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Modelling the quiet-time geomagnetic daily variations using observatory data

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Abstract

We present on-going work towards building a global model of the quiet-time geomagnetic daily variation using observatory data. We select hourly mean data during June 2006 (solar minimum). We fit Fourier series in time, with a fundamental period of 24 hours, to the data at each observatory. We then use global spherical harmonic expansions to separate the daily variation signal, as characterised by the Fourier coefficients in time, into external and induced internal contributions. The models are assessed by comparison with the input data and with Campbell's Sq model. The robustness of the separation of the field into external and induced internal sources is discussed.

Introduction

The daily variations in the Earth's geomagnetic field are caused by (primarily) ionospheric as well as magnetospheric currents. Ionospheric current vortices in northern and southern hemispheres arise from interaction of free charges (produced by solar EUV and SXR) with thermospheric winds. Current systems remain on sunlit side of Earth and cause regular daily variations in geomagnetic field as observatories rotate beneath. Daily variations depend on solar illumination and so also on: latitude, season, and the ~11 year solar cycle. Quiet-time daily variations are of interest because they are the most significant regular signal. Also, an observatory-only Sq model could be useful for Swarm Level 2 product validation

Method

•Select hourly mean values of X, Y and Z components from 5 quietest days in June 2006 (solar minimum) for 110 observatories.

•Fit Fourier series with fundamental period of 24 hours to X, Y and Z hourly mean data at each observatory, e.g.:

$$B_X = a_{0,X} + \sum_{k=1}^{4} a_{k,X}\cos\left(\frac{2\pi t}{kT}\right) + b_{k,X}\sin\left(\frac{2\pi t}{kT}\right)$$

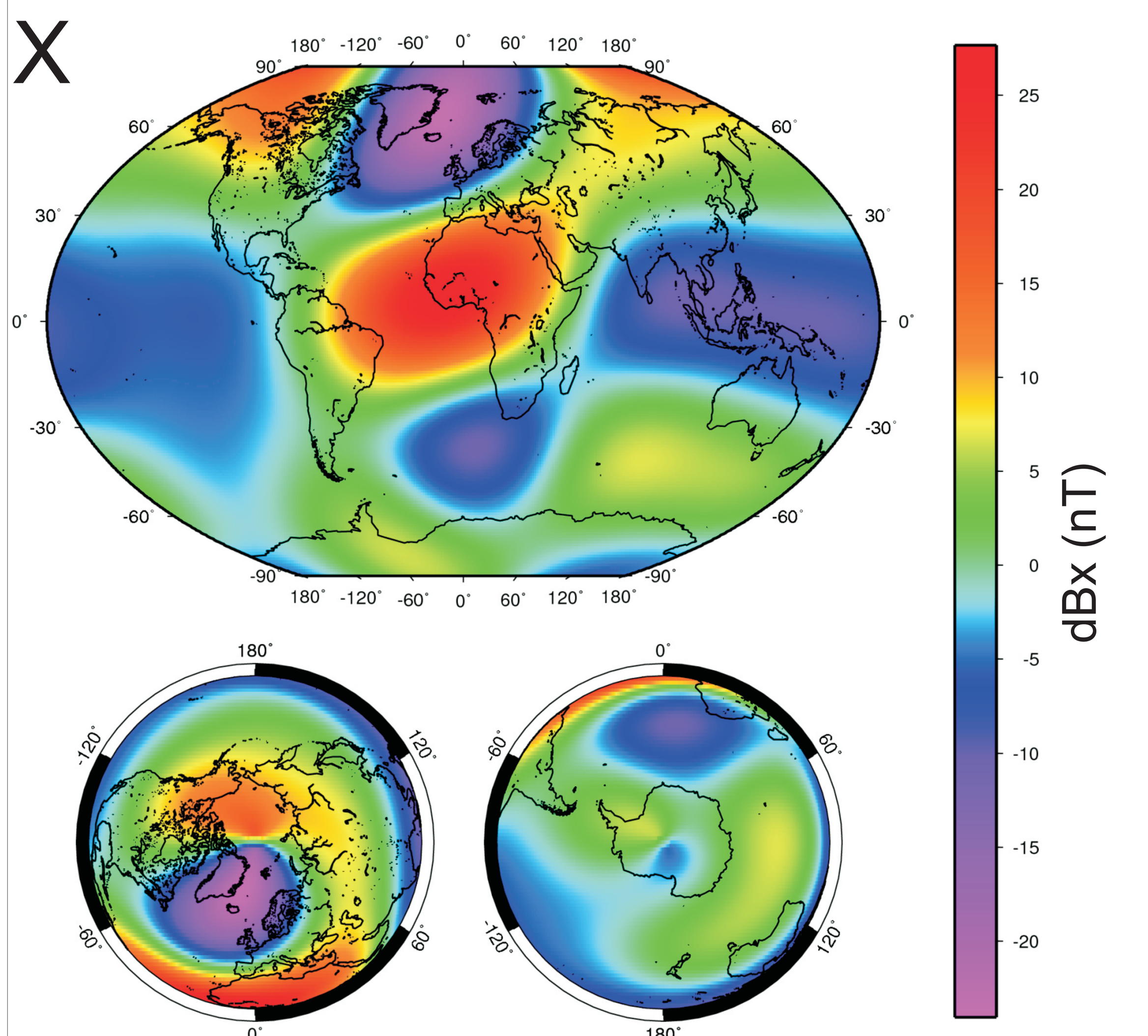
•Form input vector data for spherical harmonic model from Fourier coefficients (**B**$_{a1}$, **B**$_{b1}$, **B**$_{a2}$, etc) e.g.:

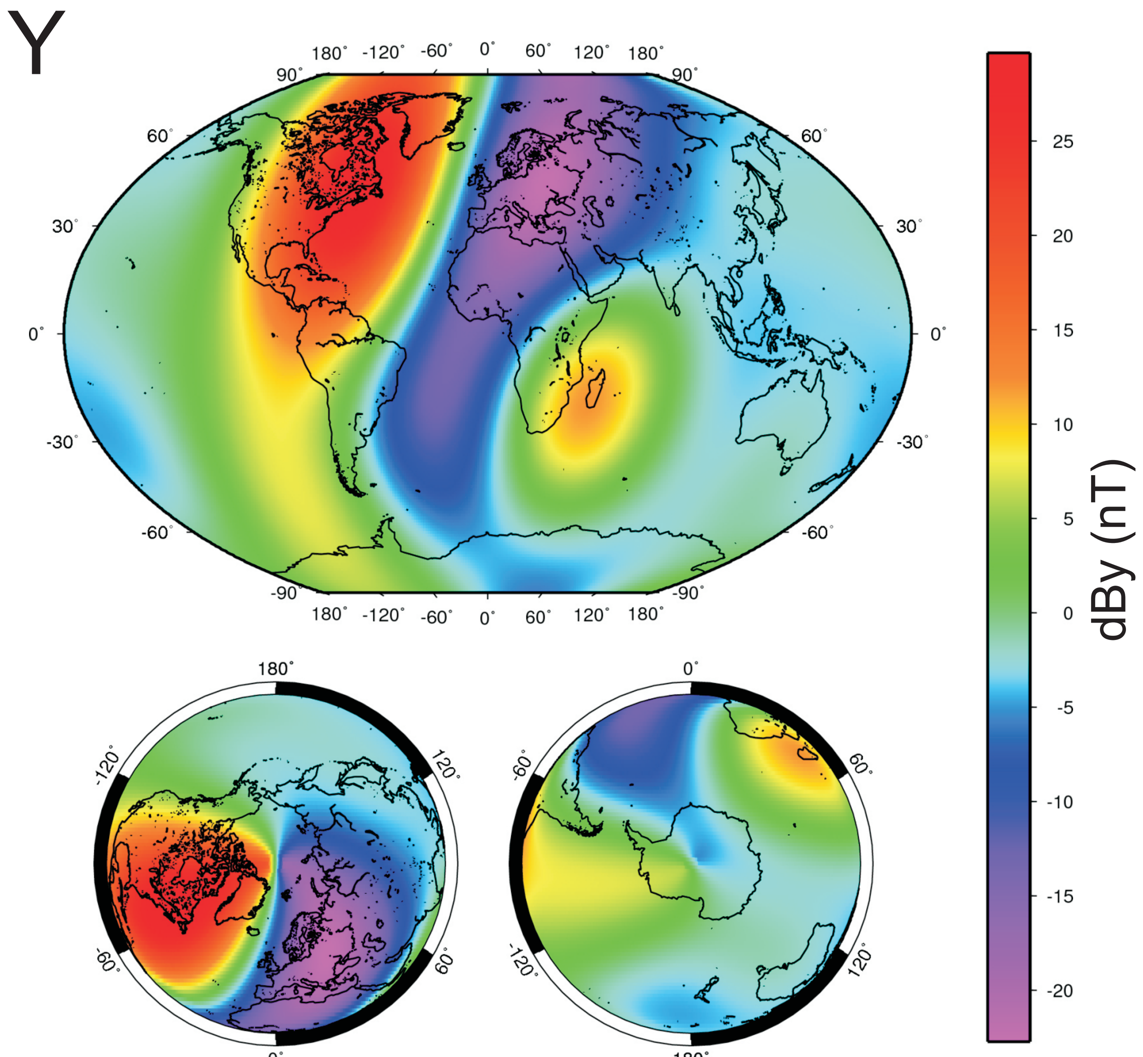
$$\vec{B}_{a1} = a_{1,X}\hat{X} + a_{1,Y}\hat{Y} + a_{1,Z}\hat{Z}$$

