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Rapid core field variations during the satellite era: Investigations using stochastic process based field models

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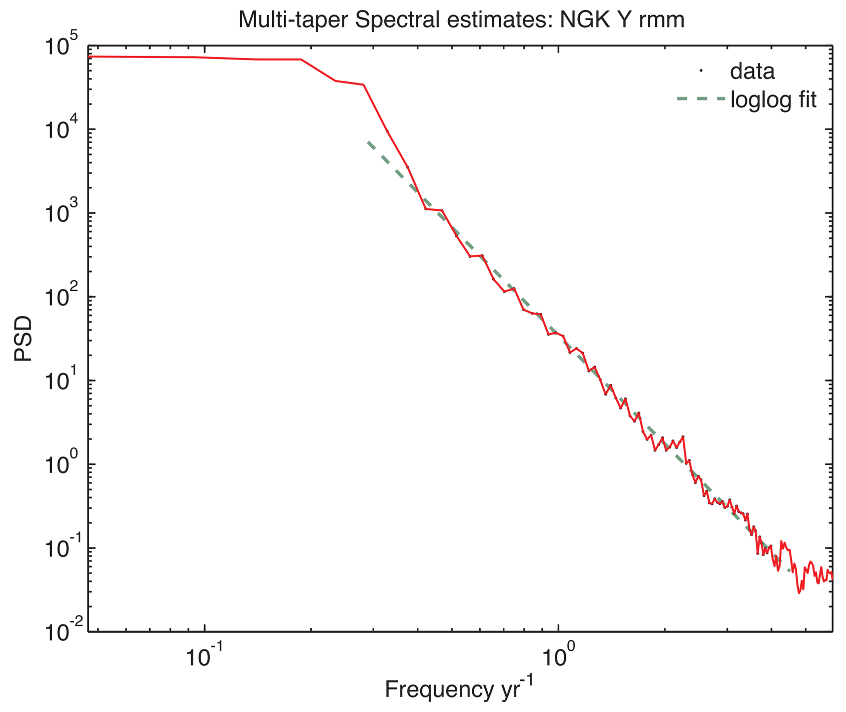
Introduction

We present an **ensemble of time-dependent geomagnetic magnetic field models**, constructed from satellite and observatory data spanning **1997.0 to 2013.7**. These models are compatible with the observed temporal spectrum of core field variations and allow sharper field changes than conventional models that penalize the second time derivative of the field. We directly invert satellite (Ørsted, CHAMP and SAC-C) and ground observatory data, co-estimating the crustal field, the external field, and Euler angles, **using the CHAOS field modelling methodology** (Olsen et al., 2006; 2013). But for the time variations of the core field we instead adopt the **stochastic process modelling technique** of Gillet et al. (2013) and obtain an ensemble of field models statistically compatible with the observations. From a Bayesian perspective, **questions of physical relevance should be asked of the entire ensemble of models** that describe the relevant probability density function, rather than of any individual model.

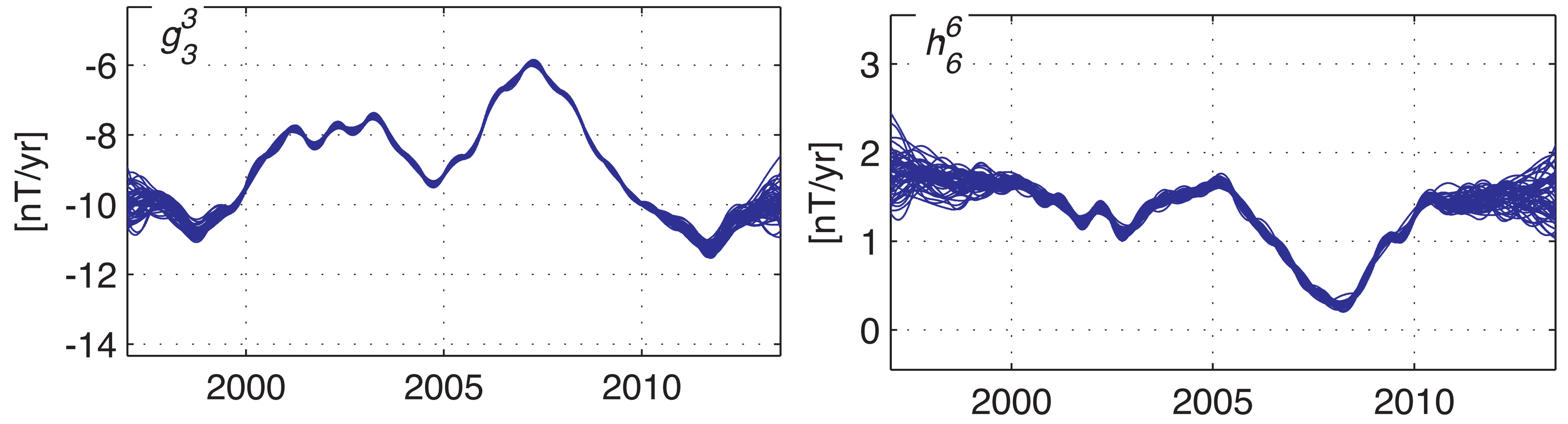
- Prior information on core field variations: Geomagnetic series recorded in ground observatories show PSD of the form $P(f) \propto f^{-4}$ for annual to decadal timescales.
- AR-2 stochastic process: temporal correlation function also possesses spectral slope of f^{-4}: use this to build the a-prior model covariance matrix.
- Adopt characteristic correlation times for each SH degree from the ratio of MF and SV spatial power spectra, derived from satellite observations.



