Modelling of geomagnetic secular variation with Swarm: past, present and future

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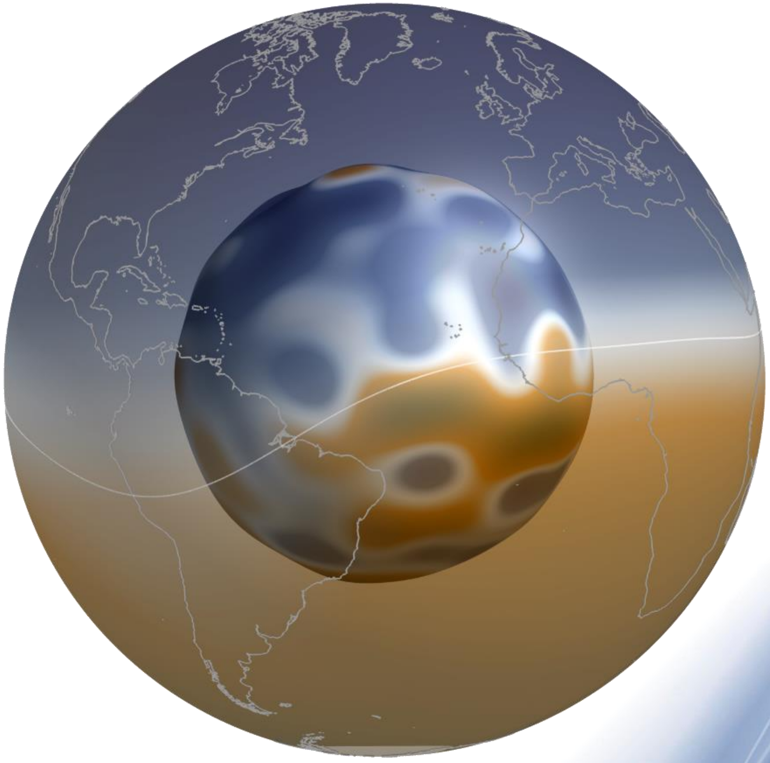
Overview

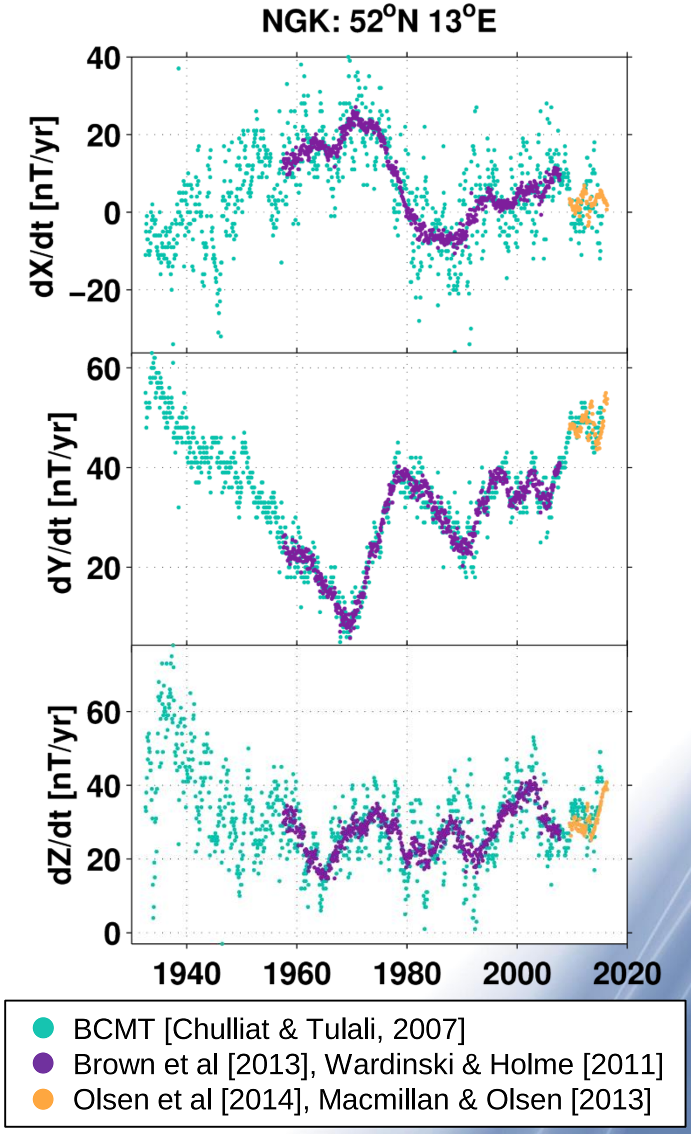
- What is secular variation?
- How have we modelled it?
- How has SV varied recently?
- How well are we capturing SV?
- Is recent SV different to past?
- How will it evolve?
- SV and the future of Swarm



<u>S</u>ecular <u>V</u>ariation?

