Comparison of Candidate Models for DGRF 1990 and IGRF 1995

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The 1995 revision of the International Geomagnetic Reference Field (IGRF) includes a definitive main-field model for 1990.0, a main-field model for 1995.0, and a forecast secular variation model for the interval 1995–2000. The four 1990.0 main-field models and four 1995.0 main-field models that were proposed as candidates have been evaluated by comparing them one with another, and also with magnetic observatory data. The comparisons indicate that the accuracies of the main-field models proposed by IZMIRAN are one and a half times higher than those of the other candidate models. The two secular variation models that were proposed have also been compared; averaging of the two models is appropriate.

1. Introduction

The 1995 revision of the International Geomagnetic Reference Field (IGRF) includes three new spherical harmonic models: a definitive main-field model of degree and order 10 for 1990.0, a main-field model of degree and order 10 for 1995.0, and a forecast secular variation model of degree and order 8 for the interval 1995–2000. Candidates for all three models were proposed jointly by the US Navy and the British Geological Survey (referred to here as the UK/US models), and also by IZMIRAN (the IZM models). In addition, a pair of candidates for each of the two main-field models was proposed by NASA—the GSP models, which included POGS satellite data, and the GS models, which did not use POGS data.

The UK/US main-field candidate models for DGRF 1990 and IGRF 1995, were derived from Project MAGNET vector aeromagnetic data covering the interval from 1988 to 1994, POGS scalar total intensity data collected during the period 1991 through 1993, and all available magnetic observatory vector annual means and repeat station data supplied by countries around the world (Quinn et al., 1995, 1997). Observatory and repeat station data collected since the production of the preliminary secular variation models were included in the linear predictions and linear regressions to give new secular variation estimates up to the year 2000 (Macmillan et al., 1997).

The GSP and GS models utilized a careful selection of data from all available sources: magnetic observatories, repeat stations, satellite surveys, aeromagnetic surveys, marine magnetic surveys, and land magnetic surveys (Sabaka et al., 1997).

To derive the IZMIRAN candidate models for 1990.0 and 1995.0 (Golovkov et al., 1997), we developed a single spatial-temporal model, IZMST. The data utilized for IZMST covered the time interval 1970 to 1994 obtained from magnetic observatories and satellite surveys, including POGO-8, MAGSAT, and POGS. The IZMST model was derived by first expanding in natural orthogonal components (NOCs) temporal series of annual means of 28 specially-chosen magnetic observatories more-or-less uniformly covering the globe; their spatial distribution was then expanded in spherical harmonics up to degree and order 10, as described by Golovkov et al. (1997). Assuming the time series of each coefficient of the spherical harmonic expansion of the geomagnetic field changes as a linear combination of the same NOCs, coefficients of these combinations for all spherical harmonic coefficients were derived from a data set including all available magnetic observatory data as well as data from the satellite surveys mentioned above. Using the NOC expansions of spherical harmonic coefficients, coefficients could be easily
Fig. 1. Differences between the GGP and IZM models at 1990 at the Earth's surface for (a) the X component, (b) the Y component, and (c) the Z component. Units are nT; the contour interval is 25 nT.
Fig. 2. Differences between the UK/US and IZM models at 1990 at the Earth's surface for (a) the $X$ component, (b) the $Y$ component, and (c) the $Z$ component. Units are nT; the contour interval is 25 nT.
Fig. 3. Differences between the GSP and UK/US models at 1990 at the Earth's surface for (a) the $X$ component, (b) the $Y$ component, and (c) the $Z$ component. Units are nT; the contour interval is 25 nT.
Fig. 4. Differences between the G0P and IZM models at 1995 at the Earth's surface for (a) the X component, (b) the Y component, and (c) the Z component. Units are nT, the contour interval is 50 nT.
Fig. 5. Differences between the UK/US and IZM models at 1995 at the Earth's surface for (a) the X component, (b) the Y component, and (c) the Z component. Units are nT; the contour interval is 50 nT.
Fig. 6. Differences between the GSP and UK/US models at 1995 at the Earth’s surface for (a) the $X$ component, (b) the $Y$ component, and (c) the $Z$ component. Units are nT; the contour interval is 50 nT.
Fig. 7. Differences between the UK/US and IZM secular variation models for 1995–2000 at the Earth's surface for (a) the dX component, (b) the dY component, and (c) the dZ component. Units are nT/yr; the contour interval is 5 nT/yr.
calculated for any epoch in the time interval being modelling. Candidate models IZM-90 and IZM-95 were obtained by combining all coefficients of NOCs from IZMST for epochs 1990 and 1995, respectively.

