GFZ Mag.num model as IGRF-13 candidate

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Intro

- The Earth's core magnetic field model `Mag.num` is the parent model for the GFZ IGRF-13 candidate submission. The model is based on geomagnetic ground observatory and Swarm satellite observations.
- Recently, global geomagnetic field models have shown that an additional, although shallow, secondary minimum of field intensity at Earth's surface has developed in the South Atlantic Anomaly since around 2005[1] . We investigate the development of this minimum over the recent years.

Modeling Results

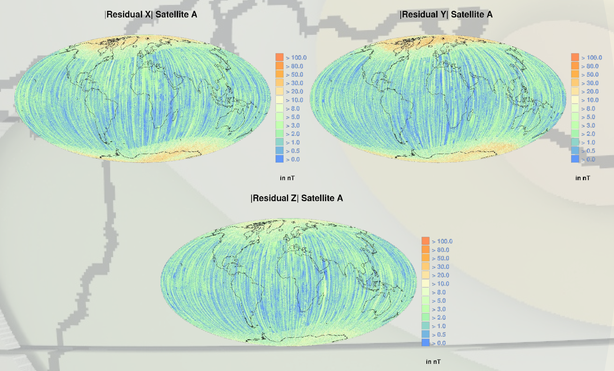
Residuals between the GFZ IGRF candidate model and data:

Type in 1	Number in 1	Bias in nT	Sigma in nT
1	266258	0.023	2.936
2	266258	-0.045	3.091
3	266258	0.215	3.215
11	773163	-1.892	37.740
12	773163	1.380	44.129
13	773163	-0.727	14.084
6	516072	0.184	3.634
7	516072	-0.136	3.737
8	516072	-0.038	5.107
16	114321	-0.541	10.432
17	114321	0.220	9.098
18	114321	-0.408	12.923

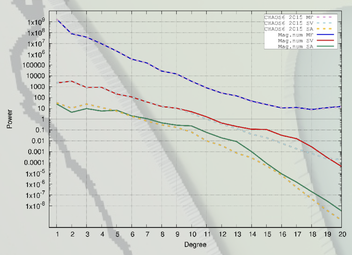
- Input data at the time of submission:
- Observatory data covered 2012-12-31 to 2019-06-27 and Swarm satellite data from 2013-11-27 to 2019-08-03.
- Epoch 2020.0 was not yet covered by the data and the estimate for that epoch was a prediction.

Type	Description
1,2,3	Satellite, X, Y, Z in GSM
6,7,8	Observatory, X Y, Z in GSM
11,12,13	Sat. in North, East, Center
16,17,18	Obs., North, East, Center

Residual Distribution



Power



- Main Field MF, in nT^2, secular variation SV, in nT^2/yr^2 and secular acceleration SA, in nT^2/yr^4, all for 2015.0;
- Less power in SA than the `CHAOS-6.x9` model[a] at low degrees. We aimed for a stiff model to account for the piecewise linear secular variation in `IGRF`.
- `IGRF` is truncated at SH degree 13 for main field and 8 for secular variation. The spectral behaviour at higher degrees therefore does not matter.

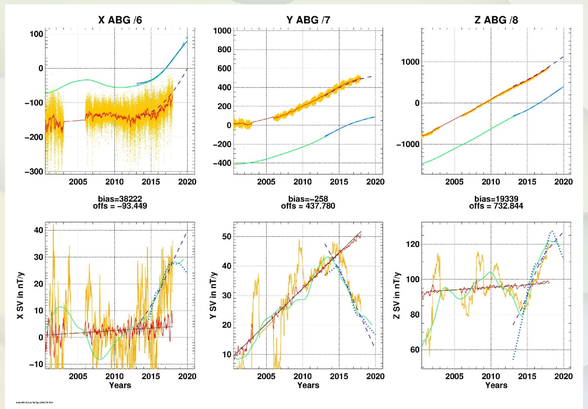
[a] Finlay et al. Earth, Planets and Space (2016) 68:112 DOI 10.1186/s40623-016-0486-1

[1] Terra-Nova et al., Relating the South Atlantic Anomaly and geomagnetic flux patches. *Physics of the Earth and Planetary Interiors*, 266:39–53, 2017.

Fit of various models to example observatory data

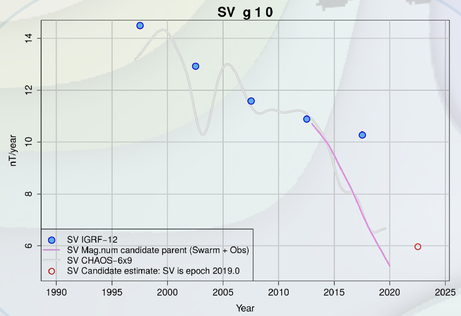
- Dashed blue line: `Mag.num` candidate parent
- orange-yellow scatter: Observatory data
- red and black lines: trend by heavy smoothing and linear fit;
- green long line: CHAOS-6 x9 model;
- blue dotted line: special `Mag.num` version by Swarm delta data based exclusively on along- and across-track differences;
- For the main field, the (`Mag.num`) estimated static observatory offsets are only applied to `Mag.num` (dashed blue line), subsequently the other appears biased – as expected.

