

Compiled aeromagnetic anomaly data improving the spatial resolution of the lithospheric magnetic field model of China and surroundings

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Research background and motivation

Understanding and modeling the Earth's magnetic field, especially its lithospheric component, is fundamental to both geoscientific research and practical applications such as geological interpretation, resource exploration, and magnetic navigation. Among the various contributors to the geomagnetic field, the lithosphere produces relatively high-amplitude, small-scale magnetic anomalies—often reaching tens of thousands of nanoteslas in regions with strong magnetization—which require high-resolution models for accurate characterization.

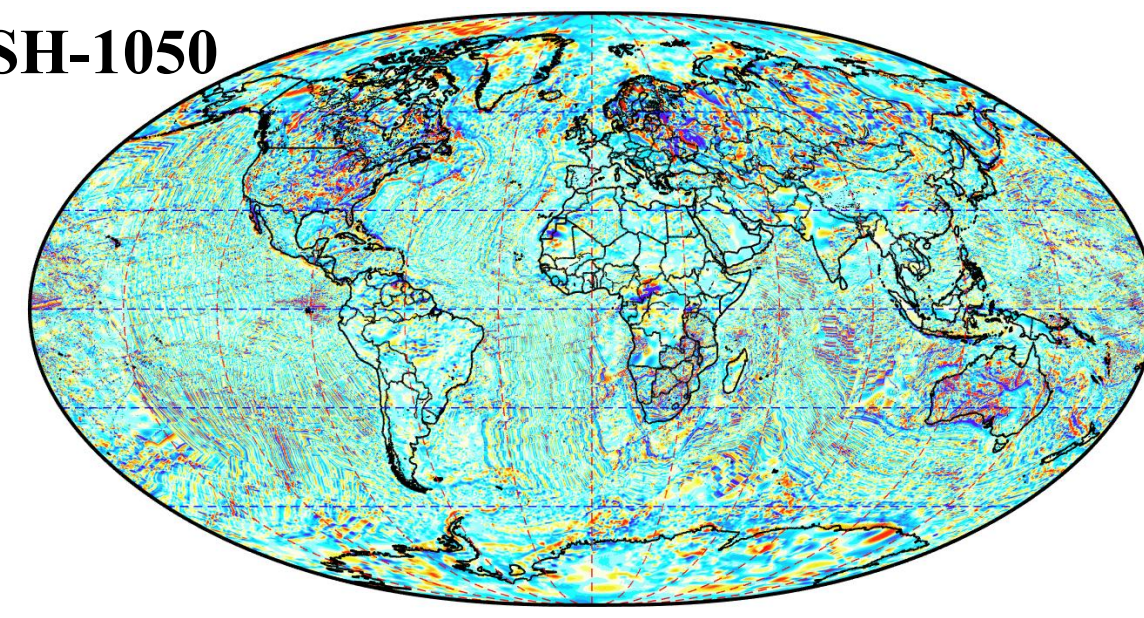
What is CUG_CLMFM3D ?

The CUG_CLMFM3D series comprises high-resolution three-dimensional lithospheric magnetic field models for China and its surroundings.

What's new in the updated model?

