Solar Cycle Variations of Magnetic Breakout Configurations

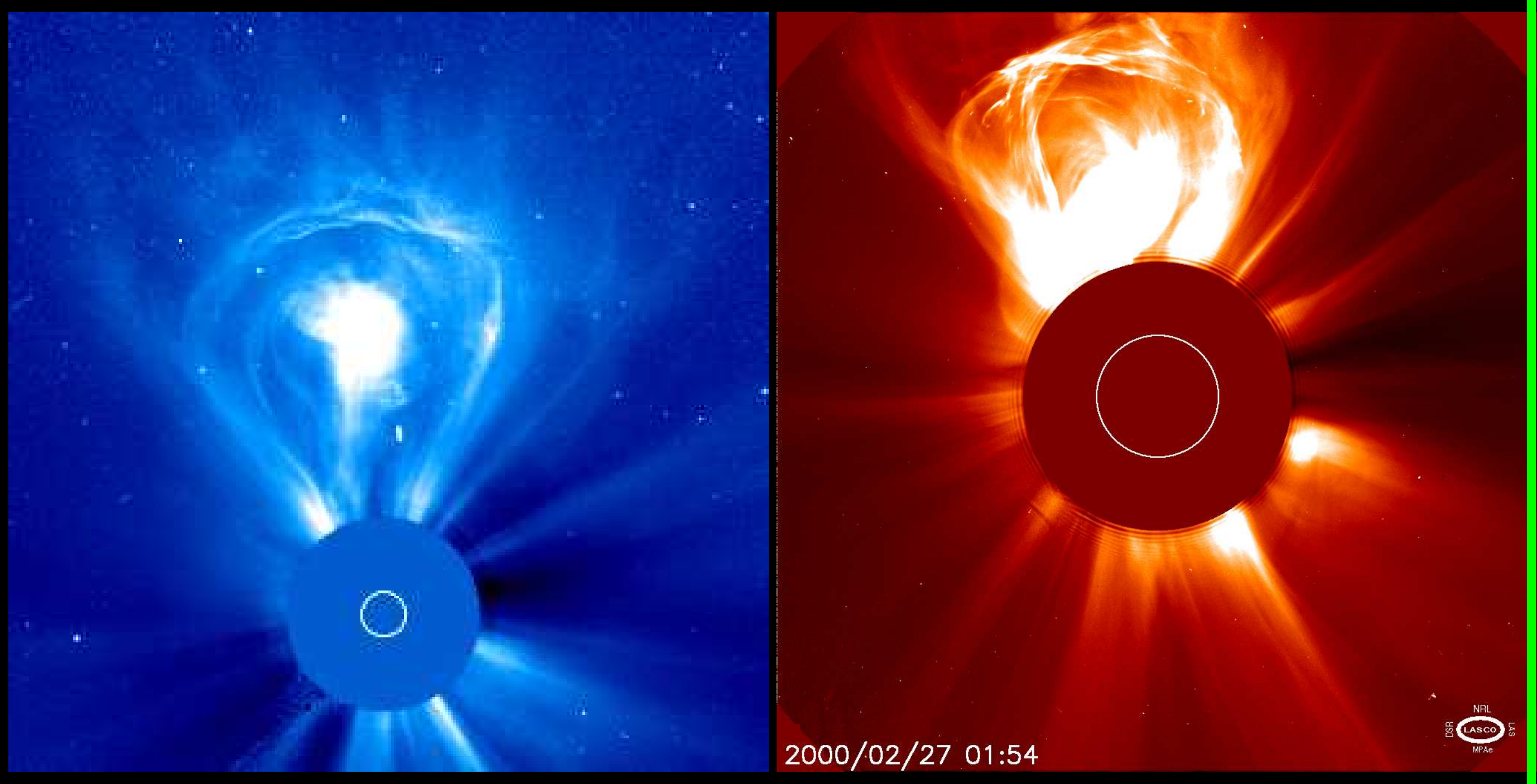
G.R. Cook[1], *D.H. Mackay*[1] *and D. Nandi*[2]

SCHOOL OF MATHEMATICS AND STATISTICS, UNIVERSITY OF ST ANDREWS, ST ANDREWS, KY16 9SS, UK[1]
DEPARTMENT OF PHYSICS, MONTANA STATE UNIVERSITY, BOZEMAN, MT 59717, USA[2]