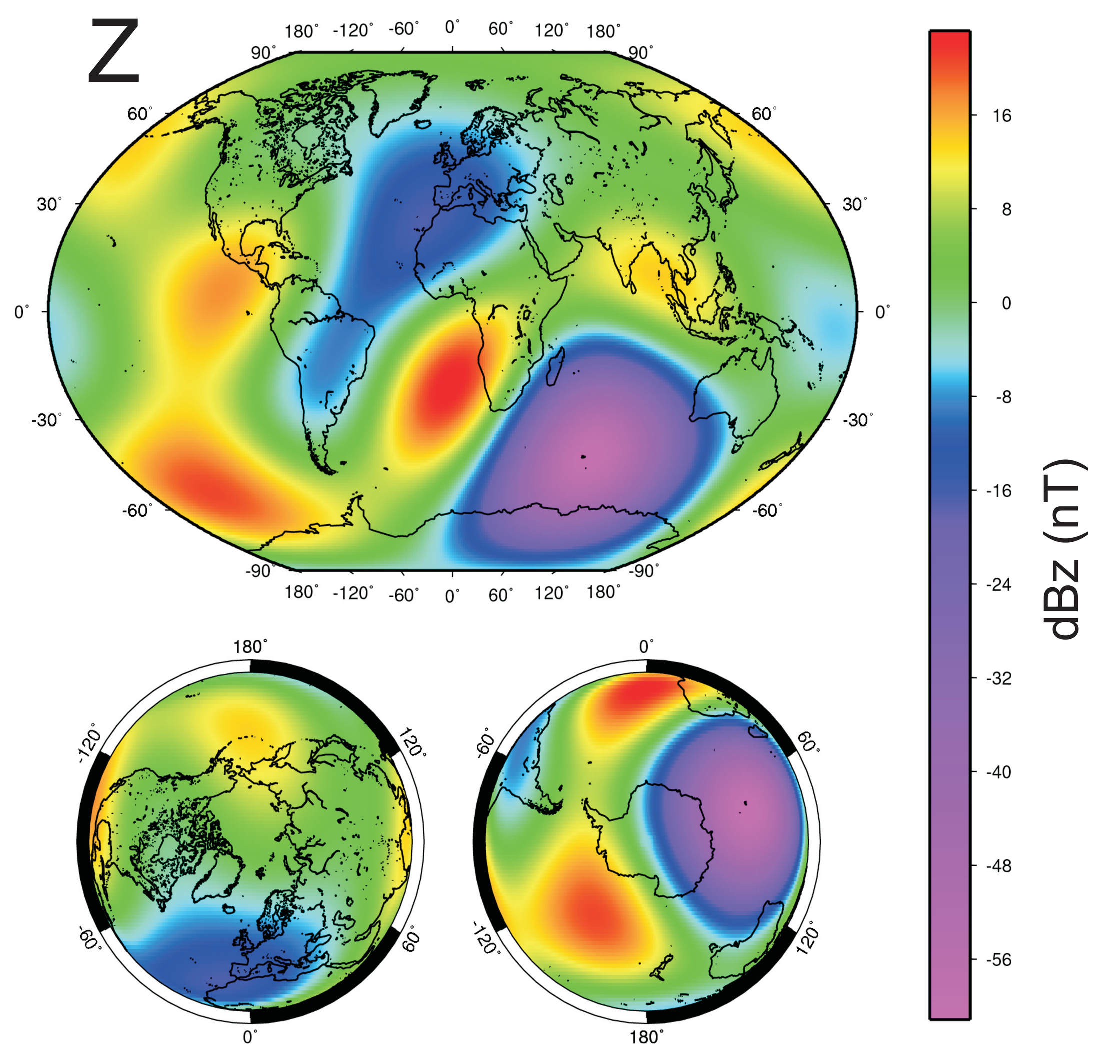
•Fit degree 4 spherical harmonic models with external$^{(e)}$ and (induced) internal$^{(i)}$ terms to each vector field, e.g.:

$$V_{a1}(r,\theta,\phi) = a\sum_{n=1}^{4}\sum_{m=0}^{n}\left[\left(A_{a1,n}^{m,i}\left(\frac{a}{r}\right)^{n+1} + A_{a1,n}^{m,e}\left(\frac{r}{a}\right)^{n}\right)\cos m\phi + \left(B_{a1,n}^{m,i}\left(\frac{a}{r}\right)^{n+1} + B_{a1,n}^{m,e}\left(\frac{r}{a}\right)^{n}\right)\sin m\phi\right]P_n^m(\theta)$$

Model output for daily geomagnetic variation about 24-hour mean at 12UT in June, 2006

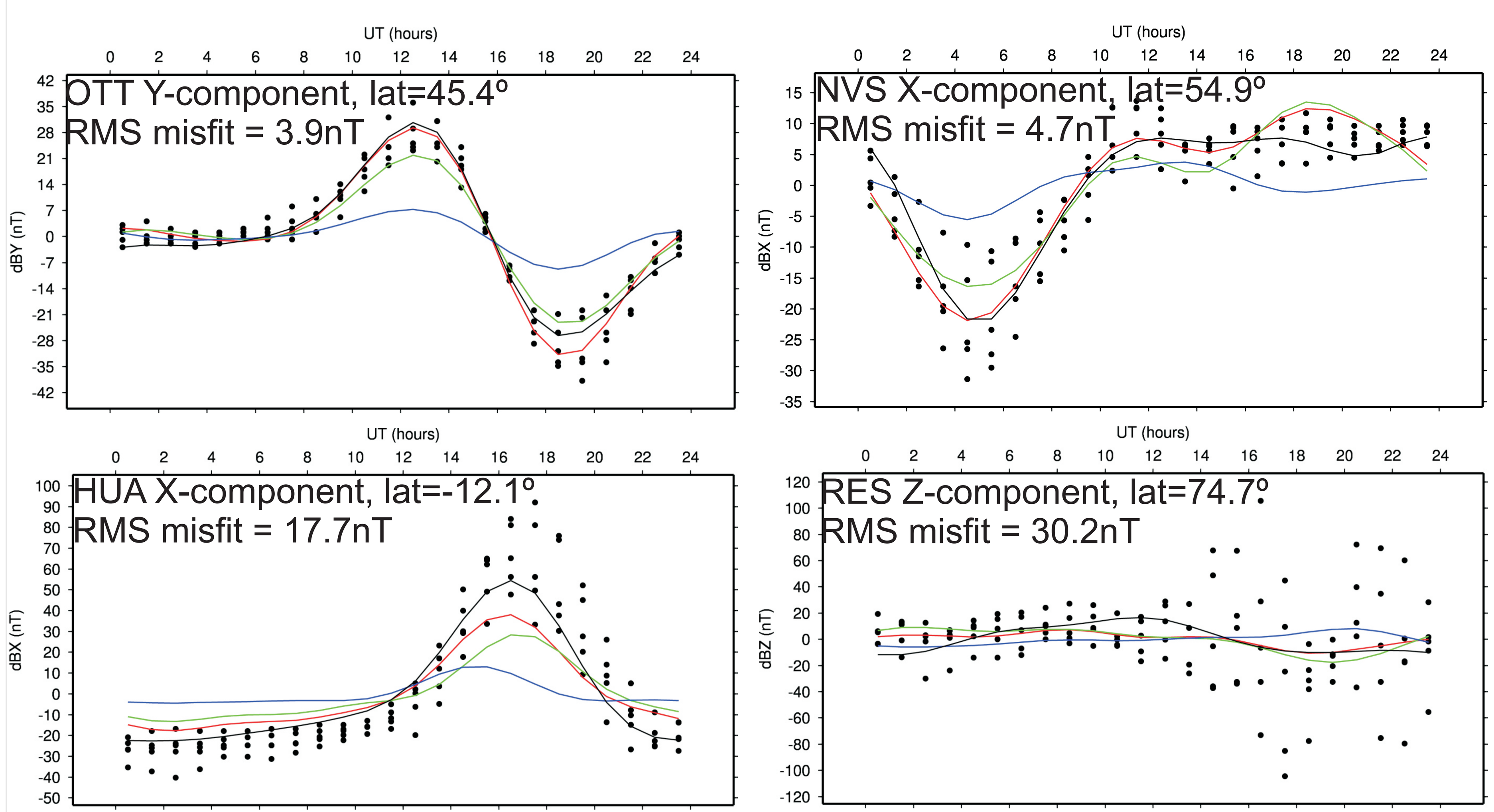






SH model output for selected observatories

