Initial results in comparison of the IGRF11 model coefficients

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Introduction

The IGRF11 candidate models have been submitted to the IAGA V-MOD committee for consideration. I have examined the models independently to decide which should be used to create the new IGRF. I have applied two tests (1) the examination of the Lowes-Mauersberger spectrum and (2) the calculation of the RMS difference between the models, displayed as images with overlaid values. I have also produced images showing the logarithm of the absolute values of the Gauss coefficients, which allows visual colour comparisons of the models. In addition, maps of the difference in the Z component for the 2010 candidate models are included

The Lowes-Mauersberger spectrum (e.g. Lowes, 1966) at the Earth's surface is calculated as:

$$S_n = (n+1)\sum_{m=0}^{n}(g_n^m)^2 + (h_n^m)^2$$

where *g* and *h* are the Gauss coefficients as supplied in the candidate models.

The RMS difference ($\sqrt{dP}_{\mathrm{i,j}}$ in nanoTesla) between models *i* and *j* at the Earth's surface is calculated by:

$$dP = \sum_{n=1}^{n_{\max}}(n+1)\sum_{m=0}^{n}\left(gh_{n\ \mathrm{i}}^m - gh_{n\ \mathrm{j}}^m\right)^2$$

where gh_n^m is the full vector of Gauss coefficients. For the DGRF and IGRF models, $l_{\max} = 13$ while for the SV forecast models the highest degree is $l_{\max} = 8$.

Some plots show what I call the 'Mean Square value of the difference between models *i* and *j* per degree'. This is defined as dP_n [in $(\mathrm{nT})^2$]:

$$dP_n = (n+1)\sum_{m=0}^{n}\left(gh_{n\ \mathrm{i}}^m - gh_{n\ \mathrm{j}}^m\right)^2$$

I will now discuss the differences between the DGRF for 2005, the IGRF for 2010 and the SV models for 2010-2015.

Definitive Geomagnetic Reference Field model (DGRF2005)

There were seven candidate models submitted for the DGRF. Five diagrams showing comparisons are shown in the following pages. The results can be summarised as:

- All models appear to be very similar
- The IZMIRAN model has the highest overall misfit values compared to the other models.
- The mean RMS difference between all models is 7.8nT, while the mean RMS difference excluding the IZMIRAN model is 5.0nT.

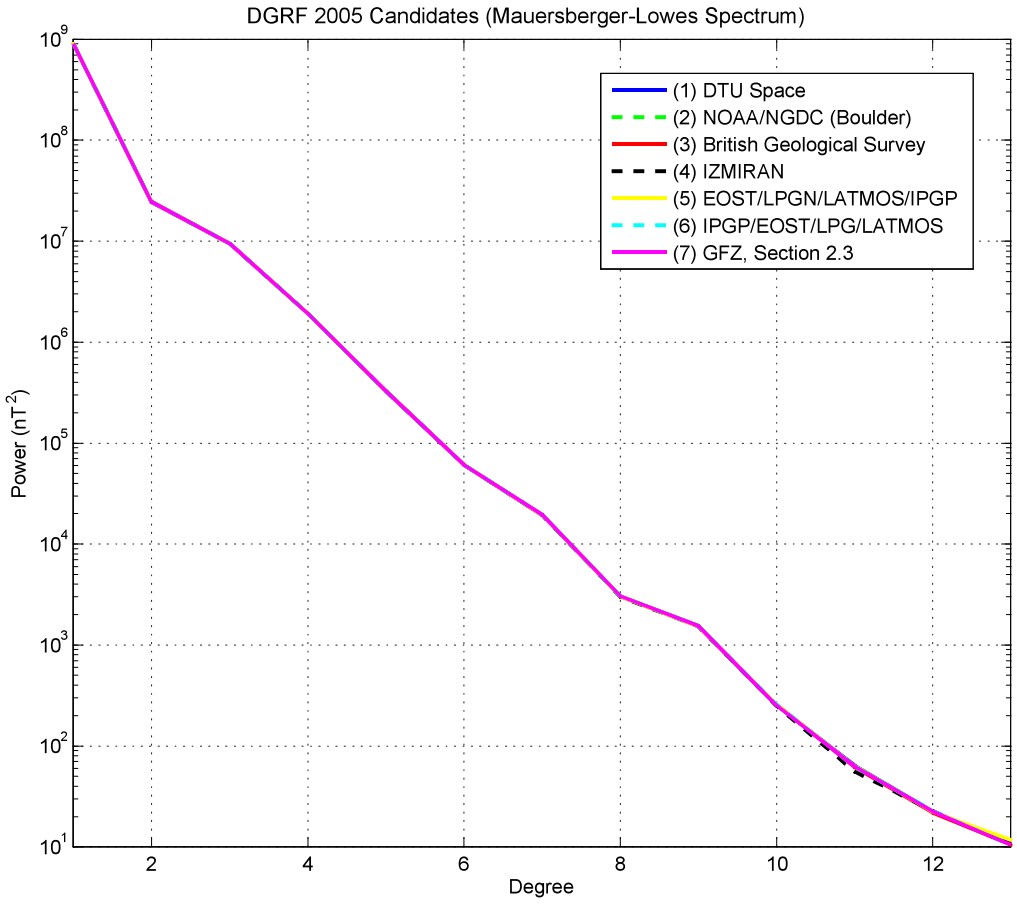

Figure 1: DRGF Lowes-Mauersberger Candidate Model Comparisons. Note the model numbers (1-7) are referred to in Figure 2 and Figure 5.

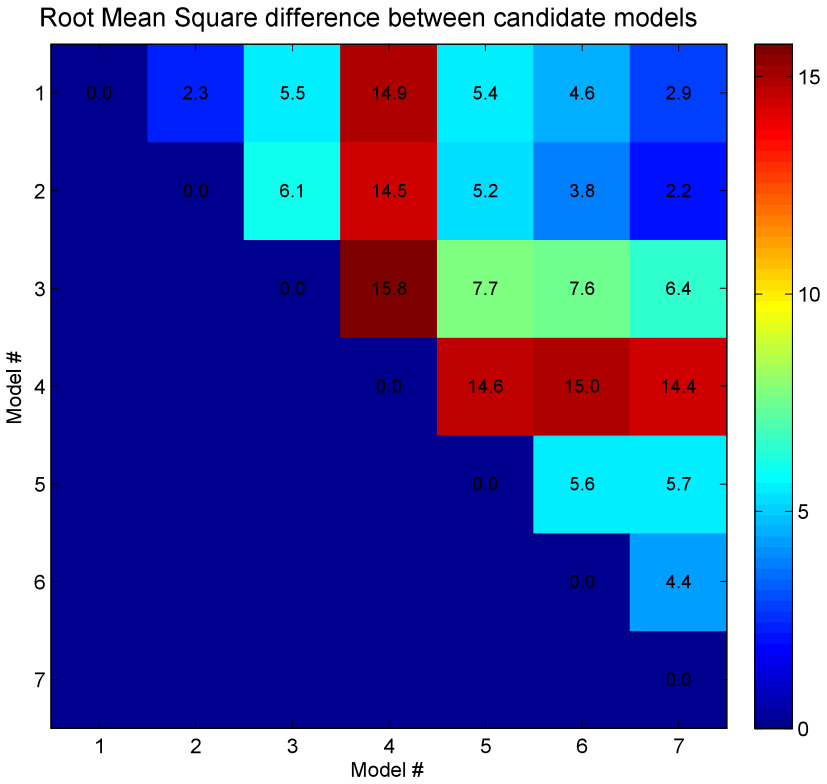

Figure 2: RMS differences between models. Note that Model #4 (Candidate D) has a consistently higher RMS misfit compared to the other models. The mean RMS difference between all models is 7.8nT, while the mean RMS difference excluding Model 4 is 5.0nT.