Abstract

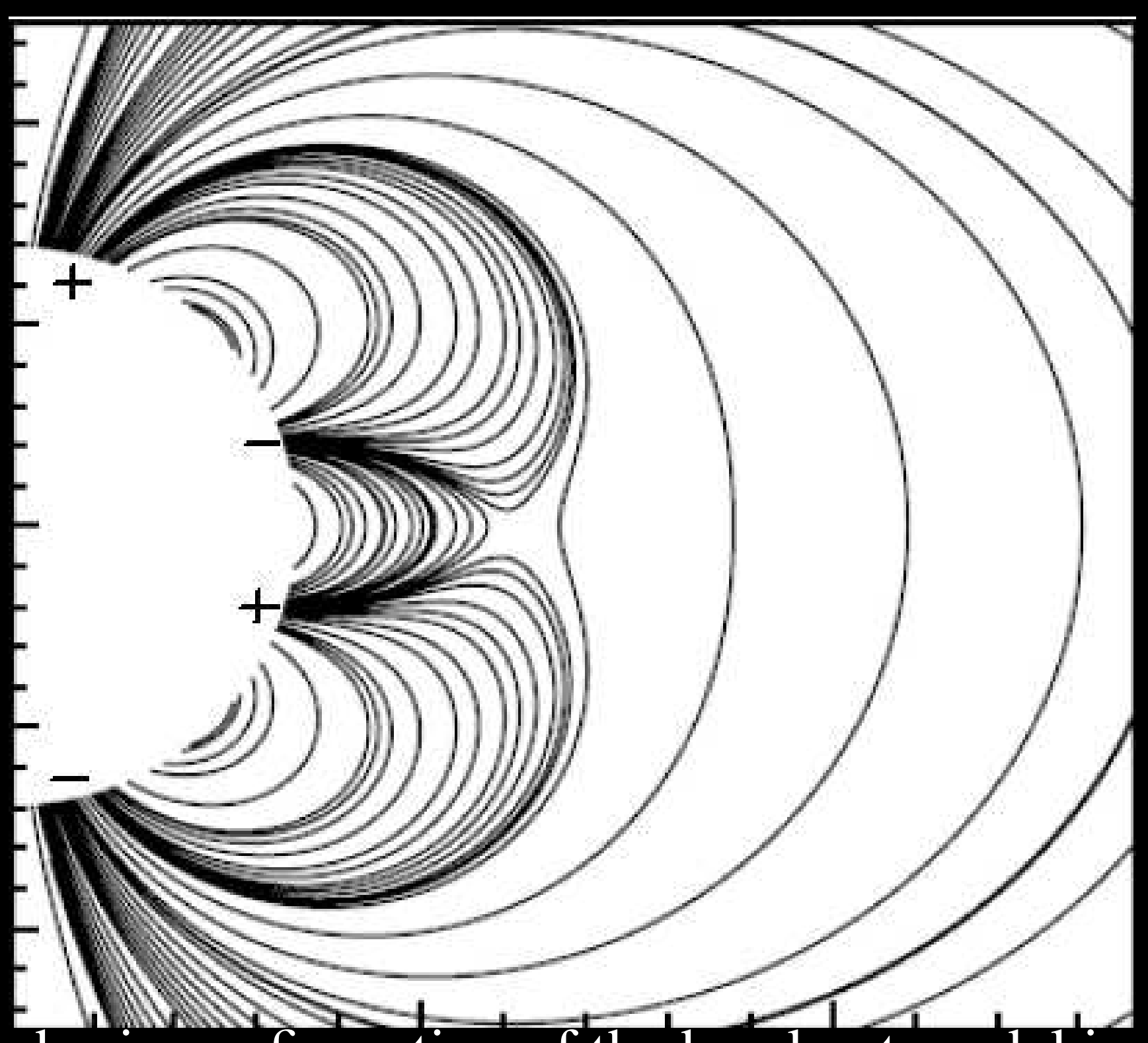
The initiation of a Coronal Mass Ejection (C.M.E.) has long been a debated subject within solar physics. Many possible models have been proposed including Flux Injection (Chen 1989,1996), Flux Cancellation (van Ballegooijen and Martens 1989) and the Breakout Model (Antiochos et. al. 1999). In our study we focus on the most recent of these, the Breakout Model. Using a flux transport code, developed by Aad van Ballegooijen, we simulate the time evolution of the radial field component at the solar surface, including both transport effects and flux emergence. We then match this simulation with observations from Kitt peak by approximately matching flux over the whole surface and at various latitudes. Using this as a lower boundary condition, we then extrapolate a potential field out to 2.5 solar radii using spherical harmonics. We then scan the whole simulation for characteristics of the breakout topology, including field line orientation changes and null points. From this we can draw conclusions as to the variation of null points linked with the breakout configurations, including their variation with latitude, variation in time, height of occurrence and how many of the nulls are connected with the global dipole of the sun.