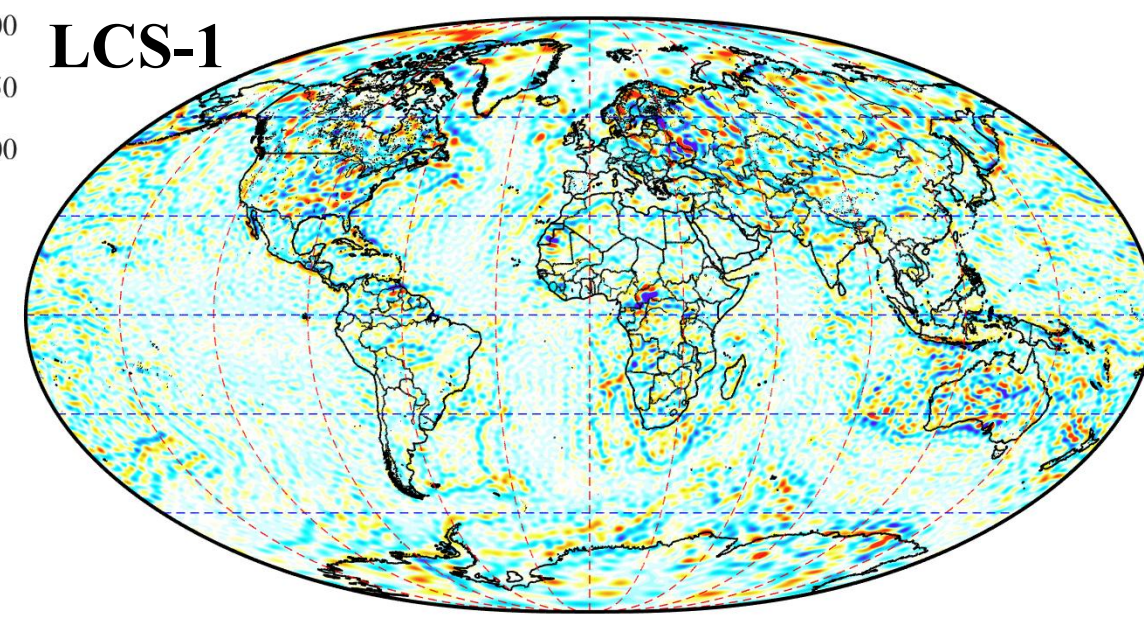
The first version, CUG_CLMFM3Dv1, is a spherical cap harmonic model integrating the WDMAMv2 (World Digital Magnetic Anomaly Map version 2) global magnetic anomaly grid and nearly a decade of CHAMP (Challenging Minisatellite Payload for Geophysical Research and Application) satellite vector data. It achieves a ~5.7 km resolution but has limitations: the WDMAMv2 grid lacks high-resolution data in the southern Xinjiang and Tibet regions, which leads to missing small- to medium-scale anomalies, and unfiltered CHAMP data introduce low-frequency conflicts with global spherical harmonic models. Above the altitude of 150 km, correlations with global models drop below 0.9. The second version, CUG_CLMFM3Dv2, addresses these issues by incorporating 5-km-resolution aeromagnetic data and rigorously processed satellite data from CHAMP, Swarm, CSES-1, and MSS-1. The comparison analysis shows that the CUG_CLMFM3Dv2 captures finer high-frequency details and more stable long-wavelength signals, offering improved magnetic anomaly maps for further geological and geophysical studies.

SH-1050



Lithospheric magnetic field models based solely on satellite data can achieve a resolution of approximately 108 km (e.g. LCS-1, Olsen et al., 2017)

When near-surface data are incorporated, the resolution can be improved to approximately 19–25 km (e.g. EMM2017; WDMAMv2, Lesur et al., 2016; SH1050, Thébaud et al., 2021.)