Our secular variation model, IZM-SV, was developed with the usual spherical harmonic expansion of a data set obtained by extrapolation to the year 2000 year of time series of annual means of X, Y, and Z from 160 magnetic observatories distributed over the globe. The extrapolation was done by hand, as described by Bondar and Golovkov (1992).

2. Comparisons of Main-Field Models

Candidate models of the main field were compared with each other. Differences in the X, Y, and Z components between GSP and IZM, UK/US and IZM, and GSP and UK/US, at both 1990 and 1995, and between the UK/US and IZM secular variation models for 1995–2000 are presented in Figs. 1–7. As the differences between the GS and GSP models are relatively small, differences between other models and the GS models are not illustrated. (The GSP models were later withdrawn as candidate models by the authors, but the similarities are such that the GSP comparisons still give a good indication of the nature of the GS models.)

The figures show that the largest differences in all components for any pair of models occur in regions where the data are most sparse. These regions are mainly the oceans in the southern hemisphere, the Indian region, and the north polar region.

For the candidate-models for DGRF 1990, the largest differences in the Y and Z components between GSP and IZM occur in the South Pacific (up to 100 nT) and in the Indian Ocean and Africa (up to 100 nT) (Figs. 1(b) and (c)). The largest differences in the X component occur in the Indian Ocean and the north polar region (both up to 50 nT) (Fig. 1(a)). For the UK/US and IZM models, the largest differences in the Z component are in the centre of Africa (up to 180 nT) (Fig. 2(c)). There are no significant differences in the X and Y components between these pairs of models (Figs. 2(a) and (b)). Differences between GSP and UK/US show a more scattered pattern (Figs. 3(a)–(c)).

For the candidate models for the IGRF 1995 main field, the most significant differences between models GSP and IZM (up to 360 nT for Z, up to 200 nT for X, and up to 250 nT for Y) are concentrated in the ocean regions of the south hemisphere (Figs. 4(a)–(c)). In contrast, the pair of models GSP-IZM and the pair UK/US-IZM have relatively small differences in all components in the Pacific ocean, but very large ones in the South Atlantic (up to 320 nT for Z and 200 nT for X) and in the Indian ocean (up to 250 nT for Y and Z, and up to 150 nT for X) (Figs. 5(a)–(c)). The pair of models GSP-UK/US (Figs. 6(a) and (b)) have significant differences in the Z and Y components in the South Pacific (up to 240 nT and 150 nT, respectively), in south-east Africa (up to 200 nT and 150 nT, respectively), and in south America (up to 180 nT and 150 nT, respectively). Differences in the X component occur only in south-east Africa (up to 140 nT) (Fig. 6(a)).

The two secular variation candidate models, UK/US-SV and IZM-SV, are similar, except in the northern part of the Indian ocean, where the differences reach 30 nT per year for the Z and Y components, and 20 nT per year for the X component (Figs. 7(a)–(c)).

3. Discussion

It is difficult to determine which models best represent the geomagnetic field over the globe. All of them fit the observational data globally with almost the same, rather high accuracy. However, the comparison of candidate models in pairs shows significant difference between models (see Table 1). This table shows the rms differences over the globe between models for the X, Y, and Z components for (a) the main-field models, and (b) the secular variation models. Differences were derived from evaluations at a set of grid points. As shown in Figs 1–7, regional differences may exceed 300 nT. To make the best choice we used observatory biases as a measure of model accuracy.

Langel and Estes (1982) noted that comparisons of main-field models with data from magnetic
Table 1. Differences between candidate IGRF models.

