Semester Report

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Ph.D. Thesis Title: Investigating the Magnetic Field in the Lower Solar Atmosphere: Relevance to Space Weather Studies
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1 Introduction

Magnetic fields play a key role in structuring the solar atmosphere and in governing phenomena such as wave propagation, energy transport, and magnetic connectivity. These processes are also closely linked to solar activity, which can influence space weather conditions. While magnetic field measurements are routinely available at the photosphere, the magnetic structure of the overlying atmospheric layers is not measured directly routinely. It often must therefore be inferred using theoretical and numerical methods.

A commonly employed first approach to this problem is to compute the magnetic field in a given solar atmospheric volume by solving elliptic boundary value problems under simplifying physical assumptions. In particular, current-free (potential) magnetic field models provide a useful and computationally efficient starting point for studying magnetic connectivity in the lower solar atmosphere.

At this early stage of my PhD, the precise thesis focus is intentionally kept flexible as the primary objective of the work conducted during this first semester was to establish a solid numerical foundation for investigating the magnetic field in the lower solar atmosphere, with the long-term goal of contributing to a deeper understanding relevant to space weather studies. This involved implementing, understanding, and validating a three-dimensional Laplace solver to approximate the magnetic field in the region bounded by a lower photospheric boundary and an upper boundary representative of the chromospheric layer.

The work completed during this semester establishes a methodological basis for future developments in more advanced magnetic field models and their application to solar atmospheric and space weather-related problems.

2 Research Work Carried Out in the Current Semester

2.1 Numerical Framework and Solver Architecture

During the first semester, my primary focus was on understanding and working with an existing three-dimensional Laplace solver formulated in spherical coordinates. The aim was not only to execute the solver, but also to understand how the numerical solution is constructed and how the underlying routines contribute to the final magnetic field reconstruction.

Under the assumption of a current-free magnetic field, the scalar magnetic potential U satisfies

$$\nabla^2 U = 0,$$

from which the magnetic field is obtained as $\mathbf{B} = -\nabla U$. The solver employs spectral decomposition in the azimuthal direction, reducing the original three-dimensional problem to a set of independent two-dimensional modified Helmholtz equations in (r, θ). These equations are solved using the FISHPACK `HWSCSP` routine [1], which serves as a numerical engine for solving elliptic boundary value problems. The magnetic field reconstruction follows from the global formulation of the problem and the imposed boundary conditions, rather than from the subroutine itself.

2.2 Boundary Conditions and Input Data

To validate the solver in a controlled manner, synthetic multipole magnetic field configurations were first used as lower boundary conditions. In addition, real solar magnetogram data from the Helioseismic and Magnetic Imager (HMI) were employed as lower-boundary input.

The magnetogram data were interpolated onto user-defined spherical grids, allowing flexibility in the choice of numerical resolution. For these initial validation tests using idealised magnetic field configurations, the computational domain was extended from $r = 1.0\,R_\odot$ to $r = 2.5\,R_\odot$. This extended upper boundary does not correspond to the chromospheric height, but was chosen to test the numerical robustness and stability of the solver over a larger volume. Small regions near the poles were excluded to avoid coordinate singularities.

2.3 Verification and Error Analysis

The numerical consistency of the solver was evaluated by comparing the reconstructed radial magnetic field component B_r at the lower boundary with the prescribed input boundary condition. Both qualitative and quantitative diagnostics were used to assess the agreement.