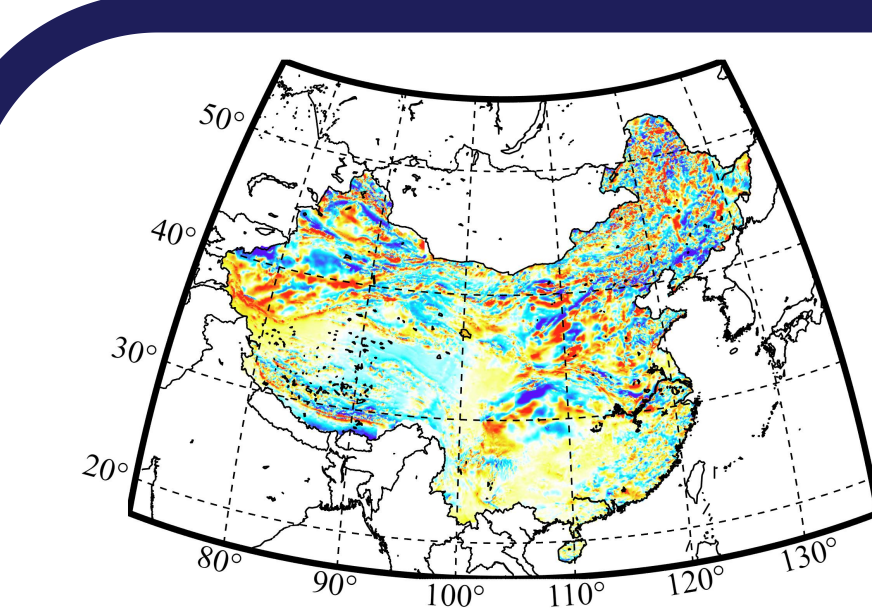
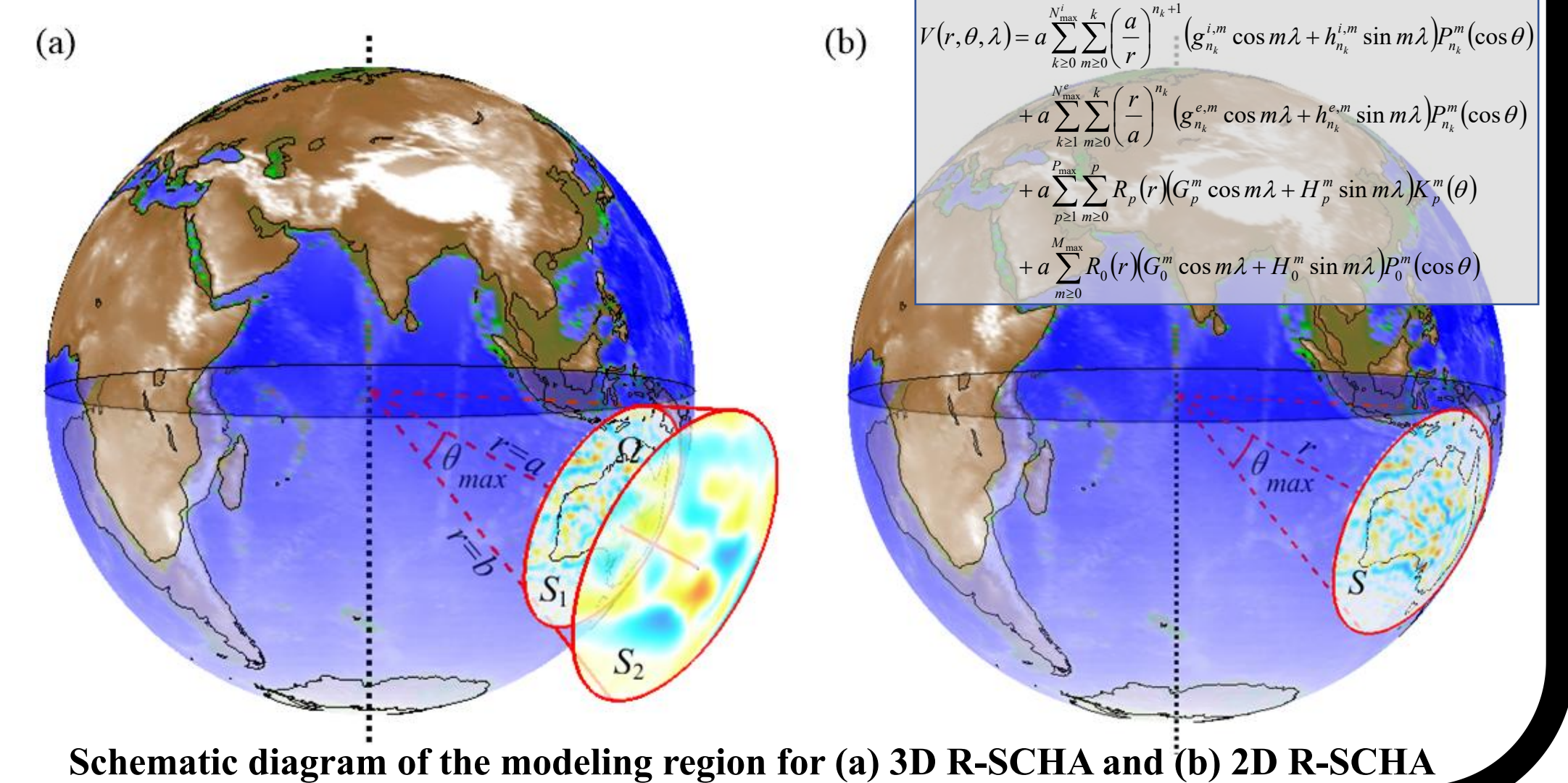
Previous studies have shown that lithospheric magnetic field models based solely on satellite data can achieve a resolution of approximately 108 km (e.g., LCS-1, Olsen et al., 2017). However, when near-surface data are incorporated, the resolution can be improved to approximately 19–25 km (e.g., EMM2017; WDMAMv2, Lesur et al., 2016; SH1050, Thébaud et al., 2021). These global models, however, rely on near-surface data from sources such as the EMAG2v3 (Meyer et al., 2017) or WDMAMv2 (Lesur et al., 2016), which use datasets with limitations in East Asia. Specifically, the lack of high-resolution data in the southern regions of Xinjiang and Tibet leads to missing small- to medium-scale details in these areas (e.g., Luo Y et al., 2024).

