How many active regions are needed to predict the solar dipole moment?

Anthony Yeates

with

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Space Climate 7 Symposium, Québec, 10-Jul-2019

Motivation

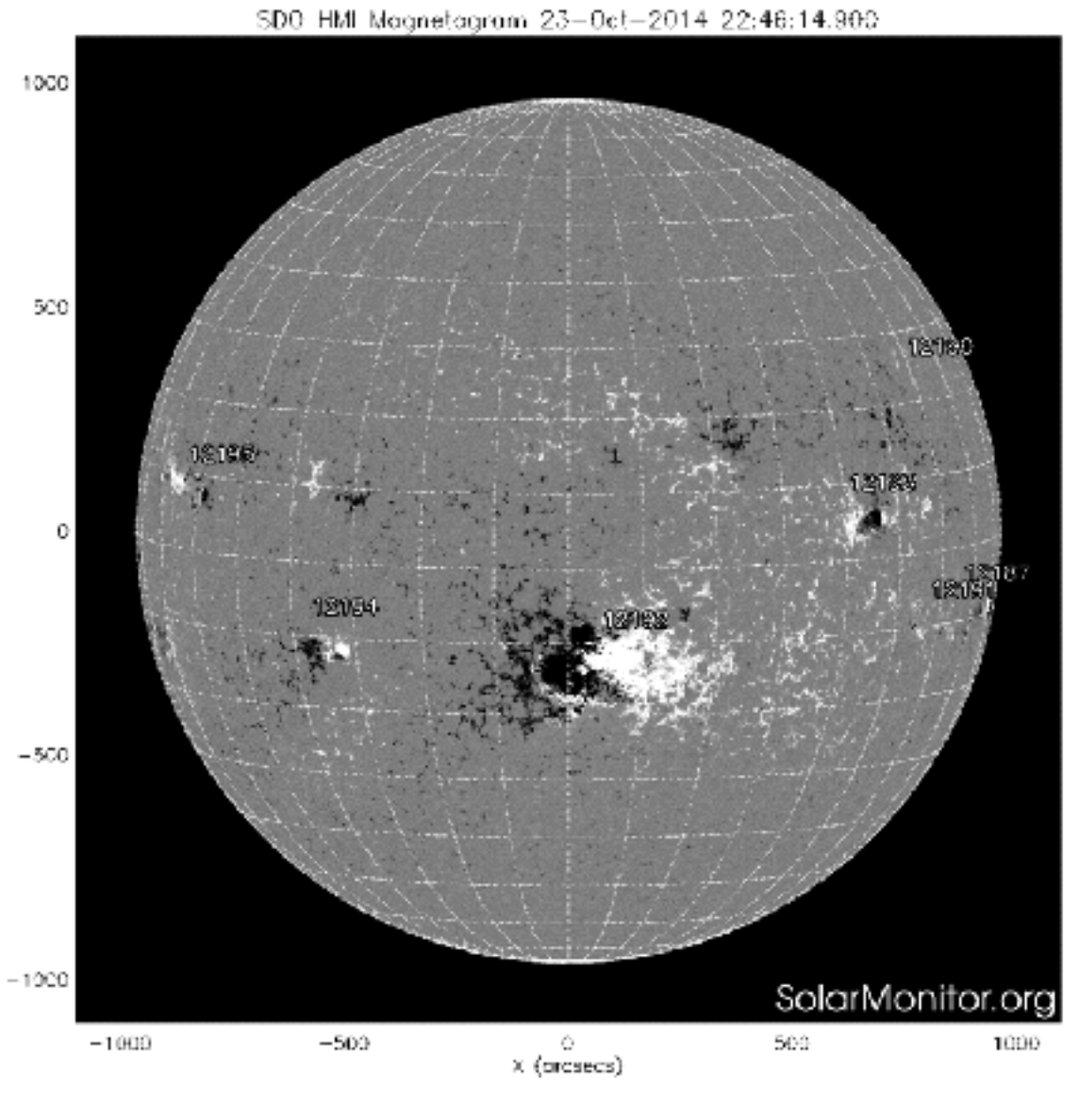
Recent hypothesis: individual "rogue" active regions can cause significant fluctuations in the polar field (and hence future cycle amplitudes).

Was this the cause of the weak Cycle 23 Minimum?

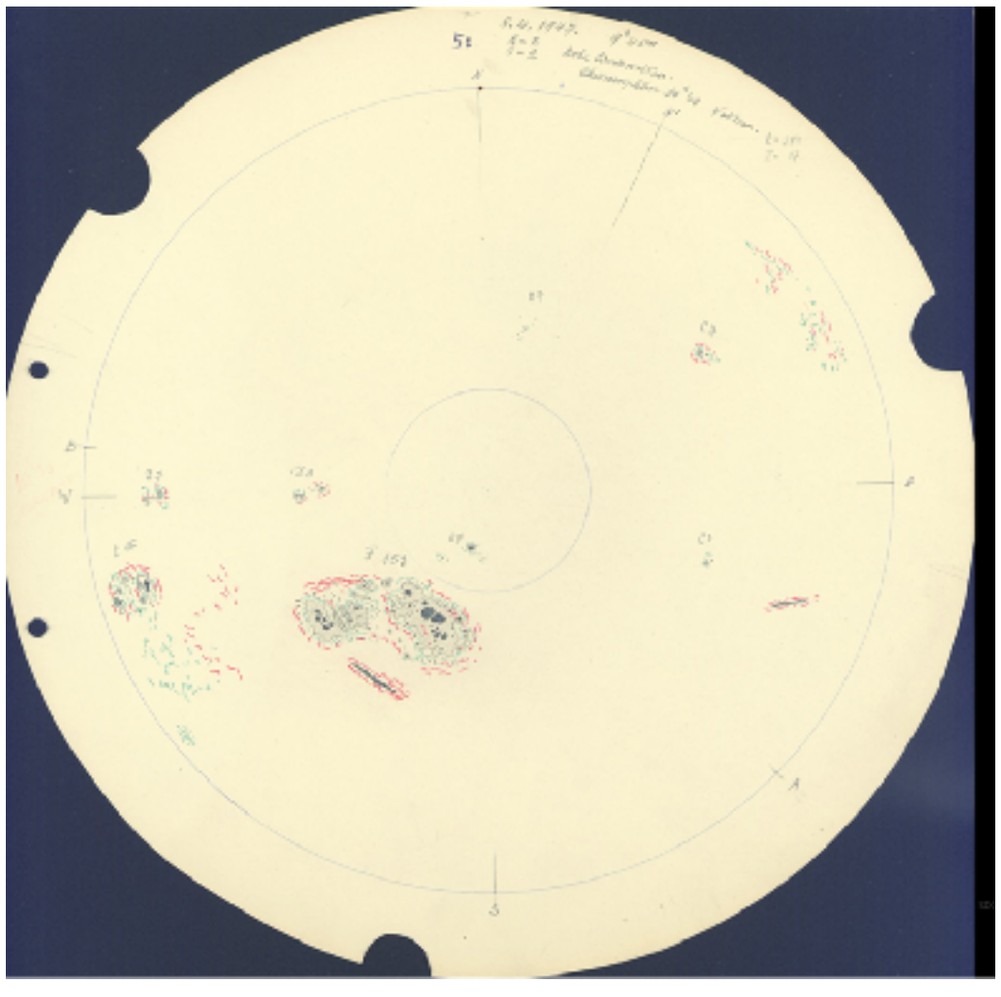
Nagy et al., *Solar Phys.* [2017]

Jiang, Cameron & Schüssler, *ApJL* [2015]

Rogues' gallery:

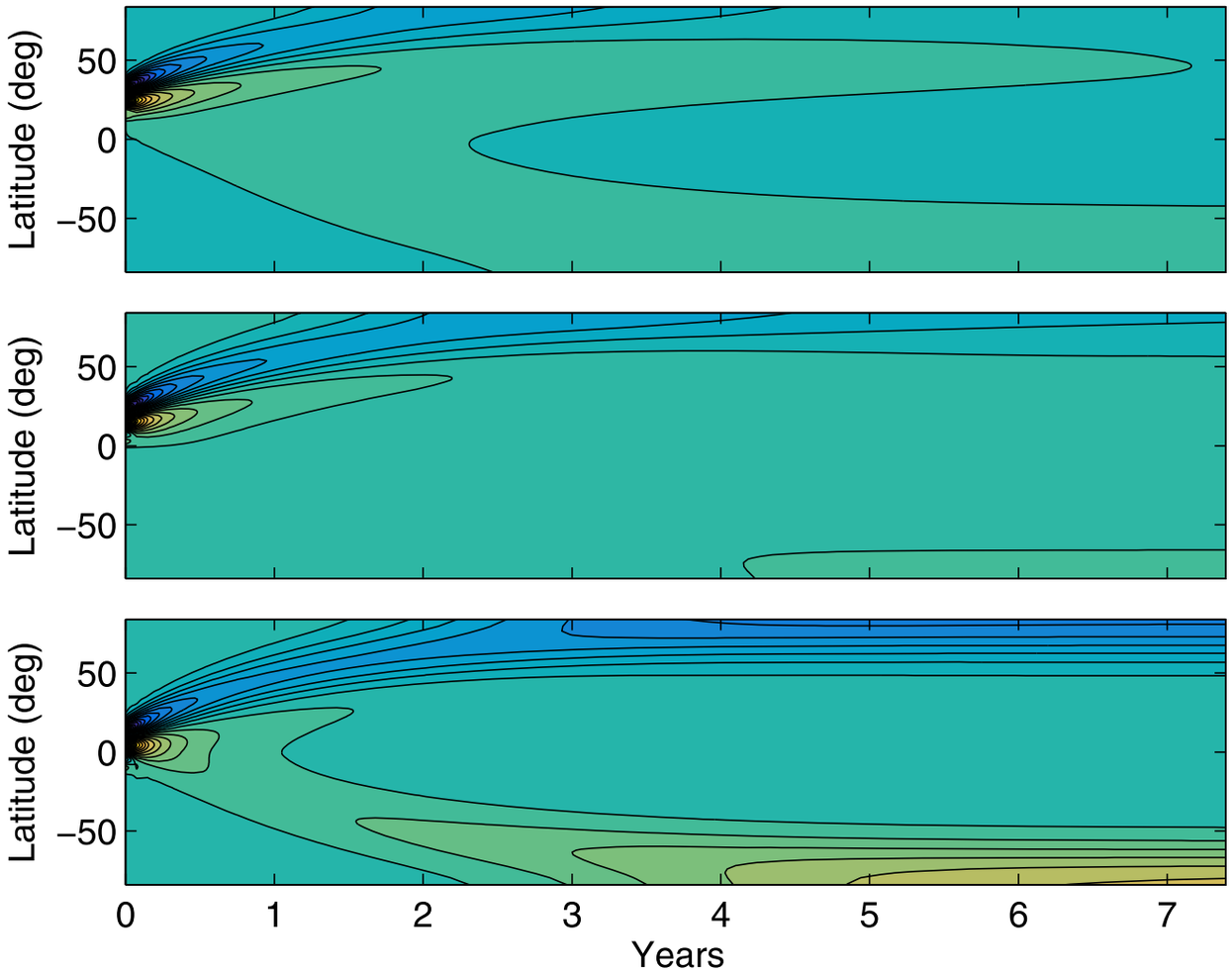


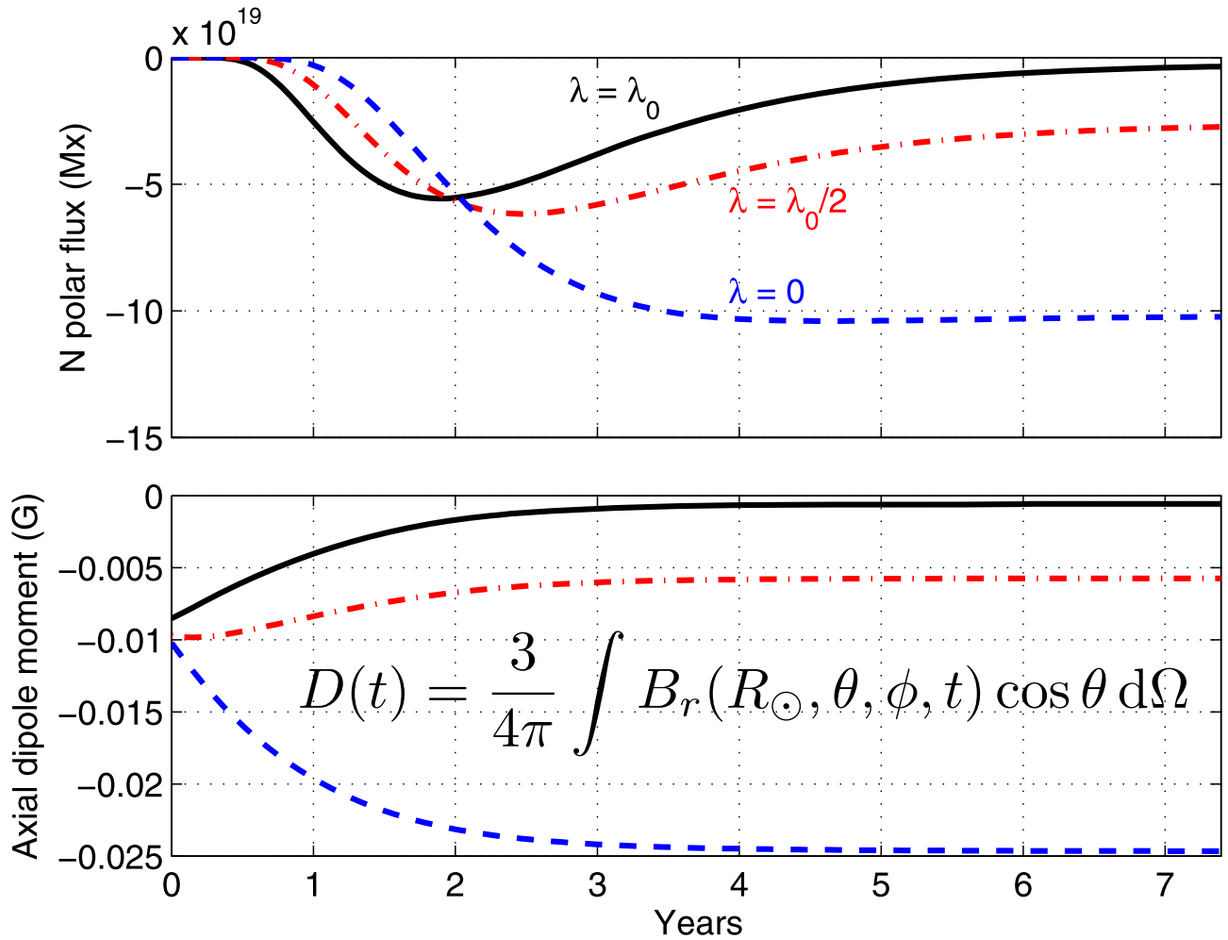
AR 12192 October 2014



Great sunspot of '47

Which regions do we care about?





Yeates, Baker & van Driel-Gesztelyi, *Solar Phys.* [2014]
Wang & Sheeley, *ApJ* [1991]

Asymptotically, polar field behaves like axial dipole moment.

Only regions near equator make a lasting contribution.

Our study

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How Many Active Regions Are Necessary to Predict the Solar Dipole Moment?

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Abstract

We test recent claims that the polar field at the end of Cycle 23 was weakened by a small number of large, abnormally oriented regions, and investigate what this means for solar cycle prediction. We isolate the contribution

Aim:

Isolate contribution of individual observed regions to end-of-cycle dipole moment.