- Continuously varying internal field
- Caused by flow and diffusion of geodynamo in outer core
- Observed timescales longer than several months
- Contributes a significant amount to observed global magnetic signal power
- Better resolved as data and models improve

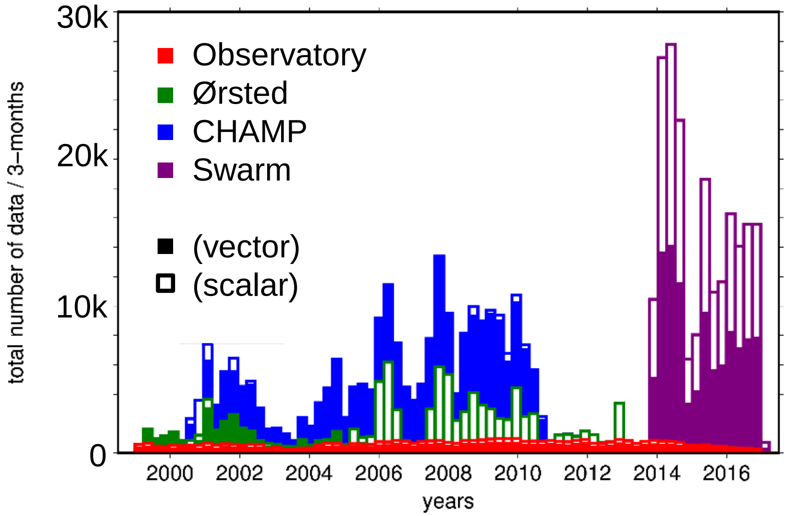
Component	Power
Core (n=1—15)	1,900,000,000 nT^2
Crust (n=16—133)	3,410 nT^2
SV (n=1—15)	7,800 $(nTyr^{-1})^2$