Consequences of Coronal Mass Ejections



A Coronal Mass Ejection (C.M.E.) is a huge ejection of mass (approximately 10^{16}kg) into interplanetary space, originating in the magnetic field of the sun. An earthward directed C.M.E. can have many effects including satellite damage, communication disruption and can be a danger to astronauts. They can also cause the Aurora Borealis in the northern hemisphere and the Aurora Australis in the southern hemisphere. The two images above show two different coronal mass ejections occurring at different times on the sun, both taken by SOHO.

The Breakout Model



The basic configuration of the breakout model is a photospheric flux distribution that is quadrapolar in nature. The figure above shows a potential field deduced from this. The coronal field then results in four regions of differing connectivity. The 2 equatorial flux regions are of opposite orientation to one another and this results in an X-Type null point occurring between the two regions of magnetic flux. This null point is a key feature in the initial configuration of the Breakout model.

Steps and Method

1. Create the surface flux transport simulation, which will be manipulated so that the levels of flux that we have over the whole surface and at various latitudes will approximately match observations taken from Kitt Peak Magnetograms.

2. Use the radial surface field harmonics to extrapolate a potential field out to 2.5 solar Radii.

3. Develop a scanning code that searches our simulation for characteristics of a breakout topology, logs these and plots field lines to show the configuration of the field at this point.

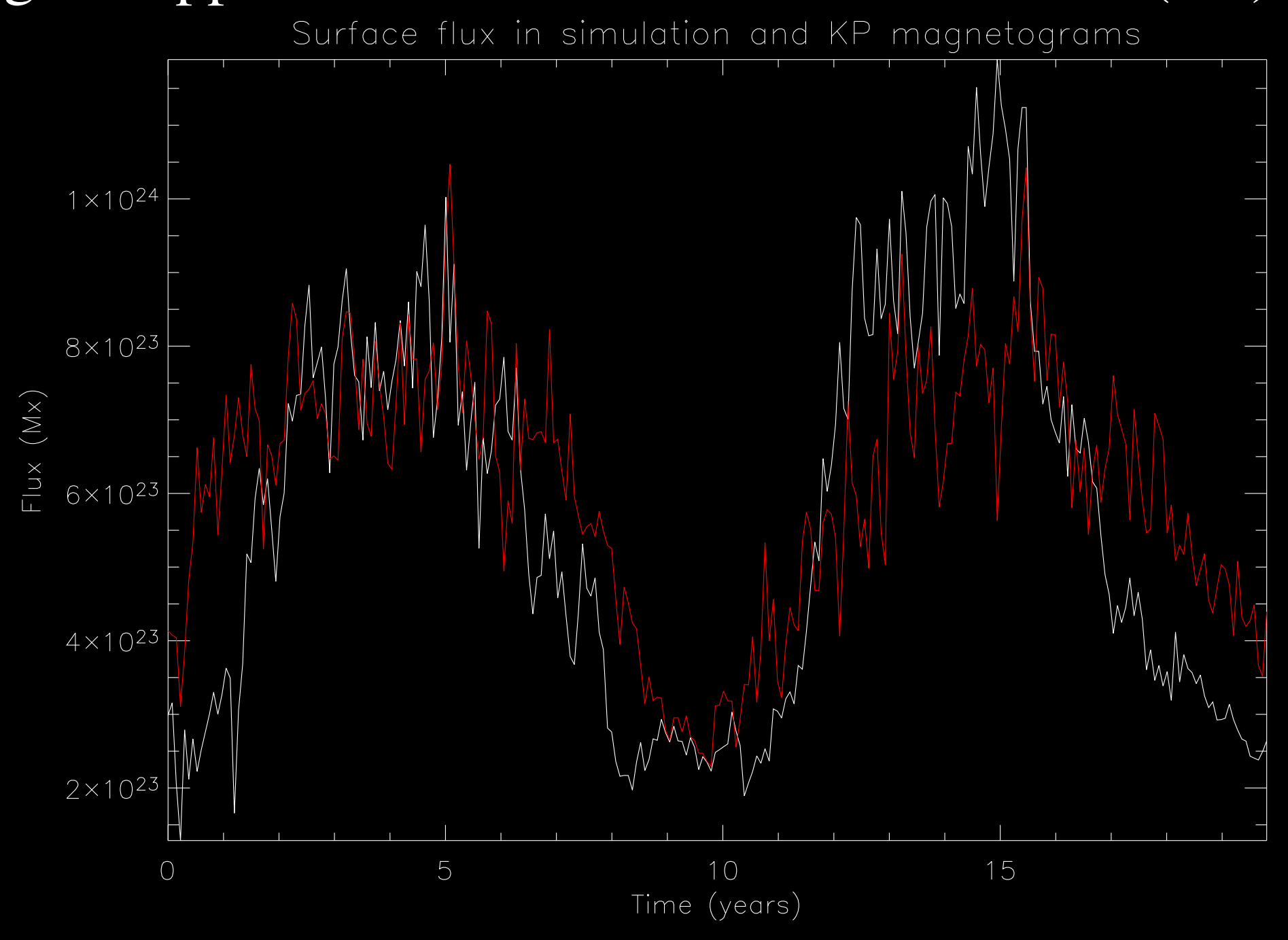
4. Apply the scanning code and use the data collected about the null points within the simulation to draw conclusions about the behaviour of the nulls (i.e. lifetime and distribution with height and latitude, numbers etc.).

