Data Selection Techniques for Non-Comprehensive Global Geomagnetic Field Models

Alan Thomson and Vincent Lesur
British Geological Survey, West Mains Road, Edinburgh EH9 3LA, UK

The geomagnetic field contains contributions from various time-varying, spatially complex, sources external to the solid Earth. Non-comprehensive geomagnetic field models may fail to reflect the characteristics of these sources and lead to inaccurate internal field models, with consequences for interpretation of Earth structure and internal dynamics. Furthermore data from satellites in low Earth orbit may be obtained in the source regions of some fields and may therefore be improperly modeled using standard potential field techniques.

Appropriate satellite data selection, to minimize the contribution of external sources, is one way of reducing the un-modeled external field 'noise' in internal field models. This has been historically a common approach to modeling, where all the sources are not explicitly modeled, and is achieved by selecting satellite data with reference to regional or global geomagnetic indices and during local nighttime.

In this paper we examine whether this approach still has value in the modern era and we test this by producing high degree (up to spherical harmonic degree 60) global field models from Orsted and Champ satellite data. These models have both internal and external field components but do not, for example, model the ionosphere. We compare these global models with comprehensive models produced by other authors and also by reference to known crustal structures.

We find that high latitude indices are useful but that the Dst index is unreliable, although the time rate of change of Dt is helpful. However such a data selection procedure inevitably leaves 'holes' in the spatial distribution of the satellite data. We therefore describe a re-selection technique, which fills these holes with slightly noisier data, and yet results in models with lower overall rms misfit. We show that there are still problems with the crustal field model for the Polar Regions and that further work on refining polar cap and auroral oval indices is therefore suggested. However the degree of agreement with the crustal model components of the (more) comprehensive models is encouraging. Future work will address the differences, by adding to model complexity and by further refining the data selection techniques.

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Project Goals

Re-investigate the use of various magnetic indices for data selection
- low (Dst), mid (Kp) latitudes, polar caps (PC), auroral electrojet (IE).

Re-examine value of other "common" filters for satellite data
- e.g. vector latitude cut-offs, local time, solar zenith angle.

Improve geographical and temporal data distribution
- iterative data re-selection technique using 1-degree tesserae.

Examine spherical harmonic degree spectral power & make inter-model comparisons
- noise, smoothness, coherency

Data

Model A: Orsted and Champ data for 2001.0-2002.5
Model B: Orsted and Champ data for 2000.0-2004.0
(good geographical and temporal distribution of vector and scalar data)

Parameterisation

n=40 internal model, linear SV to n=16
n=2 external model,
annual and semi-annual terms,
Dste and Dsti dependence of external and internal field
n=1 variations
IMF By dependence modelled in GEI frame
weighting to equalise data in equal area tesserae; L1/L2 norm
no damping/regularisation

Data Selection Options: *What Works?*

Bad: X
- Don't use Dst
- Don't use dBy/dt (a FAC proxy: J_{FAC}=0.106*dBy/dt e.g. Stauning *et al*)
- Don't use very restrictive index filters (e.g. Kp<1)

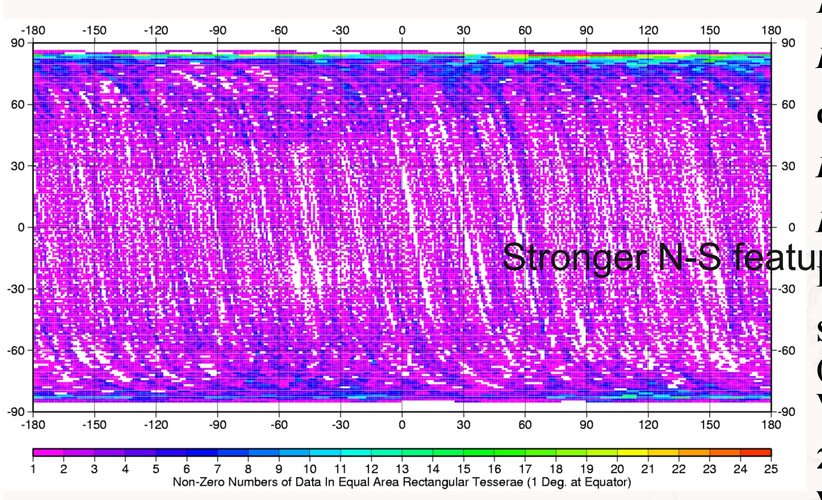
Neutral: O
- Reduce maximum vector latitude below 50 degree geomagnetic
- Zenith angle filter ON for low and middle latitudes
- Projected-F (i.e. linear inverse problem), rather than $|B|$
- Small changes in any residual ref model (e.g. IGRF+δg_n^m)

Good: ✓
- dDst/dt
- Vector data < 50 deg geomagn
- IE and PC indices for auroral and polar latitudes
- Zenith angle ON and LT filter OFF for high latitudes
- Kp and dDst/dt at low/mid lats.
- L1 (Laplacian) residual norm
- Filter vector data using "pre-model"
- Iterative data selection

First pass data (left) leaves holes in coverage. Second pass data (center) fills in holes.