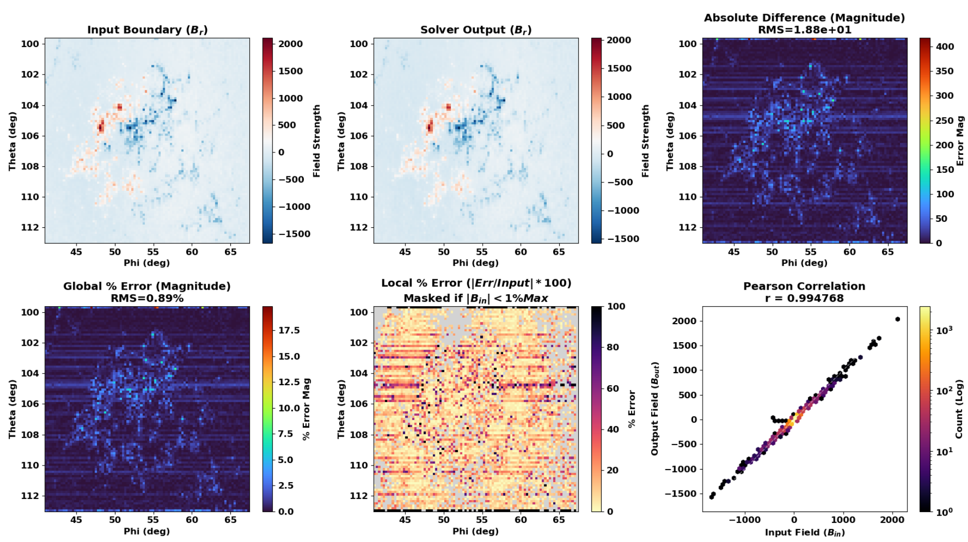
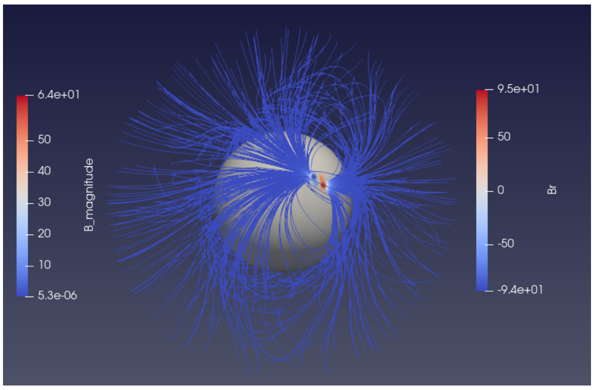


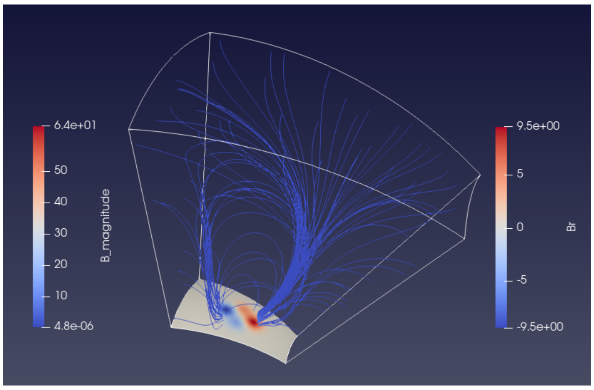
Figure 1: Boundary verification comparing the prescribed and reconstructed lower-boundary radial magnetic field B_r.

2.4 Three-Dimensional Visualization

Three-dimensional magnetic field lines were traced throughout the computational domain to assess the physical plausibility of the reconstructed solutions. The resulting visualizations provide a qualitative comparison of magnetic connectivity obtained under different domain geometries and boundary treatments.



(a) Global spherical-domain solution (FFT mode).



(b) Local spherical wedge solution (DCT mode).

Figure 2: Three-dimensional magnetic field configurations obtained from potential-field solutions with two dipole sources at the lower boundary, illustrating differences in magnetic connectivity for global (FFT) and local (DCT) spherical-domain configurations.

3 Publications

No publications were produced during this semester.

