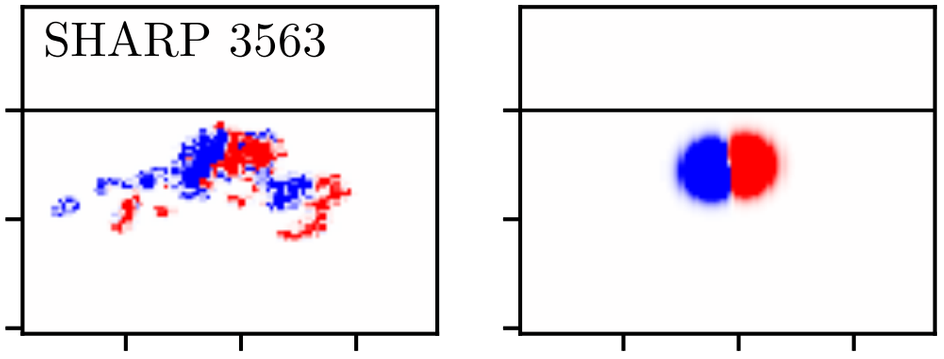
How good is the bipolar approximation of active regions for surface flux transport?

Anthony R. Yeates, *Solar Physics* **295**, 119 (2020)

- **Aim**: how does approximating active regions as bipolar magnetic regions (BMRs) affect the end-of-cycle polar field predicted by SFT models?

  [specific measure: axial dipole moment]



- **Motivation**:
  - BMRs are often used in SFT and dynamo models, especially for predictions.
  - When driven by observed BMRs, these models typically overestimate the polar field, usually fixed by eitherreducing tilt angles vs observations or reducing meridional flow (citing active region inflows).
  - Recent studies highlight that the axial dipole for more complex region shapes can evolve differently. [Iijima-Hotta-Imada *ApJ* 2019; Jiang et al. *ApJ* 2019]

- **Main conclusion**: For Cycle 24 (HMI data), approximating active regions by BMRs leads to >20% overestimate of the polar field/axial dipole.

Methodology

1. **New BMR database extracted automatically from HMI/SHARPs data.**
   - Python code for extracting database: https://github.com/antyeates1983/sharps-bmrs
   - Ready-prepared file: https://doi.org/10.7910/DVN/1Z7YMT (Harvard Dataverse) for May 2010 to April 2020:

bmrsharps_evol.txt

```
SHARPs from 2010-05-01 00:00:00 to 2020-04-06 00:00:00
-- Produced by anthony.yeates[at]durham.ac.uk --
1090
Grid resolution: 180 x 360, smoothing_param = 4
Selection criteria: (i) sep > 1 deg,  (ii) |imbalance| <  0.5
Last two columns use 10-year 1D SFT simulation with eta=350 km^2/s, v0=0.015 km/s, p=2.33, no decay term.
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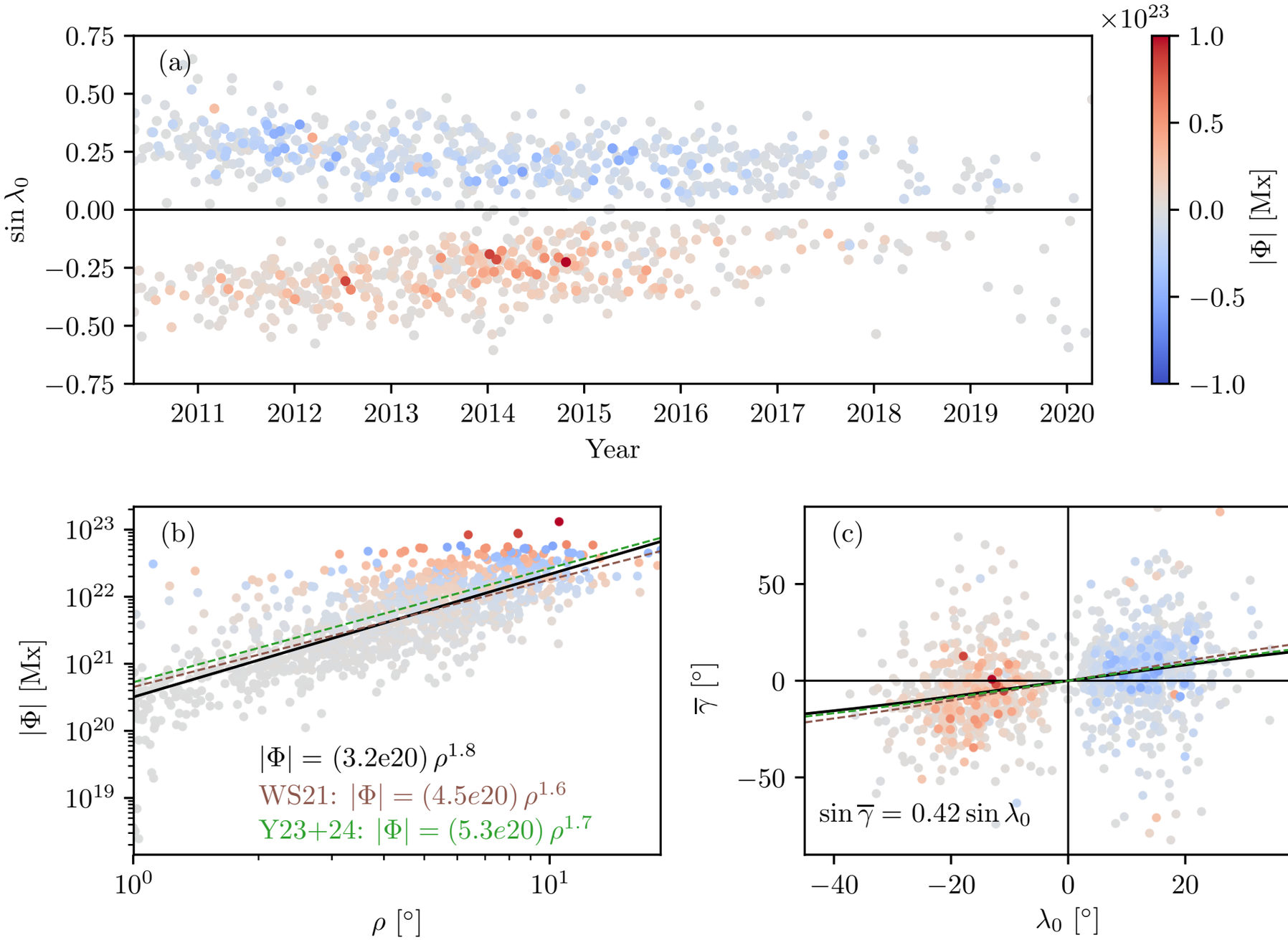
