Numerical MHD Coronal Simulations: Energy Statistics and FORWARD Analysis

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Introduction

The solar corona is the outer part of the Sun’s atmosphere. Temperatures rise rapidly from the chromosphere through the transition region, reaching temperatures of the order of $1 \times 10^6$ Kelvin in the corona. Simultaneously, the high densities in the lower atmosphere fall rapidly in the transition region and result in a low density plasma in the corona. Numerical simulations of the solar corona are important to develop our understanding of, for example, the energetics and magnetic structure, which can be difficult to interpret using observations alone. We present here the analysis of 118 solar events from a magnetohydrodynamic simulation of the solar atmosphere, that describes the upper convective zone of the Sun through the corona. This simulation shows an “extreme” active region of the Sun, with a number of flares and a coronal mass ejection (CME). We provide here statistics of the energetics of the events in the simulation.

Identifying Simulated Flare Events

Regions of the Sun with a strong electric current (known as a current sheet) have a very efficient dissipation which can cause the magnetic field topology to alter. This is a phenomena called magnetic reconnection and results in the magnetic energy stored in the corona being converted to kinetic and internal energy. Magnetic reconnection causes the sudden release of magnetic energy in the solar atmosphere, resulting in a flare or similar solar event. Simulated flares and flare-like phenomena can be observed in Figure 1, with sudden releases of magnetic energy into a combination of the work done by the Lorentz force and the resistive heating.

By studying Figure 1, 118 simulated solar events were identified, and each event’s duration and energy was estimated.

The analysis: The full energy time series is divided into subsections, and each of these shorter profiles are smoothed by a combination of boxcar averaging and Lee filtering. The smoothing parameters are dependent upon the solar activity in each time interval. By considering the locations where the sign of the gradient changes, the peak value on the smoothed profile, and the beginning and end indices of the event are determined. The beginning and end indices, and their corresponding value on the original profile, are then fitted by a straight line to model the background of the event. The energy is estimated by subtracting the background linear fit from the original profile and integrating over time from the beginning of the event to the end.

Energetics of Simulated Flare Events

The FORWARD code is a tool used for the purpose of coronal magnetometry. It compares physical properties of models with observable quantities, which helps to interpret observations of the Sun from instruments like the High Altitude Observatory’s CoMP instrument. The CoMP (Coronal Multi-channel Polarimeter) instrument measures the intensity and the linear and circular polarisation of Fe xiii at 1074.7nm. We discuss some important limitations of the FORWARD code when simulating an extremely active solar region, and investigate the evolution of a CME event from the coronal simulation.

Conclusions

This sophisticated numerical MHD model of the solar atmosphere simulates an extremely active region of the Sun with a range of different solar events that all follow a similar energy distribution.

• Approximately 75% of the magnetic energy is converted to kinetic energy by the Lorentz force, the remaining 25% is converted to the internal energy of the system by resistive heating.
• The kinetic energy quickly thermalisises, and all of this excess kinetic energy is converted to thermal energy by viscous heating.
• About 60% of the internal energy is immediately released as radiation.

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References