# MEME08: A Global Magnetic Field Model with Satellite Data Weighting

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A new data weighting scheme is introduced for satellite geomagnetic survey data. This scheme allows vector samples of the field to be used at all magnetic latitudes and results in an improved lithospheric model, particularly in the auroral regions.

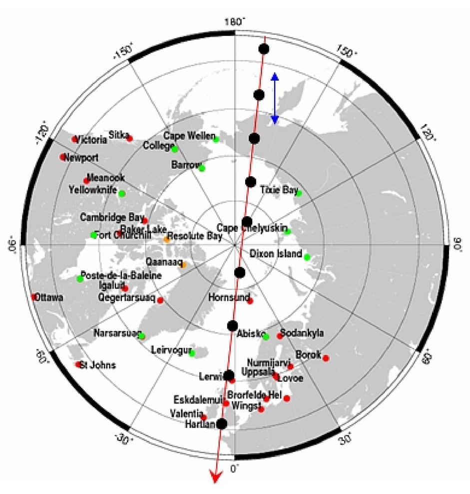
Data weights for 20-second spaced satellite samples are derived from two noise estimators for the sample. Firstly the standard deviation along the 20 seconds of satellite track, centred on each sample, is computed as a measure of local magnetic activity. Secondly a larger-scale noise estimator is defined in terms of a 'local area vector activity' (LAVA) index for the sample. This is derived from activity estimated from the geographically nearest magnetic observatories to the sample point.

Weighting of satellite data by the inverse-sum-of-squares of these noise estimators leads to a robust model of the field (called 'Model of Earth's Magnetic Environment 2008, or 'MEME08' - to rhyme with 'beam') to about spherical harmonic degree 60. In particular we find that vector data may be used at all latitudes and that there is no need to use particularly complex model parameterizations, regularisation, or prior data correction to remove estimates of un-modelled source fields.

## 1. Introduction & Data

We use the same data filters as Thomson & Lesur (TL, 2007) and a similar parameterisation, e.g. a yearly, piece-wise linear secular variation and a *VMD* index dependence of external terms. We also use the '2-pass' data approach of TL but we have extended the satellite data set of TL in the following way:
(i) CHAMP & Ørsted vector and scalar data were used for 1999-2007 inclusive (previously 2001-2004);
(ii) Scalar data were used only where no vector sample was available;
(iii) CHAMP data were used at calibration level version 50, downloaded in early 2008;
(iv) Quiet, night-time (2300 - 0500 UT) hourly means from WDC observatories were used.
Unlike TL, the second pass data were given a relative weight of 0.2, as compared to the first pass data. This best-fit weight was determined by examining the misfit of model to the combined first and second pass data set as the weight was varied between zero and one. In terms of parameterisation, we have modified the model of TL by limiting the linear time dependence of the internal field to degree 13. However we extended the lithospheric component initially to degree 100, thereby spreading noise and un-modelled small-scale sources across a wider bandwidth. We truncate our final model (MEME08) to a maximum degree determined by the coherence observed with xCHAOS (Olsen & Mandea, 2008), GRIMM (Lesur *et al,* 2008) and MF6 (Maus *et al*, 2008).

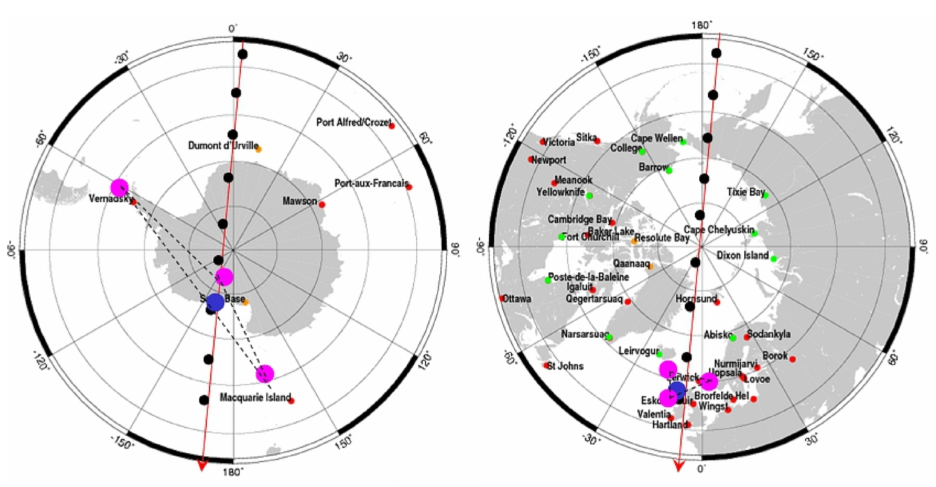
## 2. Satellite Data Weighting and Model Tests