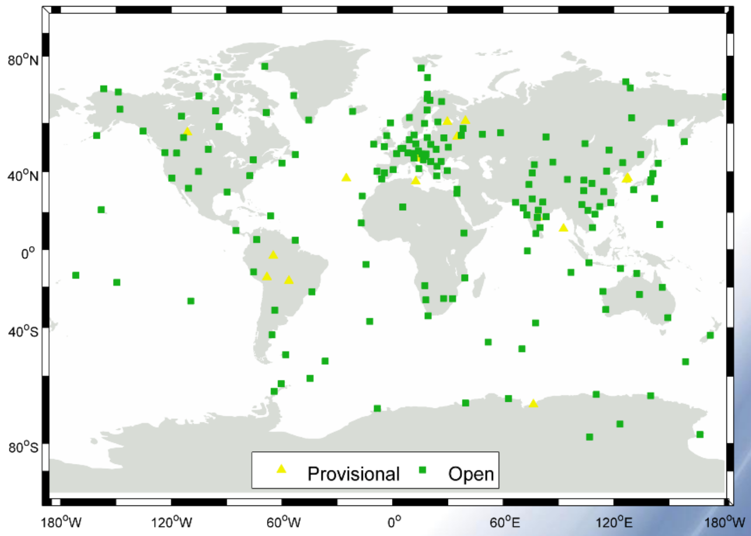
BGS MEME

Model of the Earth's Magnetic Environment

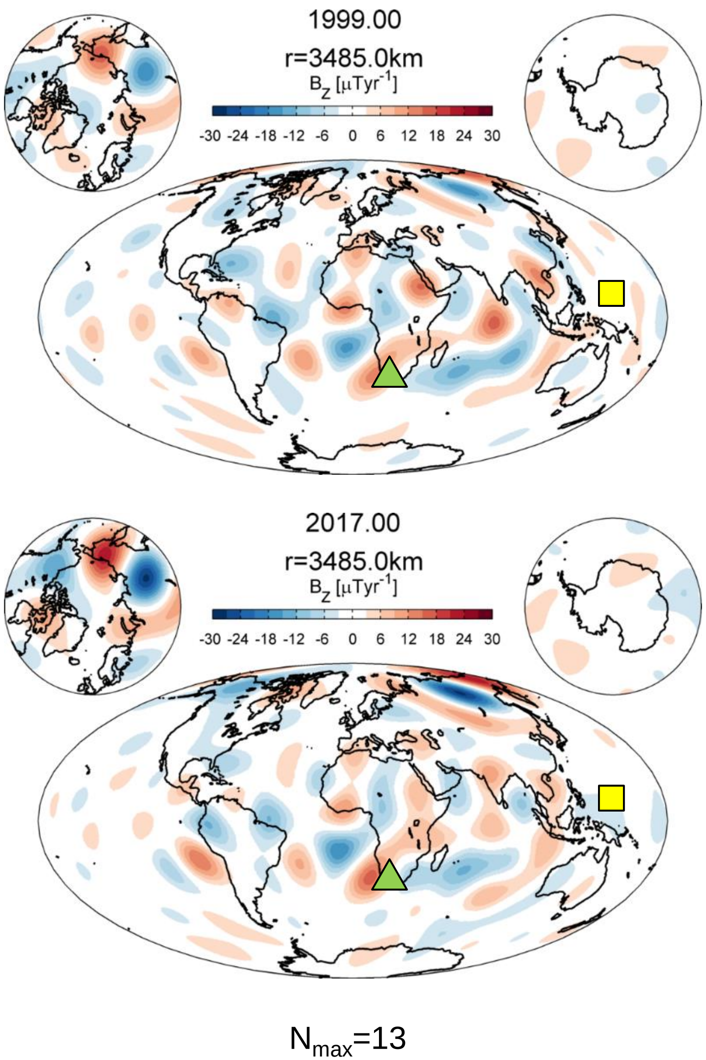
- Spherical harmonic model of internal and external sources
- 1M Ørsted, 4M CHAMP, 4M Swarm satellite data
- 1M hourly mean ground observatory data
- Vector and scalar measurements
- CHAMP and Swarm along-track gradients
- Swarm across-track gradients