Above: Power spectrum from 16 yrs Niemegk Y robust monthly means, derived after Sq and Dst removed. Slope is -4.3 between 8 and 0.6 yrs.

An ensemble of core field models

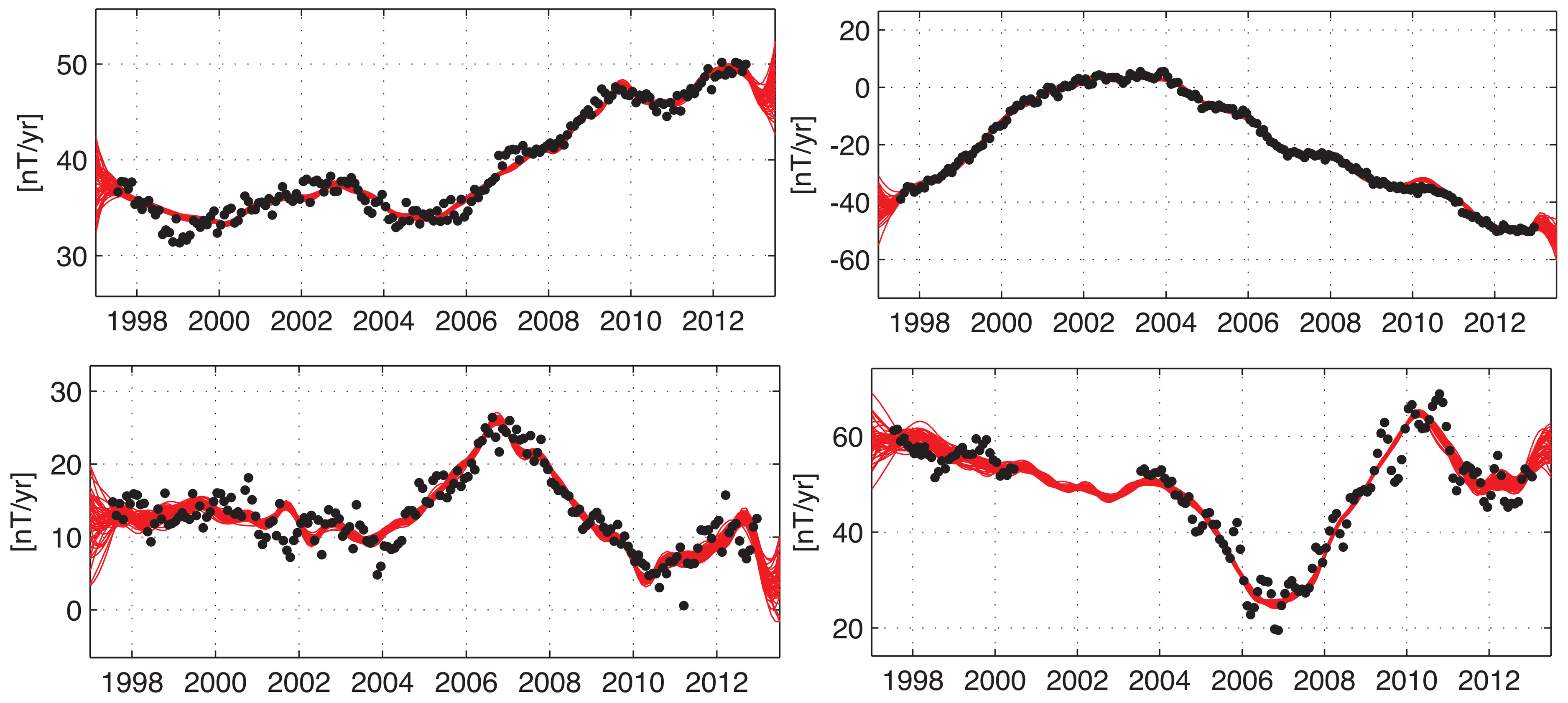
- Time-dependent core field up to degree 20, cubic splines with 0.5 yr knot spacing.
- AR-2 prior time correlation (spectral slope -4), rather than d^2/dt^2 smoothing.
- Crustal field to degree 80; External field to degree 2.



