IPGP main field candidate for IGRF 2020

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This short note provides some information on the way the IPGP candidate to the main field model 2025 for the IGRF-14, has been built. It is organised in three sections on magnetic data, on the modelling process and on the derivation of the IGRF 2025.

1 Magnetic data

1.1 Origin of the data sets

Two types of data are used :

- Hourly mean vector observatory data from all available observatories from 2021 to 2024.5 as provided through the files `SW_OPER_AUX_OBS_2` version 0141. (Macmillan & Olsen 2013)
- Satellite vector data from the SWARM-A satellite for the era spanning 2021 to 2024.5 as provided through the files `SW_OPER_MAGA_LR_1B` in their version 0606 or 0605 depending on availability.

No scalar magnetic field strength data are used. The full data set spans 2021. to 2024.5.

1.2 Selection criteria

We distinguish between "high latitude" (HL) data and "mid to low latitude" (ML) data. HL data are at magnetic latitudes $|\theta| > 55°$.

For all satellite data, the following criteria apply :

- ML data are selected for local times between 11.00 pm and 5.00 am, and rejected for sunlit ionosphere.
- Data are selected for positive values of the IMF vertical component: $B_{IMF}^{Z} > 0$.
- Data are selected for D_{st} values inside $[-30 : 30]\,nT$ and its variation $\dot{D}_{st}$ between $[-100 : 100]\,nT/day$
- Data are selected to one value per minute at HL , and one value every 30 seconds at ML.

For observatory hourly mean data, the following criteria apply :

- Data are selected for local times between 11.00 pm and 5.00 am, and rejected for sunlit ionosphere.
- Data are selected for positive values of the IMF vertical component: $B_{IMF}^{Z} > 0$.
- Data are selected for D_{st} values inside $[-30 : 10]\,nT$ and its variation $\dot{D}_{st}$ between $[-100 : 100]\,nT/day$

1.3 Data weights

The variances attributed to each type of data are given in the table 1.3. The inverse of the variances are used to weight the data.
HL data are handled in the usual North, East, Center (NEC) reference frame, whereas ML data are used in a Solar Magnetic (SM) reference frame, reducing this way the correlations between vector data component errors.

Component	Sat. ML	Sat. HL	Obs. ML	Obs. HL
X	$\sigma^2 = 9\text{nT}^2$	$\sigma^2 = 100\text{nT}^2$	$\sigma^2 = 16\text{nT}^2$	$\sigma^2 = 36\text{nT}^2$
Y	$\sigma^2 = 9\text{nT}^2$	$\sigma^2 = 81\text{nT}^2$	$\sigma^2 = 16\text{nT}^2$	$\sigma^2 = 25\text{nT}^2$
Z	$\sigma^2 = 16\text{nT}^2$	$\sigma^2 = 81\text{nT}^2$	$\sigma^2 = 25\text{nT}^2$	$\sigma^2 = 36\text{nT}^2$

Table 1: *Data variances for each data type*

2 Modelling method and model parameterisation

The approach used to build this candidate is an iterative Kalman filter process. It consists in two successive steps : analysis and prediction. Forty five iterations of the Kalman filter are necessary to cover the full data time span. These are followed by a smoothing process. The approach is the same as in (Ropp & Lesur 2023). The time step of the Kalman process is 365.25/4 days. The output of the process is a series of snap-shot models of the core and the secular variation 365.25/4 days apart.

2.1 Model definition

All sources (except the observatory offset) are described through spherical harmonics. The model includes at each Kalman filter step the following sources :

- Constant main field (up to SH degree 18)
- Constant secular variation (up to SH degree 18)
- Lithospheric field (from SH degree 15 to 30) - A known crustal field (Lesur et al. 2013) is subtracted from the data for degrees 30 to 110.
- Static external field in GSM coordinate system (SH degree 3)
- Static external field in SM coordinate system (SH degree 3)
- D_{st} dependant external field (SH degree 3)
- IMF B_Y dependant field in SM coordinate system (SH degree 3)
- Internal induced field generated by magnetospheric sources (SH degree 6)
- Internal induced variation field (SH degree 6)
- D_{st} dependant induced field in SM(SH degree 3)
- Observatory offsets (3x219 parameters)

The model also includes a description of the core surface flow, but it does not affect significantly the core field model derived and is not presented here.

2.2 Prior information

For each analysis Kalman step, the prior information of each model component is provided through the description of a Gaussian distribution characterised by a mean and a covariance matrix. This information is derived from the combination of the outputs of the previous Kalman prediction step with the default prior information setting. At the initial Kalman analysis step, the model and associated covariance matrix for year 2020.8 of the Swarm `L2` model `SW_OPER_MCO_SHA_2Y` is used to predict a first model. The default settings are the same as in Ropp & Lesur (2023)

Between each analysis step all model components, outside the main field, are predicted assuming AR1 stochastic processes with given time scales. These are set to 11years for the SV, infinity for the lithosphere and 100 days for the observatory offsets such that possible baseline errors are not detrimental to the modelling process. Other components are assumed to have time scales shorter than the analysis time interval ($\simeq 91$ days).

3 Estimation of the IGRF 2025

The series of field models derived through the iterative Kalman filter process has been built over the time interval 2021-2025, extending a pre-existing series that started in 1999. It includes snapshots of the main field and a co-estimated secular variation. Although a field model for 2025 is part of the modelling process, the SV and core field model from 2024 to 2025 are not as accurate as the models built for previous years. Therefore the candidate main field for 2025 is estimated by linear extrapolation of the 2024 core field and SV models. The posterior covariance matrices that are outputs of the Kalman filter process, are also extrapolated to 2025. Their diagonal elements give the formal variances of the model parameters. The model candidate IGRF_2025 is therefore provided together with the square-root of diagonal covariance matrix elements as uncertainty estimates.

References

Lesur, V., Rother, M., Vervelidou, F., Hamoudi, M. & Thébault, E. (2013), 'Post-processing scheme for modeling the lithospheric magnetic field', *Solid Earth* **4**, 105–118.
URL: *www.solid-earth.net/4/105/2013/*

Macmillan, S. & Olsen, N. (2013), 'Observatory data and the swarm mission', *Earth, Planets and Space* **65**(11), 1355–1362.

Ropp, G. & Lesur, V. (2023), 'Mid-latitude and equatorial core surface flow variations derived from observatory and satellite magnetic data', *Geophysical Journal International* . ggad113.
URL: *https://doi.org/10.1093/gji/ggad113*