Method:

sft_data - flux transport model that assimilates observed active regions
github.com/antyeates1983/sft_data

Input: 3+ solar cycles of synoptic maps from NSO/KPVT and SOLIS

Surface Flux Transport Model

sft_data model

Yeates, Baker & van Driel-Gesztelyi, *Solar Phys.* [2014]

$$\frac{\partial B_r}{\partial t} = \hat{\boldsymbol{r}} \cdot \nabla \times \left[\left(v_\theta \hat{\boldsymbol{\theta}} + v_\phi \hat{\boldsymbol{\phi}} \right) \times \hat{\boldsymbol{r}}\, B_r - \eta \nabla \times \left(\hat{\boldsymbol{r}}\, B_r \right) \right] - \frac{B_r}{\tau} + S(\theta, \phi, t)$$

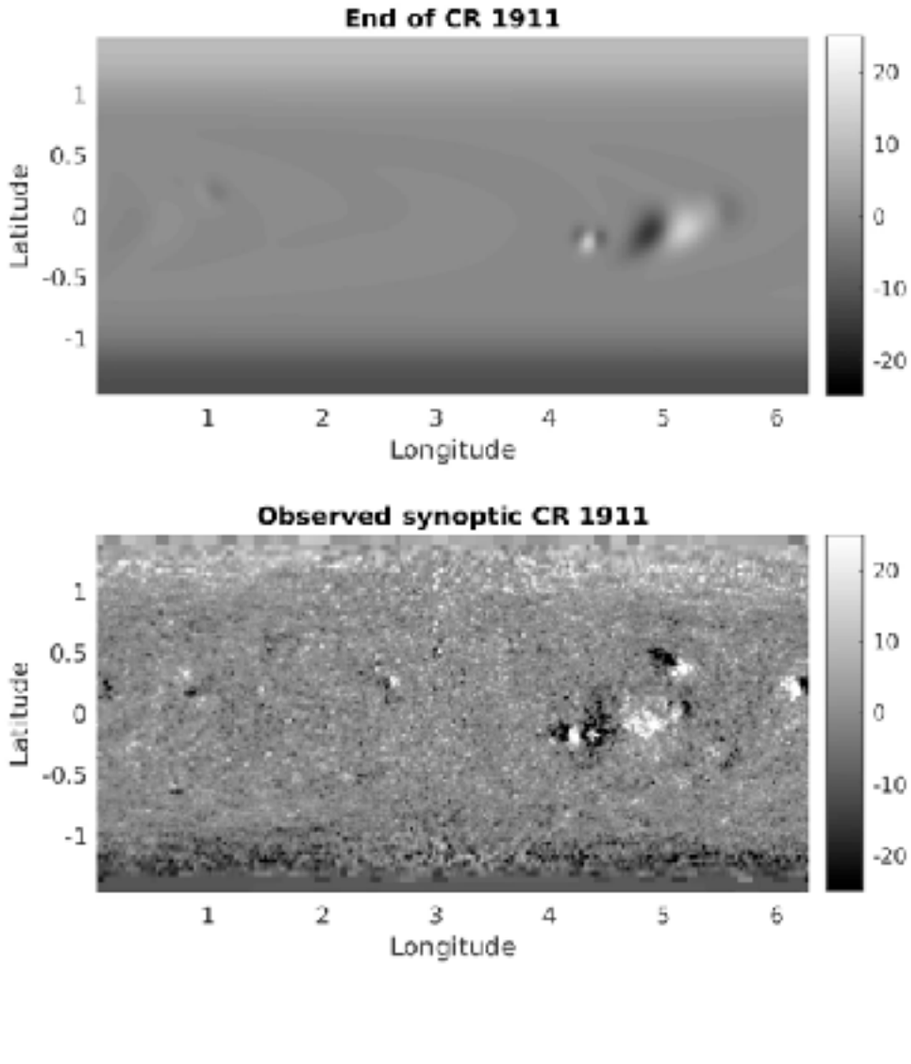
differential rotation

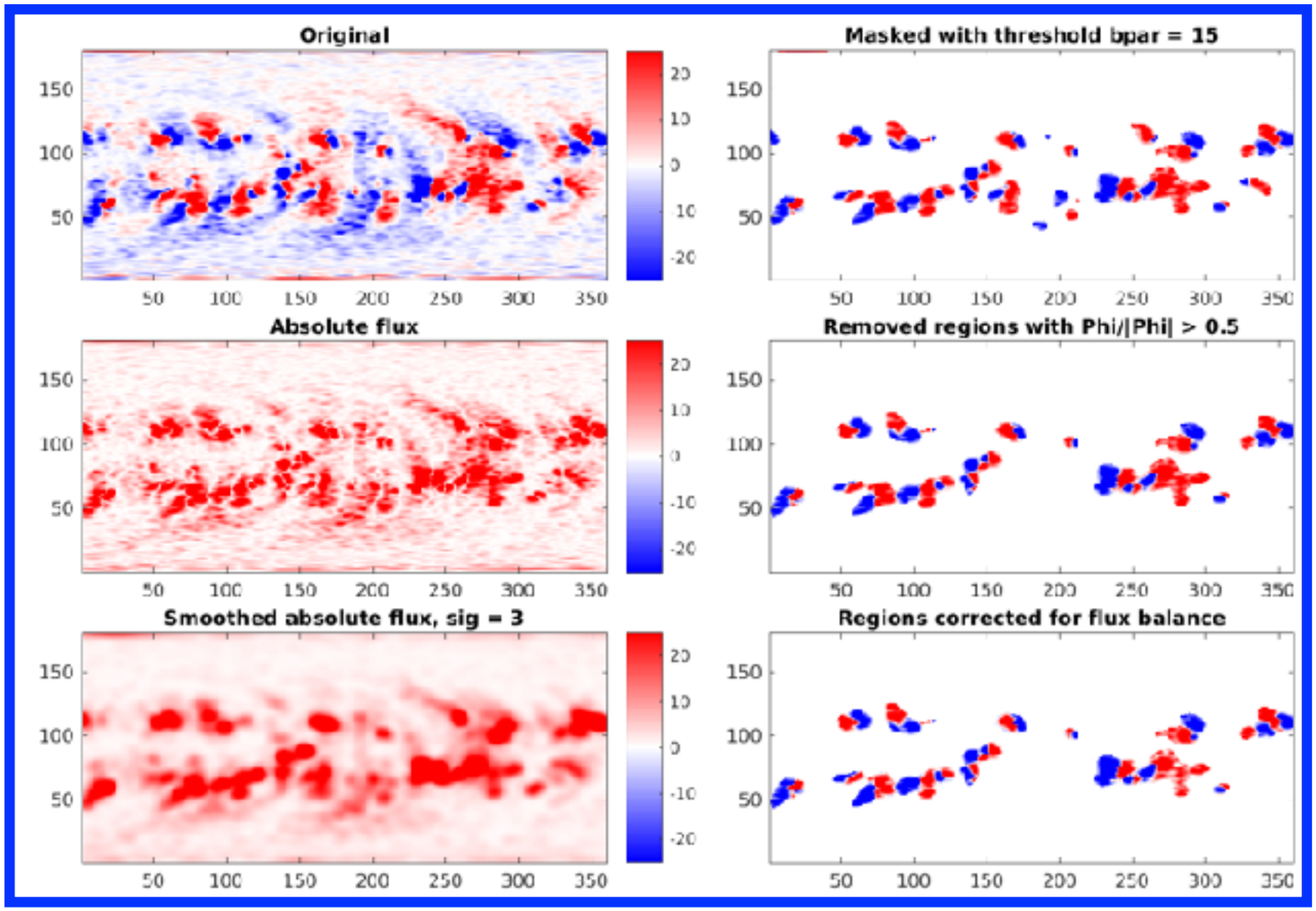