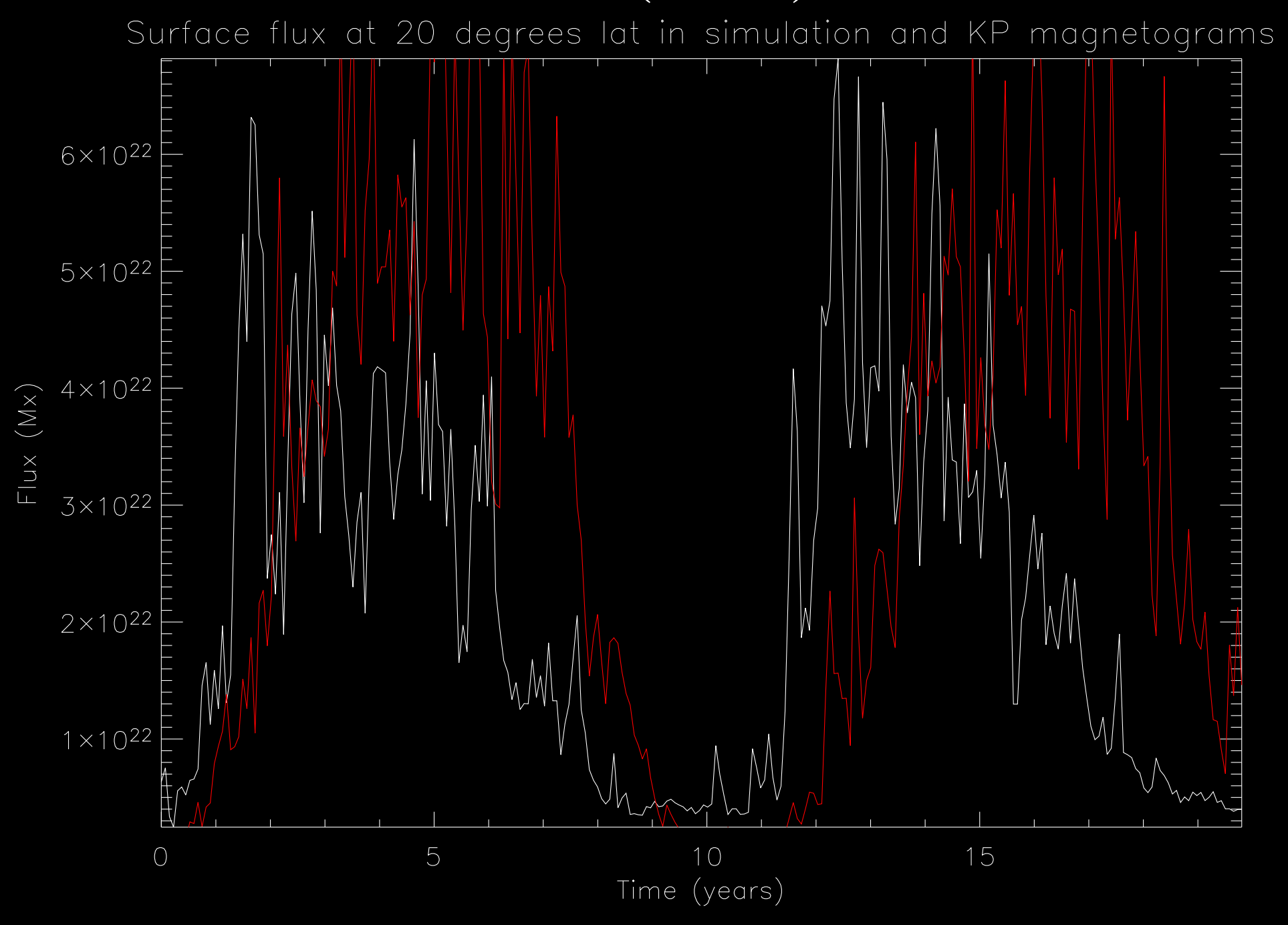
Simulation

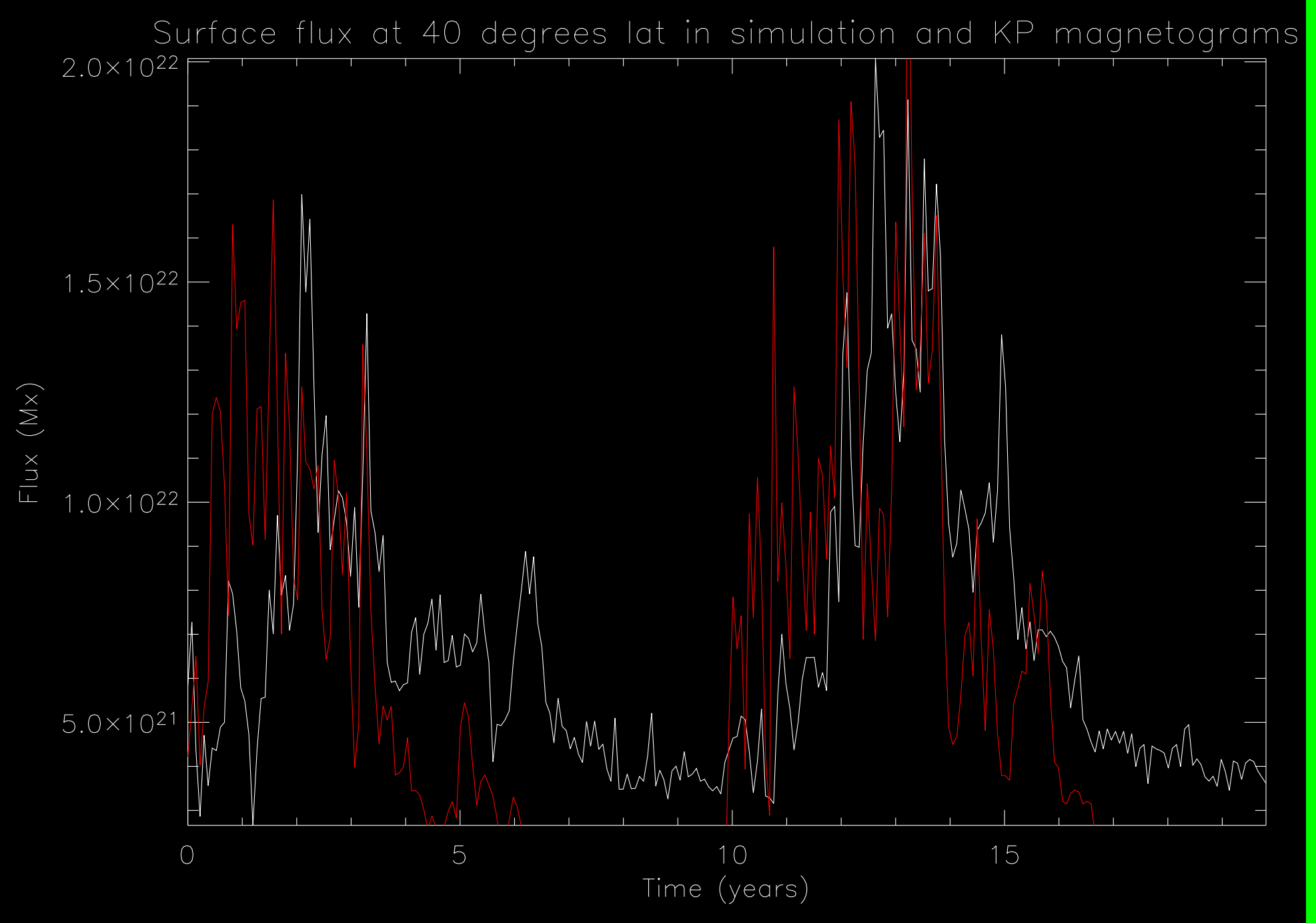
When creating the flux transport simulation we evolve the radial magnetic field component,B_r, at the photosphere forward (including the effect of flux emergence). This is done using,