Model Parameterization

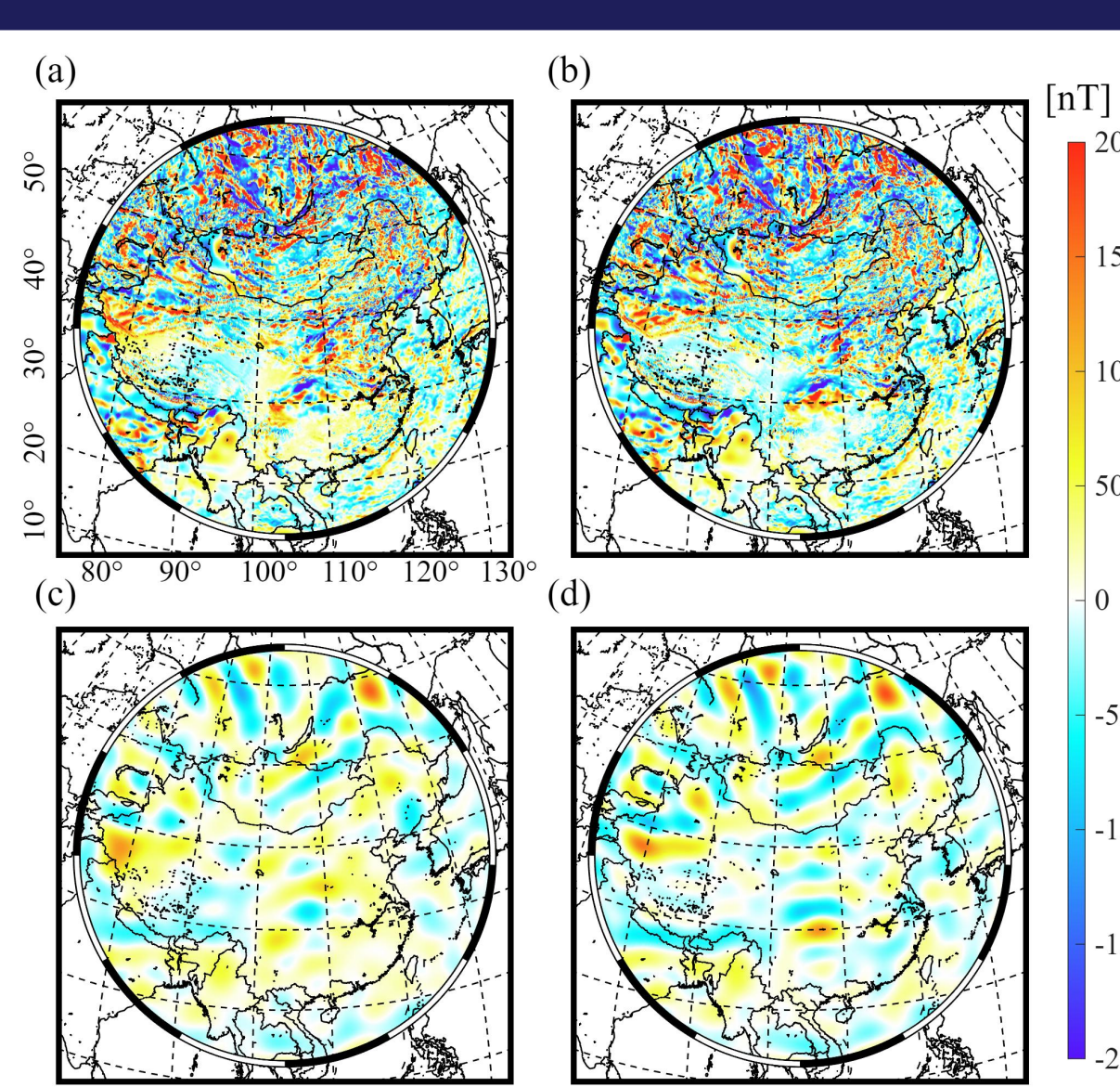
Revised Spherical Harmonic Analysis, R-SCHA

Revised spherical cap harmonic analysis (Thébaud, 2003; Thébaud et al., 2004, 2006a) is a potential field modeling technique applied at a regional scale.