Sample graphs show below: hourly means from 5 quietest days (dots); total-, internal-, external-signals from SH model; and Campbell's Sq model (black line). Examples are for observatories at mid-latitudes (OTT, NVS) where the model performs well, and at low-latitudes (HUA) and polar latitudes (RES) where model performs poorly.

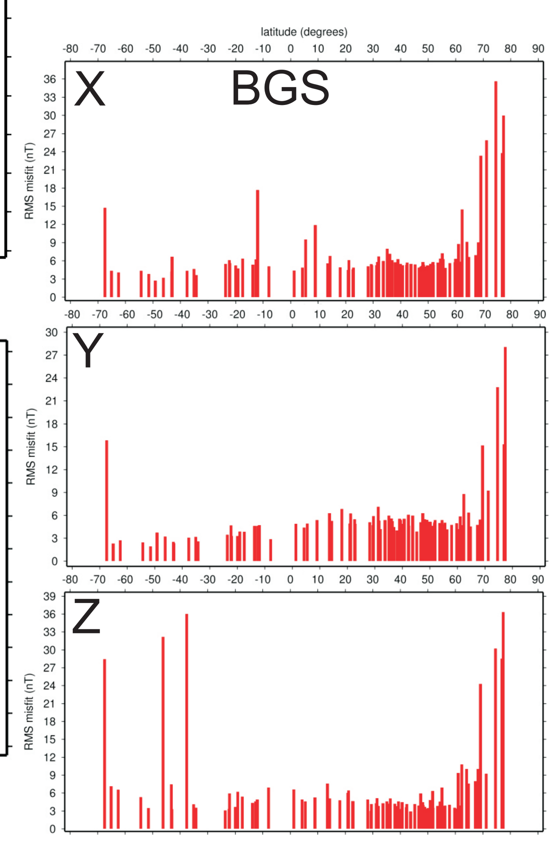


External/internal separation

Ratio external/induced internal shown in Table below. Physics suggest ratio > 1 (Olsen, 1993, 2005) but results here are mixed. Separation not robust.