SHARP	NOAA	CM time	Latitude	Carr-Longitude	Unsgnd flux	Imbalance	Dipole	Bip-Separation	Bip-Tilt	Bip-Dipole	Pred-Dip-Real	Pred-Dip-Bip
1	11067	2010-05-07	24.58757	172.96456	3.92405e+21	0.09477	4.60159e-04	5.37126e+00	3.20001e+00	4.52749e-04	4.55467e-06	9.21374e-06
2	11064	2010-05-03	12.12164	223.73779	1.35016e+21	-0.25154	-1.18855e-03	5.23233e+00	-2.35854e+01	-1.17753e-03	-1.10364e-03	-1.52003e-03
10	11066	2010-05-04	-26.16036	206.66967	1.76675e+21	0.22983	2.04643e-04	2.82886e+00	1.73911e+02	2.05394e-04	2.34530e-06	1.92804e-06
12	11068	2010-05-10	-19.89266	134.14394	3.52810e+21	0.31224	-1.20625e-03	4.11376e+00	-1.68141e+02	-1.19192e-03	-8.52827e-05	-1.33604e-04
14	11070	2010-05-05	20.25744	194.70160	6.00410e+20	-0.03259	-1.69209e-04	1.22874e+00	-3.46432e+01	-1.86002e-04	-1.52502e-05	-1.68076e-05
26	11072	2010-05-23	-15.21733	316.68772	6.99753e+21	-0.03534	1.53796e-03	3.65048e+00	1.71658e+02	1.53320e-03	6.97488e-04	8.00380e-04
38	11073	2010-06-02	12.88378	194.19472	2.22336e+21	-0.09996	-1.87460e-03	3.53620e+00	-3.46612e+01	-1.86447e-03	-1.87190e-03	-1.91126e-03
40	11075	2010-05-30	-19.66521	230.70519	1.16558e+21	0.01622	5.13498e-04	2.26303e+00	1.51270e+02	5.09108e-04	5.84839e-05	5.83800e-05
43	11076	2010-06-01	-19.66000	196.18004	2.08037e+21	-0.11159	1.28108e-04	2.37732e+00	1.76333e+02	1.23387e-04	1.95448e-05	1.41248e-05
44	0	2010-06-02	-33.12716	184.92852	5.97273e+20	-0.15399	3.06956e-05	1.46305e+00	1.74403e+02	2.84019e-05	1.53281e-08	1.42752e-08
47	0	2010-06-10	15.19621	88.08352	7.74446e+20	-0.00963	4.37134e-04	2.37736e+00	3.48945e+01	4.35103e-04	2.21568e-04	2.23777e-04
57	11082	2010-06-20	28.39895	303.46702	4.48632e+21	0.20622	4.19290e-03	3.60712e+00	4.32266e+01	4.15153e-03	1.62768e-05	1.67351e-05
66	0	2010-06-28	15.71528	199.80528	2.13414e+21	-0.02659	-2.28356e-03	3.47132e+00	-4.81243e+01	-2.26704e-03	-1.00413e-03	-1.03158e-03