The completeness, orthogonality, and convergence of the basis functions, along with the null flux condition of the method, make R-SCHA effective for potential field modeling and forward prediction. As a result, this analysis has been widely used in lithospheric magnetic field modeling (e.g., Vervelidou et al., 2018; Thébaud et al., 2021; Zhang P et al., 2024), main magnetic field modeling (e.g., Talarn et al., 2017), and paleomagnetic field modeling (e.g., Pavón-Carrasco et al., 2021; Fan YC et al., 2024), among others.



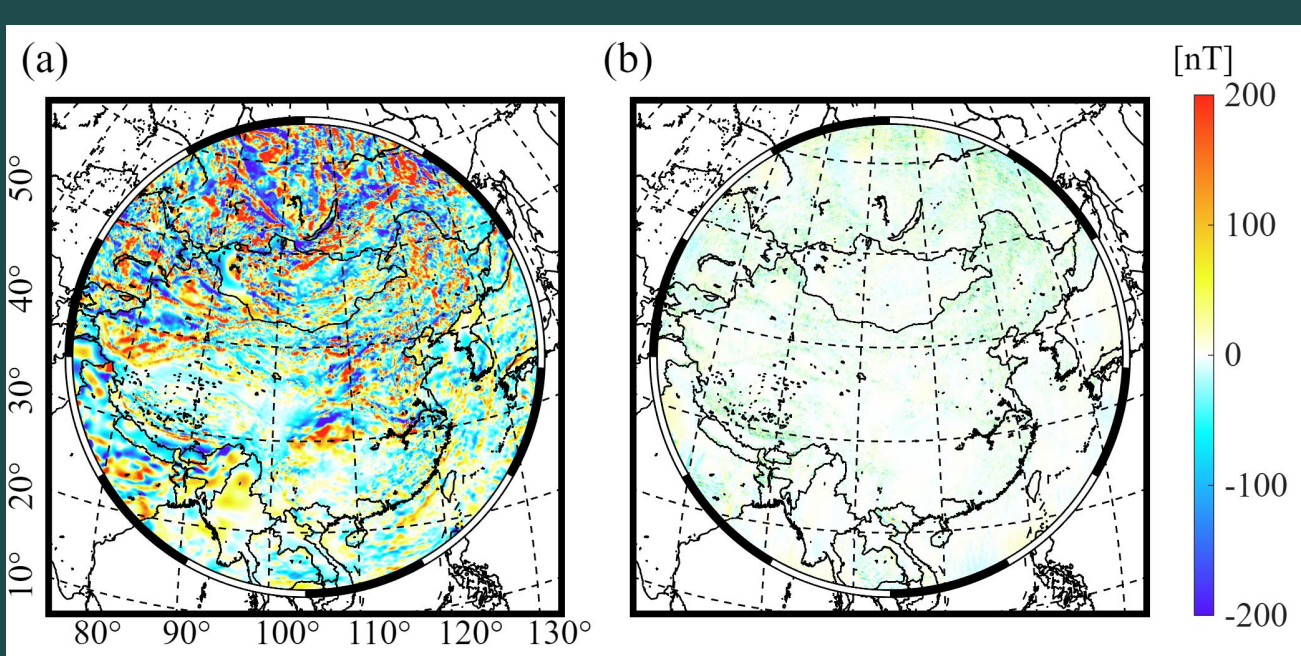
- The compiled airborne magnetic anomaly map of continental China is used as the near-surface data for the modeling;
- To maintain the integrity of the near-surface data, we embedded the continental China magnetic data into the EMAG2v3 compiled global magnetic anomaly grid (Meyer et al., 2017);
- To prevent computational instability due to low-frequency conflicts between near-surface and satellite-surveyed data, we utilized an extraction and replacement scheme (Zhang P et al., 2022).



- The LIB products from the CHAMP (Maus, 2007; time period: 07/19/2000 to 09/17/2010), Swarm Alpha and Bravo (Friis-Christensen et al., 2006; Olsen et al., 2016; time period: 01/01/2014 to 12/31/2024), CSES-1 (Shen XH et al., 2018; Yang YY et al., 2021; time period: 01/01/2024 to 07/31/2024), and MSS-1 (Zhang KK, 2023; time period: 11/02/2023 to 12/31/2024) satellite missions were collected.
- Only data from periods of the Earth's relatively low magnetic activity were retained.
- The contributions from the core field and the external field were simulated and extracted using the CHAOS-8.2 model.
- A high-pass spherical harmonic filter (Thébaud et al., 2017) with a degrees/orders of 15 was designed to remove the uncorrected low-frequency signals.
- Finally, vector data from regions equatorward of $\pm 55^\circ$ magnetic latitude were further selected