meridional flow

supergranular diffusion

"radial" decay

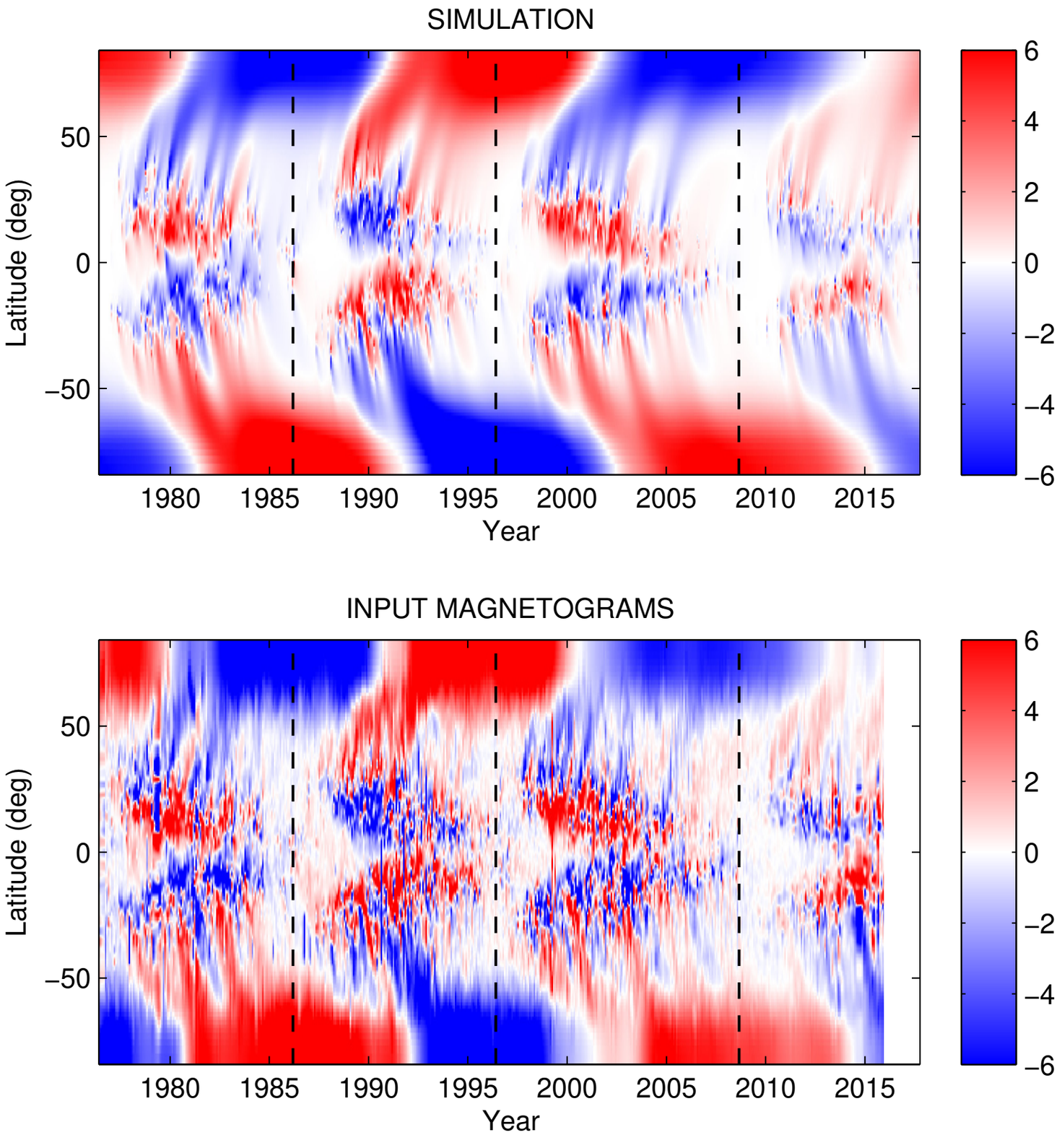
emergence





Parameter optimization

Whitbread, Yeates, Muñoz-Jaramillo & Petrie, *A&A* [2017]



We optimized against the butterfly diagram using MPIKAIA (genetic algorithm).

Charbonneau & Knapp [1995]

cf. Lemerle, Charbonneau & Carignan-Dugas, *ApJ* [2015]

Optimal parameters:

$$B_0 = 6.7\,\mathrm{G} \quad [0, 15]$$

$$\eta = 466.8\,\mathrm{km^2\,s^{-1}}\ [325.7, 747.3]$$

$$\tau = 10.1\,\mathrm{yr} \quad [3.6, 31.9]$$

$$v_\theta(\theta) = -v_0 \sin^p\theta \cos\theta$$

where

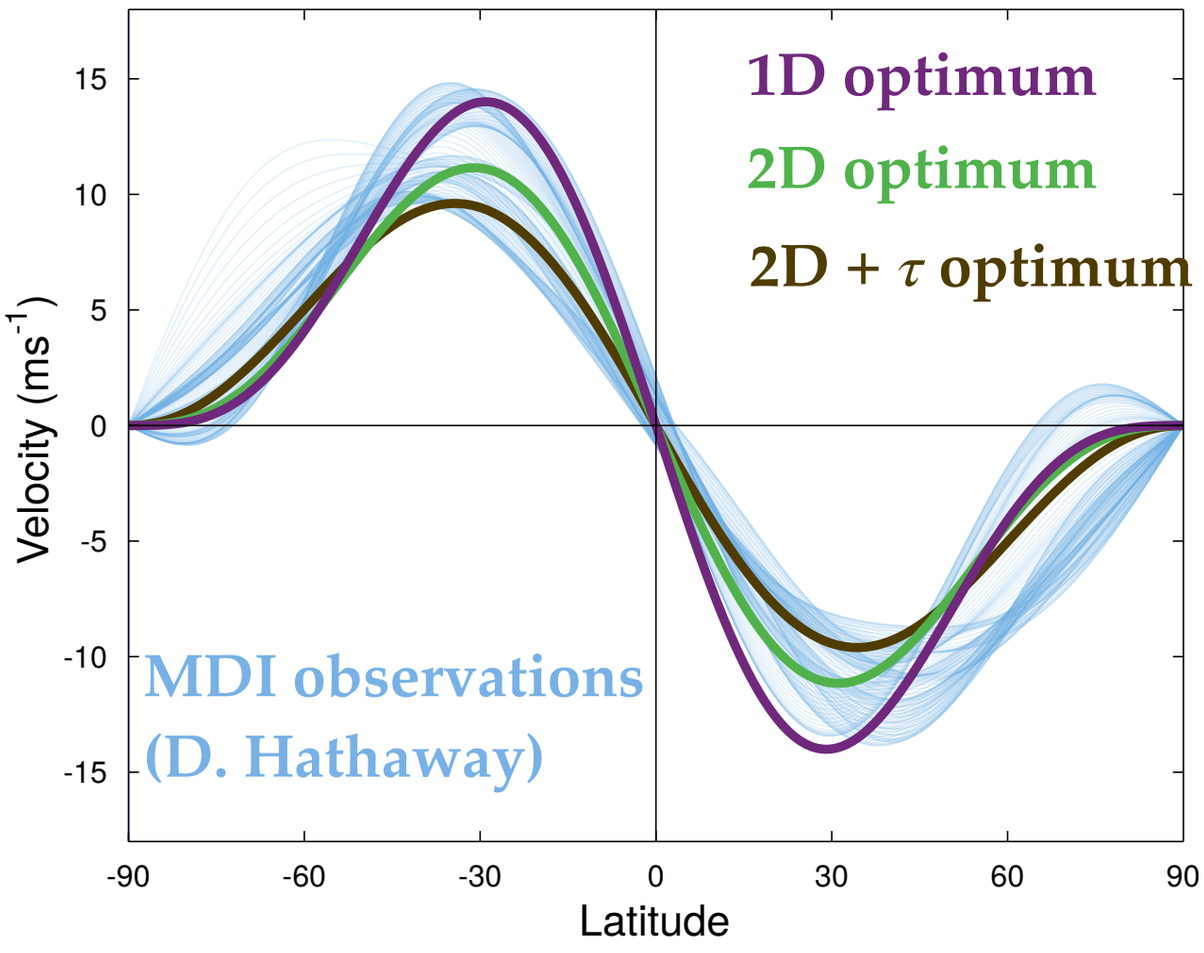
$$v_0 = 9.2\,\mathrm{m\,s^{-1}} \quad [5.6, 11.9]$$

