THE EFFECTS OF THE SURFACE INFLOWS ON MODULATING SOLAR CYCLES

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Introduction

Surface flux transport models (SFT) describe the evolution of large-scale photospheric magnetic fields, assuming near-radial surface fields. Their evolution is represented by the radial component of the MHD induction equation. Differential rotation and poleward meridional flow account for advection, while diffusion is attributed to the mixing action of supergranular flows[1].

The poloidal field transforms into the toroidal field via the BL mechanism, a nonlinear process crucial for amplifying amplitude and variability in the solar cycle. The tilt angle of sunspot groups significantly influences the formation of the poloidal field derived from the toroidal field via the BL mechanism. The efficiency of poloidal field generation by BMRs diminishes when they emerge at higher latitudes. [2] directed attention towards "latitude quenching" (LQ), as this nonlinear modulation mechanism is called [3].

Observations on the solar surface reveal the presence of converging flows surrounding BMRs [4] [5]. These inflows collectively generate average flows around the activity belt, and their intensity is contingent upon the level of flux within the solar cycle, as demonstrated by [6] and [7]. The average poleward meridional flow undergoes a modest change of about 25% between the maximum and minimum phases of the solar cycle. This variation is partially attributed to surface inflows directed towards significant active regions [4] [8] [6]. The inflows, while significant and reaching a substantial fraction of the mean axisymmetric poleward meridional flow at mid-latitudes, are confined spatially to the belts housing active regions.

Objectives

This study aims to investigate how surface inflows towards active-region belts act as a quenching mechanism for the solar dynamo, considering the presence or absence of Latitude Quenching (LQ). In particular, we employ the model formulation introduced by [6] and its subsequent modifications [9].

Model

The 1D surface flux transport (SFT) equation describing this process :

$$\frac{\partial B_R}{\partial t} = -\frac{1}{R\sin\theta}\frac{\partial}{\partial\theta}[u_\theta(R,\theta)B_R\sin\theta] - \Omega(R,\theta)\frac{\partial B_R}{\partial\varphi} + \frac{\eta_R}{R^2}\left[\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial B_R}{\partial\theta}\right) + \frac{1}{\sin^2\theta}\frac{\partial^2 B_R}{\partial\phi^2}\right] - \frac{B_R}{\tau_R} + S_{BMR}(\theta,\varphi,t)$$

Meridional flow profile [2]

$$u_c = u_0\sin(\pi\times\lambda/90)$$

λ is the latitude, u_o is the amplitude of the meridional flow velocity.

Latitude Quenching [10]

$$\lambda_0(t,i) = \left[26.4 - 34.2\left(\frac{t}{p}\right) - 16.1\left(\frac{t}{p}\right)^2\right]\left(\frac{\lambda_i}{14.6}\right)$$

$$\lambda_i = 14.6 + b_{lat}\left(\frac{A_n - A_0}{A_0}\right)$$

Surface Inflows [6] [9]

Axisymmetric bands of converging latitudinal flow as perturbations on meridional flow.

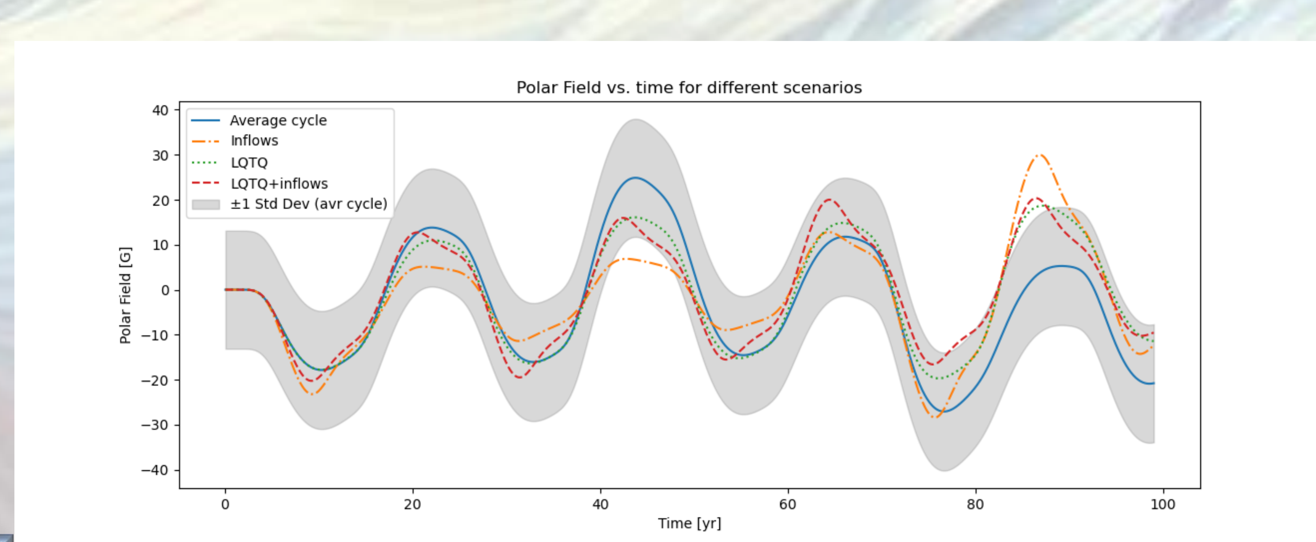
$$\Delta v(\lambda,t) = \begin{cases} -v_0\sin\left(\frac{\lambda-\lambda_c}{\Delta\lambda_v}\right) & if\ -\pi < \frac{\lambda-\lambda_c}{\Delta\lambda_v} < \pi \\ 0 & otherwise \end{cases}$$