67	11085	2010-06-28	-21.91311	200.48488	1.52761e+21	0.12114	-1.72414e-03	3.67840e+00	-1.29731e+02	-1.71826e-03	-9.65460e-05	-9.30680e-05
86	11087	2010-07-15	19.49569	335.55594	1.83895e+22	-0.03850	1.92913e-02	8.97116e+00	1.67619e+01	1.90763e-02	4.51918e-03	3.39163e-03
87	0	2010-07-09	19.52667	100.34961	3.89123e+20	0.31597	8.57507e-05	1.09127e+00	2.98810e+01	1.07181e-04	1.02349e-05	1.26450e-05
89	11088	2010-07-15	-20.59370	337.44025	7.32340e+20	-0.40323	-4.75846e-05	2.18557e+00	-1.75765e+02	-5.06708e-05	-3.01310e-06	-4.10831e-06
92	11089	2010-07-25	-22.90078	203.23528	2.05991e+22	-0.02122	9.70499e-03	5.68659e+00	1.67930e+02	9.61091e-03	3.75159e-04	3.86887e-04
97	0	2010-07-24	13.34402	220.46158	3.58470e+20	0.37365	-2.40001e-05	1.31483e+00	-6.98935e+00	-3.34932e-05	-1.63547e-05	-2.89587e-05
98	11090	2010-07-29	22.49662	149.96277	5.08242e+20	-0.32211	5.19955e-04	5.30587e+00	2.90281e+01	5.15122e-04	2.10756e-05	2.42236e-05
104	11092	2010-08-04	15.89691	76.61377	1.30975e+22	-0.14607	3.23345e-02	9.35438e+00	3.96531e+01	3.19762e-02	1.51923e-02	1.88848e-02
114	11095	2010-08-09	-16.74810	4.55401	4.01993e+21	0.22351	3.77086e-03	7.36436e+00	1.61984e+02	3.73241e-03	1.23802e-03	1.42898e-03
115	11093	2010-08-10	14.64567	348.66903	1.22733e+22	-0.49672	-6.87333e-03	3.36876e+00	-2.35482e+01	-6.81773e-03	-3.63902e-03	-4.21641e-03
131	11098	2010-08-14	14.04513	302.18062	2.14102e+21	0.12191	4.55119e-04	3.55713e+00	8.23495e+00	4.47399e-04	3.66343e-04	3.29530e-04
146	11102	2010-08-29	26.81754	103.17549	2.51881e+21	-0.33635	5.07201e-04	3.23274e+00	9.33950e+00	4.99081e-04	5.70436e-06	3.65075e-06

2. **1D SFT simulations of dipole moment** [all regions + individual regions separately].