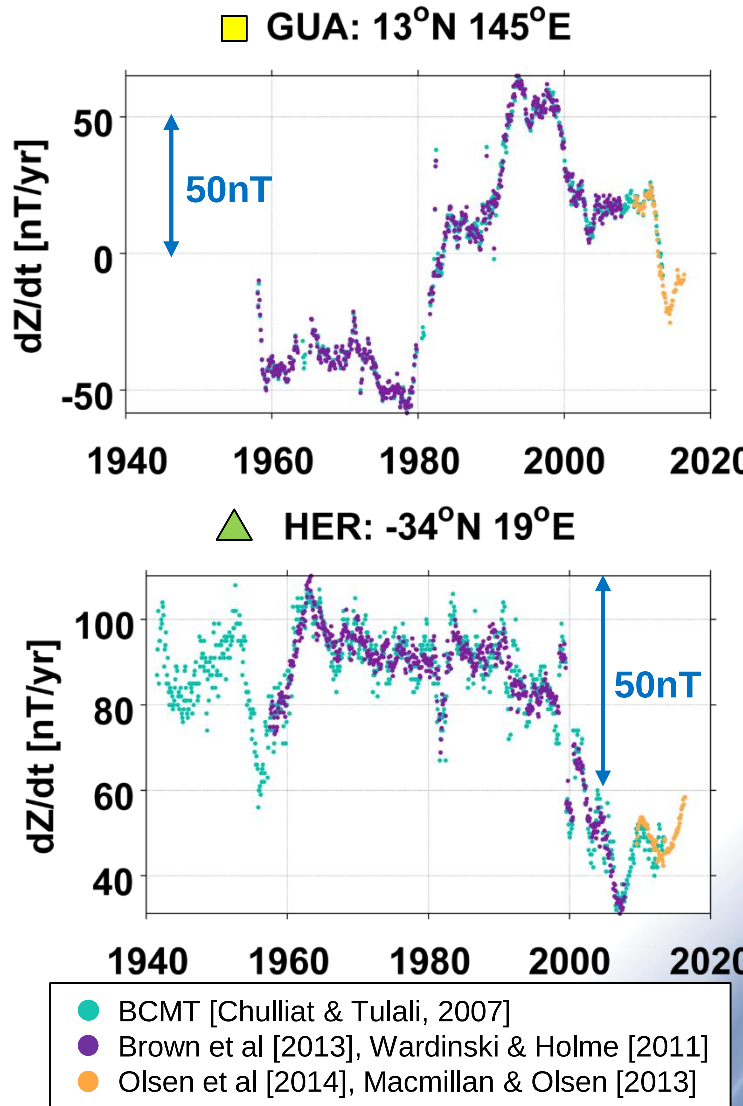


INTERMAGNET observatories, 2016

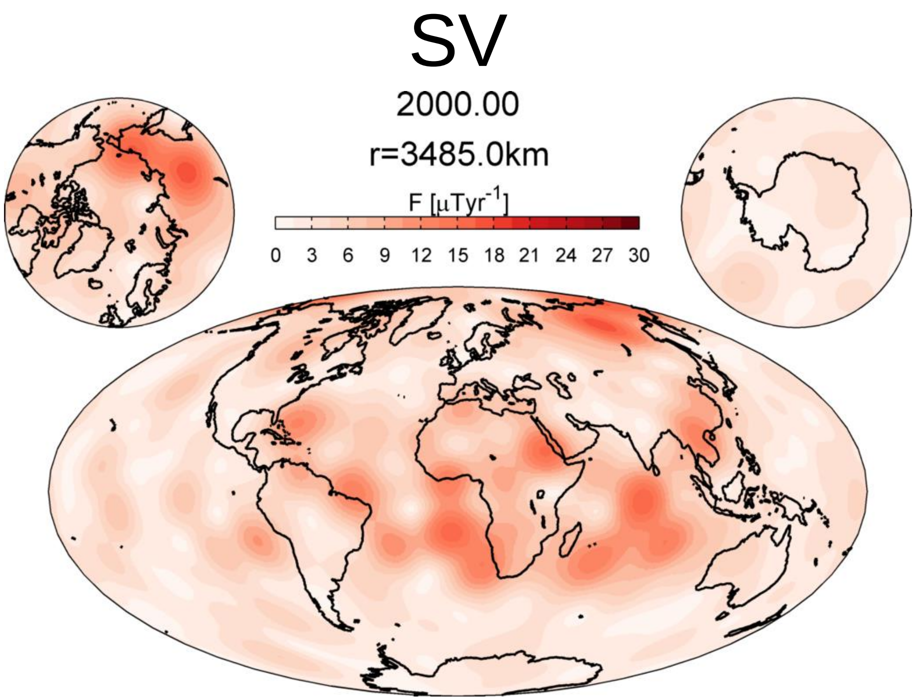


Recent SV – the “quiet Pacific”