Surface inflows amplitudes as a modified form of these bands, where its amplitude is cycle dependent in another case.

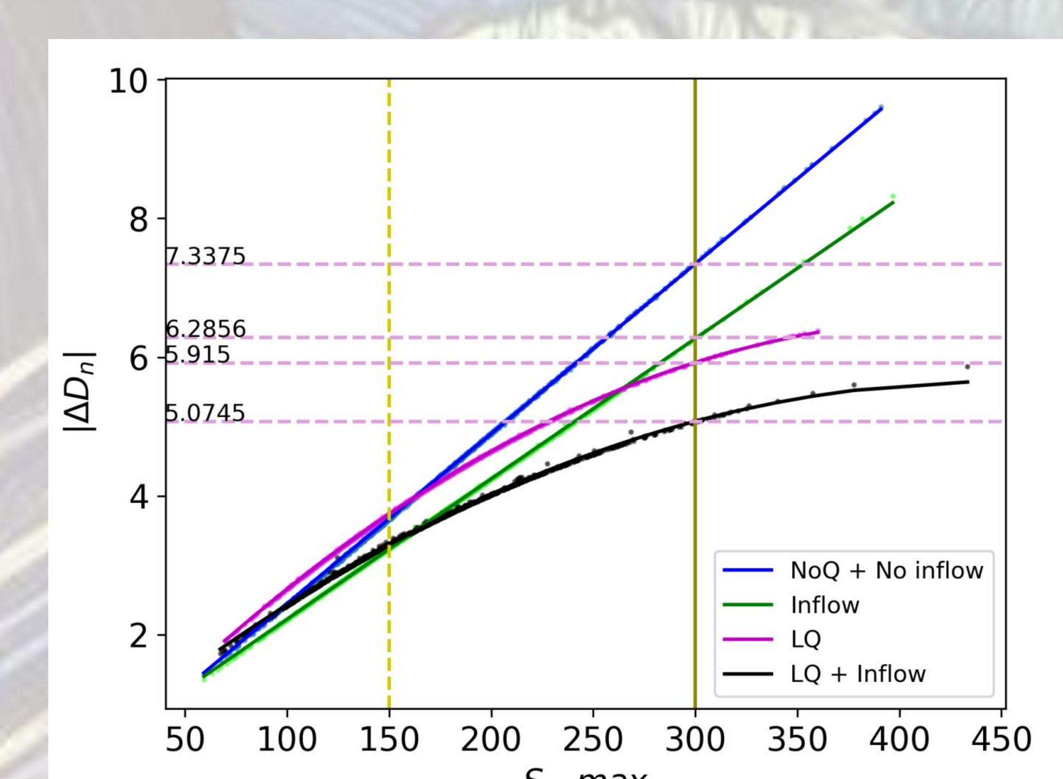
$$v_0 = v_{00}\,arctan(S_n/F_{00})$$

Parameters Range [9] [11]