4 Studies in the Current Semester

During this semester, I have completed the following subjects, all with excellent grades,

- FIZ/5/058 – Physics of the solar atmosphere
- FIZ/5/009 – Radio astronomy I.
- FIZ/5/055 – Solar System plasma physics

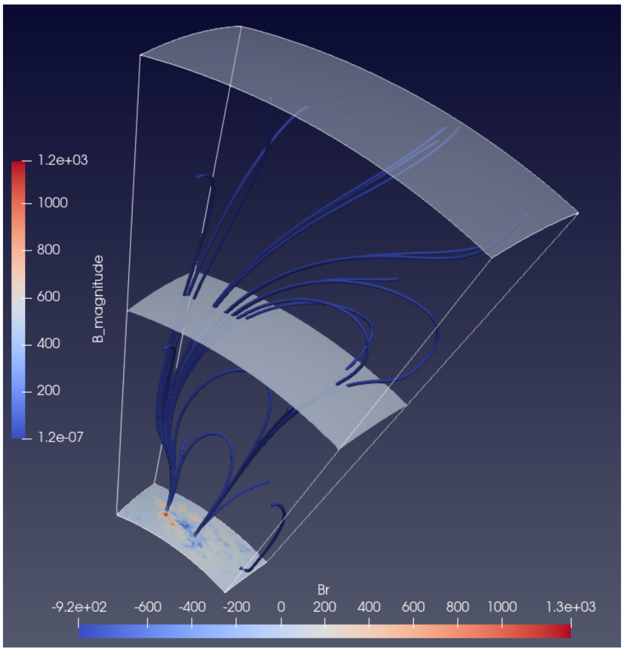
5 Outlook

Future work will build on the validated Laplace solver framework by extending the modeling approach toward more realistic magnetic field configurations in the lower solar atmosphere. While the current implementation uses a single lower boundary condition, an important next step is to introduce observational constraints at multiple lower solar atmospheric heights.

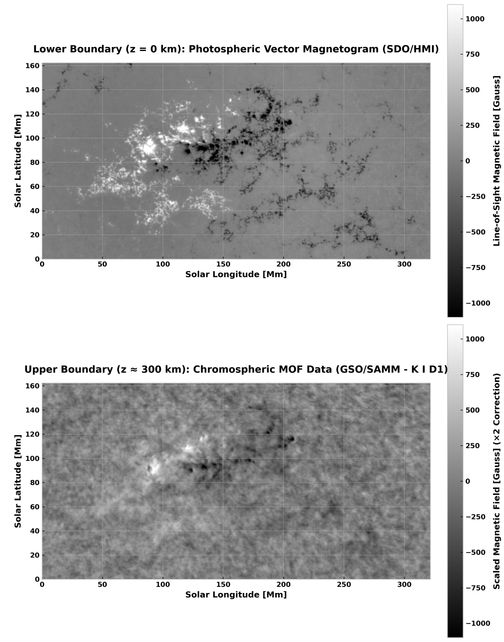
Photospheric vector magnetograms from SDO/HMI will continue to define the lower boundary, as illustrated in Figure 3, while chromospheric magnetic field information derived from

GSO/SAMM MOF observations will be incorporated as an additional constraint at an intermediate height. The upper boundary can then be treated using simplified or analytical assumptions.

Introducing such multi-height constraints is expected to improve the reconstruction of the magnetic field in the region between the photosphere and chromosphere and provides a natural bridge between single-boundary potential field models and more advanced force-free formulations.



(a) Lower boundary: Photospheric magnetic field from SDO/HMI vector magnetogram.



(b) Intermediate boundary: Chromospheric magnetic field inferred from GSO/SAMM MOF observations.

Figure 3: Conceptual illustration of the proposed multi-boundary approach for magnetic field reconstruction in the lower solar atmosphere. Photospheric vector magnetograms from SDO/HMI define the lower boundary, while chromospheric magnetic field information from MOF observations provides an additional constraint at an intermediate height.

In parallel, linear force-free magnetic field configurations will be explored by solving the Helmholtz equation in Cartesian geometry using FISHPACK routines [2], with the longer-term goal of improving magnetic field modeling relevant to space weather studies.

References

[1] Paul Swarztrauber and Roland Sweet. *FISHPACK: Efficient Fortran Subprograms for the Solution of Elliptic Partial Differential Equations*. National Center for Atmospheric Research, 1975. NCAR Technical Note TN/IA-109.

[2] NCAR. *FISHPACK Documentation*, 1999. Version 4.1.