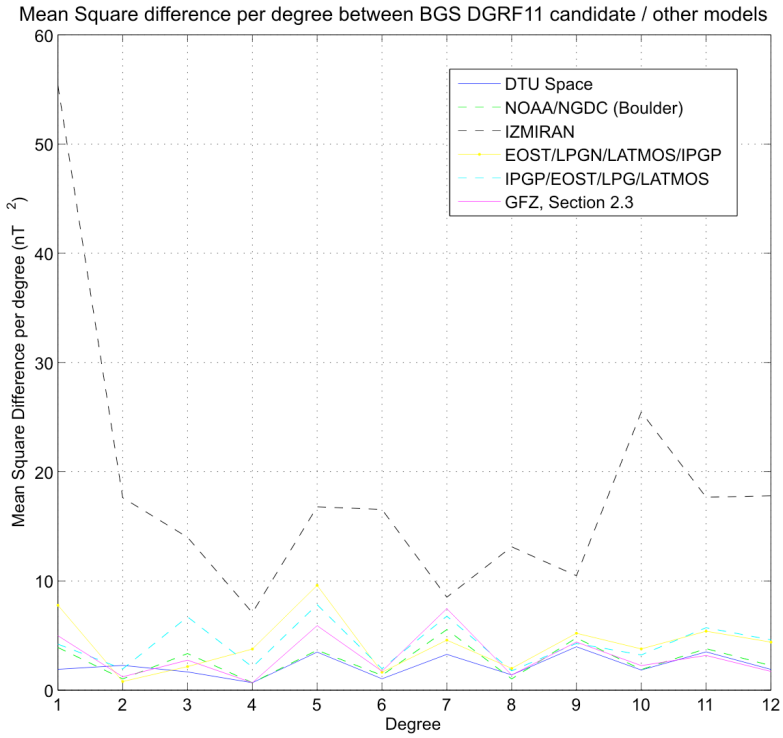

Figure 3: The Mean Square difference per degree between the BGS model and each of the other models. As can be seen, there is a marked increase in difference between the IZMIRAN and other models at degrees 1 and 2. This is not obvious on the LM spectrum plot (Figure 1).

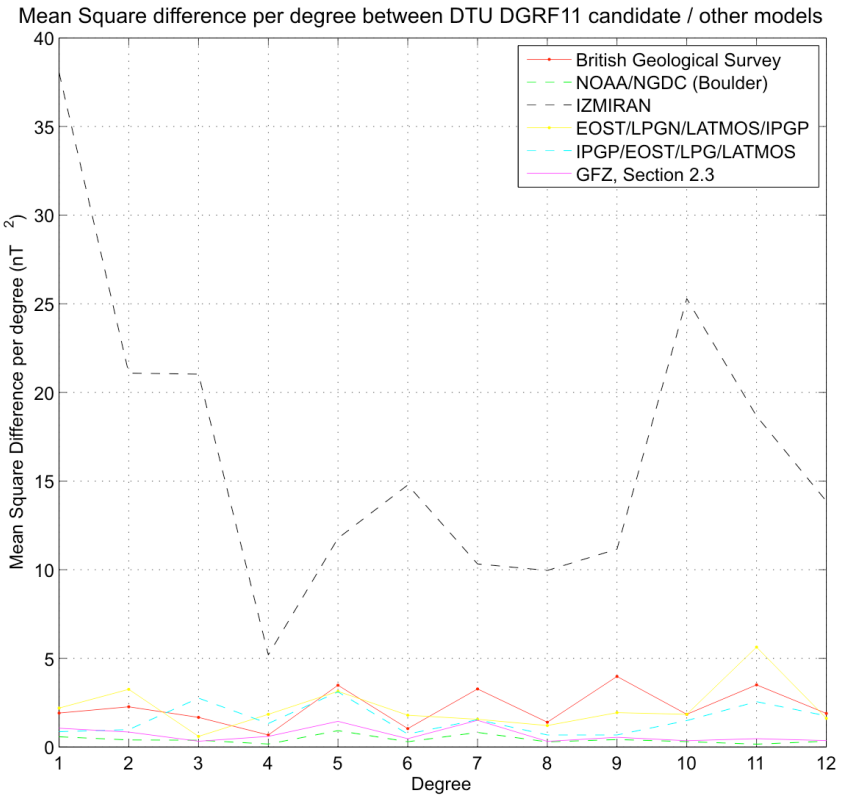

Figure 4: For comparison, the Mean Square difference per degree between the DTU model and others shows that the IZMIRAN model is not as similar to the other models.

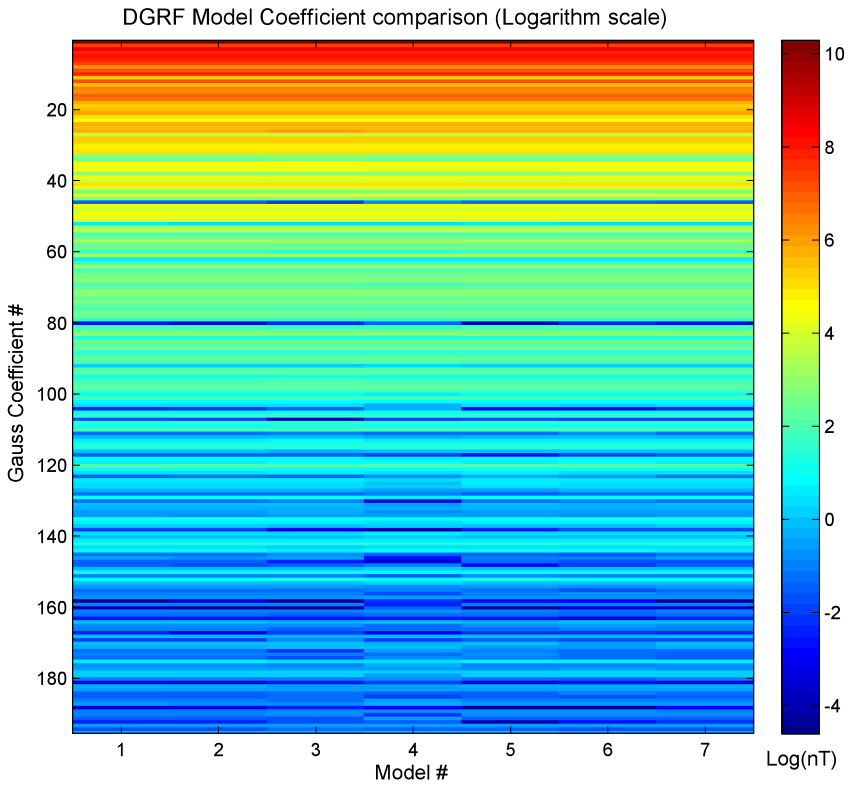

Figure 5: An image of the logarithm of the absolute values of the Gauss coefficients of each of the seven models. This indicates that there is good agreement of the models at lower degrees. Model 3, 4, 5 and 6 (Candidates C to F) vary most at higher degrees.