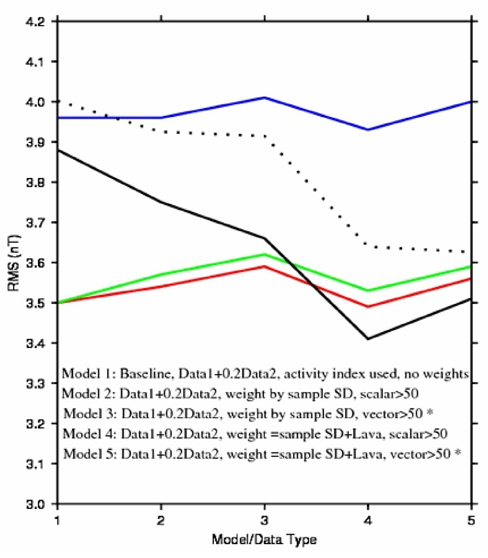
Data weights are defined for each satellite sample independently for each of the vector components of the measured field. The data weight for each component is the inverse sum-of-squares of two terms. The first term is the sample standard deviation in nT, typically less than about 10 nT for the selected quiet-time data. The second term is the satellite's 'local area vector activity', or LAVA index, which is dimensionless, and given at a half-integer resolution on a scale of zero to ten.

**Left: Sample standard deviation.** Satellite data are selected from the 1-second data set at a 20-second sampling interval (black spots). The standard deviation (ideally a measure of any localised external field activity and of any varying measurement noise) is then computed from the twenty measurements centred on the sample point, i.e.on a track segment of around 150 km length (e.g. blue arrow).

**Right**: **LAVA.** For each observatory we determine its external variation field by subtracting a quiet night-time level. We determine the absolute value of the variation field at each minute, for each vector component, and for each observatory, over the duration of the model. We bin these to construct cumulative probability density curves for the variations. These define the LAVA scales for each component at a given observatory. Any observed variation at an observatory then has an equivalent LAVA index. We interpolate the LAVA indices from the three nearest observatories to the geographic ground position of the satellite,

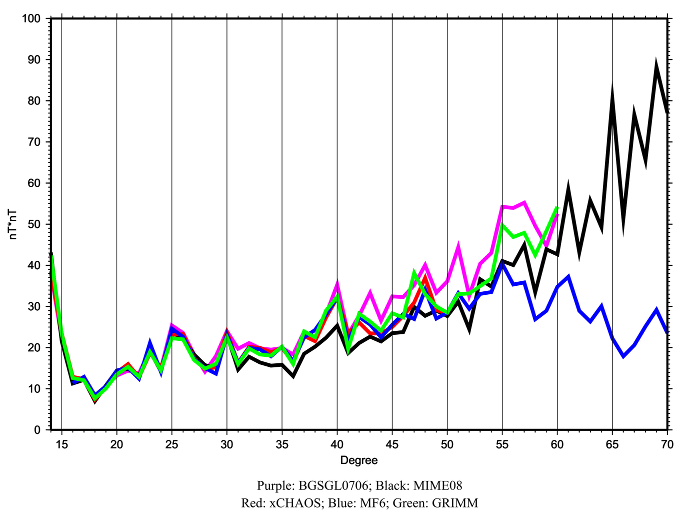


**Right:** Five models are fit to the combined first- and second-pass satellite-only data sets. These models differ according to which data weighting is applied to the satellite sample and whether vector or only scalar data are used above 50 degrees geomagnetic latitude. The weighted L2 misfit is the dotted line. The *X, Y, Z, F* un-weighted misfits are also shown as solid red, green, blue and black lines respectively. For more clarity the un-weighted *F*-misfit is shown here minus 5.5 nT and the weighted L2 misfit is shown with 3.0 nT added (e.g. model 1 weighted misfit is actually 1.0 nT). Model 5 (vector data at all latitudes + combined data weight) is best in terms of weighted misfit.