$$p = 2.33 \quad [1.12, 3.95]$$

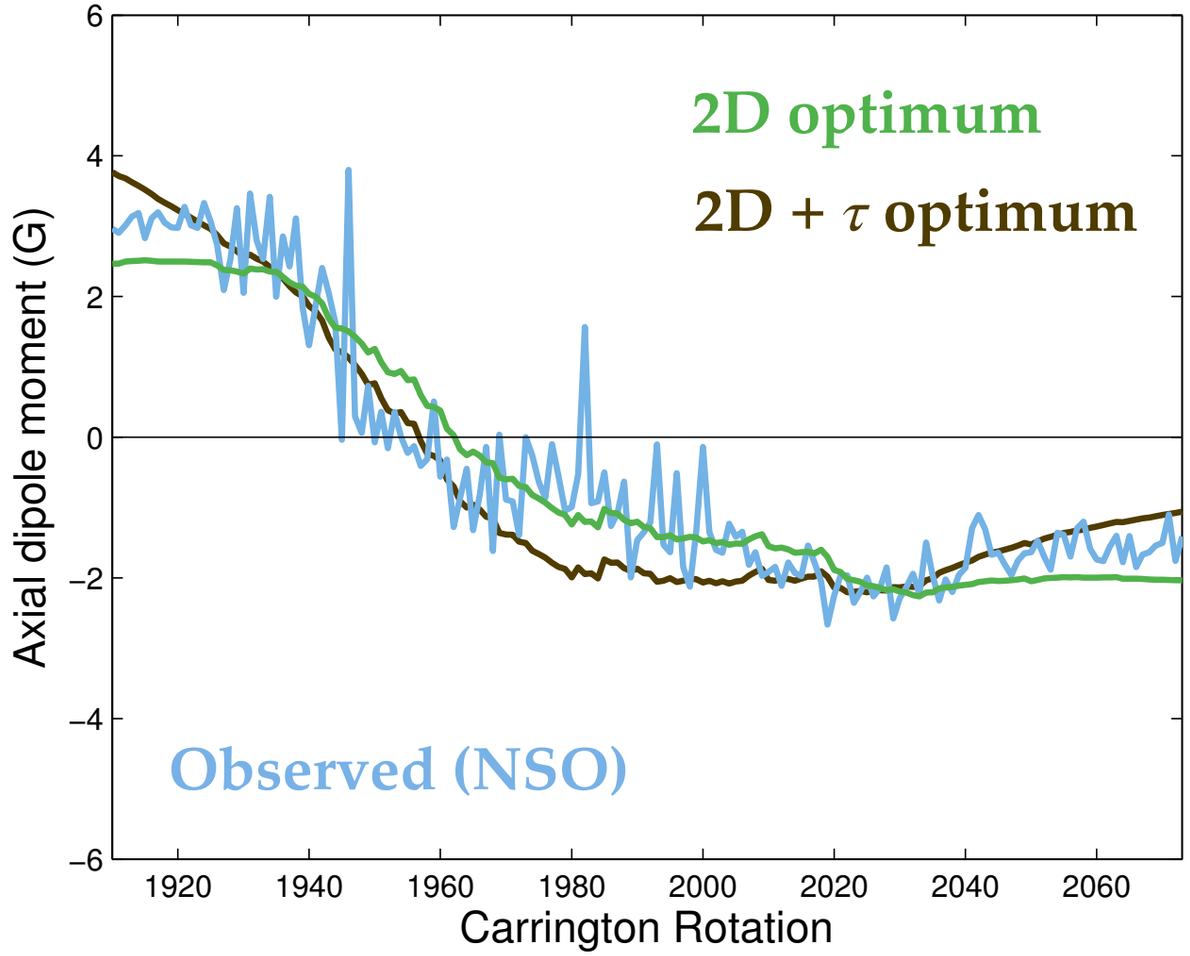
Validation [Cycle 23]

Whitbread, Yeates, Muñoz-Jaramillo & Petrie, *A&A* [2017]

Meridional flow



Axial dipole

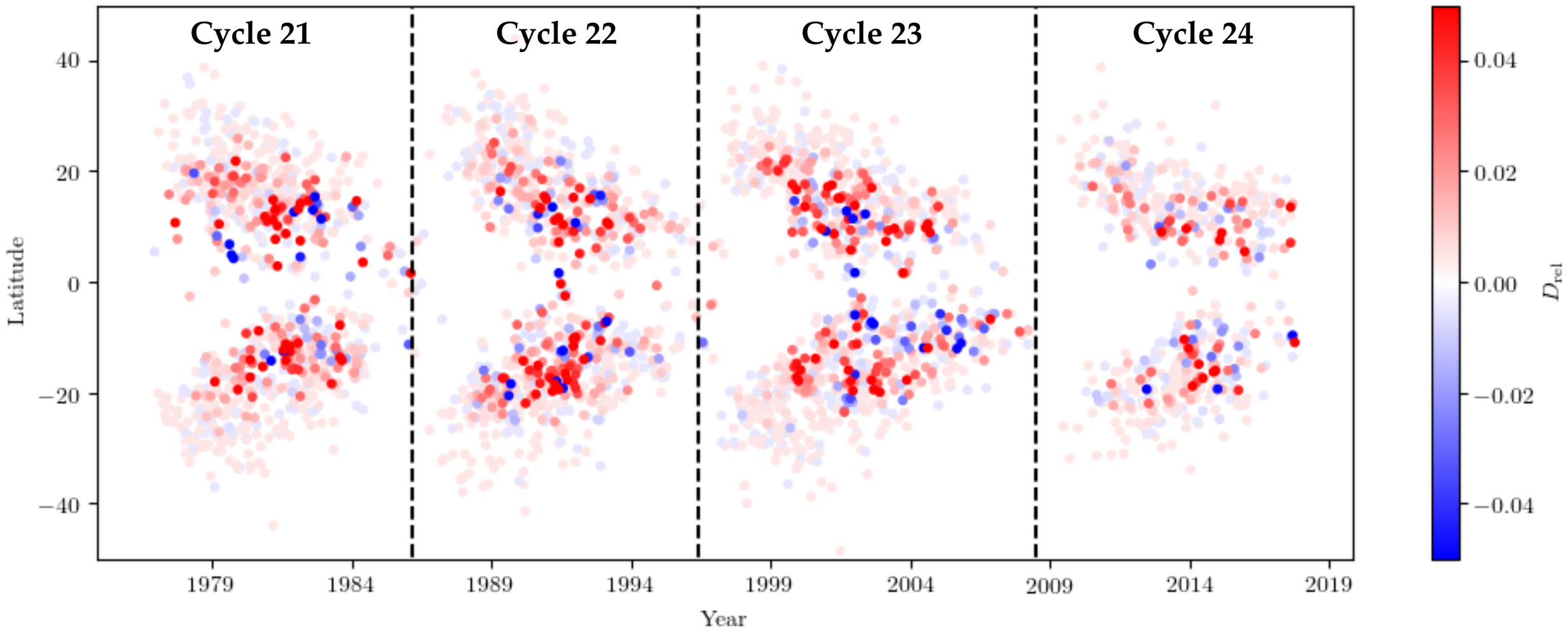


Results

Overview

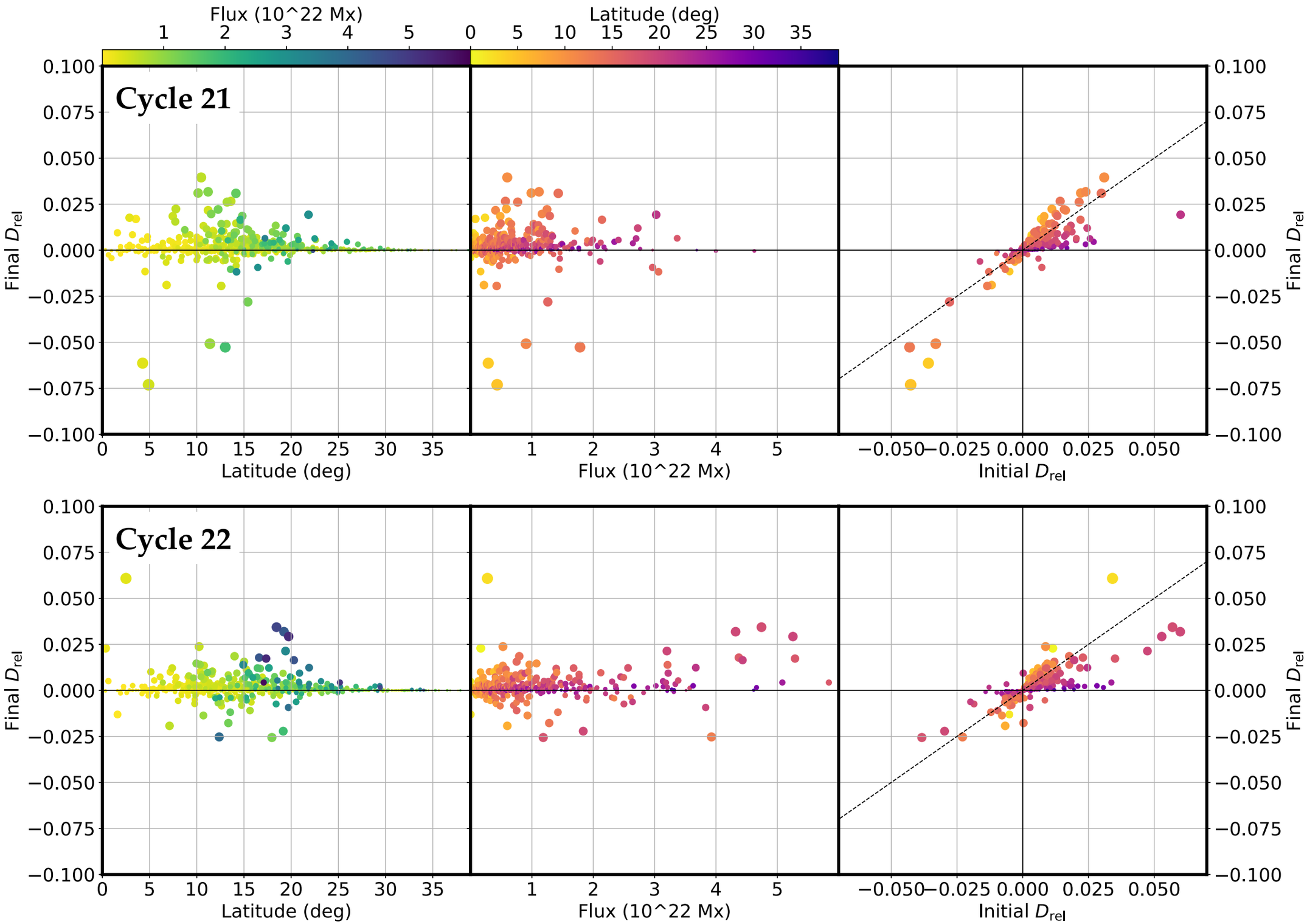
We simulated each region individually to determine its final dipole contribution

$$D_{\mathrm{rel}}^{(i)} = \frac{D^{(i)}(t_{\mathrm{end}})}{D_{\mathrm{tot}}(t_{\mathrm{end}}) - D_{\mathrm{tot}}(t_{\mathrm{start}})}$$