International Geomagnetic Reference Field model (IGRF2010)

There were seven candidate models submitted for the IGRF. Again, five diagrams are shown in the following pages. The results can be summarised as:

- All models again are very similar.
- The IZMIRAN model has the highest overall misfit values compared to the other remaining models.
- The mean RMS difference between all models is 11.5nT.

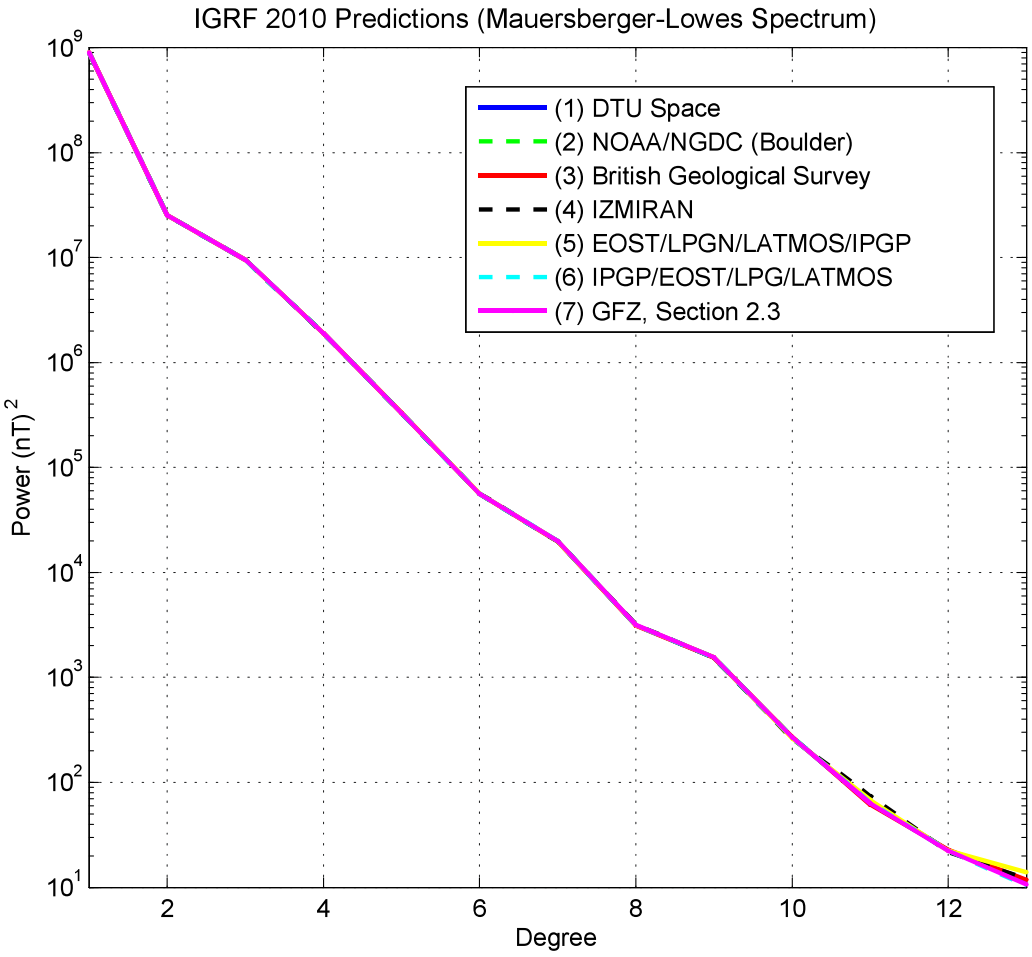

Figure 6: IRGF Lowes-Mauersberger Candidate Model Comparisons. Note the divergence of the models at degree 10 and higher. Note the model numbers (1-7) are referred to in Figure 7 and Figure 10.

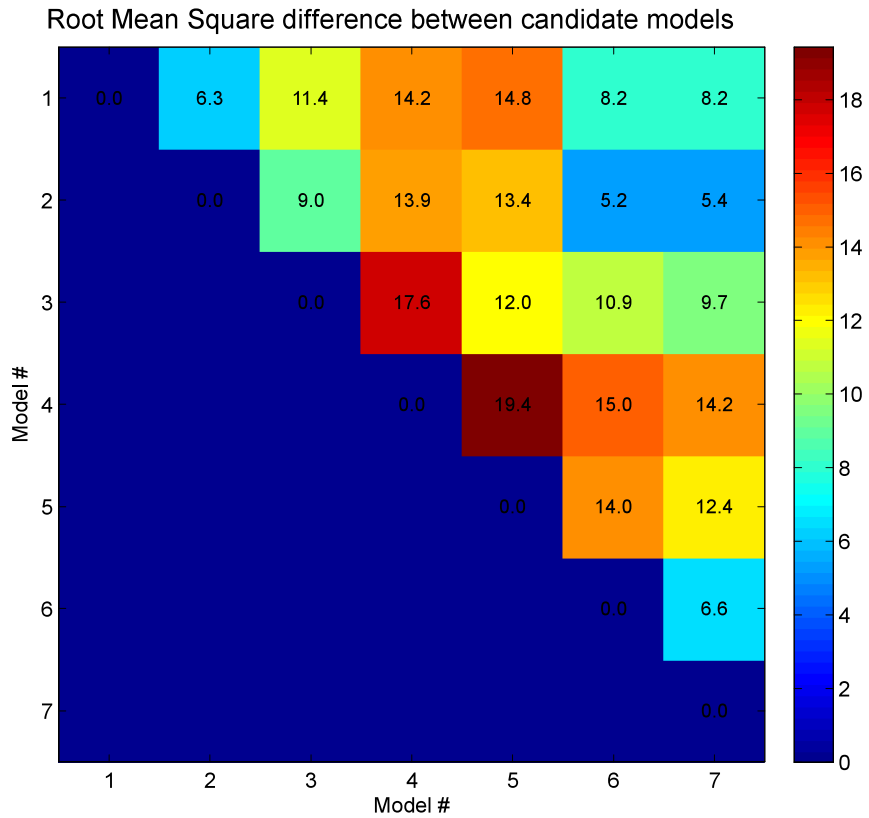

Figure 7: RMS differences between models. Note that Model #4 and 5 (Candidate D and E) have a small but consistently higher RMS misfit compared to the other models. Overall the mean misfit between the models is 11.5 nT. If Candidate D and E are removed, the mean RMS difference is reduced to 8.1nT.