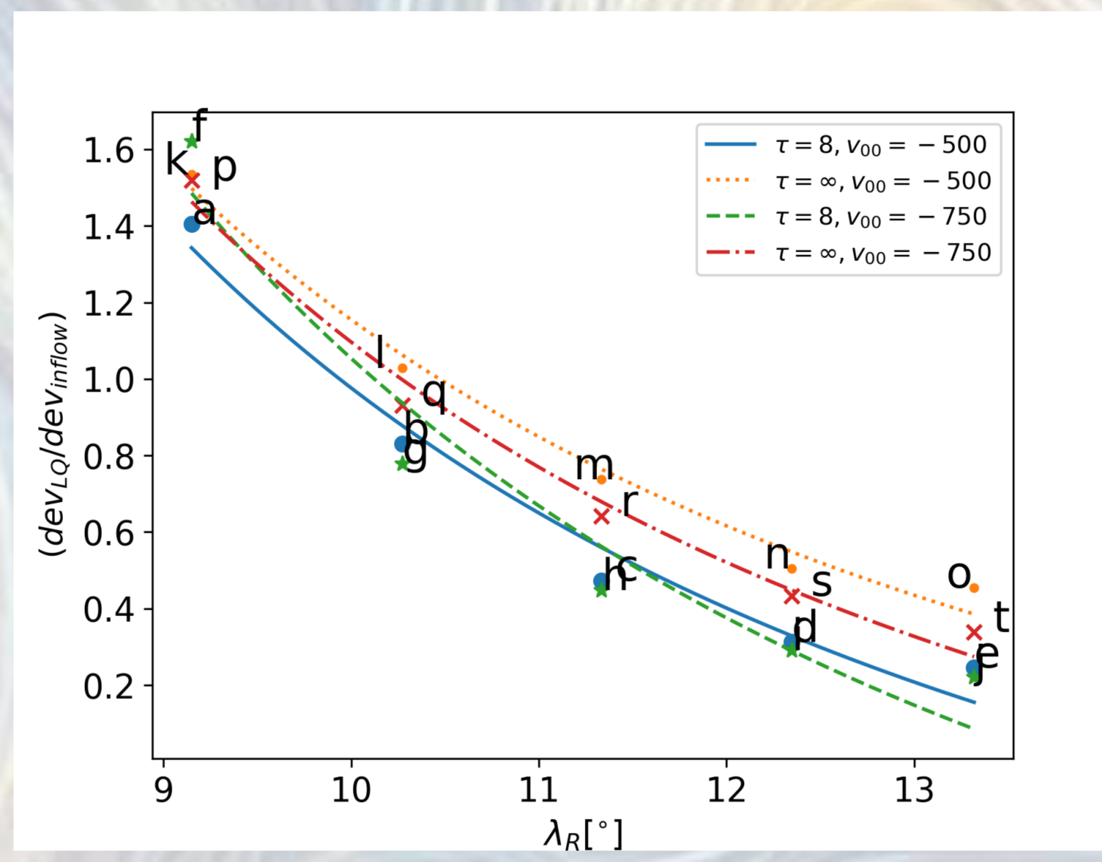
The range of u_o was 11 & 15 ms^{-1}, for η between 250-650 Km^2s^{-1}, and τ in the range 8 & ∞ yr. *For surface inflows:* v_0 is 5 ms^{-1} and for v_{00} is -500 and 750 cms^{-1}. $F_{00} = 4.99\times10^{-21}$Mx.



