IGRF-14 Candidate Models Submitted by NOAA NCEI

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1) Submitted Models

Candidate for 2020.0 Main Field (DGRF)
Candidate for 2025.0 Main Field (IGRF)
Candidate for 2025.0-2030.0 Secular Variation (IGRF-SV)

2) Data Preprocessing

We used Level 1b MAGx_LR (1 Hz) Swarm data, baseline 0605/0606, from satellites Alpha and Bravo, covering the period from January 1, 2018, to September 30, 2024. Outliers were removed using various criteria, including data flags and the rate of change along the orbital track. The data were then decimated (one out of every ten) and selected for geomagnetic activity and local time using the following criteria:

- Kp < 1+, Kp (t-3h) < 1+
- |Dst| < 20 nT
- -3 nT < IMF By < 3 nT
- 0 nT < IMF Bz < 5 nT
- 0000 ≤ Local Time ≤ 0500

The data were corrected for the crustal field using the MF7 model and for the magnetospheric field using the CHAOS-7.18 external field model.

3) Parent Models

Twenty-four pairs of main field (MF) and secular variation (SV) models were fitted to one-year windows of data at epochs ranging from 2018.5 to 2024.25, using a 0.25-year time step. The fitting method was Iteratively Reweighted Least Squares (e.g., Olsen et al., 2002), using IGRF-13 as the starting model for each epoch, applying Huber weights, and removing outliers at the final iteration. The maximum spherical harmonic degree and order for the MF and SV models were 18 and 15, respectively. Both the MF and SV were slightly regularized. The MF was regularized using a minimum energy norm at the core (Gubbins, 1983). The SV was regularized with a single damping parameter applied to all coefficients.

Only vector data were used in the modeling that led to the candidate models. We tested different configurations with a mix of scalar (e.g., at high latitude) and vector data, but the quality of the models was consistently superior when using vector data only.

To validate each model, we inspected the model statistics (see Table 1) and examined plots of the power spectra, coefficient correlations, matrices of coefficient differences, and maps of spatial differences against independently derived reference models.

Table 1: Example of model statistics for parent model at epoch 2020.0. This model was derived from 55,086 vector triples at polar latitudes (above ±50 degrees geomagnetic dipole latitude) and 148,484 vector triples at non-polar latitudes. The number of parameters was 615. RMS stands for root mean square.

	Mean misfit (nT)	RMS misfit (nT)	Weighted mean misfit (nT)	Weighted RMS misfit (nT)
B_r (all latitudes)	0.02	1.64	0.04	1.43
B_θ (all latitudes)	-0.36	2.73	-0.19	2.22
B_ϕ (all latitudes)	-0.22	3.24	-0.19	2.56
B_r (polar latitudes)	-0.17	2.48	-0.10	2.01
B_θ (polar latitudes)	-0.95	3.92	-0.54	2.88
B_ϕ (polar latitudes)	-0.18	4.63	-0.22	3.42
B_r (non-polar latitudes)	0.10	1.18	0.09	1.16
B_θ (non-polar latitudes)	-0.13	2.13	-0.07	1.95
B_ϕ (non-polar latitudes)	-0.24	2.54	-0.18	2.22

4) Candidate Models Derivation

Cubic smoothing splines were fitted to the series of parent model coefficients. The DGRF candidate was extracted from the cubic splines at epoch 2020.0. The IGRF MF and SV candidates were determined by extrapolating the cubic splines using the spline time derivative at the last data point (2024.25).

5) Candidate Models Validation

A different set of candidate models was independently prepared using an alternative methodology and compared to the models presented here. For each model, the same plots and maps used for validating the parent models were prepared and examined.

In addition, the SV models were compared to the secular variation determined at 41 globally distributed ground-based observatories. We used hourly mean values compiled by the British Geological Survey for years 2015-2024 (Macmillan & Olsen, 2013; updated August 2024). We limited the observatories to those located below ±55 degrees geomagnetic latitudes. Most observatories had data coverage up to June 30, 2024, and all had coverage until June 1, 2024. We selected data for geomagnetically quiet condition (ap $\leq$ 10) and restricted the analysis to local times between 0000 and 0500 to reduce the influence of disturbance signals.

We fitted cubic splines with knots separated by one year for the X, Y and Z components in a least-square sense. Secular variation at each observatory was determined by subtracting the spline value at the beginning and end of a year window centered on the SV epoch. The spline model was then linearly extrapolated to 2025.0 using the slope at the last knot. We calculated the global mean and root mean square (RMS) of the differences between model SV and ground-based SV. The RMS errors were computed after removing the global means from all the differences (see Table 2).

Table 2: Mean and zero-mean root mean square (RMS) of the differences between secular variation inferred from the candidate SV model and observatory data at the 41 selected observatories.

	X Mean (nT/yr)	X RMS (nT/yr)	Y Mean (nT/yr)	Y RMS (nT/yr)	Z Mean (nT/yr)	Z RMS (nT/yr)
IGRF SV	0.14	4.63	-0.4	3.51	-0.73	3.86

References

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