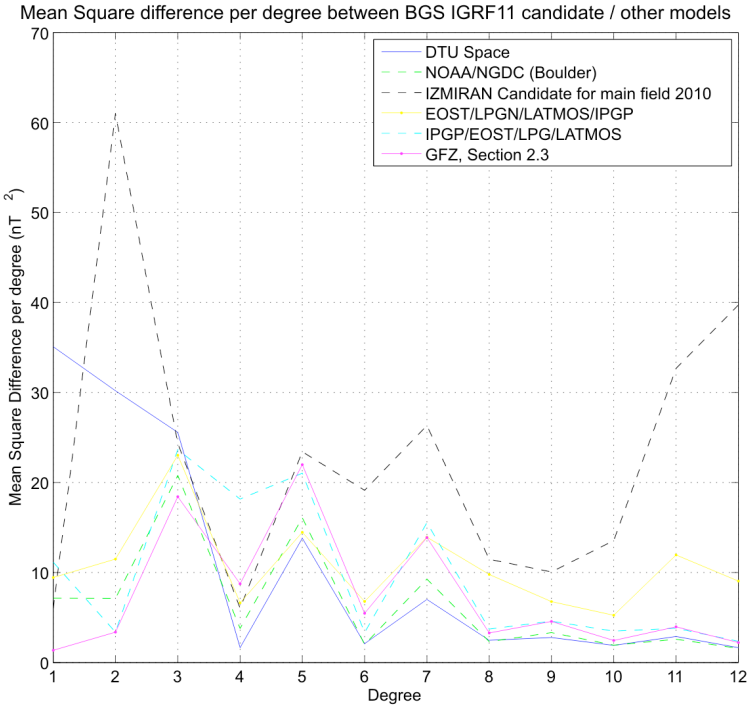

Figure 8: Mean Square difference per degree between the BGS and other models. The IZMIRAN model is misfit most strongly at degrees 2, 11 and 12.

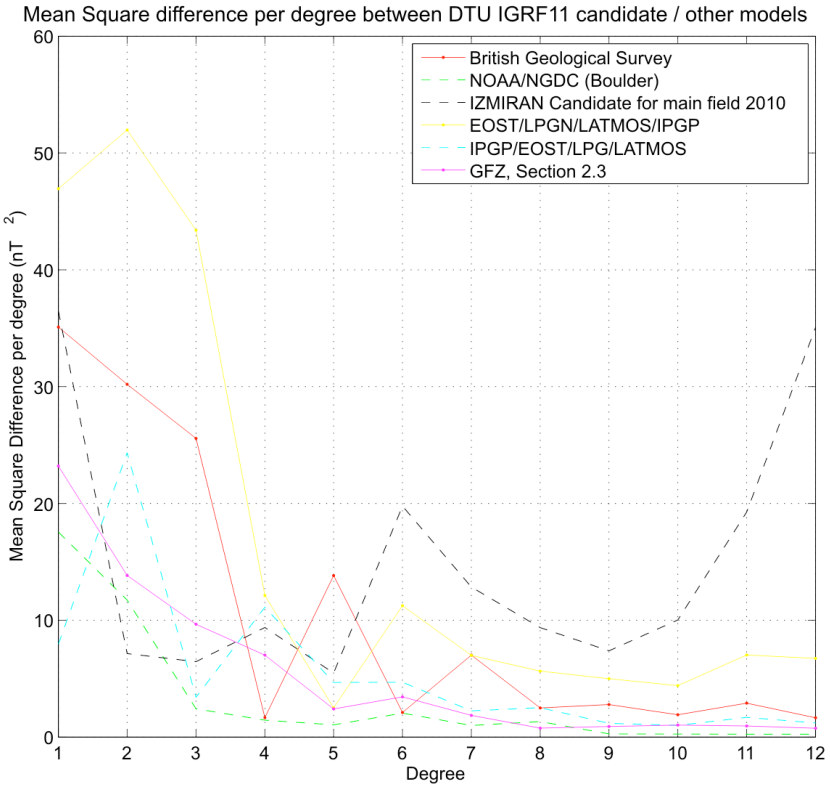

Figure 9: The DTU model compared to other models. Interestingly, much of the difference between the EOST candidate and the other models in the lower degrees, though the IZMIRAN model is misfit at degrees 11 and 12.

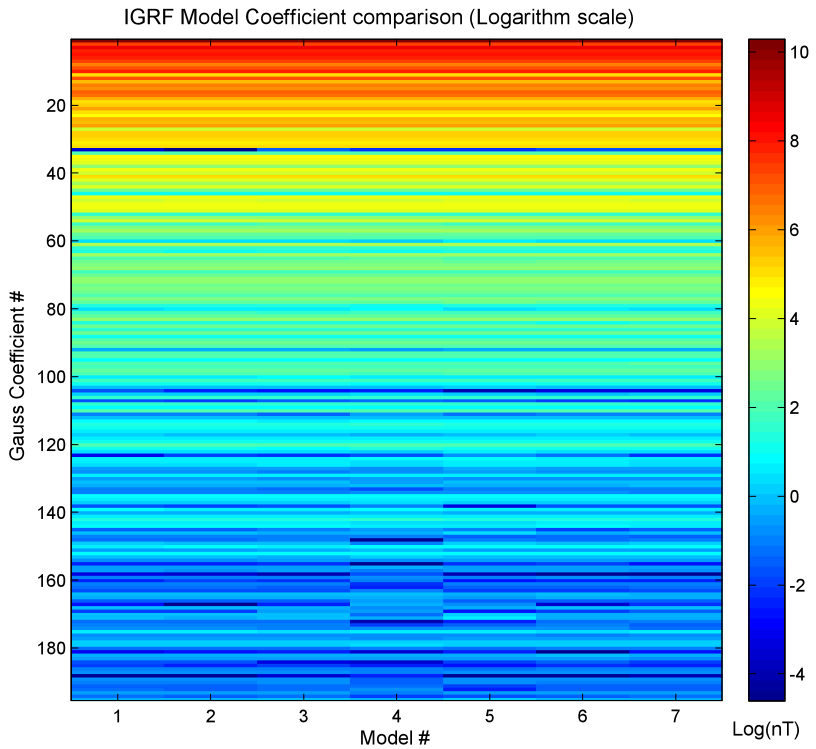

Figure 10: An image of the logarithm of the absolute values of the Gauss coefficients of each of the seven models. This indicates that there is good agreement of the models at lower degrees, though models 4, 5 and 6 differ from models 1, 2 and 3 in the higher degrees. Model 4 (Candidate D) looks slightly different to the others.

IGRF11 SV forecast/prediction

There were eight candidate models submitted for the IGRF SV model 2010-2015. Again, five diagrams are shown in the following pages illustrating the comparisons. The results are more difficult to summarise as there is widespread disagreement:

- The DTU model has the largest g_1^0 coefficient by about 30%.
- Most other models appear to predict a smaller SV change, though the GFZ model has slightly higher coefficient values at degree 5 and above.
- Models 2, 4 and 7 appear to produce the largest average RMS difference between the models, if one compares the various results in Figure 12.
- The mean RMS difference between the models is 14.3nT/yr. If certain models are removed, there is not a particularly large change in the mean. E.g. removing Model #7 reduces the mean RMS difference to 12.2nT/yr.

A simple arithmetic mean would not really be a suitable compromise either, as this 'smears out' the information in the predictions. However, this may be the most diplomatic solution, as there are no obviously 'incorrect' models but little consistency between the SV models.