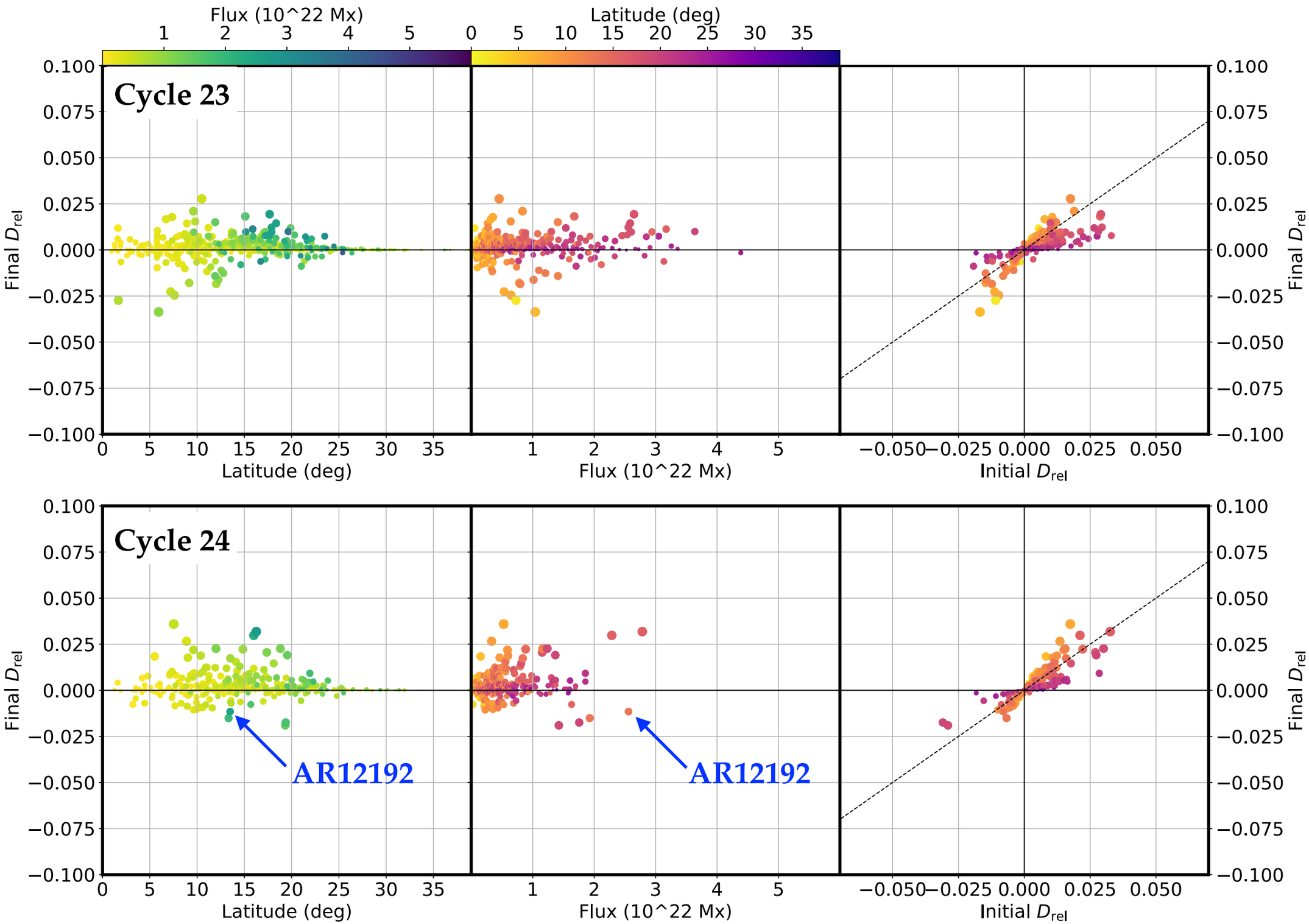


anti-Joy regions: 903/3165

Region properties

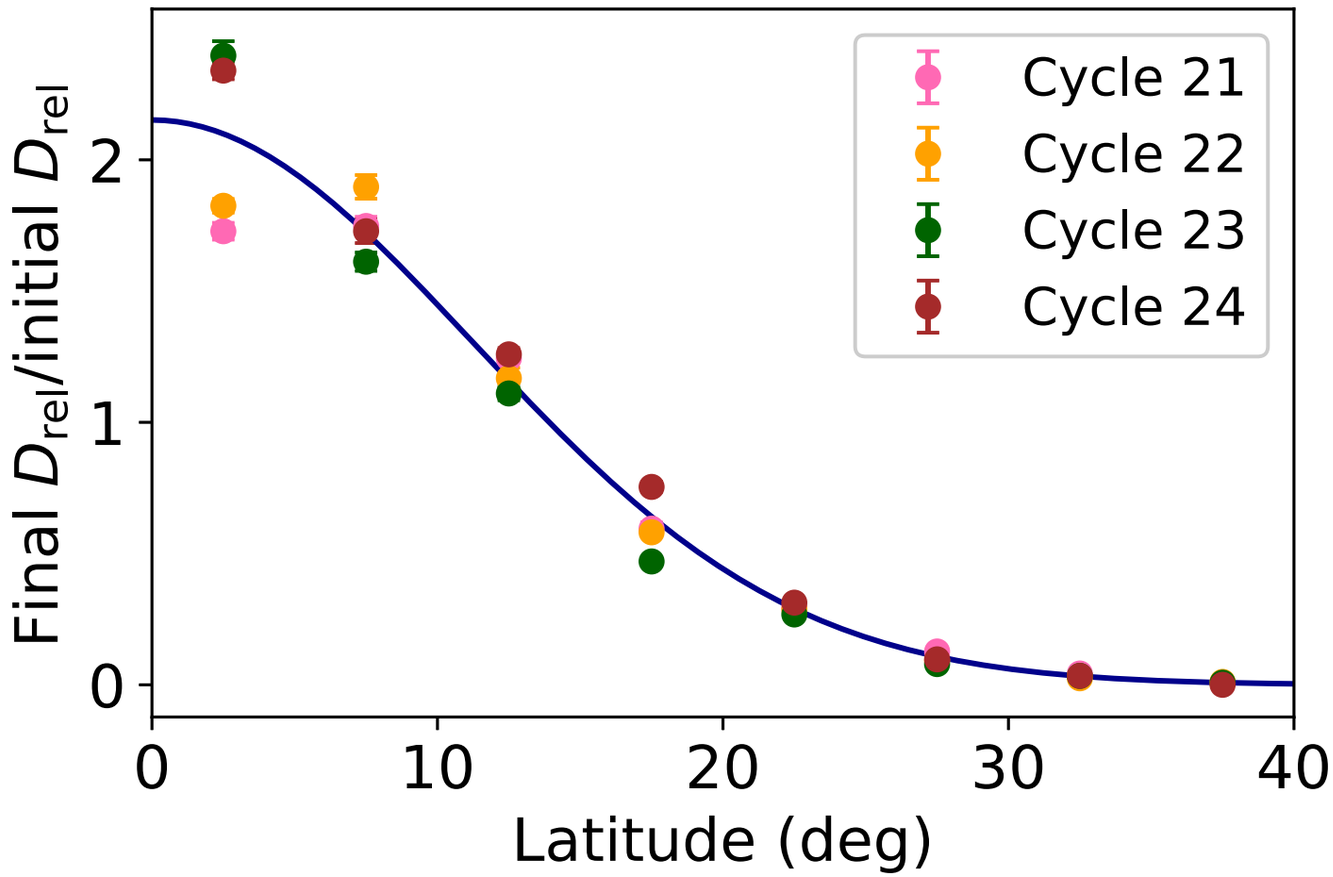


Region properties



Amplification factor

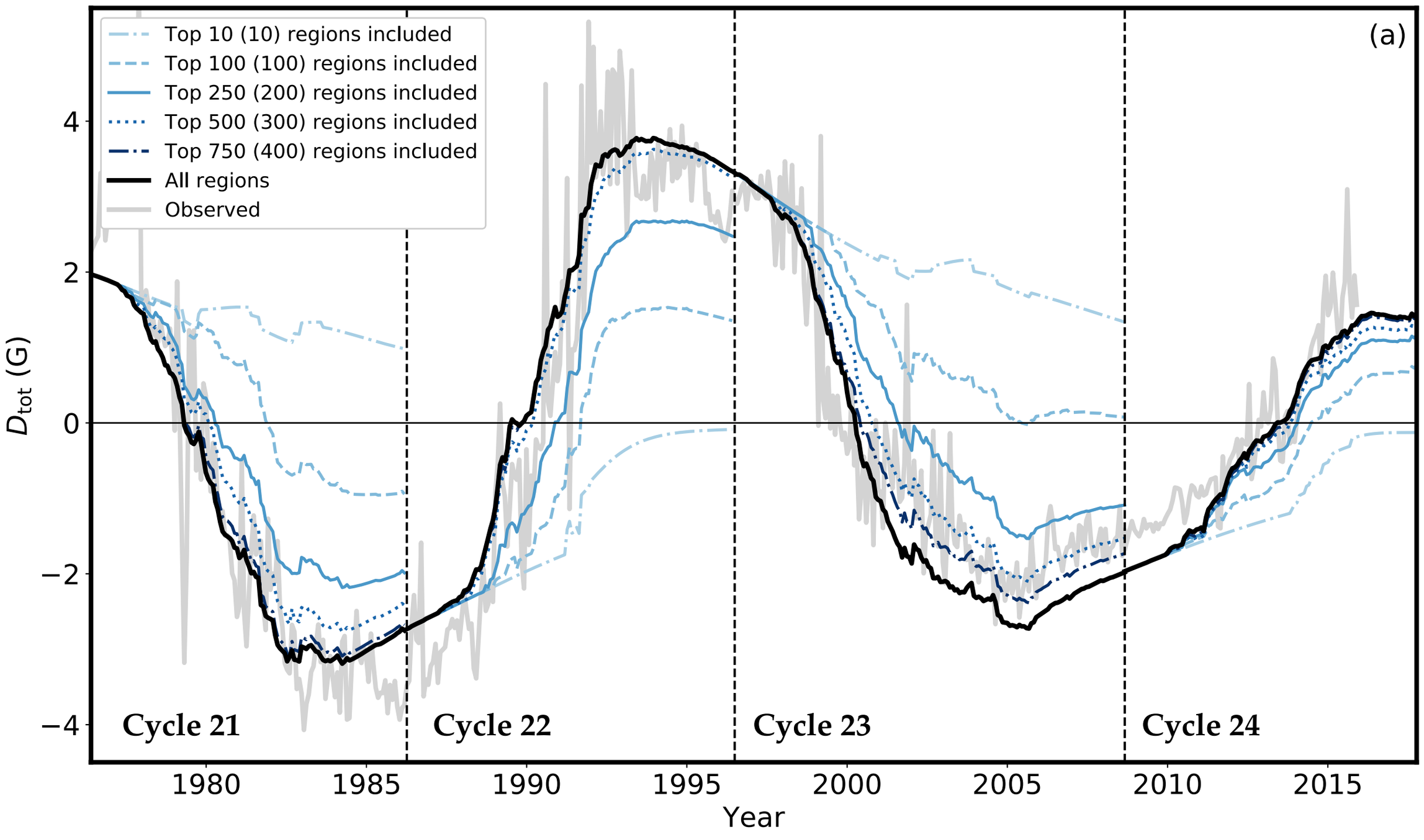
Ratio of final to initial dipole moment **primarily determined by latitude**.



$$\sim \exp\left[-\left(\frac{\lambda}{15.8^\circ}\right)^2\right]$$

cf. Jiang, Cameron & Schüssler, *ApJ* [2014] **who found** $\sim \exp\left[-\left(\frac{\lambda}{10.5^\circ}\right)^2\right]$

How many regions are needed?