$$\frac{\partial \overline{B}}{\partial t} = \frac{\partial}{\partial s}\left[\frac{D}{R_\odot^2}(1-s^2)\frac{\partial \overline{B}}{\partial s} - \frac{v_s(s)}{R_\odot}\sqrt{1-s^2}\,\overline{B}\right] \qquad s = \cos\theta$$

Bipolar Magnetic Region database

- Fit single magnetogram for each SHARP, at time closest to central-meridian.
- Fitted 1090 SHARPs out of 3671 [sufficiently bipolar, large enough, no repeats].
- Parameters chosen to match magnetic flux, size and tilt angle, but also axial dipole [at time of observation].



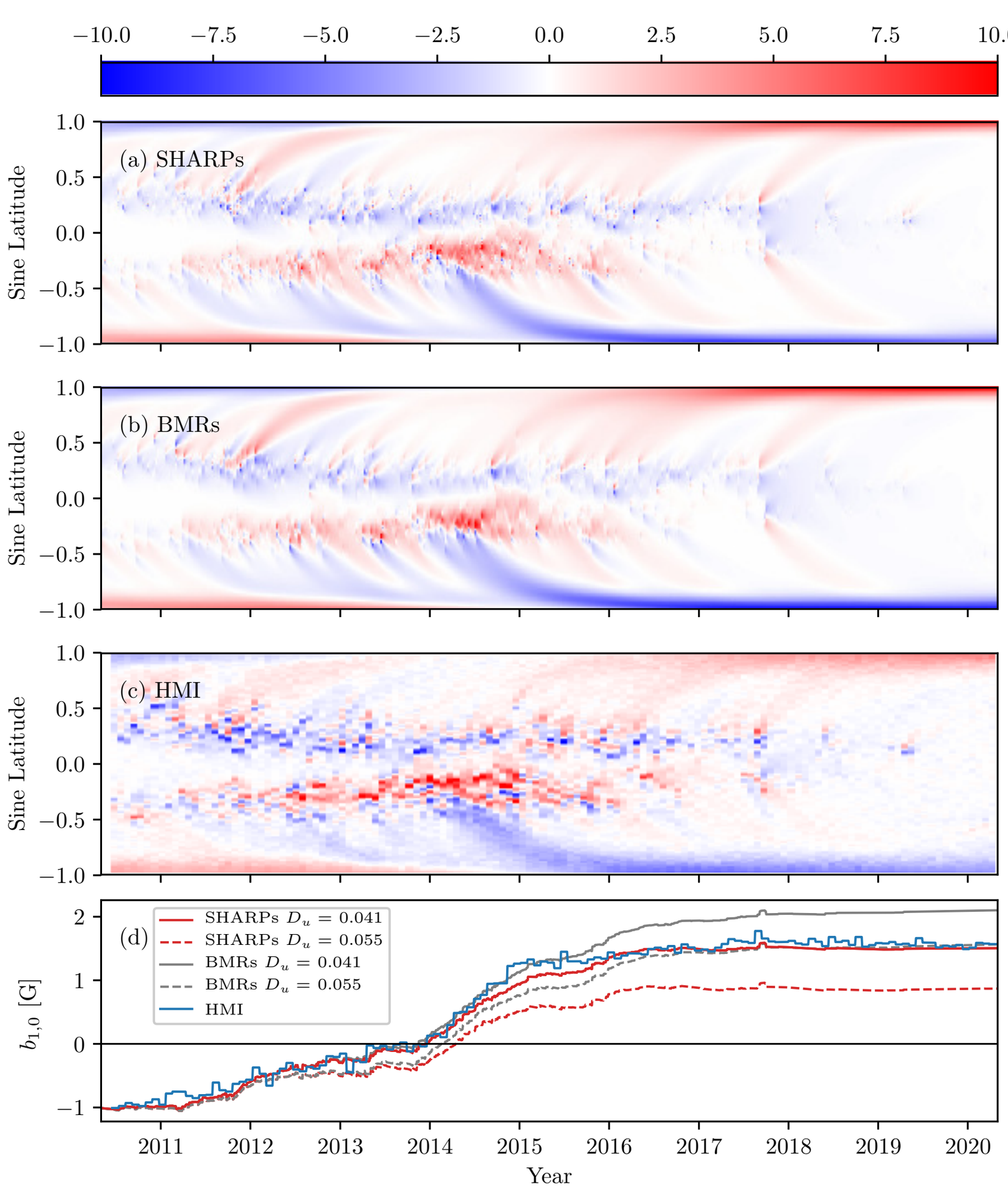