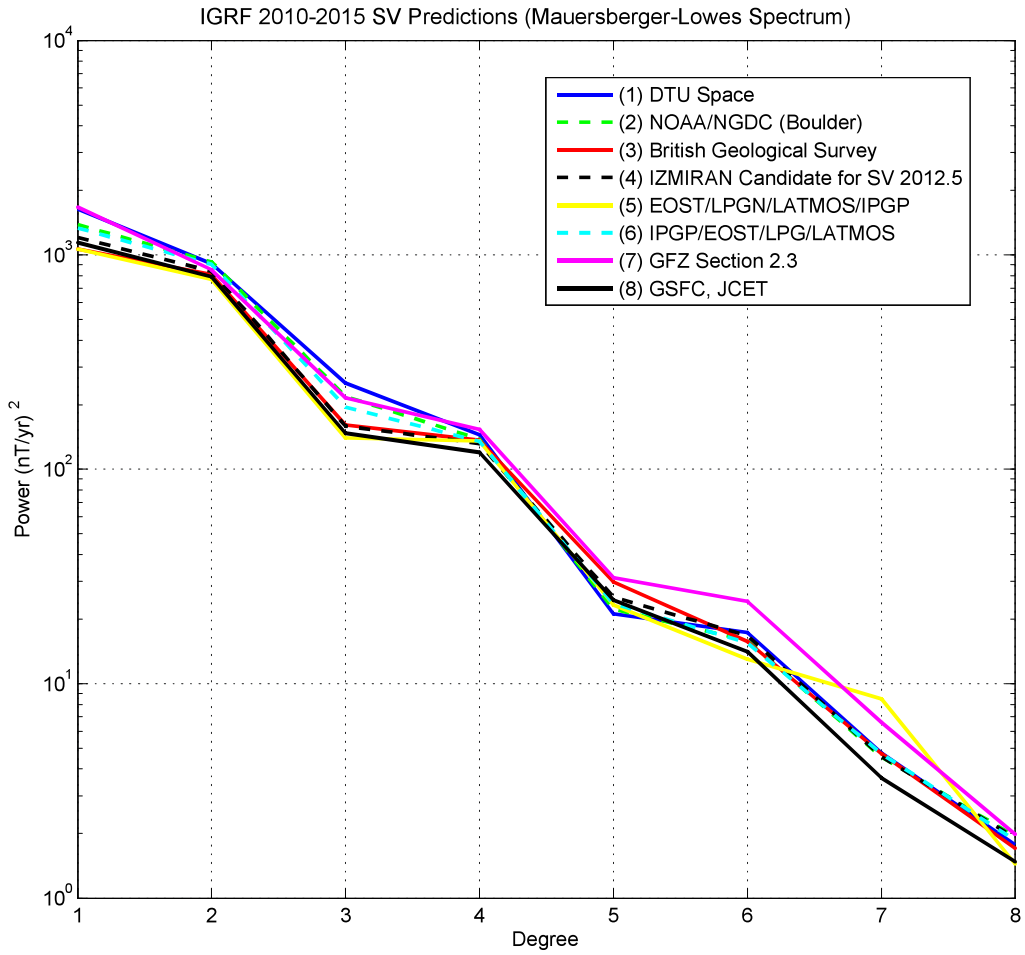

Figure 11: SV 2010-2015 forecast Lowes-Mauersberger Candidate Model Comparisons. Note the model numbers (1-8) are referred to in Figure 13 and Figure 15.

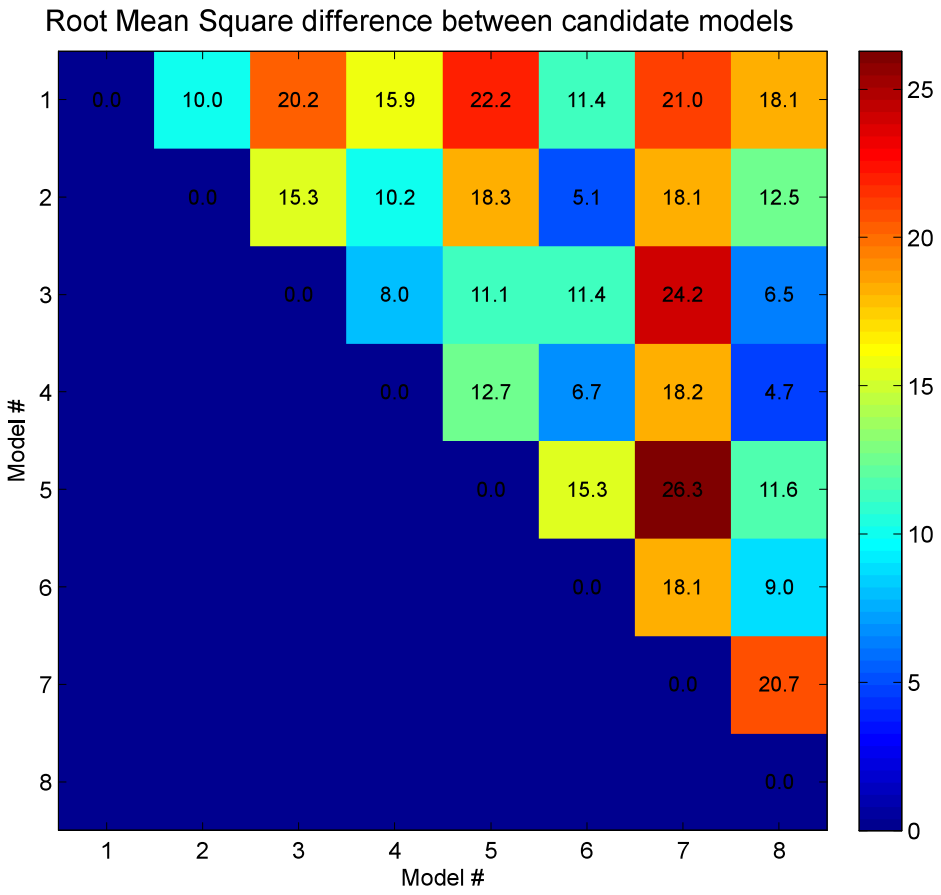

Figure 12: RMS differences between models. The mean RMS difference between all models is 14.3nT/yr.

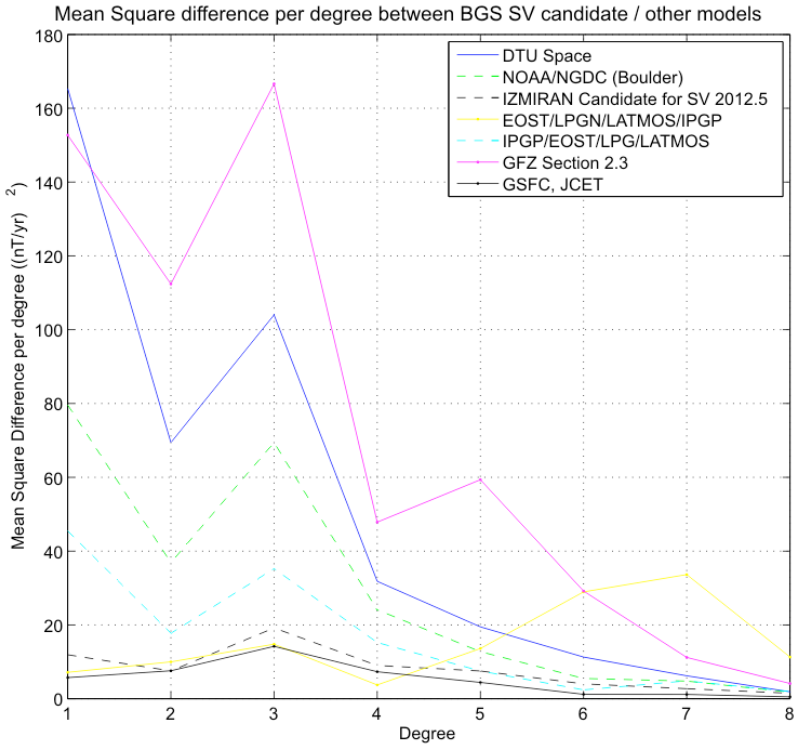

Figure 13: The Mean Square difference per degree between the BGS model and each of the other models. Some models differ significantly in the low degrees but all models appear similar at higher degrees – most likely because the coefficients are all small.

