effects of the observational boundary and the extrapolation parameters to be investigated independently.

The SOLIS/VSM observations will also be examined in greater detail to verify their observational characteristics, including their spectral-line origin, temporal correspondence with the HMI data, and formation-height interpretation. This will strengthen the physical interpretation of the comparison between the two observational datasets.

The analysis will then be extended to additional active regions and, where possible, to time-dependent observations. In the longer term, the objective is to investigate magnetic field reconstruction using both photospheric and lower-atmospheric magnetic field measurements simultaneously, providing a more realistic description of the magnetic structure of the lower solar atmosphere.

References

[1] C. E. Alissandrakis. On the computation of constant-alpha force-free magnetic field. *Astronomy and Astrophysics*, 100:197–200, 1981.

[2] S. Biswal, M. B. Korsós, M. K. Georgoulis, A. Nindos, S. Patsourakos, and R. Erdélyi. Case studies on pre-eruptive x-class flares using r-value in the lower solar atmosphere. *The Astrophysical Journal*, 974(2):259, 2024.

[3] M. B. Korsós, A. Ludmány, R. Erdélyi, and T. Baranyi. On flare predictability based on sunspot group evolution. *Astrophysical Journal Letters*, 802:L21, 2015.

[4] T. Wiegelmann and T. Sakurai. Solar force-free magnetic fields. *Living Reviews in Solar Physics*, 9:5, 2012.