Above: Evolution of rate of change of coefficients $d/dt(g_3^3)$ (left) and $d/dt(h_6^6)$ (right); 50 models shown.

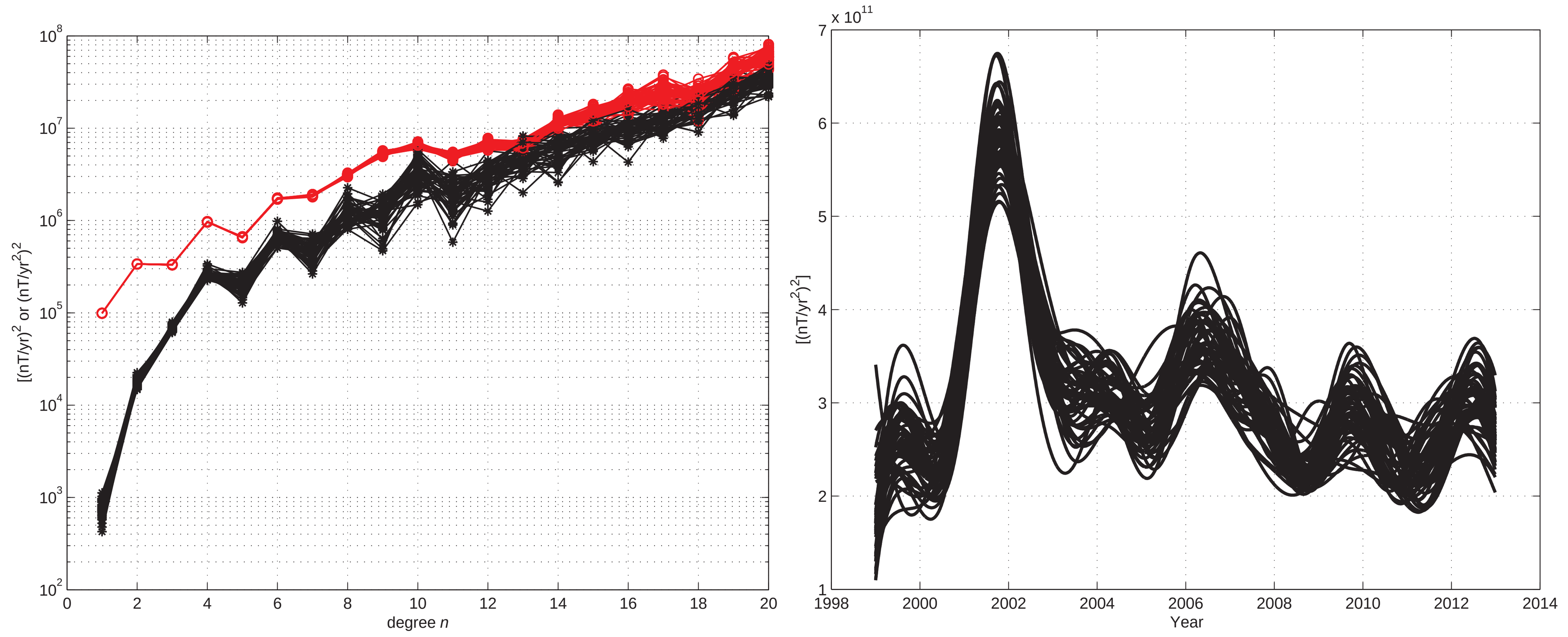
- Ensemble spread larger after September 2010 when no longer have CHAMP data.