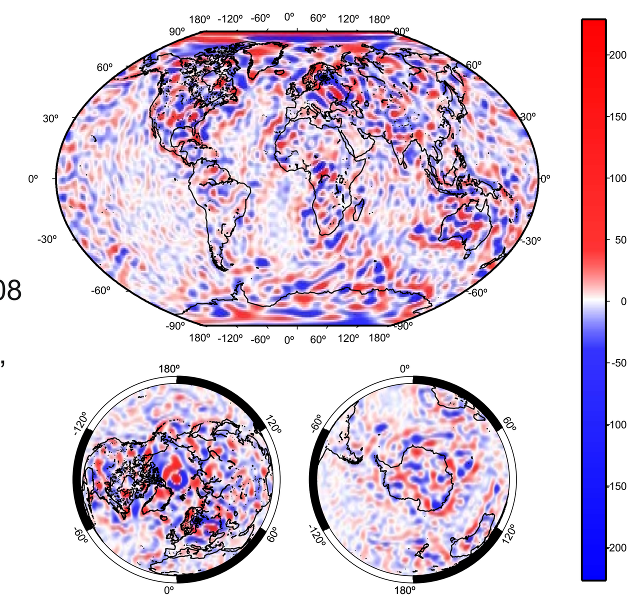


## 3. Results - MEME08

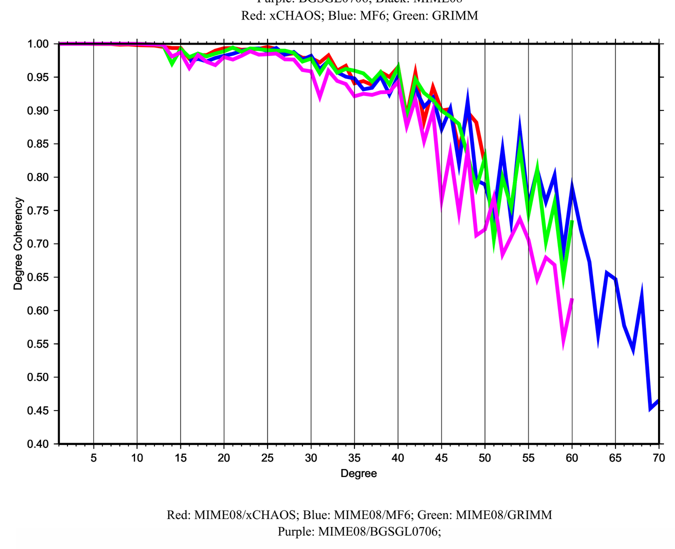
The power spectrum of the MEME08 'parent' model, to degree 70 is shown below, in comparison with BGS/G/L/0706 (Thomson and Lesur, 2007), xCHAOS (Olsen and Mandea, 2008), GRIMM (Lesur *et al*, 2008) and MF6 (Maus *et al*, 2008). In the Figures below we also show the degree coherence observed between these models, percentage normalized coefficient sensitivity matrices, and geographical maps of the vertical field and field differences at the Earth's surface (see Olsen *et al*, 2006, and Langel and Hinze, 1998, for coherency and sensitivity function definitions). All models are evaluated at epoch 2002.0 in these Figures. We also show the inverse square root of the covariance matrix for the *Z*-component of the field sampled by the CHAMP satellite for the final model. Here the tesseral weighting of data, carried over from TL, has been removed to demonstrate just the impact of the combined standard deviation and LAVA weighting. The auroral zones and polar caps are clearly picked out by the method, as one might have expected. However even at mid and low latitudes the weighting scheme can be seen to pick out particular satellite tracks and groups of measurements as being noisy.



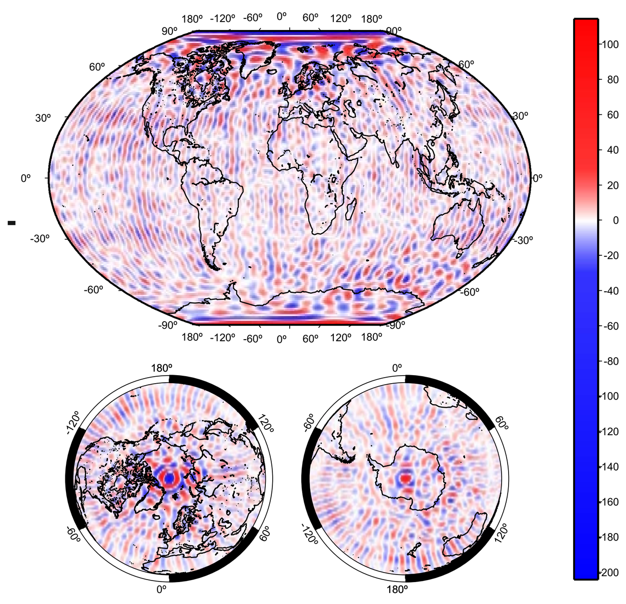
**Left:** Power Spectra of models.