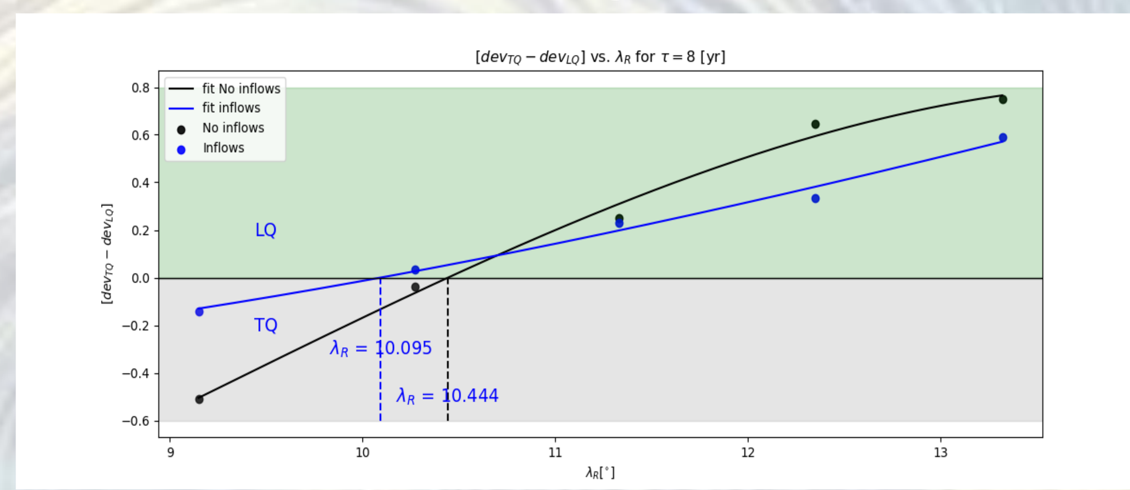
Results



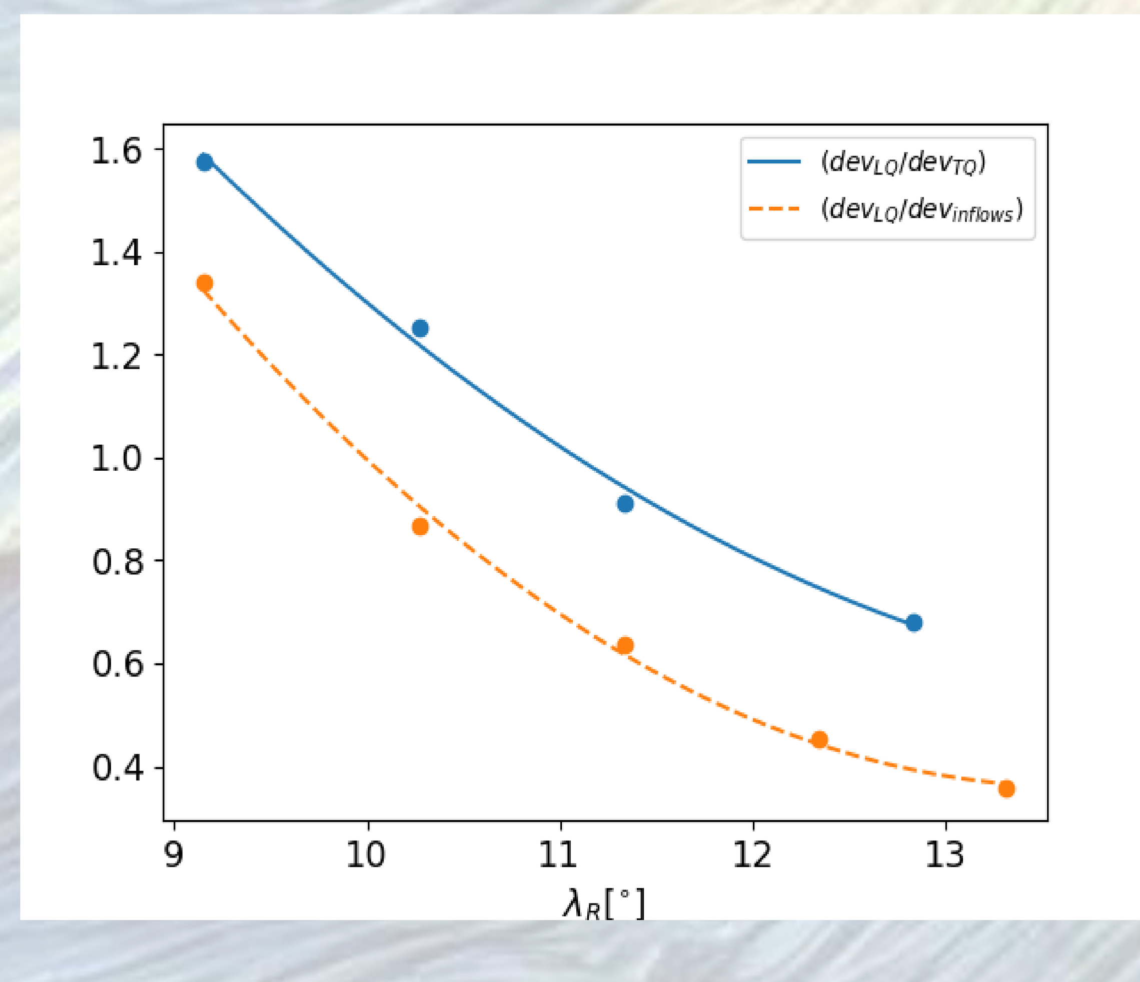
1. Results confirm that including surface inflows in the model produces a lower net contribution to the dipole moment in the presence of the latitude quenching mechanism.



2. The relative importance of LQ vs. inflows is inversely correlated with the dynamo effectivity range (λ_R). suggesting a potential nonlinear mechanism contributing to the saturation of the global dynamo.



3. For lower $\lambda_R \lesssim 10^\circ$, TQ is always dominating over LQ, and for higher λ_R, LQ dominate.



4. The relative importance for LQ vs. TQ is higher than LQ vs. inflows, suggesting inflows may contribute to TQ

References

[1] Yeates, A. R., et. al. 2023, Space Sci. Rev., 219, 31.
[2] Jiang, J. 2020, ApJ, 900, 19.
[3] Petrovay, K. 2020, Living Rev. Sol. Phys., 17, 2.
[4] Gizon, L. 2004, Sol. Phys., 224, 217.
[5] González H. et. al. 2008, Sol. Phys., 252, 235
[6] Jiang, J. et. al. 2010, Astrophys. J., 717, 597.
[7] Cameron, R. et. al. 2012, A&A, 542, A127.
[8] Cameron, R. & Schüssler, M. 2010, Astrophys. J., 720, 1030.
[9] Nagy, M. et. al. 2020, JSWSC, 10, 62.
[10] Talafha, M. et. al. 2022, A&A, 660, A92.
[11] Petrovay, K. & Talafha, M. 2019, A&A, 632, A87.

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