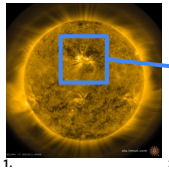
Analyzing the Structure of Coronal Loops in MURaM Radiation MHD Simulations

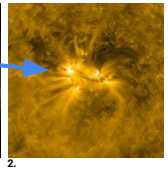
M. L. David[1], M. Rempel[2], A. Malanushenko[3]

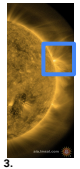
[1]Carleton College, [2]High Altitude Observatory, NCAR, [3]High Altitude Observatory, NCAR | contact email: davidm2@carleton.edu

Abstract: Coronal loops are emission features that trace out parts of the solar magnetic field in the corona, and as such they provide important information about the magnetic and thermal structures of the solar corona. However, observations of these features are limited by the resolution of the instruments used to study them. Here, we clarify those limitations through analyzing observational data and modeling synthetic data using MURaM radiative code and answer three main questions: **how does the number of loops identified in observational data depend on viewing angle? Does the number of loops identified in synthetic observations depend on the resolution of the numerical simulation?**

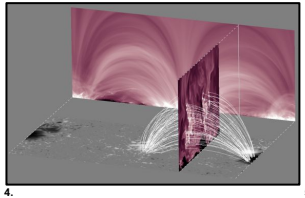
Introduction: Coronal loops are loops of magnetic field that begin and end in active regions in the Sun's corona, tracing out where the Sun's complex magnetic field is disrupted. The study of these loops is incredibly complex, in part due to the limitations of the instruments we use to observe them. The Atmospheric Imaging Assembly on board the Solar Dynamics Observatory, for example, can only capture images with resolution of 0.6 arcseconds per pixel, while the High-Resolution Coronal Imager is able to capture images with a resolution of 0.13 arcseconds per pixel. Modeling [3], however, offers an additional tool for gathering information about these structures, with the ability to artificially manipulate the resolution of images computed from a 3 dimensional data cube. In this case, the MURaM radiative code, a multidimensional MHD code, is vital in creating a simulation in which coronal loops can be studied in more detail, and with more control [8].

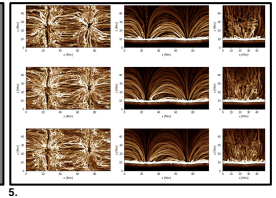

1.


2.


3.

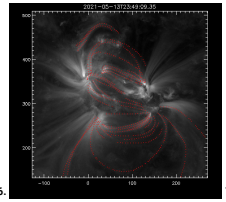
Figures:
1, 2, 3. Close-ups from AIA of active region w/ coronal loops
4. Visualization of 3D MURaM simulation [2]
5. Simulated MURaM emission

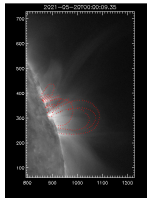

4.


5.

References:
[1] Williams et al, ApJ, 892:134 (2020)
[2] Malanushenko et al, (2021, under review)
[3] Aschwanden et al, Solar Physics, 290 (2015)
[4] Cirtain, J.W. (2005). [Doctoral dissertation, Montana State University]. Montana State University
[5] Chen, F. (2015). [Doctoral dissertation, Georg-August University School of Science].
[6] Malanushenko et al, ApJ, 783:102 (2014)
[7] McCarthy et al, ApJ, 913:1 (2021)
[8] Rempel, M., ApJ, 834:10 (2017)
[9] Malanushenko et al, ApJ, 41:863 (2009)

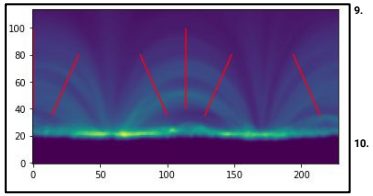
Method — Manual loop counting with observables:
— Images of a chosen active region on 4 different days and at 3 different wavelengths (171Å, 193Å, 211Å) are restored in IDL and loops are traced using previously written program [9]
— Number of loops for each day and at each wavelength are recorded

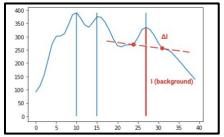

6.


7.

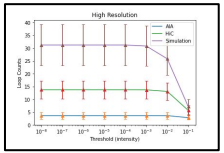
Figures:
6. Image taken of sunspot on 05/13/21, loops traced in IDL
7. Image taken of same sunspot on 05/20/21, loops traced in IDL

Method — Automatic loop counting function for MURaM simulation: :
— Compute images using synthetic AIA data, synthetic HiC data, and data native to the simulation. This is done at 3 different resolutions (grid spacing=64km, 96km, 192km)
— Analyze with automatic loop tracing function in Python:
— Run a separate function which plots "paths" through the images
— Feed these paths into the loop counting function, which computes an intensity profile of the image along the specified paths
— Tally each local maximum on the intensity curve as a loop


8.



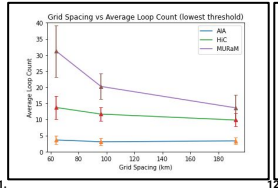
9.



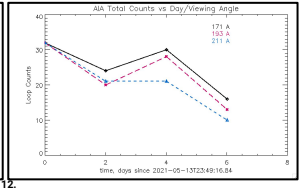
10.

Figures:
8. Synthetic AIA image with two loop bundles, with 6 "paths" plotted in red
9. Intensity profile of synthetic AIA image with local maxima marked
10. Plot of threshold vs loop count at high resolution

Results:
— Number of loops found in synthetic AIA does not depend on resolution of the simulation, while the number of loops counted in native resolution data and synthetic HiC does go up with higher numerical resolution
— Number of loops counted in observables from AIA does depend on viewing angle
— We find 72% fewer loops using the automatic counting function rather than counting by hand



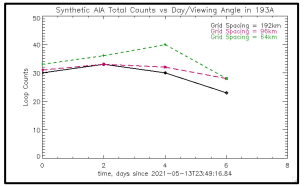
11.



12.

Conclusions:
— Appears that the numerical resolution of the simulation affects the amount of structure observed most when the data itself is at a higher resolution [1] (synthetic HiC vs synthetic AIA) — indicates that our simulation is robust
— Unclear why the number of loops counted changes with viewing angle for AIA

Future work:
— Repeat manual loop counting process but with synthetic images at comparable viewing angles to the observables — did this already but without correct blurring applied
— Recount loops using automatic function but first subtract background emission



13.

Figures:
11. Grid spacing/resolution vs loop counts for 3 data sets
12. Day/viewing angle vs loop counts for real AIA data
13. Day/viewing angle vs loop counts for synthetic AIA data