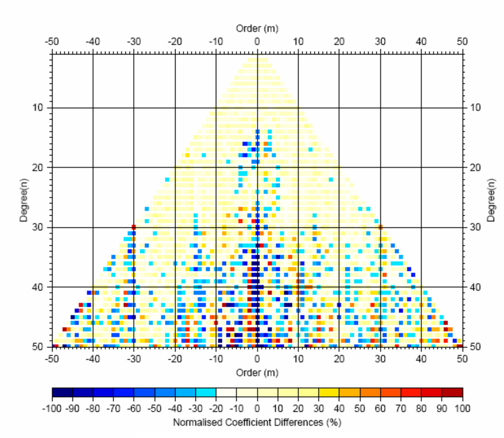
**Right:** MEME08 *Z*-component, degrees 15-60, at Earth's surface.



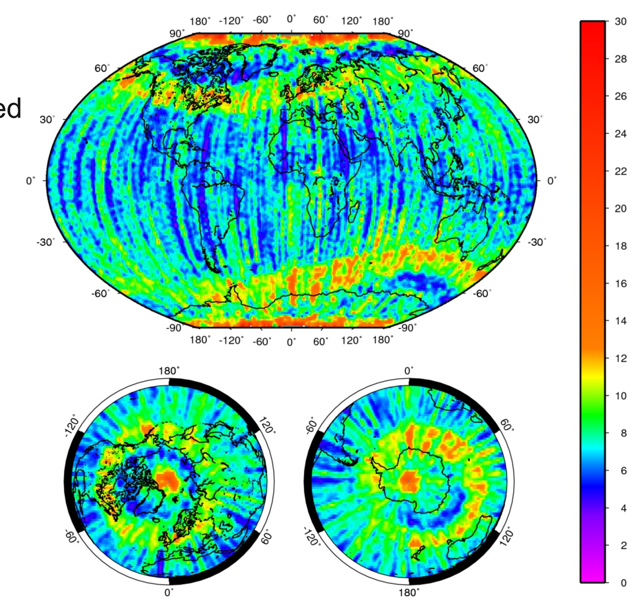
**Left:** Degree coherency of models.



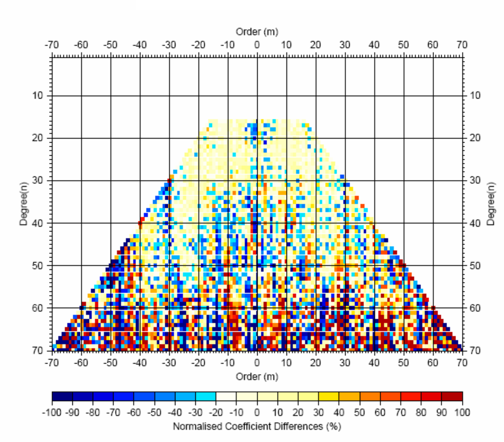
**Right:** GRIMM - MEME08, Z-component, degrees 15-60, at Earth's surface.



**Left:** Sensitivity matrix comparison between MEME08 and xCHAOS.



**Right:** The combined standard deviation and LAVA weight factors for the *Z* component of CHAMP data, in nT.



**Left:** Sensitivity matrix comparison between MEME08 and MF6.

## 4. Conclusions

MEME08 takes advantage of a novel data weighting approach for satellite field measurements. This approach is based on an independent estimation of the smaller-scale external field variations, considered as a noise source that mixes with the internal field that we wish to recover. We have found by experimentation that both types of data weight are useful although the LAVA index has perhaps more impact, compared to the sample standard deviation, on model fit. There may scope for further investigation of the relative importance of each term but clearly on a pragmatic level the method works.

The MEME08 lithospheric model is consistent with other recent models that have different approaches to external field rejection and is arguably robust to around spherical harmonic degree 60. MEME08 has a lower power spectrum to degree 60 and less evidence of along-track 'striping' compared to other models. However more work is perhaps needed to constrain the model within a few degrees of the geographic poles where satellite and surface data are either unavailable, or where existing satellite data may be relatively down-weighted by the magnetic activity level.

We also remark that the external field noise estimates have been used as weights rather than as data selection options. This was done mainly to avoid further decimating satellite data sets used for global modelling, particularly at high latitudes. Further work using these activity measures for data selection may however be worthwhile.

LAVA indices should be readily derivable for variometer data, given the algorithm and its simple baseline definition. Variometer network data, when added to INTERMAGNET data, would then definitely improve our ability to determine the localised activity present in satellite data, not least at high latitudes. Hence variometer networks can be seen to have a role to play in future global magnetic field modelling and in future satellite magnetic survey missions.

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