(a) RMS differences between candidate models for each of DGRF 1990 and IGRF 1995.

| Model pair       | 1990.0 | 1995.0 |
|------------------|--------|--------|
|                  | \(X\) (nT) | \(Y\) (nT) | \(Z\) (nT) | \(X\) (nT) | \(Y\) (nT) | \(Z\) (nT) |
| UK/US-IZMST      | 26.5   | 26.1   | 40.5   | 66.9   | 61.8   | 97.2   |
| GSP-IZMST        | 31.5   | 30.4   | 48.4   | 82.1   | 87.4   | 129.4  |
| GS-IZMST         | 32.5   | 31.4   | 50.2   | 83.1   | 90.9   | 132.2  |
| GSP-UK/US        | 35.4   | 35.6   | 55.4   | 48.6   | 57.3   | 84.3   |
| GS-UK/US         | 36.1   | 36.1   | 56.6   | 50.1   | 60.4   | 87.8   |

(b) RMS differences between candidate models for IGRF (SV) 1995–2000.

| Model pair       | \(dX\) (nT/year) | \(dY\) (nT/year) | \(dZ\) (nT/year) |
|------------------|------------------|------------------|------------------|
| UK/US-IZM        | 6.8              | 6.9              | 10.8             |

Table 2. Observatory bias* changes from epoch 1980.0 to 1990.0 (i.e., \(\text{rms}\{1980obs - DGRF 1980\} - \text{rms}\{1990obs - model 1990\}\)).

| Model | \(X\) (nT) | \(Y\) (nT) | \(Z\) (nT) |
|-------|------------|------------|------------|
| GS    | 33.4       | 32.5       | 62.3       |
| GSP   | 32.5       | 32.3       | 60.8       |
| UK/US | 32.9       | 30.7       | 58.1       |
| IZMST | 22.9       | 26.4       | 38.4       |

*rms of results from 116 observatory annual means.

Table 3. Observatory bias* changes from epoch 1980.0 to 1995.0 (i.e., \(\text{rms}\{1980obs - DGRF 1980\} - \text{rms}\{1995obs - model 1995\}\)).

| Model | \(X\) (nT) | \(Y\) (nT) | \(Z\) (nT) |
|-------|------------|------------|------------|
| GS    | 22.7       | 32.0       | 47.6       |
| GSP   | 22.7       | 31.0       | 47.0       |
| UK/US | 24.6       | 23.4       | 45.0       |
| IZMST | 31.2       | 28.1       | 25.7       |

*rms of results from 25 observatory annual means.
observatories have limited usefulness because of the presence of contaminating crustal fields (local magnetic anomalies). An *observatory bias* can be calculated from the difference between the measured value of the geomagnetic field at an observatory and the value computed at the same location using the DGRF. Since the crustal sources of magnetic anomalies do not vary in time, the observatory bias is essentially time-independent (although that part of the crustal field induced by the main field will vary with the secular variation). An observatory bias can be calculated for any epoch by using the appropriate DGRF model. If the biases for two epochs differ, then one or both of the DGRFs are incorrect. It is generally accepted that the DGRF is most accurate for epoch 1980, being derived from the extensive MAGSAT dataset. Thus, the observatory biases for this epoch are considered to be the best estimates of the crustal component at each observatory. By comparing biases for 1980 with those for other epochs, we can estimate the accuracy of the DGRF at those epochs.

Accordingly, we first obtained biases for 116 magnetic observatories by taking the differences between the annual means for 1980 and DGRF 1980. This was then repeated for epoch 1990, using each of the candidate models for DGRF 1990 in turn. The rms differences between biases for epochs 1980 and 1990 for each of the $X$, $Y$, and $Z$ components are presented in Table 2. The table shows that all of the candidate models for 1990, with the exception of IZM, describe the spatial structure of the field with similar accuracy: to about 60 nT in $Z$ and 30 nT for $X$ and $Y$. The accuracy of the IZM model is about 40 nT for $Z$ and 20 nT for $X$ and $Y$.

Table 3 was prepared in the same way as Table 2, but for epoch 1995. Observed annual means for 1995 were available from 28 magnetic observatories and were used to obtain biases for 1995 for comparison with corresponding values for 1980. Table 3 shows clearly that the bias differences are of the same order as for 1990, and almost the same for the different candidate models. This is a surprisingly good result considering that the observatory annual means for 1995 were not used in the development of any of the candidate models. This is an argument in favour of the IZM model, but maybe it is not good enough to choose IZM in preference to others. Averaging of the candidate models seems to be appropriate.

### 4. Conclusion

The comparison shows that there is little difference between the candidate models, and each main-field model produces observatory biases that are consistent with those computed using DGRF 1980 (which we consider to be the most accurate main-field model for epoch 1980). We recommend that the candidate models for each of DGRF 1990, IGRF 1995, and the secular variation model for 1995–2000 be given equal weight.

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