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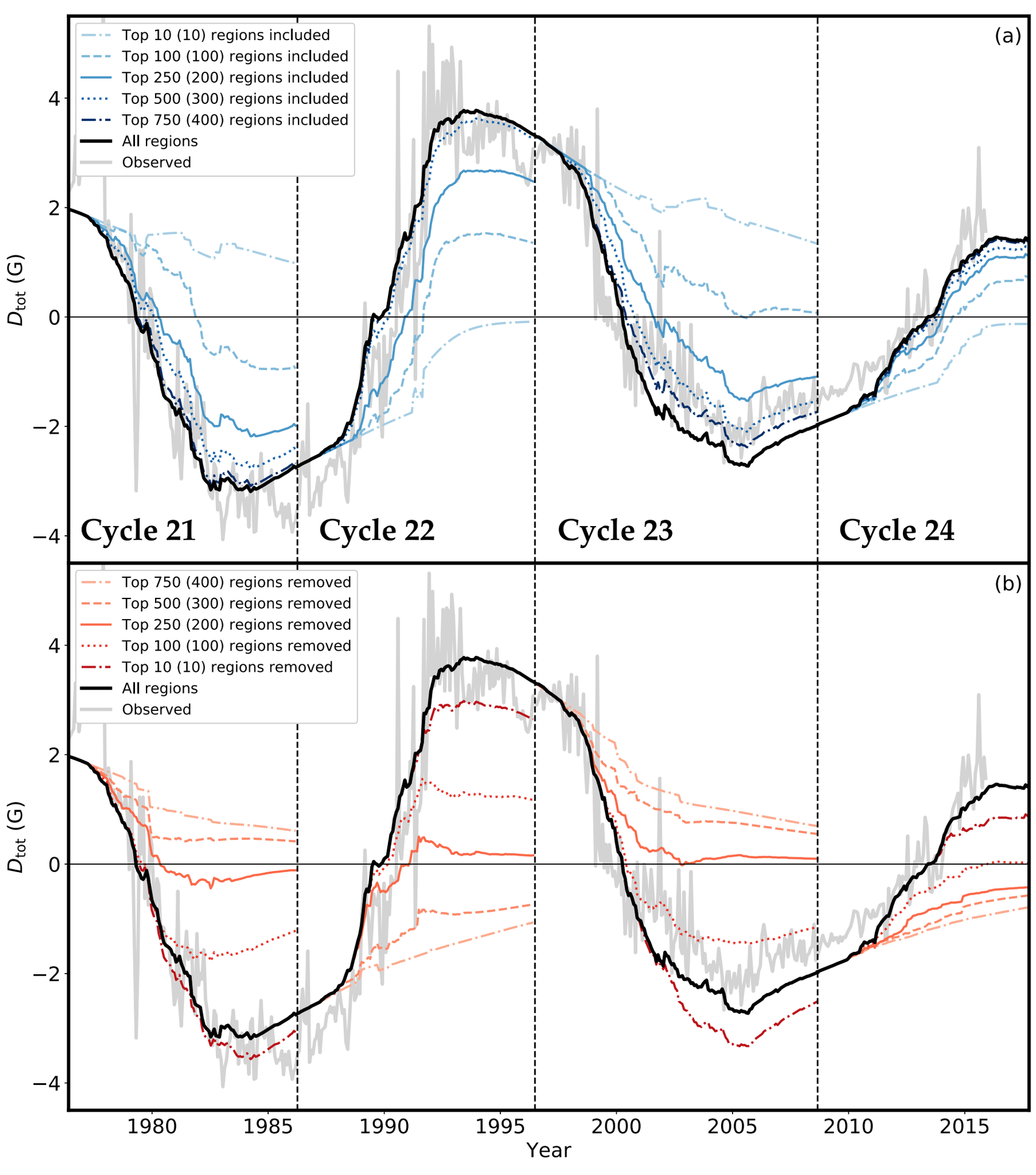
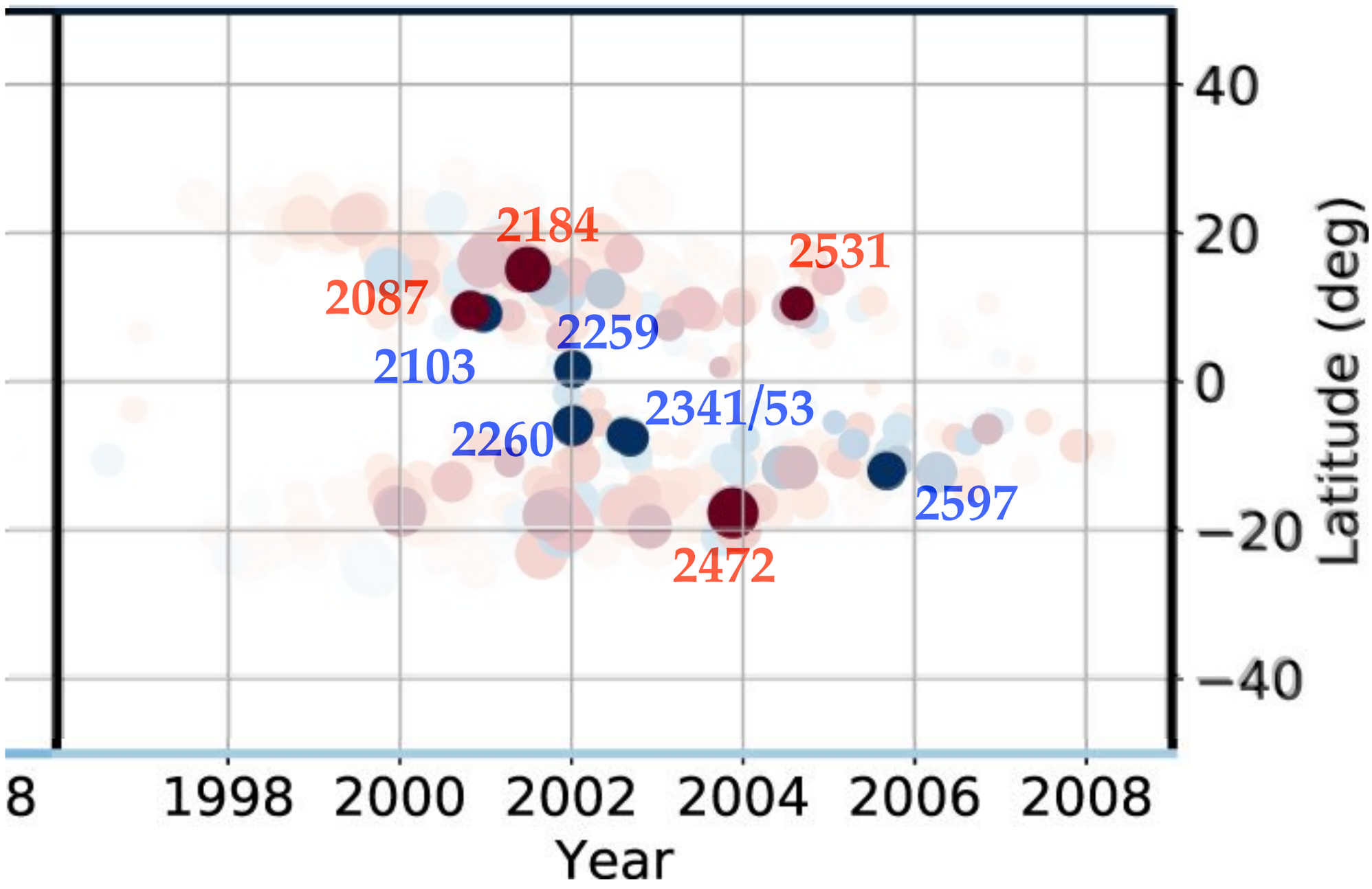
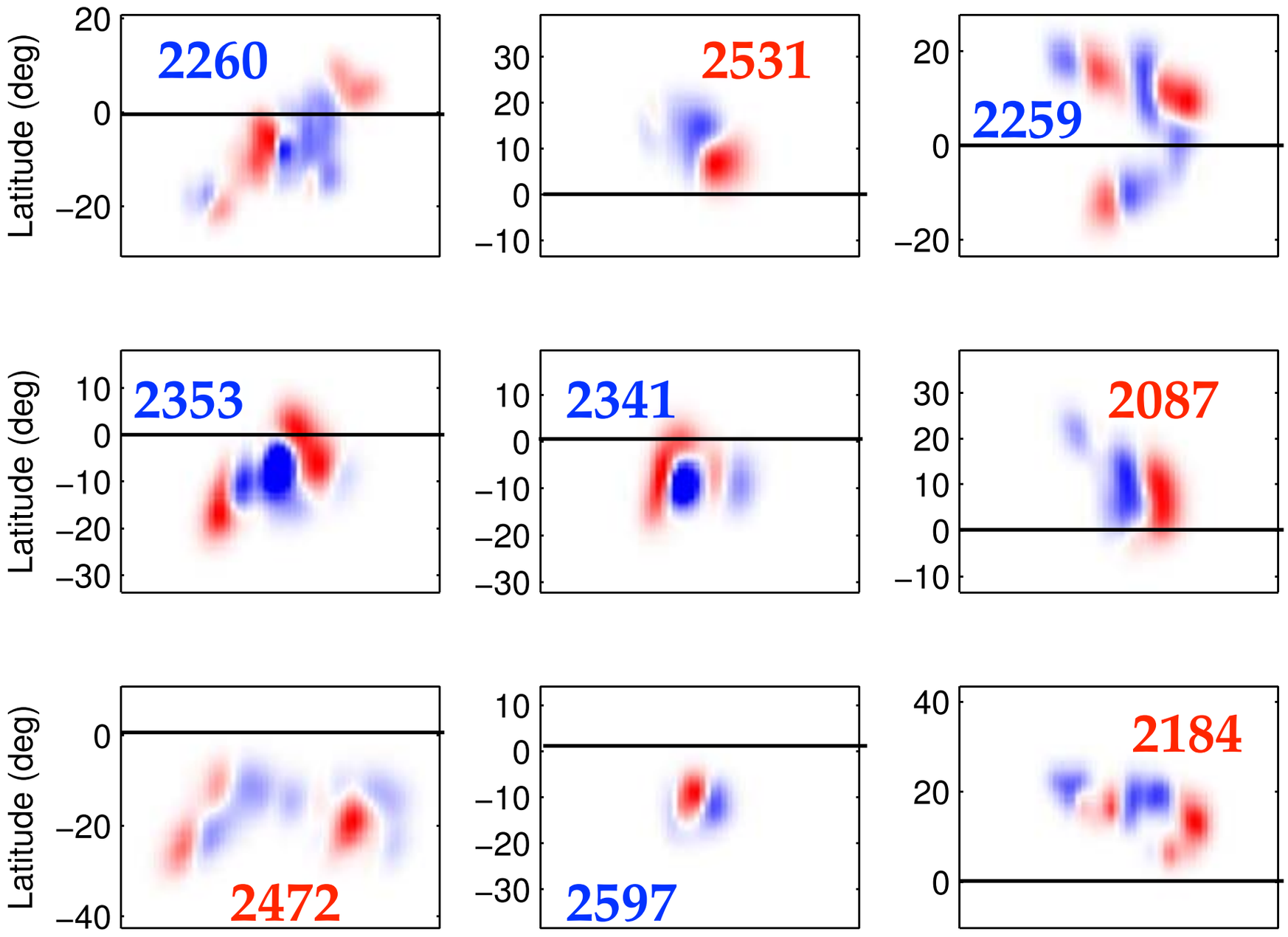


Strongest contributors in Cycle 23



Strongest contributors in Cycle 23



Conclusions

Estimated contribution of each active region to the end-of-cycle dipole using SFT model.

- **Outliers exist, in support of the "rogue active region" hypothesis.**
- **Polar field at end of Cycle 23 was weakened >15% by top 10 contributors.**
- **BUT the overall weakening wasn't caused by a handful of regions.**

If Babcock-Leighton is correct, this limits solar cycle predictability!

Whitbread, Yeates, Muñoz-Jaramillo & Petrie, *A&A* [2017] **- optimization**

Whitbread, Yeates & Muñoz-Jaramillo, *ApJ* [2018] **- dipole contributions**

github.com/antyeates1983/sft_data - SFT code

https://doi.org/10.7910/DVN/FMY6UR - observed dipole moment data

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LIVING WITH A STAR LWS NASA

Durham University

Original (with decay)

Without decay