$$\frac{\partial \mathrm{B}_r}{\partial \mathrm{t}} = \frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta(-\hat{U}\mathrm{B}_r + \hat{D}\frac{\partial \mathrm{B}_r}{\partial\theta})) - \Omega\frac{\partial \mathrm{B}}{\partial\phi} + \frac{\hat{D}}{\sin^2\theta}\frac{\partial^2 \mathrm{B}_r}{\partial\phi^2},$$

where $\hat{U}(\theta)$ is meridional flow, $\hat{D}$ is the diffusion coefficient and $\Omega(\theta)$ is differential rotation. Once created, the next step was to match the surface flux at various latitudes and over the whole solar surface. Below we see graphs of the flux over the whole solar surface and at 20° and 40° latitude. They show a good approximation between our simulation (red) and Kitt Peak observations (white).





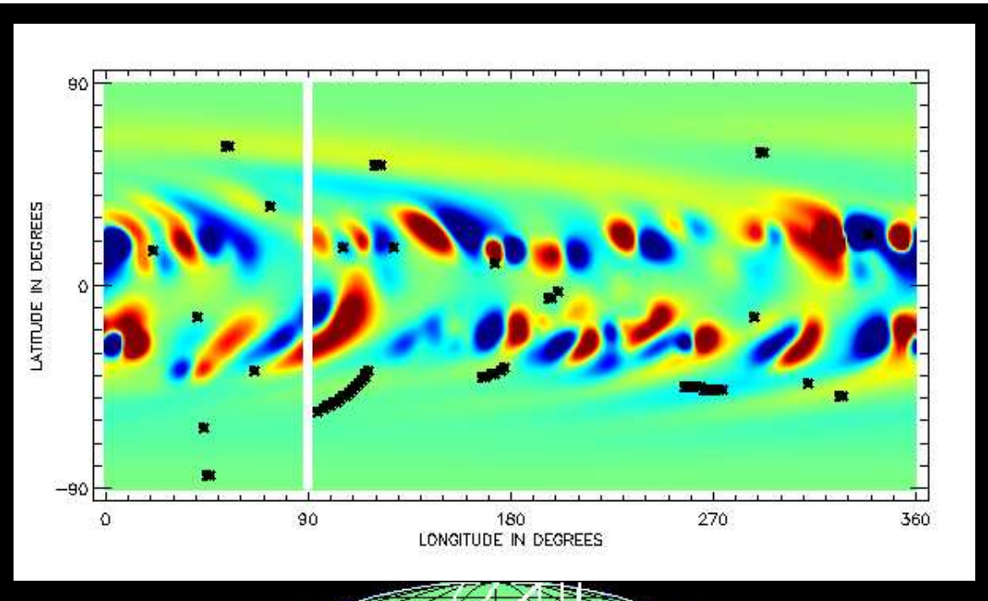


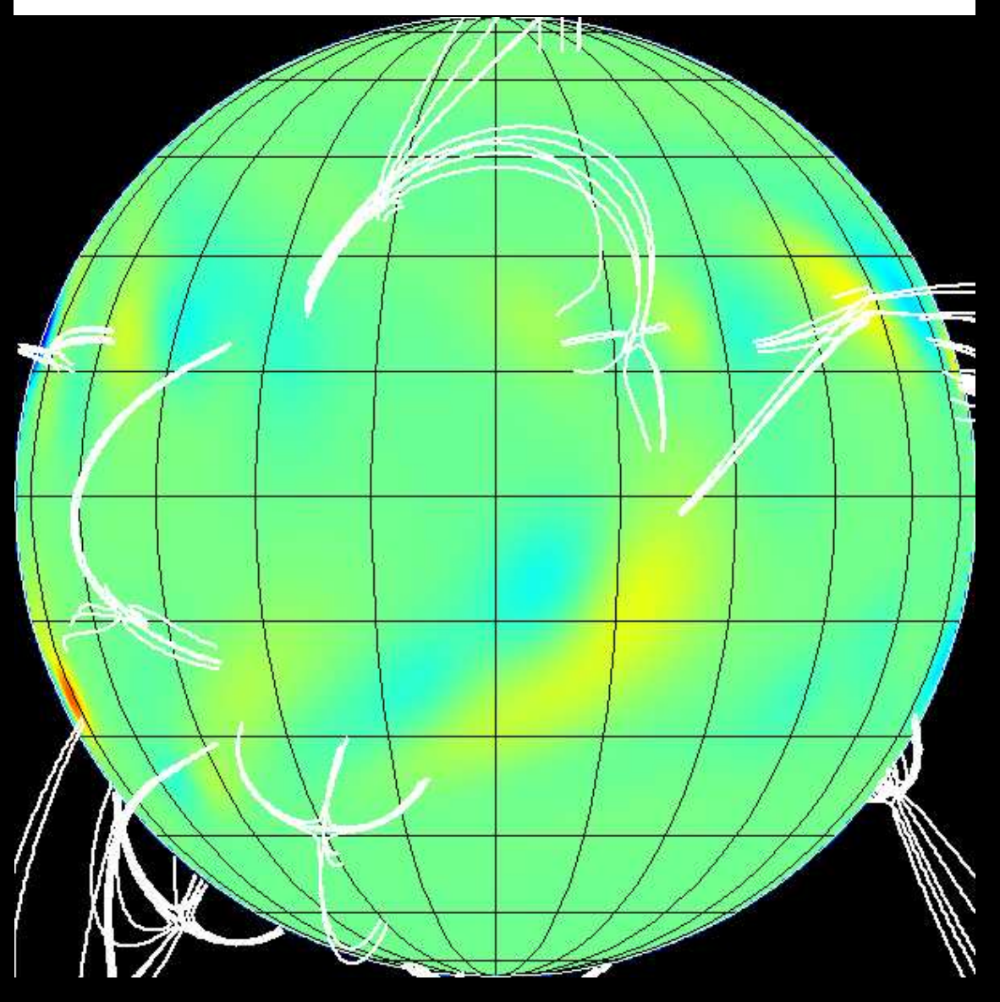
We then calculate a potential field out to 2.5 solar radii using,

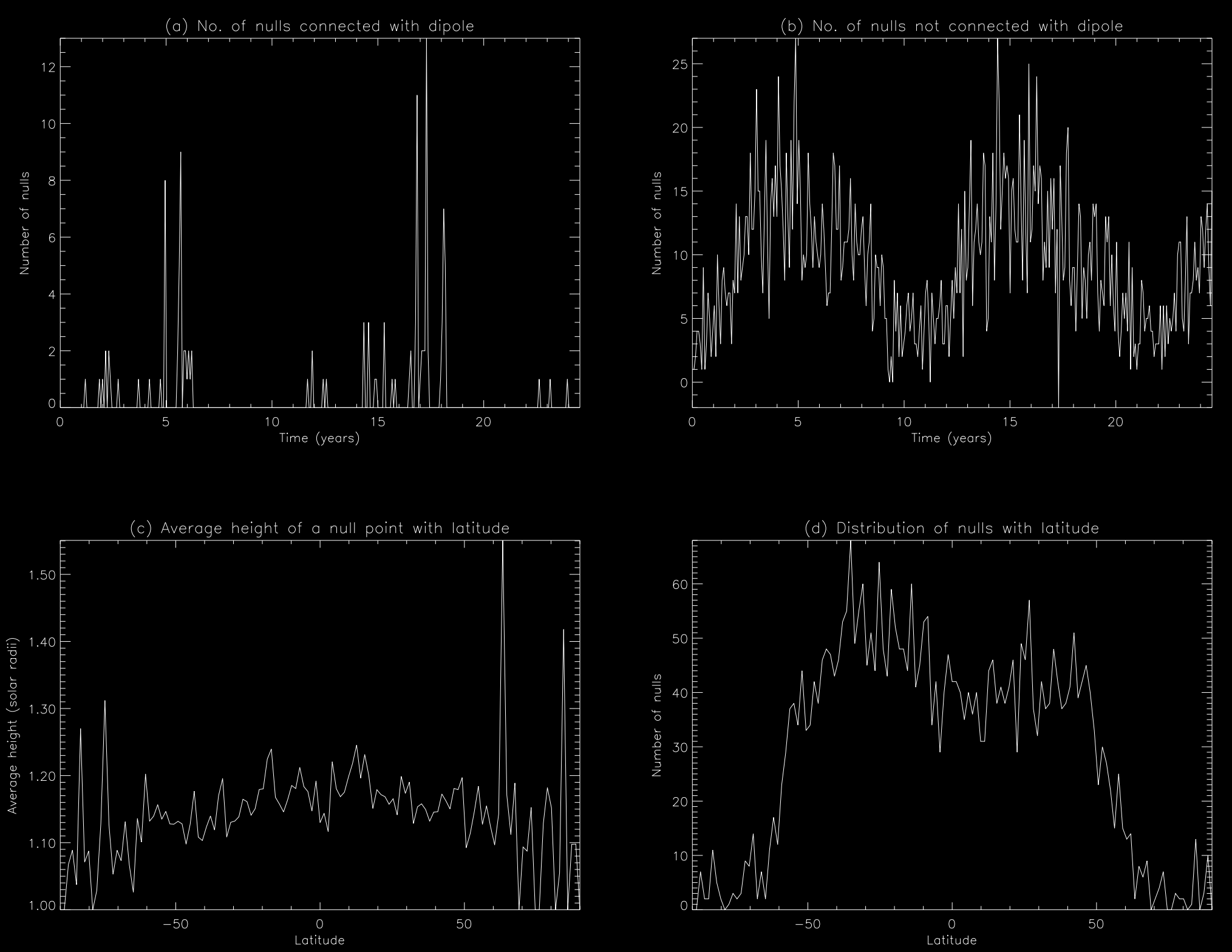
$$\mathrm{B}_r(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \mathrm{D}_{lm}\mathrm{Y}_{lm}(\theta,\phi),\ \mathrm{B}_\theta(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \mathrm{C}_{lm}\frac{\partial \mathrm{Q}}{\partial\theta}e^{im\phi} \text{ and } \mathrm{B}_\phi(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \frac{im}{\sin\theta}\mathrm{C}_{lm}\mathrm{Y}_{lm}(\theta,\phi)$$

