RAS Specialist Discussion Meeting

Flux emergence and its consequences in the solar atmosphere

October 14th, RAS Lecture Theatre, Burlington House, London

Timetable

10.00 – 10.30

Coffee in the RAS Library.

10.30 – 10.35

Welcome and introduction.

Session 1 Chair: Dr Chris Prior

10.35 – 11.10

Dr Salvo Guglielmino, Catania. *Magnetic flux emergence: observational evidence and its consequences in the solar atmosphere* (Invited)

11.10 – 11.25

Dr David MacTaggart, Glasgow. *The pre-penumbral magnetic canopy.*

11.25 – 11.40

Dr Stephane Regnier, Northumbria. *The birth of an active region.*

11.40 – 11.55

Professor Alan Hood, St Andrews. *Sunspot rotation and coronal consequences.*

11.55 – 12.10

Dr Anthony Yeates, Durham. *Incorporating flux emergence in global coronal simulations.*

12.10 – 12.25

Miss Sally Dacie, UCL. *The magnetic field distribution of active regions during their emergence and decay phases.*

12.30 – 13.30

Lunch (not provided).

Session 2 Chair: Dr Karen Meyer

13.30 – 14.05

Dr James Leake, NRL. *A Review of Numerical Modeling of Magnetic Flux Emergence in the Solar Atmosphere*. (Invited)

14.05 – 14.20

Dr Petros Syntelis, St Andrews. *On the mechanism of recurrent eruptions.*

14.20 – 14.35

Mr Tim Whitbread, Durham. *Parameter optimization of surface flux transport models.*

14.35 – 14.50

Dr Vasilis Archontis, St Andrews. *Emerging flux and solar jets: observations and numerical experiments.*

14.50 – 15.00

Concluding remarks and end of meeting.

Abstracts (in chronological order)

Dr Salvo Guglielmino, Catania. *Magnetic flux emergence: observational evidence and its consequences in the solar atmosphere*:

The emergence of magnetic flux in the photosphere is a process with a highly hierarchical structure that spans from large scales well represented by sunspots down to the limit of current observational capabilities, the so-called internetwork fields. At every scale, the appearance of emerging flux regions (EFRs) involves the upper atmosphere of the Sun, through the interaction between the pre-existing ambient fields and the new flux, with different manifestations. I will report on some flux emergence events at different scales. In particular, I will show the results of recent studies that have been devoted to the analysis of small-scale EFRs, thanks to the advance of high-resolution observations. I will also include episodes that reveal signatures of dynamical phenomena interpreted as the response of the upper layers of the solar photosphere to the modification of the magnetic field configuration, induced by the newly emerging flux.

Dr David MacTaggart, Glasgow. *The pre-penumbral magnetic canopy*:

Penumbrae are the manifestation of magnetoconvection in highly inclined (to the vertical direction) magnetic field. The penumbra of a sunspot tends to form, initially, along the arc of the umbra antipodal to the main region of flux emergence. The question of how highly inclined magnetic field can concentrate along the antipodal curves of umbrae, at least initially, remains to be answered. Previous observational studies have suggested the existence of some form of overlying magnetic canopy which acts as the progenitor for penumbrae. In this talk, we propose that such overlying magnetic canopies are a consequence of how the magnetic field emerges into the atmosphere and are, therefore, part of the emerging region. We show, through simulations of twisted flux tube emergence, that canopies of highly inclined magnetic field form preferentially at the required locations above the photosphere.

Dr Stephane Regnier, Northumbria. *The birth of an active region*:

We analyse the first instants of an emerging active region. Using SDO/HMI continuum images and magnetograms, we detect the birth of active region AR 11076 in May 29 2010 by following back in time the identified region as registered by NOAA on 1st June 2010. We notice that one polarity appears at the network boundary of a supergranular cell. We follow the evolution of the active region magnetic field during the first few days using a potential field approximation. We show how the magnetic energy and the connectivity of the field lines evolve during the emergence period. We distinguish between the internal changes corresponding to a twisted flux tube passing through the photospheric layer, and the external changes that are consequences of reconnection with the pre-existing coronal field.

Professor Alan Hood, St Andrews. *Sunspot rotation and coronal consequences*:

The rapid rotation of sunspots are often accompanied by solar eruptions and flare activity. We present the results of 3D MHD simulations of the emergence of a twisted toroidal flux tube from the solar interior and its expansion into the lower corona.

We demonstrate that the untwisting motion of the sub-photospheric field causes the rotation of sunspots and that the twist stored in the interior is injected into the solar atmosphere. Significant vertical vortical motions develop within the two newly formed sunspots. These motions untwist the interior field and twist up the atmospheric field, creating a stressed coronal field that can subsequently erupt.