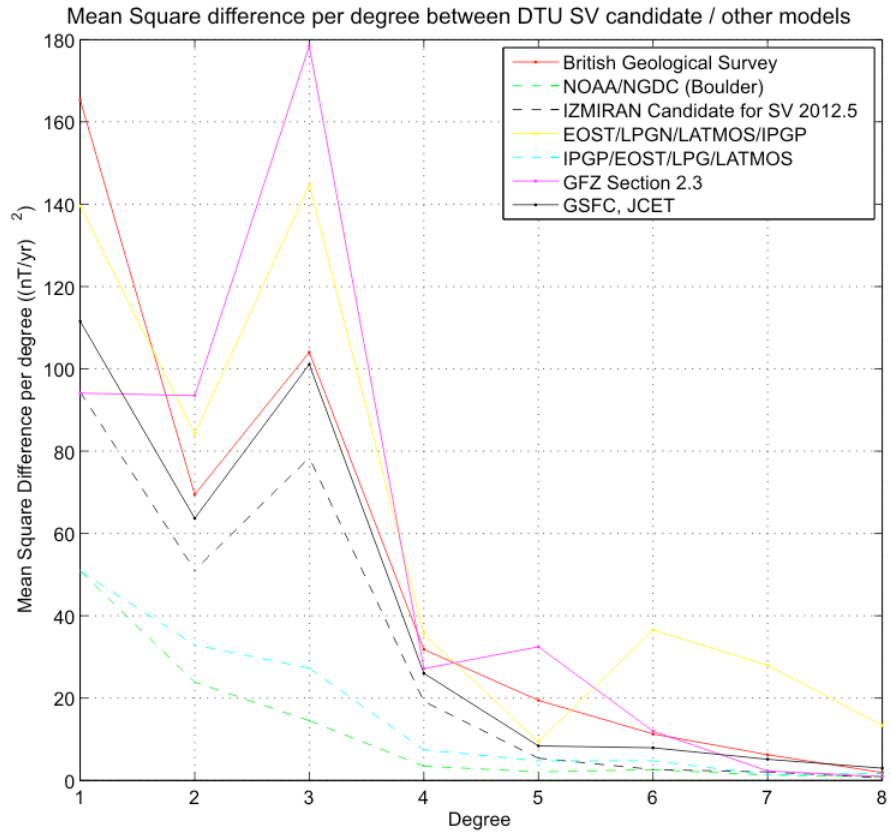

Figure 14: For comparison, the Mean Square difference per degree between the DTU model and others shows a spread of differences similar to those in Figure 13.

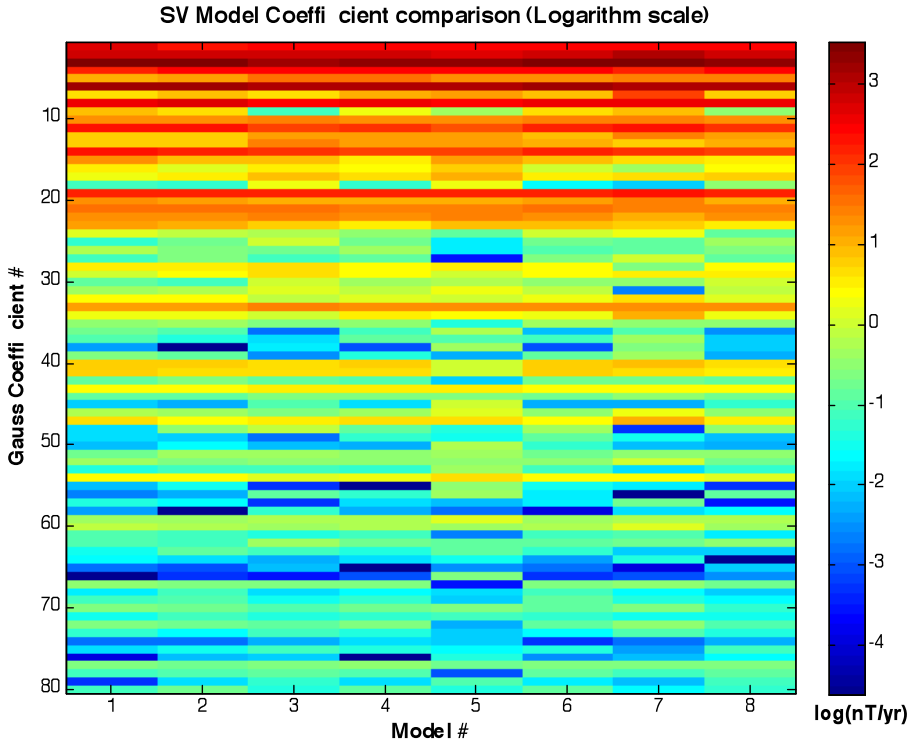

Figure 15: An image of the logarithm of the absolute values of the Gauss coefficients for each of the eight models. This indicates that there is relatively large disagreement between the models at all degrees.

Spatial Variations of the IGRF11 2010 models

An analysis of the spatial differences between the IGRF11 models for 2010 was carried out. Difference between model coefficients were used to synthesis differences in the Z component at the Earth's surface. There are 21 separate comparisons made. The model differences are contoured every 5nT and annotated every 10nT. Positive differences are in red, negative in blue.

