From the Tachocline Into the Heliosphere

Andrés Muñoz-Jaramillo
Montana State University
www.solardynamo.org

Anthony Yeates
Durham University

Active Regions and the solar cycle

- Most visible signature of the solar cycle.
- Shapers of the solar corona.
- Drivers of solar activity and space weather.
A crucial link in the propagation of the solar cycle

Poloidal $r - \theta$

Toroidal $\phi$
A crucial link in the propagation of the solar cycle

Poloidal $r - \theta$ \hspace{2cm} Differential Rotation \hspace{2cm} Toroidal $\phi$
A crucial link in the propagation of the solar cycle

Poloidal \( r - \theta \)  \hspace{1cm}  Toroidal \( \phi \)

Differential Rotation

Emergence and Decay of Tilted Active Regions
• Is AR emergence and decay the crucial link in the dynamo that we believe it to be?

• If so, what is the connection between the surface and internal large scale magnetic field?
We calibrated a century of MWO facular observations using magnetic data from WSO and MDI. This results in a century of direct proxies for both the toroidal and poloidal fields.


- This results in a century of direct proxies for both the toroidal and poloidal fields.
Both relationships agree with our current understanding of the solar cycle.
• What is the connection between the surface and internal large scale magnetic field?  
Technical Challenges

• Hundreds of flux-tube eruptions within a single solar cycle.
• Whole convection zone as computational domain.
• Flux-tube emergence is a 3D process.
The First 3D Kinematic Dynamo

\[
\frac{\partial \vec{B}}{\partial t} = \nabla \times \left( \vec{v} \times \vec{B} + \eta \nabla \times \vec{B} \right)
\]

\[
\vec{v} = r \sin(\theta) \Omega \hat{e}_\phi + \vec{v}_p
\]
Flux-tube emergence is driven by prescribed helical flows.

We can control with a high degree of precision the properties of the resulting active regions (position, size, flux and tilt).
This allows us to study the interaction between active regions as they rise during the cycle.

We can easily couple this 3D model to coronal models since surface flux-transport is naturally included.
We drive simulations using SOLIS data.
And find very good agreement between the observed and simulated total surface unsigned flux.
Surface vs. Interior

Only 7% of the total poloidal energy is contained in the top third of the convection zone.
We find a good correlation between surface unsigned flux and internal poloidal energy.
• Is AR emergence and decay the crucial link in the dynamo that we believe it to be?
Yes, observations and simulations suggest that this is the case.

• What is the connection between the surface and internal large scale magnetic field?
The surface contains but a fraction of the poloidal energy, but it is strongly in phase with the internal energy.