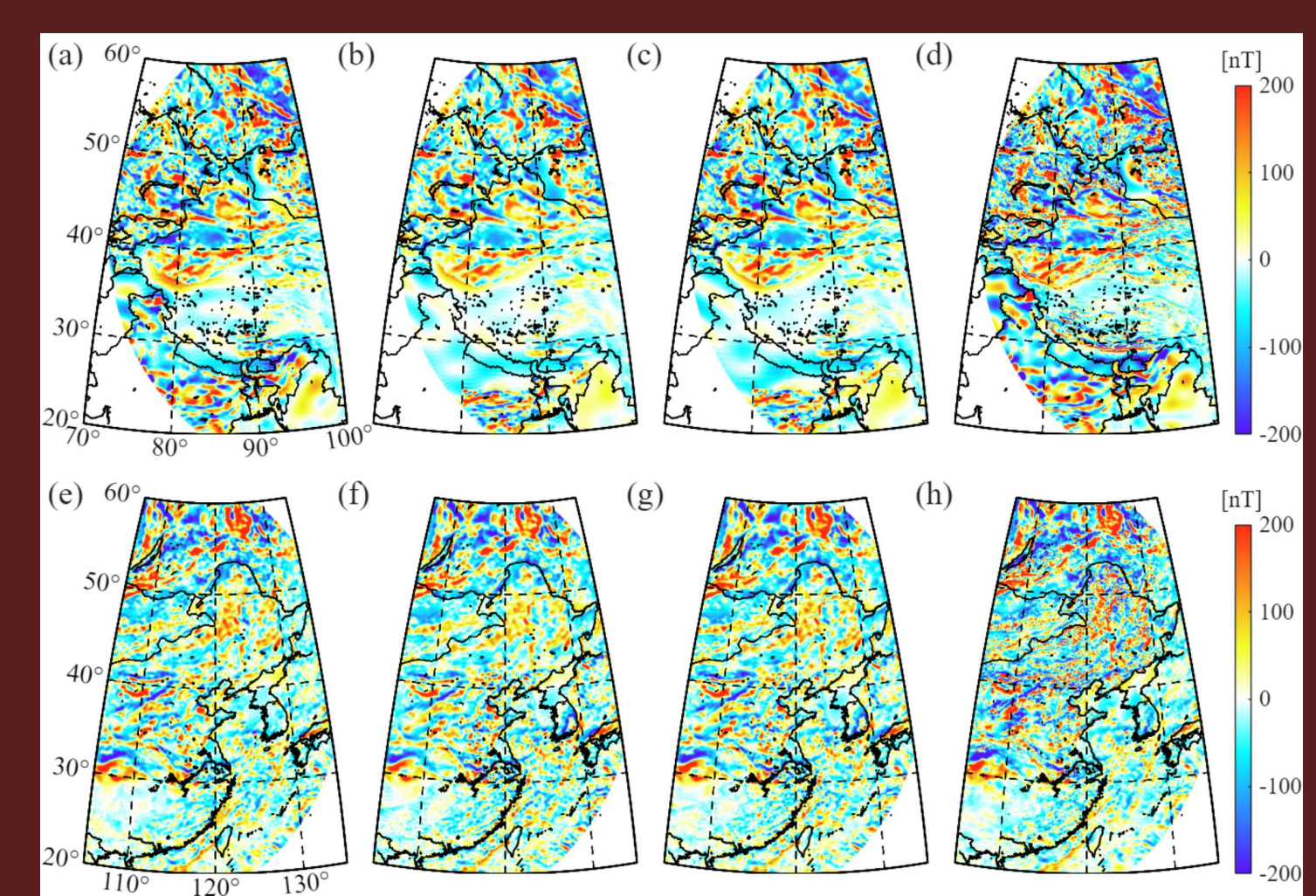
Modeling parameters and data fit analysis

- The aperture of the cone θ_0 is set to 27° (1° larger than the data selection area), and the radii of the two spherical caps r_1 and r_2 are set to $a - 15$ km and $a + 550$ km, respectively. This setup mitigates the Gibbs effect by ensuring that the modeled area is fully covered and slightly larger than the coverage of the modeling data.
- The maximum truncation indexes of the internal and external Legendre basis are set to 530 and 18, respectively, allowing the model to achieve up to 3500 and 120 spherical harmonic degrees/orders at the near surface and 300 km altitude, respectively. The maximum truncation index for the Mehler and constant basis is set to 3, considering the data gap between the near-surface and satellite data.
- The inverse of the standard deviation for both near-surface and satellite data is used as the data weight in the optimization to balance the model fit across different data sets.