Dr Anthony Yeates, Durham. *Incorporating flux emergence in global coronal simulations*:

Flux emergence is an essential driver for models of the global magnetic field in the solar corona. In turn, these models form a critical interface between solar surface observations and reconstructions of the interplanetary magnetic field, such as those used in space-weather forecasting. At present, the community is beginning to move toward evolving, time-dependent models. In this talk, I will discuss how observations of flux emergence are being incorporated in these evolving global models. I will highlight some of the challenges we face, and the importance of dealing carefully with (necessarily) incomplete observations.

Miss Sally Dacie, UCL. *The magnetic field distribution of active regions during their emergence and decay phases*:

Although the temporal evolution of active regions (ARs) is relatively well understood, the processes involved continue to be the subject of investigation. We study how the magnetic field of a series of ARs evolves with time to better characterise how ARs emerge and disperse. We examine the temporal variation in the magnetic field distribution of 37 emerging ARs. A kernel density estimation plot of the field distribution was created on a log-log scale for each AR at each time step. We found that the central portion of the distribution is typically linear and its slope was used to characterise the evolution of the magnetic field. The slopes were seen to evolve with time, becoming less steep as the fragmented emerging flux coalesces. The slopes reached a maximum value of $\sim$-1.5 just before the time of maximum flux before becoming steeper during the decay phase towards the quiet Sun value of -3. Comparisons with models suggest that convective processes are important during both the emergence and decay phases.

Dr Petros Syntelis, St Andrews. *On the mechanism of recurrent eruptions*:

We report on three-dimensional MHD simulations of recurrent small scale Coronal Mass Ejection (CME) -like eruptions using flux-emergence simulations and study their formation and eruption mechanism. These eruptions have the size and energies of small prominence eruptions. The erupting flux ropes are formed due to the reconnection of J-loops (formed by shearing and rotation) and are located inside torus unstable magnetic envelope field. The flux ropes eruptions are triggered by the action of a tension removal mechanism, such as the typical tether-cutting where the envelope field reconnects with itself. Another side tether-cutting is also found. There, the envelope field reconnected with the J-loops. We report similar mechanisms creating three more eruptions in a recurrent manner. Simulations of higher magnetic energy flux tubes showed that the kinetic energies of these eruptions can also increase to reach the energies of small sized CMEs.

Mr Tim Whitbread, Durham. *Parameter optimization of surface flux transport models*:

The demand for accurate predictions of solar activity calls for precise calibration of solar cycle models. We present a surface flux transport (SFT) model that inserts bipolar magnetic regions (BMRs) into the simulation on the day of emergence. A genetic algorithm is used to search for a parameter set which produces the best fit between real and model butterfly diagrams for Cycle 23. We also consider a two-dimensional model which assimilates active regions into the simulation and compare it with the one-dimensional case. The entire population from the optimization process can be retrieved and analysed to find ranges of 'acceptable' parameter values. We find that these ranges and optimum solutions are in reasonable agreement with results from literature. Due to the easily-adaptable nature of the models, the optimization process can be repeated for other cycles in order to analyse cycle-to-cycle variation and to find parameter values which accurately reproduce key aspects of the solar cycle.

Dr James Leake, NRL. *A Review of Numerical Modeling of Magnetic Flux Emergence in the Solar Atmosphere*:

As the source of coronal magnetic field, and hence of solar activity, the evolution of magnetic flux generated in the convection zone, and its ultimate emergence into the solar atmosphere, has rightly received extensive study in the field of solar physics. Where observations cannot probe, and analytic approaches cannot solve, numerical modeling has been a vital tool to increase our understanding of the fundamental processes of magnetic flux emergence. I will review the recent advances in numerical modeling of magnetic flux emergence, in an era where both idealized simulations can help explain the fundamental process acting when magnetic field from the convection zone emerges and interacts with the coronal field, and where more realistically-focused simulations can reproduce observed consequences of magnetic flux emergence on various scales. Both approaches have merit and restrictions, and with the advent of data-driven atmospheric models, we can hope to answer some of the most important questions related to solar activity.

Dr Vasilis Archontis, St Andrews. *Emerging flux and solar jets: observations and numerical experiments*:

The Sun is covered by high-speed jets transporting mass and energy into the solar corona and feeding the solar wind. Recently, a dichotomy of solar coronal jets was suggested: there are jets that fit the 'standard' reconnection scenario between emerging and pre-existing magnetic fields (i.e. 'standard' jets) and others, which are associated with blowout eruptions (i.e. 'blowout' jets). We present observational examples of the two types of jets and results from recent numerical models, which show the standard-to-blowout transition.