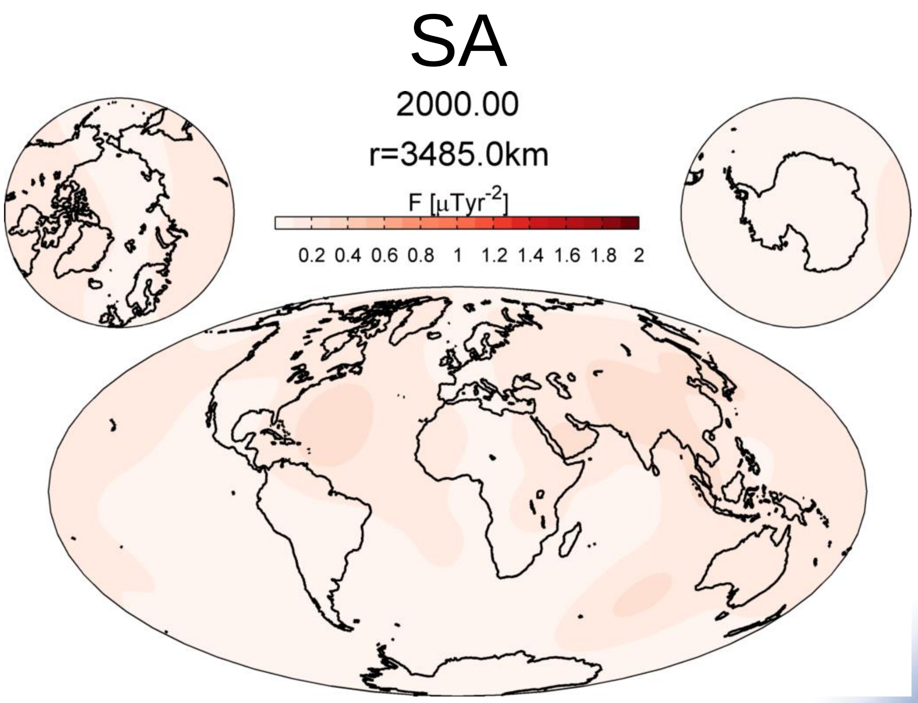




Recent SV



N_{max}=13



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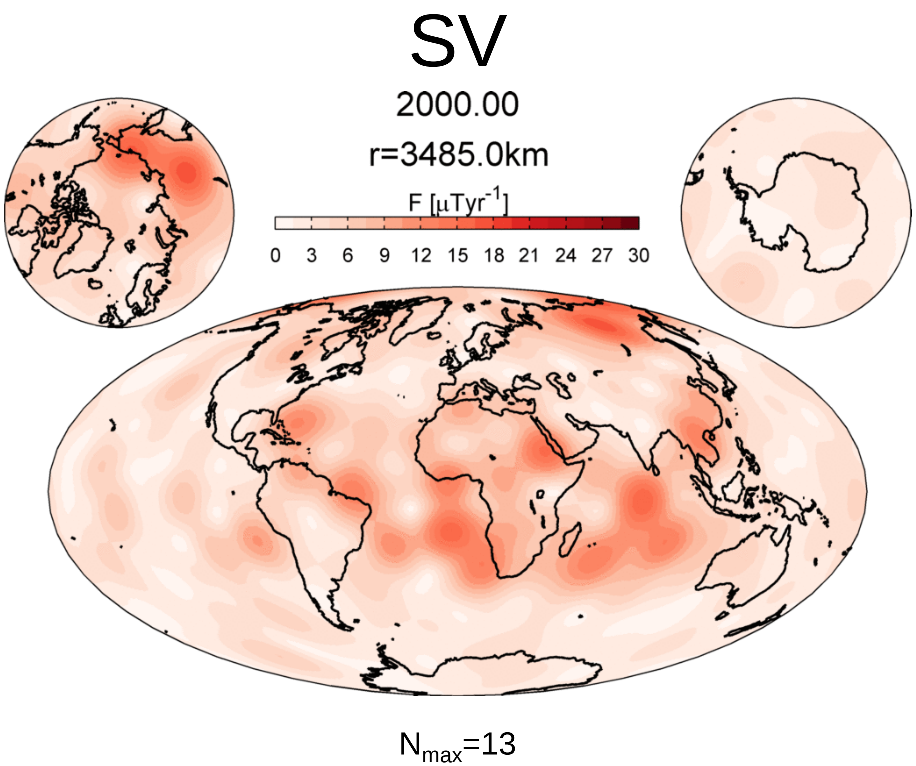
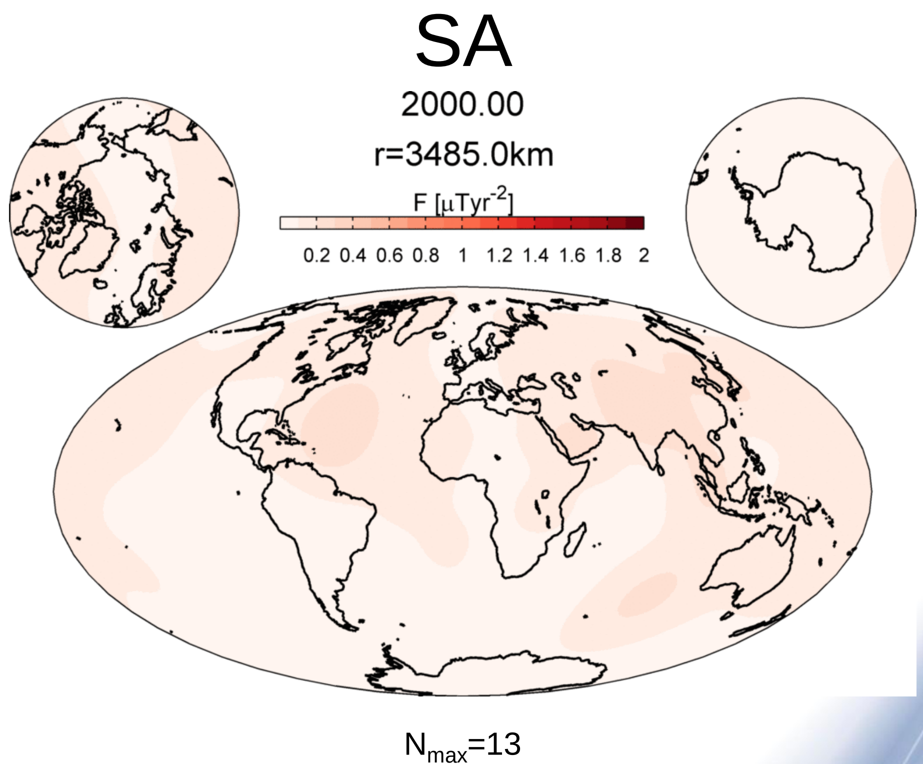
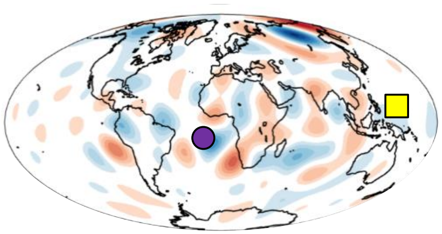
Recent SV