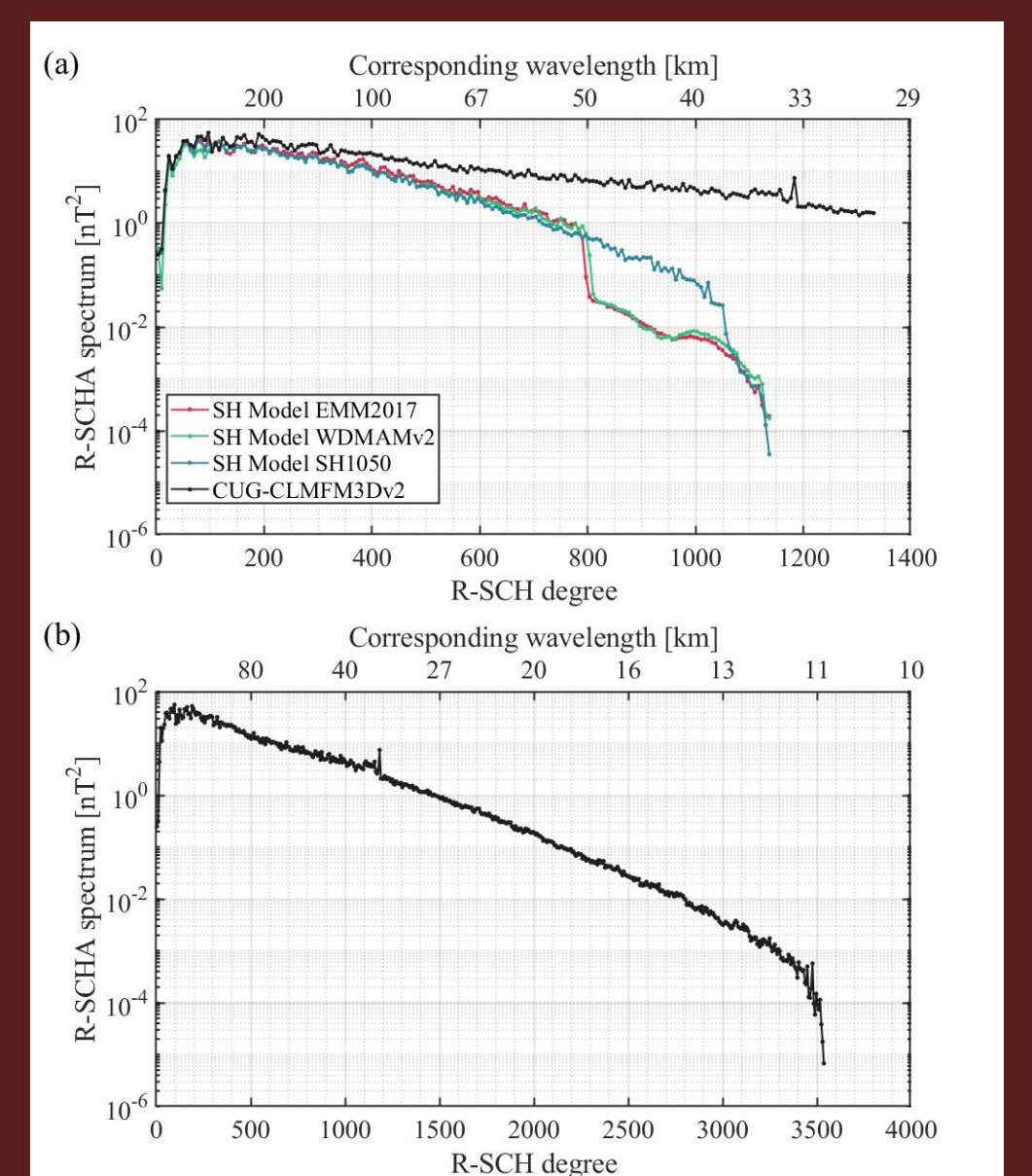


The reconstructed data and fitting residuals demonstrate that the model has successfully captured the details of lithospheric magnetic anomalies across all scales. The unfitted anomalies in the near-surface data are predominantly short-wavelength features that fall beyond the resolution capability of the model. In the satellite data, the unfitted signals primarily appear in the northern and eastern components, where high-amplitude noise is distributed along the satellite orbit. Compared with CUG_CLMFM3Dv1, the low-frequency replacement process in the near-surface data and the along-track filtering applied to the satellite data have effectively eliminated any low-frequency conflicts between the two datasets.