L1 model obtained by initially setting degrees >40 to zero then releasing constraint. Model B: 4 years data.

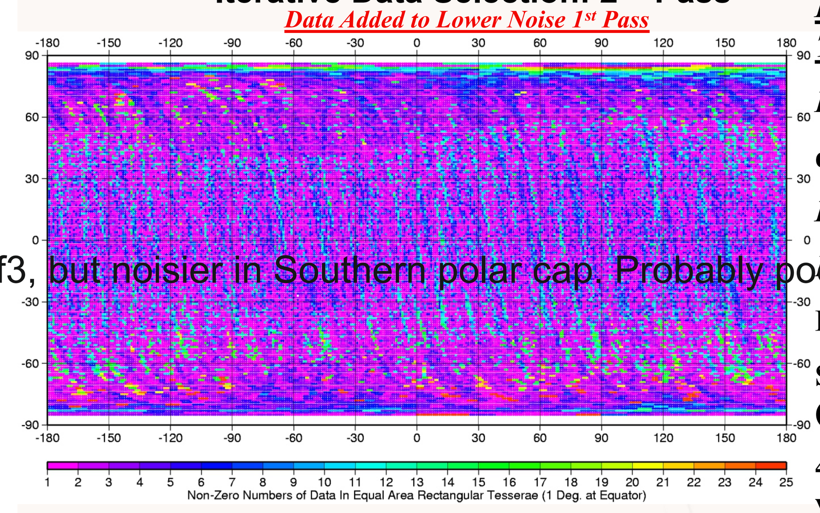
Iterative Data Selection: 1st Pass



Typical Filtering
- Kp (<1+)
- dDst/dt (<5)
- IE (<30)
- PC (<0.2)
- LT/Zenith
- Solar Wind (0<Bz<6; V_{SW}<450)
- 2-sigma vector resids

Iterative Data Selection: 2nd Pass

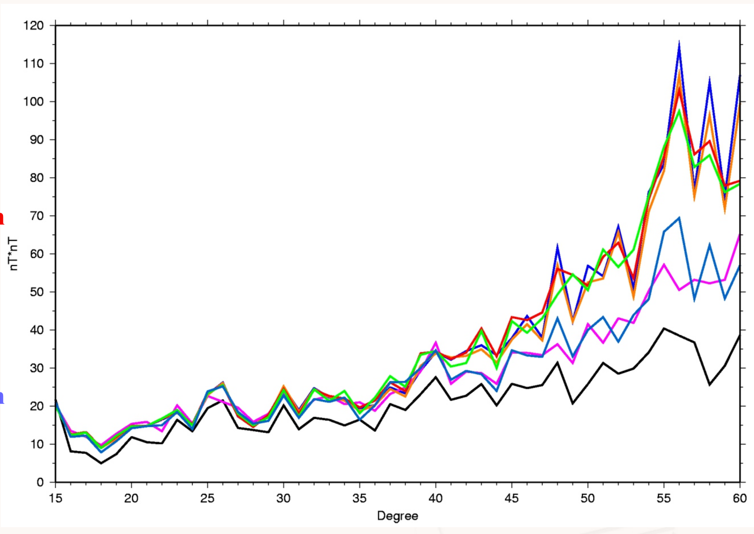
Data Added to Lower Noise 1st Pass



Only in Empty Tesserae
- Kp (<2+)
- dDst/dt (<20)
- IE (<100)
- PC (<1)
- LT/Zenith
- Solar Wind (|B|<10)
- 4-sigma vector resids

CM4 MF3

- L2 Norm, 5 years Satellite and Observatory Data
- L2 Norm, 5 years Satellite Data Only
- L2 Norm + 5x zenith angle weight
- L2 Norm + 5x zenith angle weight + Dste/Dsti (Maus)
- L1 Norm + 5x zenith angle weight + Dste/Dsti (Maus)
- 'Model B'



Stronger N-S features, compared to Mf3, but noisier in Southern polar cap. Probably poorer PC index selection.