where $\mathrm{D}_{lm} = \mathrm{B}_{lm}(\mathrm{R}_0,\mathrm{t})\left[\frac{(l+1)(\frac{\mathrm{r}}{\mathrm{R}_0})^{-l-2}+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}(\frac{\mathrm{r}}{\mathrm{R}_0})^{l-1}}{l+1+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}}\right]$, $\mathrm{C}_{lm} = \mathrm{B}_{lm}(\mathrm{R}_0,\mathrm{t})\left[\frac{(\frac{\mathrm{r}}{\mathrm{R}_0})^{-l-2}-(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}(\frac{\mathrm{r}}{\mathrm{R}_0})^{l-1}}{l+1+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}}\right]$, $\mathrm{Q}_{lm}(\theta)$ are the associated Legendre Polynomials and $\mathrm{Y}_{lm}(\theta,\phi)$ are the spherical harmonics. In each solar cycle approximately 4000 bipoles are emerged.

Initial Results and Conclusions







On the left is an example of one of the null point distributions within the simulation, with nulls marked in black. The image below it is of the field configurations around some of the nulls, between 0° and 180° longitude and centred on the equator.

The graphs to the left show null point distributions within our simulation. They show the numbers of null points connected with the global dipole (a), the number of nulls not connected with the global dipole (b), the average height of nulls against latitude (c) and the distribution of nulls with latitude (d). From these graphs we draw several conclusions.

- The numbers of null points vary throughout the entire two solar cycles with the amount of flux present at that time.

- We see more null points present at lower latitudes on the sun (between approximately ±50° latitude).

- With the presence of nulls, and therefore breakout topologies, over the equatorial region of the sun, we will see earthward directed coronal mass ejections occurring from this.

- There are very few nulls connected with the global dipole. This means that the majority of the nulls occur due to lower latitude flux emergence and are not dependant on the global dipole.

- The Breakout model is applicable throughout the entire solar cycle.

Contact: Graeme Cook
Address: School of Mathematics and Statistics, University of St Andrews,
St Andrews, KY16 9SS, UK
Email: *graeme@mcs.st-andrews.ac.uk*
WWW: http://www-solar.mcs.st-andrews.ac.uk/ graeme

References

A.A. van Ballegooijen, N.P. Carteledge and E.R. Priest. *ApJ*, 501:866-881, July 1998.

S.K. Antiochos, C.R. DeVore and J.A. Klimchuk. *ApJ*, 510:485-493, January 1999.

P.J. MacNeice, S.K. Antiochos, A. Phillips, D.S. Spicer, C.R. DeVore and K. Olson. *ApJ*, 614:1028-1041, October 2004.