







Monitoring long-term field variations with Swarm data: Geomagnetic Virtual Observatories

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Probing Earth's core dynamics from Space

- Earth's magnetic field is generated by motions in the liquid metal outer core 'the geodynamo'
- Planetary-scale process, satellites give the necessary global data coverage
- *Swarm* trio has been carefully monitoring magnetic field changes for past 5 years
- Providing us with detailed information on time variations of the geodynamo







South Atlantic Anomaly, region of weak magnetic field 2014.5









South Atlantic Anomaly, region of weak magnetic field 2019.5









South Atlantic Anomaly, change over past 5 years



-500-400-300-200-100 0 100 200 300 400 500 nT





'Single event' electronic upsets detected by Swarm satellites





9th Swarm QWG



Data sources for geodynamo studies

- (i) Direct use of Swarm measurements
- But huge datasets, source separation
- (ii) Time-dependent SH models (e.g. CHAOS, GRIMM, COV-OBS, gufm1)
- V. useful, but difficult to obtain error estimates



- (iii) Times series of processed vector field at fixed locations, as long as possible
- But satellites are moving at 7 km/s !
 - -> construct geomagnetic 'virtual observatories' (GVO's) [Mandea and Olsen, 2006]





Monitoring field changes using space-based time series: Geomagnetic Virtual Observatories (GVOs)

- Take data within a cylinder around target point (e.g. 700km radius, 300 sites, 1 or 4 months windows)
- Robust fit to local Cartesian potential

$$V(x, y, z) = \nu_x x + \nu_y y + \nu_z z + \nu_{xx} x^2 + \nu_{yy} y^2 - (\nu_{xx} + \nu_{yy}) z^2 + 2\nu_{xy} xy + 2\nu_{xz} xz + 2\nu_{yz} yz - (\nu_{xyy} + \nu_{xzz}) x^3 + 3\nu_{xxx} x^2 y + 3\nu_{xxz} x^2 z + 3\nu_{xyy} xy^2 + 3\nu_{xzz} xz^2 + 6\nu_{xyz} - (\nu_{xxy} + \nu_{yzz}) y^3 + 3\nu_{yyz} y^2 z + 3\nu_{yzz} yz^2 - (\nu_{xxz} + \nu_{yyz}) z^3$$

- Evaluate field from this potential at target location
- Misfit provides useful variances for resulting estimates





Observed global rate of change of radial field 2014-2019







RMS misfit of GVOs to swarm data: radial field, 2014-2019







RMS misfit of GVOs to swarm data: southward field, 2014-2019







Swarm DISC GVO project

- Partners: **DTU, BGS**, release date June 2020
- 2 time resolutions: **1 month**, **4 month**
- 300 sites, equal area distributed: observed field, core field, and core field SV
- Error estimates: misfit to *Swarm* data, comparisons with other field models
- Validation against ground observatories → assessment of fidelity of satellite SV
- Aim: operational production of GVO series as a new long-term L2 data product





Example: Changes in field intensity seen by GVO series







Example: Changes in field intensity seen by GVO series







Comparison with selected ground observatories









Summary

- Latest data from the *Swarm* satellites shows magnetic field is continuing to weaken in the south Atlantic region
- Rapid field weakening is now occurring in western South America
- And also south-west of Africa, where a second minimum in the field intensity is becoming increasingly prominent
- Satellite-based times series at fixed locations ('geomagnetic virtual observatories') are a suitable means of globally tracking long-term field changes









South Atlantic Anomaly, percentage changes