n	1	1	2	2	2	3	3	3	3	4	4	4	4	4
m	**0**	**1**	**0**	**1**	**2**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**4**
a1	0.4	2.0	0.4	2.9	3.4	1.9	2.6	0.8	2.1	0.8	1.5	0.8	1.2	0.1
b1	8.3	7.2	1.9	1.6	2.0	3.0	4.4	2.2	0.7	5.7	2.7	2.4	4.9	1.3
a2	2.5	2.8	11.7	0.4	2.8	1.5	1.1	7.1	1.9	1.9	0.6	0.4	0.6	5.6
b2	7.4	1.9	0.1	1.1	3.4	1.1	1.4	1.9	1.7	1.3	0.4	1.2	1.4	0.5
a3	5.5	1.4	1.9	0.6	3.2	10.3	1.7	1.6	3.1	0.2	2.4	0.5	2.8	3.5
b3	0.2	1.4	0.6	0.6	1.5	25.9	0.8	1.5	6.0	0.9	1.1	1.0	1.1	0.5
a4	1.2	0.6	0.0	0.6	2.0	1.0	0.6	1.8	0.7	1.5	0.1	2.2	1.0	2.2
b4	17.1	1.3	4.0	2.0	1.9	0.2	0.1	4.8	1.6	55.0	1.0	1.9	1.9	1.5

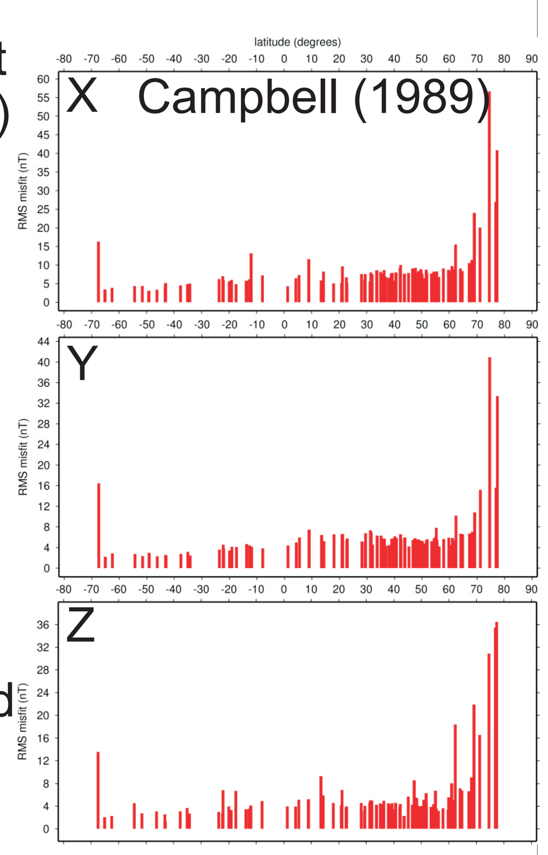
RMS differences vs latitude



Plots of differences between input data to BGS model and BGS (left) and Campbell (right).

BGS differences lowest for mid-latitudes, worst for polar latitudes. Differences also increase around equator, particularly for X-component, due to electrojet.

BGS and Campbell (1989) comparable although latter has fewer problems with electrojet and poor coverage (e.g. southern Indian Ocean in Z)



Conclusion

•Model output is consistent with Sq current system, particularly in northern hemisphere

•Daily variation in polar regions and around dip equator not well modelled

•At mid-latitudes results consistent with Campbell's Sq model

•Some issues to resolve re: separation

Future work

•Weighting data according to success of Fourier model when fitting spherical harmonic model

•Use 1-D conductivity model, as in e.g. Olsen et al. (2005), Thomson &Lesur (2007), to improve separation

•Produce something at least as good as Campbell's Sq model for use in Swarm Level 2 product validation

References & acknowledgements

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