ABG	Lat	18.52	Lon	72.87	Alibag, India



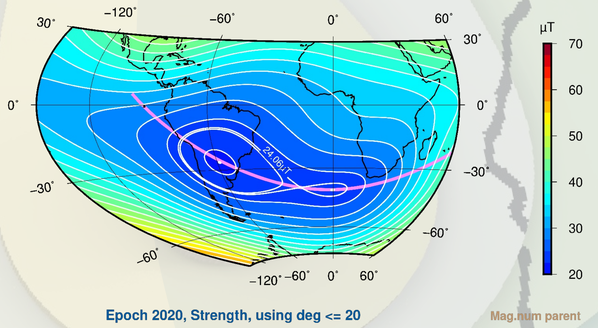
Derivation of IGRF SV candidate model

- Tailored for the IGRF:
  - Given that we opted for a model with stiff temporal behaviour, as required for the IGRF, the SV of our model is in good agreement with the SV of the CHAOS model.
  - As the trend of the SV signal may change faster than on 5 year intervals and might contain leakage from solar activity variation, we decided not to use any dedicated forecast built on the Swarm data period only. We finally have chosen to use the well data covered SV value of `Mag.num` of epoch 2019.

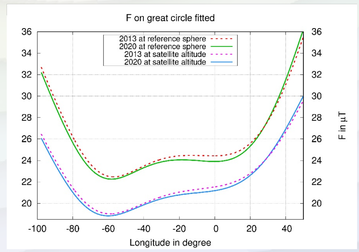


South Atlantic Anomaly

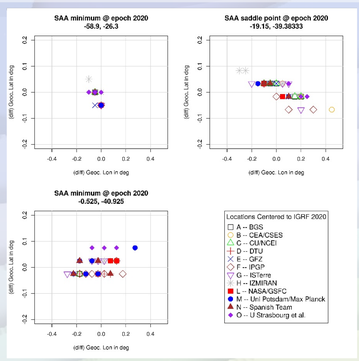
Geomagnetic Field Strength (at surface reference sphere)



- The minima are marked with white dots. The Great circle (light magenta) is fitted to minima and saddle points for [2013, 2020]
- Eastern weak minimum; shows extra contour lines for the saddle point (labeled) and both minima.



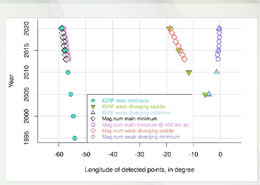
- Model predictions **along** the fitted circle on the reference sphere and at satellite altitude (assumed on 450 km)
- Stronger intensity decrease from 2013 to 2020 in the eastern, than the more pronounced western minimum
- Only an intensity plateau, but no second eastern minimum observed at satellite altitude.



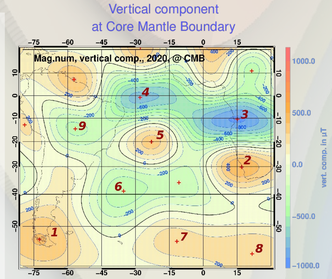
- Scatter in the locations of the two SAA minima and the saddle point from the comparison of all IGRF candidate models.
- The comparison of the SAA minima and drifts in all IGRF candidate models shows the robustness of our findings.

Drifts

Extrema points (min and max) are taken by applying GMT (version 5.4.3) function `grdmath` on a grid by forward calculation on numerically equidistant values in Latitude and Longitude;

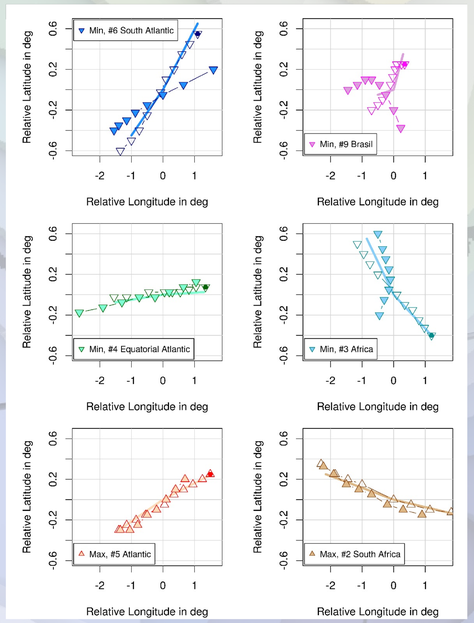


Vertical component
at Core Mantle Boundary



Continued westward drift of the western minimum and eastward drift of the eastern minimum at Earth's surface.

Relative drift of selected extrema (min and max) for `Mag.num` yearly for epochs 2013.0 to 2020.0, `IGRF` (2010, 2015, 2020) and `CHAOS` (2010 – 2019, 2010 marked with a full dot), centralized using the epoch 2015 value taken from IGRF.



- Full triangles `Mag.num`, hollow triangles `CHAOS`, solid lines: `IGRF`;
- all reverse flux patches are drifting westwards;
- on this fairly small scale, the drift for some CMB extrema of the models differ.

Conclusion

- We investigated the recent evolution of the SAA in the GFZ Mag.num model, which served as parent for our IGRF candidate models.
- A comparison with all other candidate models shows a good agreement of the location of the two minima without any prominent outliers.
- The individual IGRF parent models may differ in detailed drift behaviour at the CMB for prominent features. However, both CHAOS and Mag.num indicate that the westward drift of the eastern SAA minimum at Earth surface is not linked to eastward drift of reverse flux at the CMB. We propose that it is due to the interplay of several flux patches and their intensity changes.
- See paper submitted to EPS special issue, Rother et al. *The Mag.num core field model as a parent for IGRF-13, and the recent evolution of the South Atlantic Anomaly*
- and `https://www.gfz-potsdam.de/magmodels/`.

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