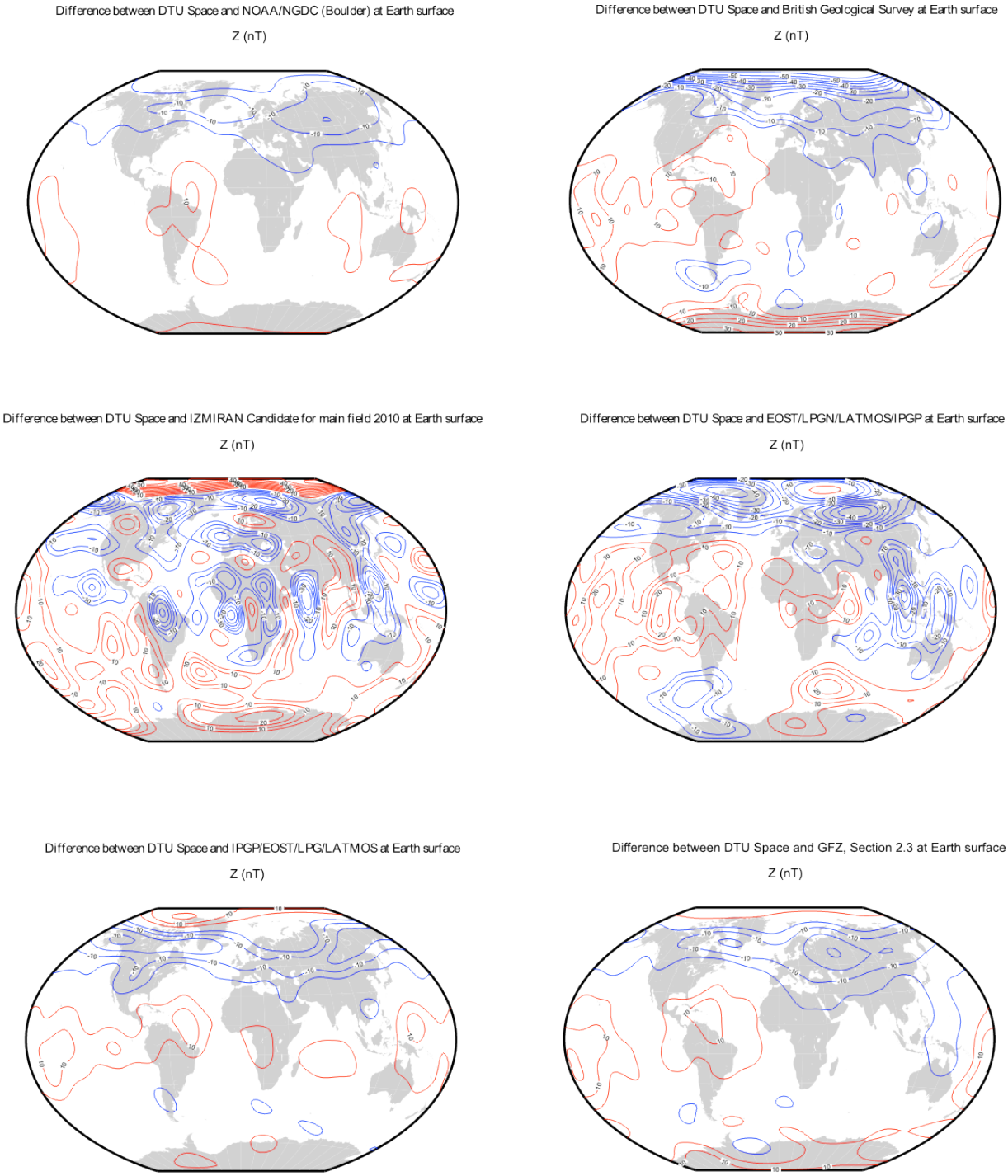

Figure 16: Differences in the Z component between the IGRF11 DTU candidate model (Candidate A) and the other candidates.

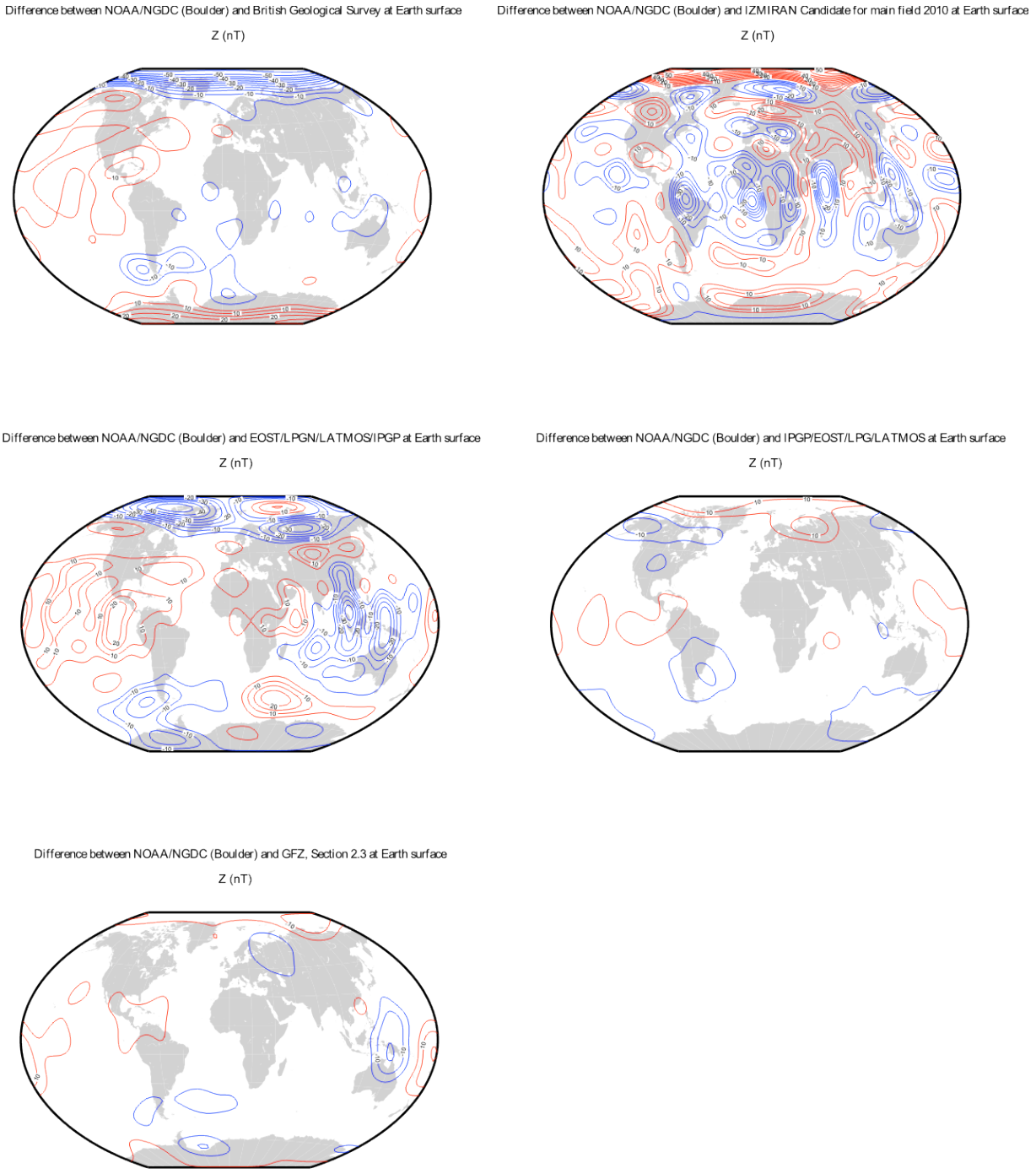

Figure 17: Differences in the Z component between the IGRF11 NOAA candidate model (Candidate B) and the other candidates.