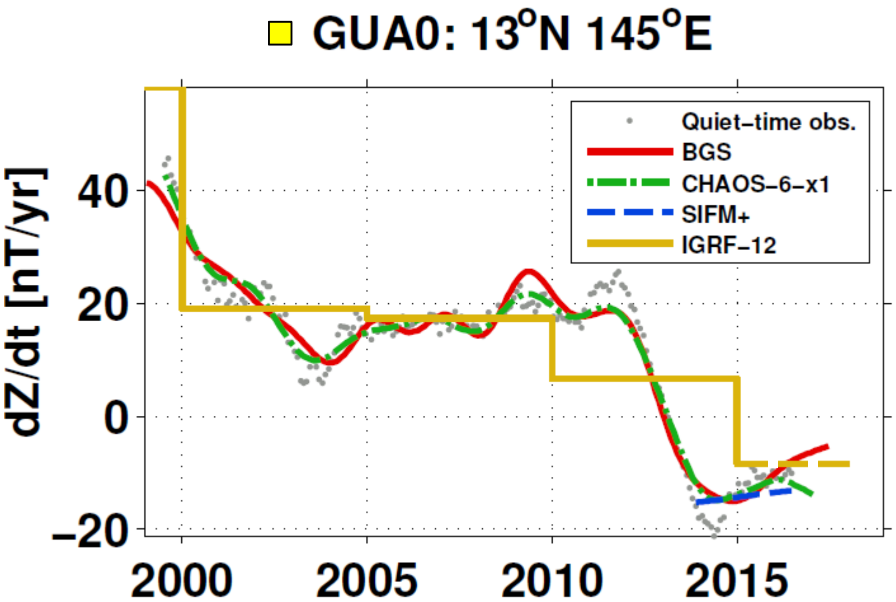


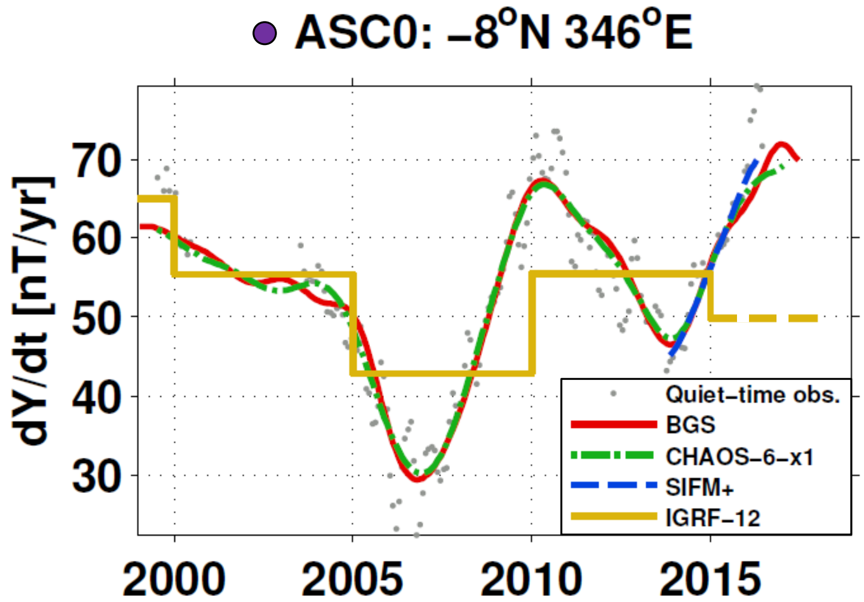


- SV largely consistent at CMB over last 18 years
- High SV over Siberia
- SA more variable, strong along 90°E meridian