Recent rapid secular variation events



Above: Fit of 50 models from ensemble to annual differences of monthly means at ground observatories. Top left: dB_ϕ/dt) from Niemegk, Germany. Top right: dB_r/dt from Kakioka, Japan. Bottom left: dB_θ/dt from Hermanus, South Africa. Bottom right: dB_ϕ/dt) from Ascension Island.

- Rapid secular variation is well captured by the ensemble of core field models.
- Most prominent recent changes in west Africa and Atlantic sector (Chulliat et al., 2010).



Above left: SV and SA spatial power spectra at CMB for 50 ensemble members. Above right: SA norms for 50 ensemble members, summed to degree 8 at the CMB, spline fit using annual knots.

- Maxima of secular acceleration (SA) occur in 2001/2002, 2006/2007 and 2009/2010.

References

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Friis-Christensen E. and Wilhjelm, J. Polar Cap Currents for Different Directions of the Interplanetary Magnetic Field in the Y-Z Plane, *J.* Geophys. Res., *80*, 1248–1260, 1975.
Gillet. N. et al., Stochastic modeling of the Earth's magnetic field: Inversion for covariances over the observatory era, *Geochem.* Geophys. Geosys., *14*, 766–786, 2013.
Olsen, N. et al., CHAOS - a model of the Earth's magnetic field derived from CHAMP, Ørsted, and SAC-C magnetic satellite data, Geophys. J. Int, *166*, 67–75, 2006.
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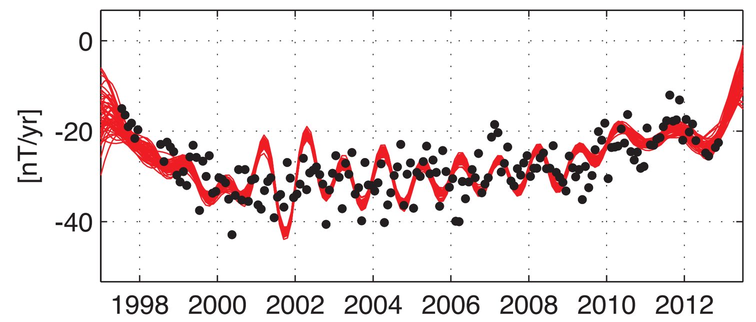
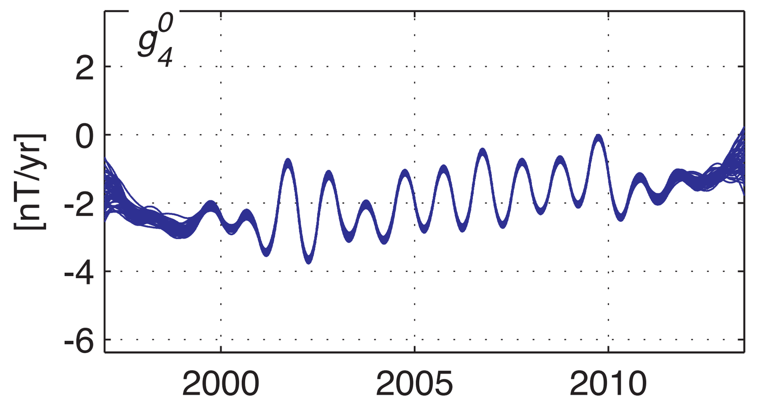
A problem: coherent Ionospheric signal at polar latitudes