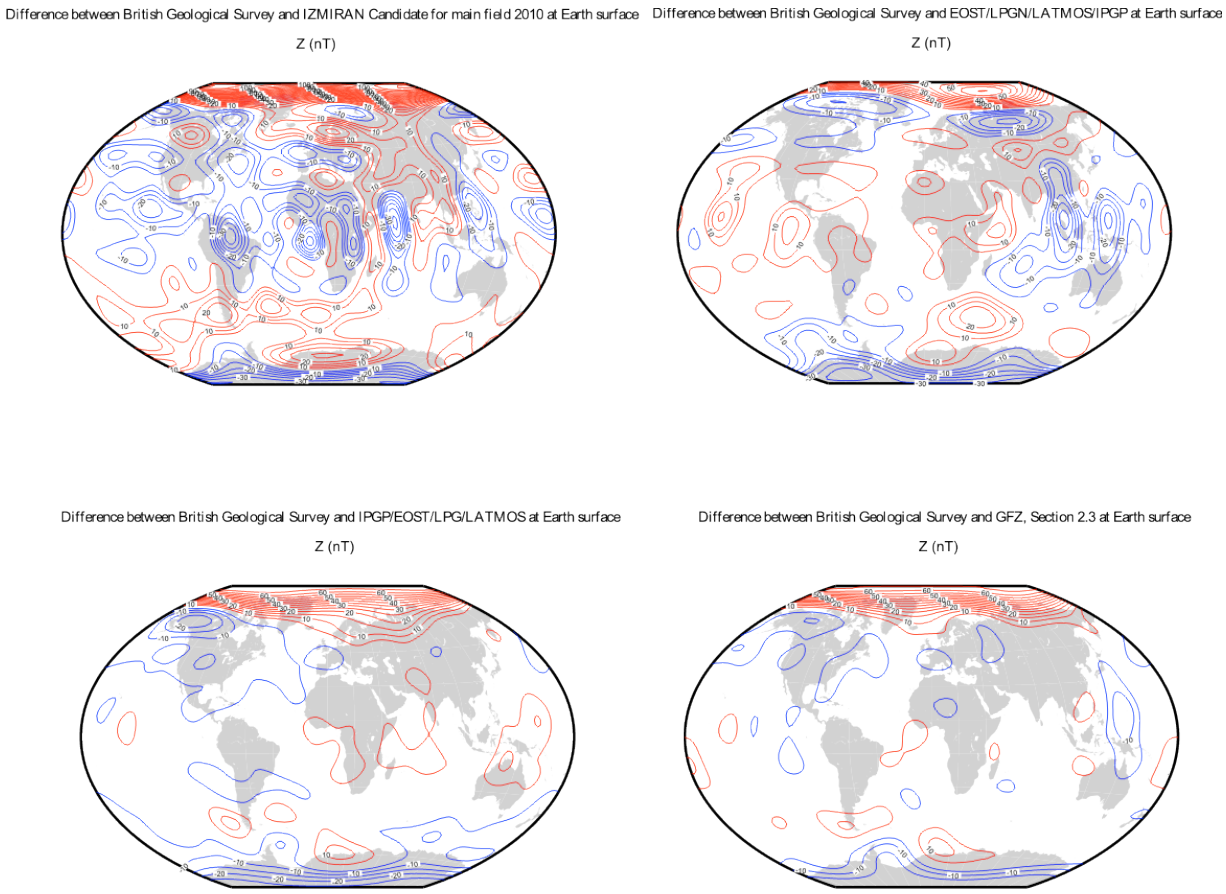

Figure 18: Differences in the Z component between the IGRF11 BGS candidate model (Candidate C) and the other candidates.

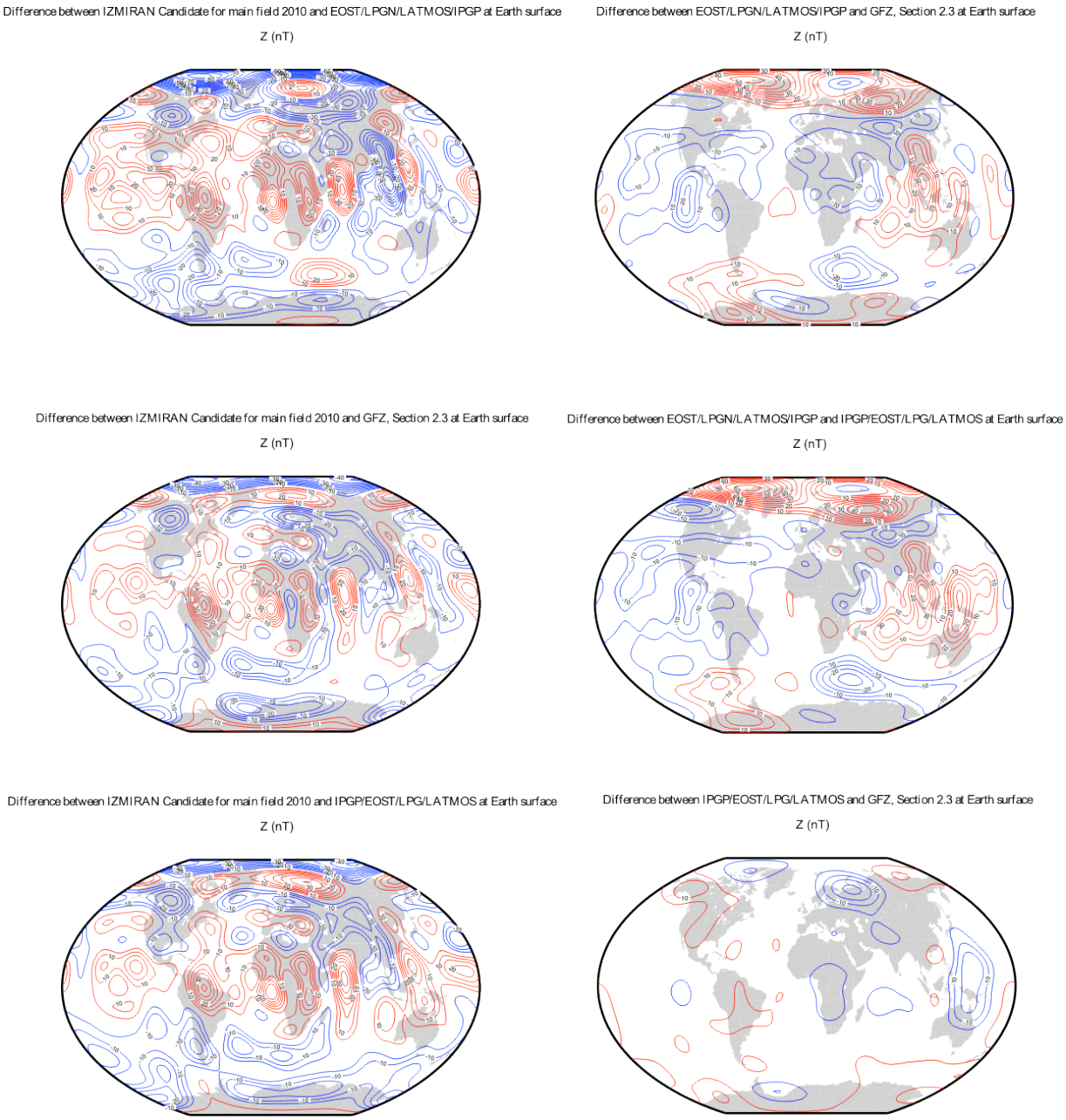

Figure 19: Differences in the Z component between the IGRF11 IZMIRAN, EOST, IPGP and GFZ candidate modes (Candidates D, E, F and G).

Conclusions

The candidate magnetic field models submitted for the DGRF and IGRF model are very similar. The DGRF candidates have approximately 5nT RMS average difference between them while the IGRF models have an average RMS difference of 11.5nT. As most models are using similar data sets and modelling techniques, this should be of no surprise. Analysis of the spatial variation between models shows most of the differences occur in the high latitude regions, particularly in the northern hemisphere.

References

Lowes, F.J., 1966, *Mean-Square Values on Sphere of Spherical Harmonic Vector Fields*, J. Geophys. Res., Vol. 71, p.2179