Capture of jerks

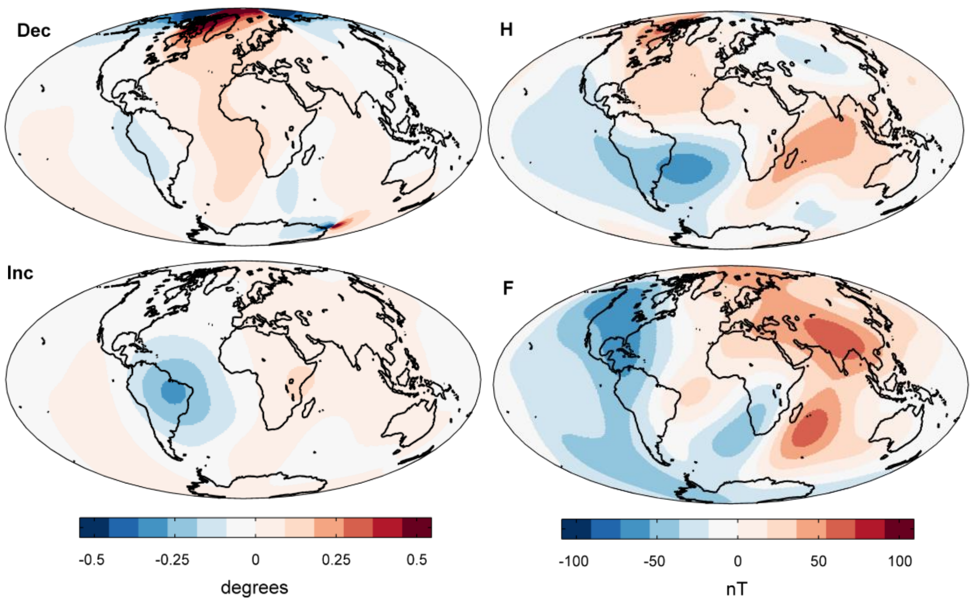


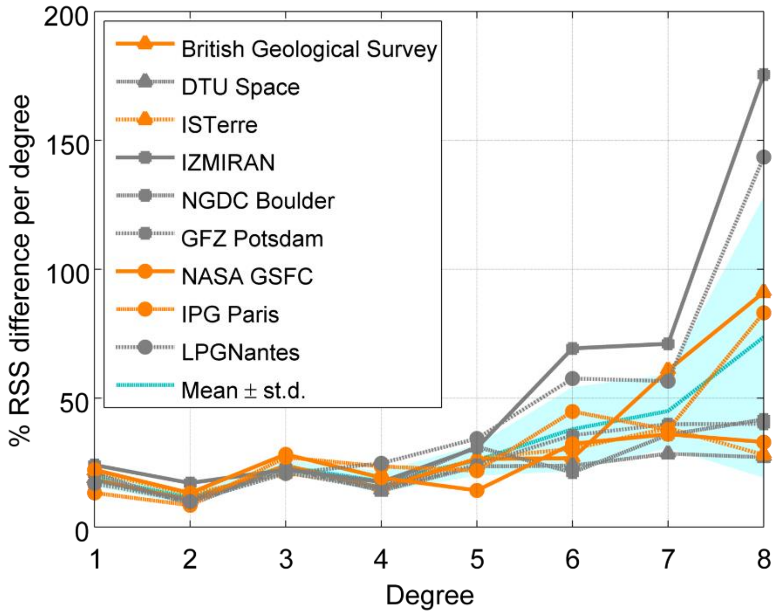




- Jerks in 1999, 2003, 2005, 2007, 2011, 2014, …
- Last few years' SV has shown widespread jerks
- Strongest SA over Indian Ocean / Central Africa
- Data quality and modelling capability improving

Model forecasts





- MEME shows 20% coefficient difference to IGRF-12 to 2016.5, compounding field differences beyond 2017
- All IGRF-12 SV candidates perform to a similar level globally
- Jerks through 2014–15 mean capturing latest SV is not trivial

SV monitoring and the future of Swarm

Orbit scenario	Effect	Lifespan
Lower Alpha & Charlie	Constellation removed, improved crustal field capture, Bravo unaffected	<2022 for constellation, >2025 for Bravo
Maintain altitudes	Constellation prolonged	>2022 for constellation, >2030 for Bravo
Slow/fix LT drift	Improved external field capture	<2022 for constellation, >2025 for Bravo

- Ørsted and CHAMP have shown a single satellite can monitor global SV
- But Swarm constellation allows improved modelling of several field sources, benefitting SV modelling
- Prolonging the mission is crucial, especially without a successor