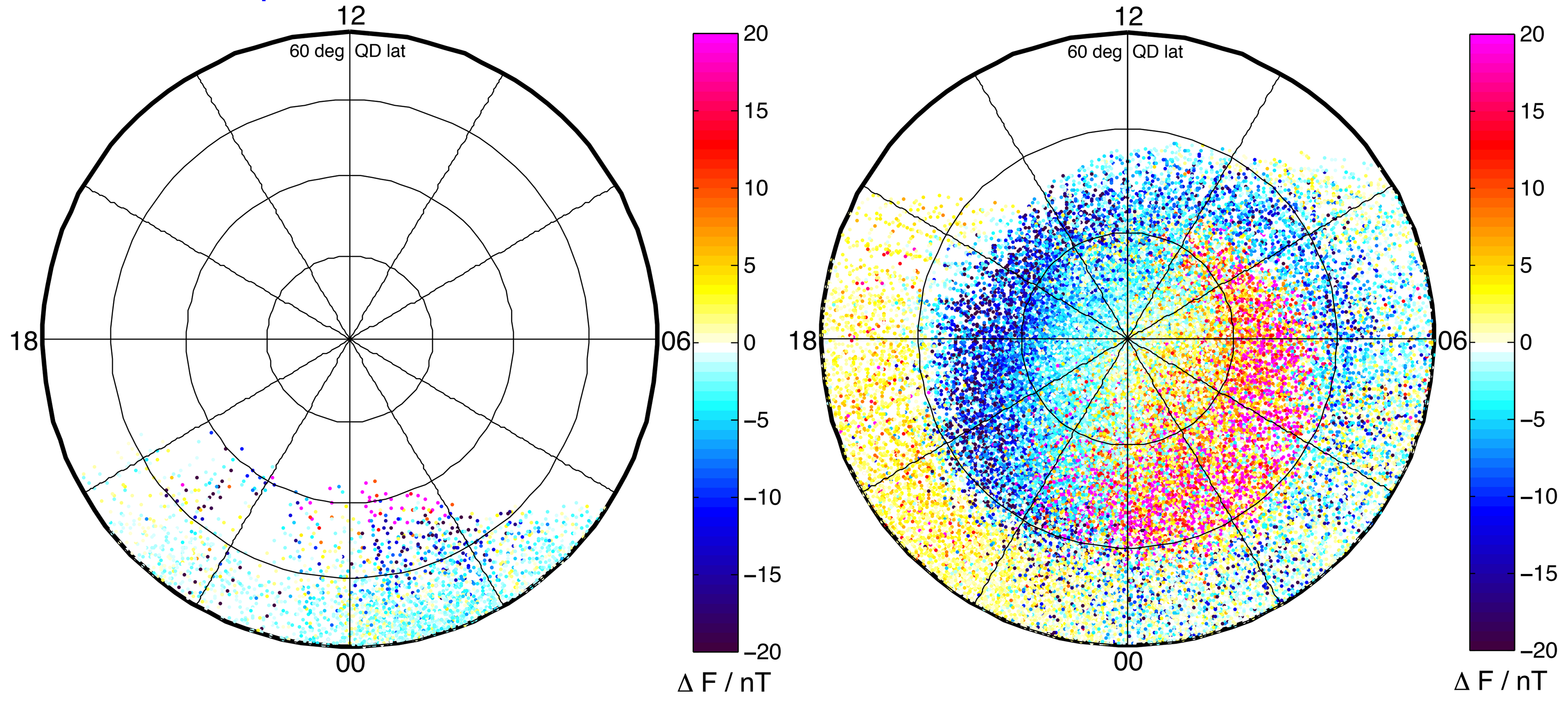
- Further interpretation is hampered by the presence of annual oscillations coherent in all ensemble members.
- Amplitude increases towards auroral latitudes and is strongest when solar activity is strongest e.g. 2002/2003.
- Most obvious in the core field when CHAMP data are available.
- Residuals (CHAMP scalar data - CHAOS-4 model) show coherent structure in QD latitude vs MLT co-ordinate system.
- Associated with the westward and eastward polar electrojet currents respectively at dawn and dusk (e.g. Friis-Christensen and Wilhjem, 1975).
- Correlated field internal to satellites in winter hemisphere while data absent in summer hemisphere $-->$ annual oscillation.



Above: Annual oscillations of all ensemble members as auroral latitudes approached. e.g.dB_r/dt at Macquarie Island, Aust.



Above: This oscillation is clearly evident in zonal coefficients e.g. $d/dt(g_4^0)$.



Above: Scalar field residual between CHAMP data (2008-2010) and the CHAOS-4 field model, at high latitudes in the northern hemisphere. Plotted in a magnetic latitude / local time frame, for summer (left) and winter (right).

Conclusions

- We derived a new ensemble of core field models spanning 1997.0 to 2013.7.
- These capture rapid SV events and highlight the impact of changing data sources.
- But we also obtain spurious annual fluctuations of the core field model.
- Due to unmodelled coherent signals e.g. polar electrojet seen in scalar data.
- Correlated errors need to be explicitly accounted for in future inversions if we are to fully exploit *Swarm* data for study of rapid core dynamics.

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