Crustal Magnetic Field

'Model B' Vertical Field
SH Degree 16-60

400km Altitude

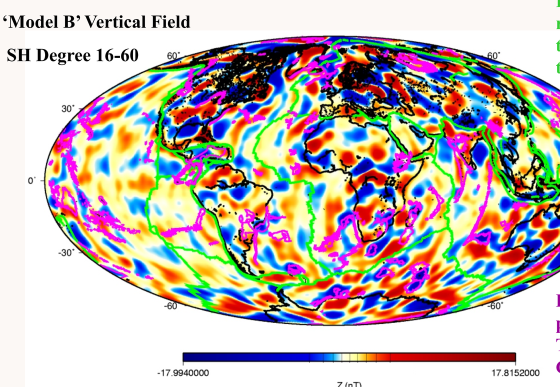
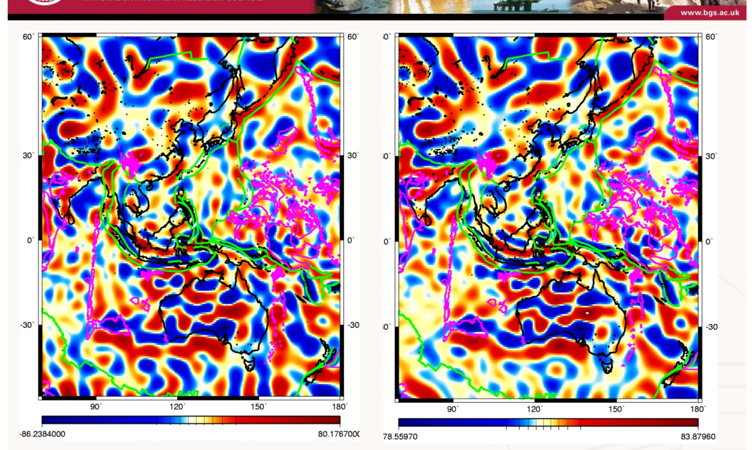
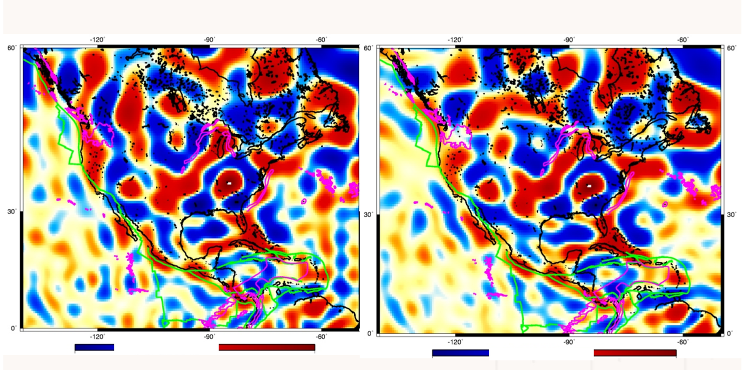


Plate spreading ridges, subduction trenches and transforms

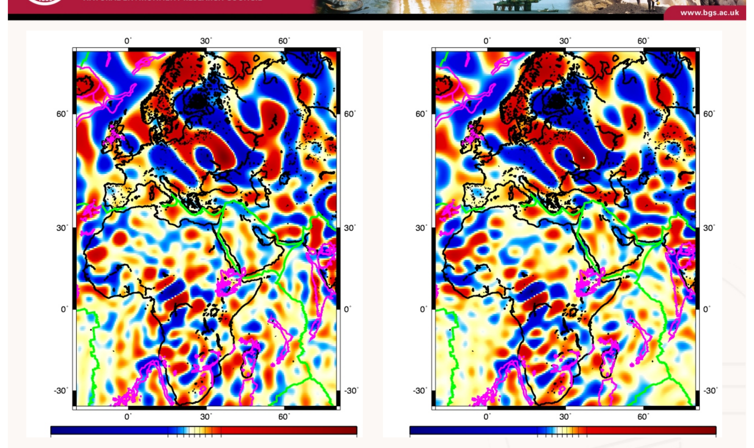
Large igneous provinces (U. of Texas, Inst. For Geophys.)



East Asia: Vertical Field at 50km altitude: Degree 16 -60. Left: 'Model B'. Right: 'MF3'



North&Central America: Z Field at 50km; Degree 16-60, Left: 'Model B', Right: 'MF3'



Europe & Africa: Vertical Field at 50km: Degree 16 -60. Left: 'Model B'. Right: 'MF3'

Conclusions

It is possible to improve existing internal field models using:

Appropriate indices for data selection at particular latitudes: don't use 'wrong' index for 'wrong' region; avoid Dst, use dDst/dt

Simple filters – local time, solar zenith angle, 2sigma w.r.t. unsophisticated pre-model

-> *Relatively uncomplicated external field model, e.g. no ionosphere model*

New things:

Iterative data selection, to fill in 'holes' in coverage, is particularly relevant for models of higher spherical harmonic degree ("better to have noisier data than none")

-> *Can do all this with automated processing, no need for 'checking satellite tracks, data one by one'*

…Next…

Data weighting

A priori weighting of un-modelled external fields (e.g. Tsyganenko 2004)?

New Indices/Data

Wider Auroral Zone Monitor; Canadian 'Canopus' Array?
Improved ring current proxy (Dst) – Dst is not reliable
Use observatory data directly in place of indices ?; INTERMAGNET
Problems in southern polar cap with PC

Model Parameterisation

Particularly the external field – more sources included explicitly

Collaboration

Working within the UK 'Geospace' consortium: University of Liverpool & RAL