Conclusions

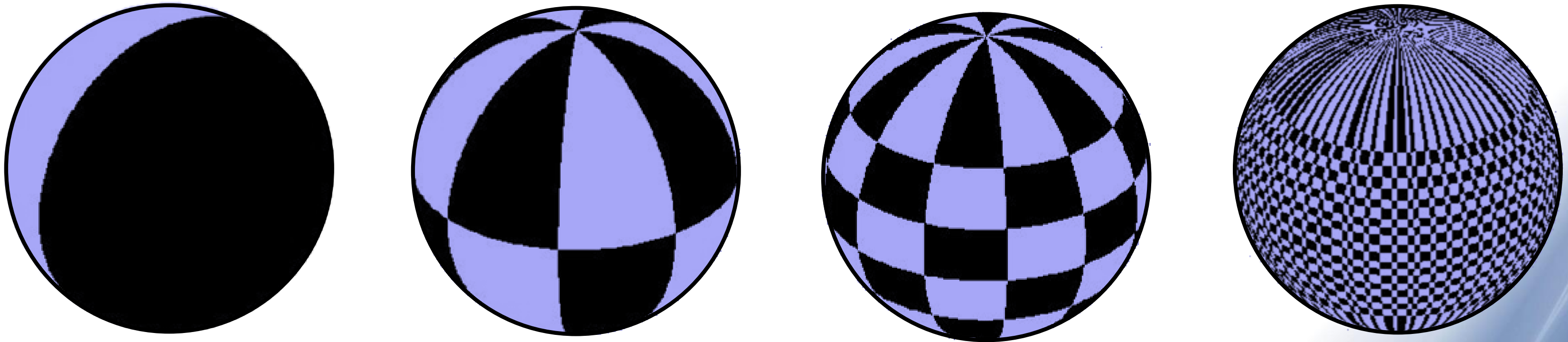
- SV is being effectively captured by Swarm – especially in conjunction with other data sources
- Recent SV not obviously different to past, but data and modelling are improving
- Challenge is improving our modelling techniques and physical understanding
- Global field models will continue to explore the potential of Swarm constellation data.

BGS MEME

Model of the Earth's Magnetic Environment

$$\boldsymbol{B} = \nabla V$$

$$V = a \sum_{n}^{N} \sum_{m}^{n} \left(\left(\frac{a}{r}\right)^{n+1} \left(g_n^m(t) \cos m\phi + h_n^m(t) \sin m\phi\right) \right.$$



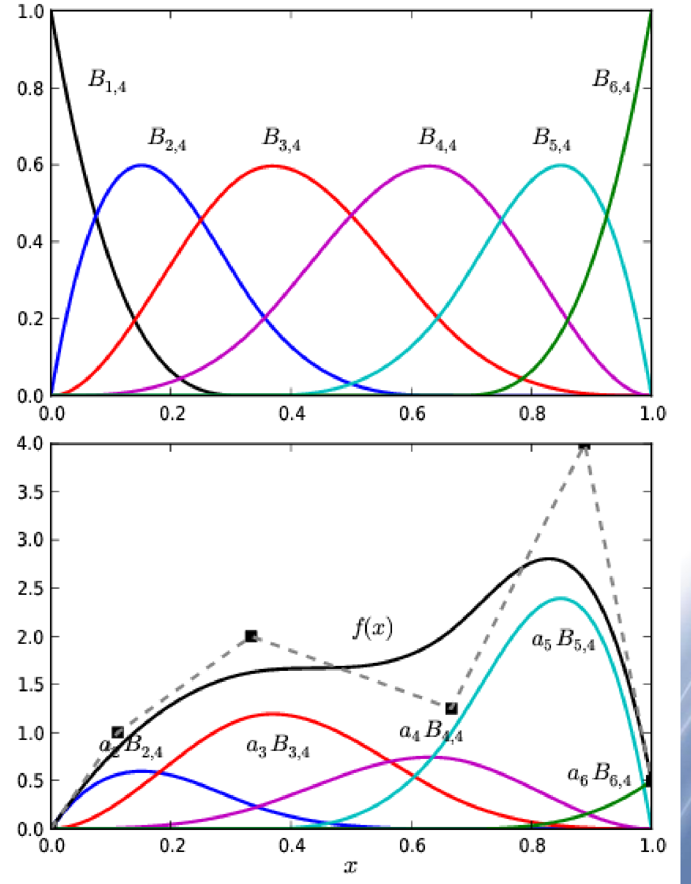
Increasing *n* and *m*

BGS MEME

Model of the Earth's Magnetic Environment

- Order 6 temporal spline n=15 core and n=1 magnetosphere
- Regularisation of 2nd and 3rd time derivative of B_r

- Vector Magnetic Disturbance parameterised n=1 internal and external field, 3 monthly
- Sun synchronous, annual- and semi-annual components
- High degree static lithospheric model



Foivos et al [2014], Mon.Not.Roy.Astron.Soc.