Results

SFT driven by SHARPs

SFT driven by BMRs

Observed

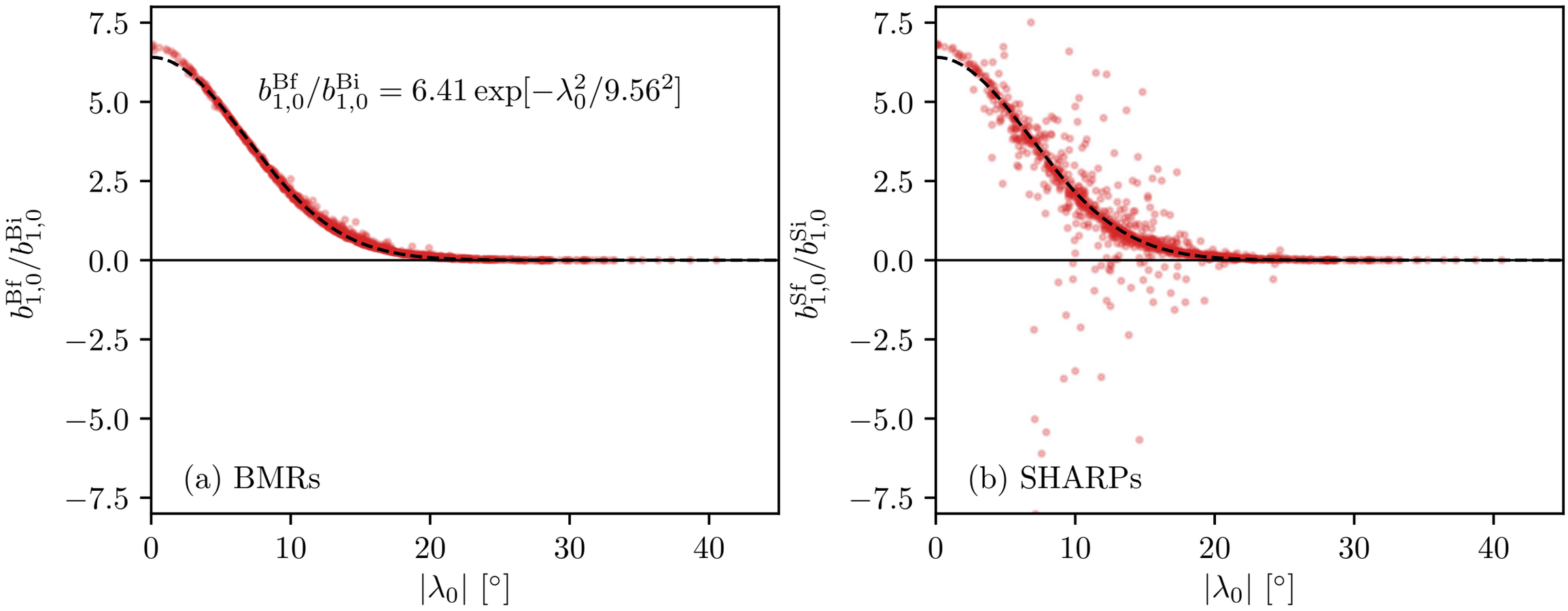
Axial dipole



Dipole “amplification”

- Compare ratio of SFT-predicted final to initial axial dipole moment [individual runs]
- For BMRs, this is a Gaussian depending primarily on latitude [Jiang-Cameron-Schüssler *ApJ* 2014; Petrovay-Nagy-Yeates *JSWSC* 2020]

BMRs **SHARPs**



- For real shapes, there is scatter compared to the BMR model.
- More regions are below the curve than above, leading to the weaker dipole [these are non-dipolar regions with enhanced cancellation].