Comparison in the spatial and frequency domain



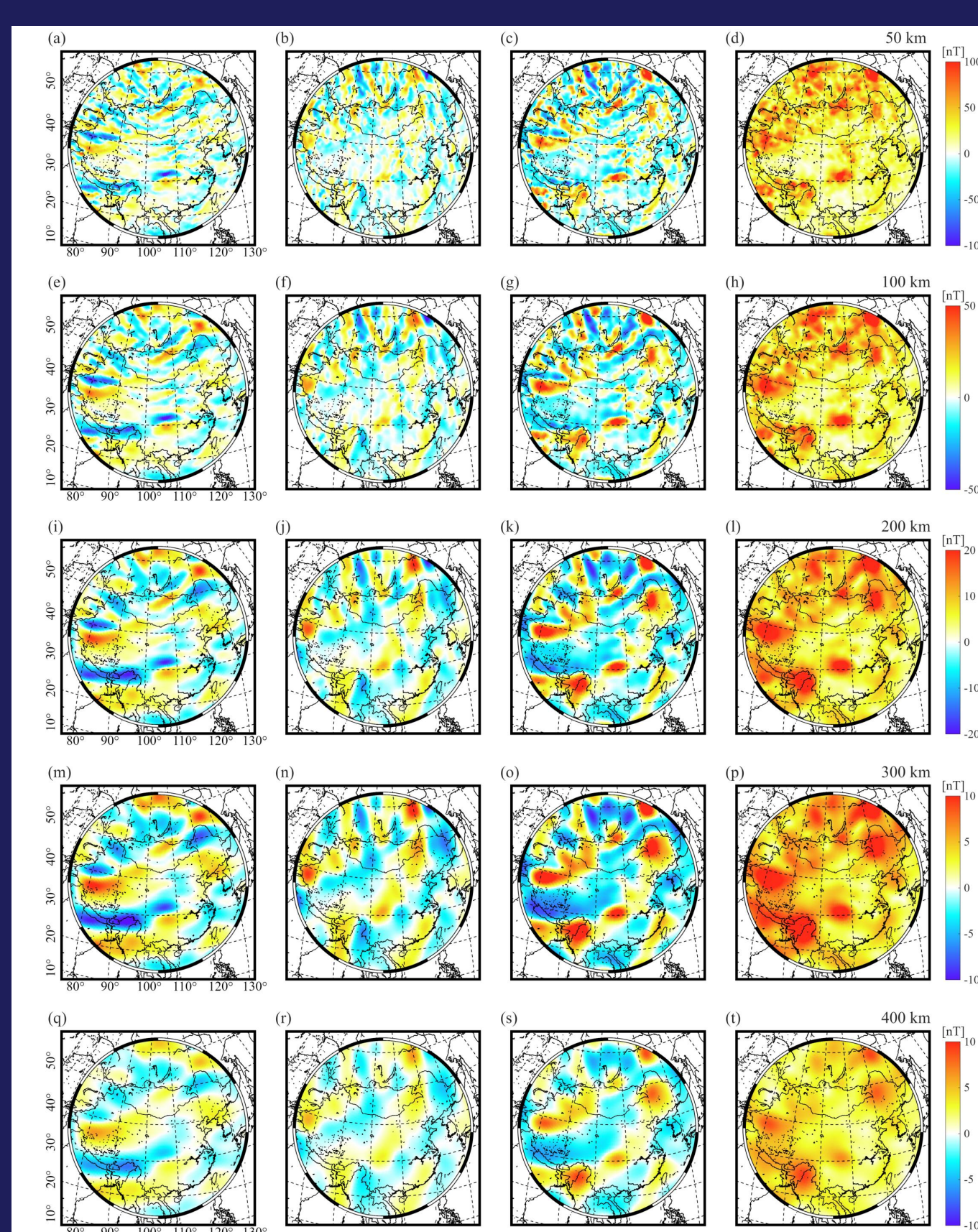
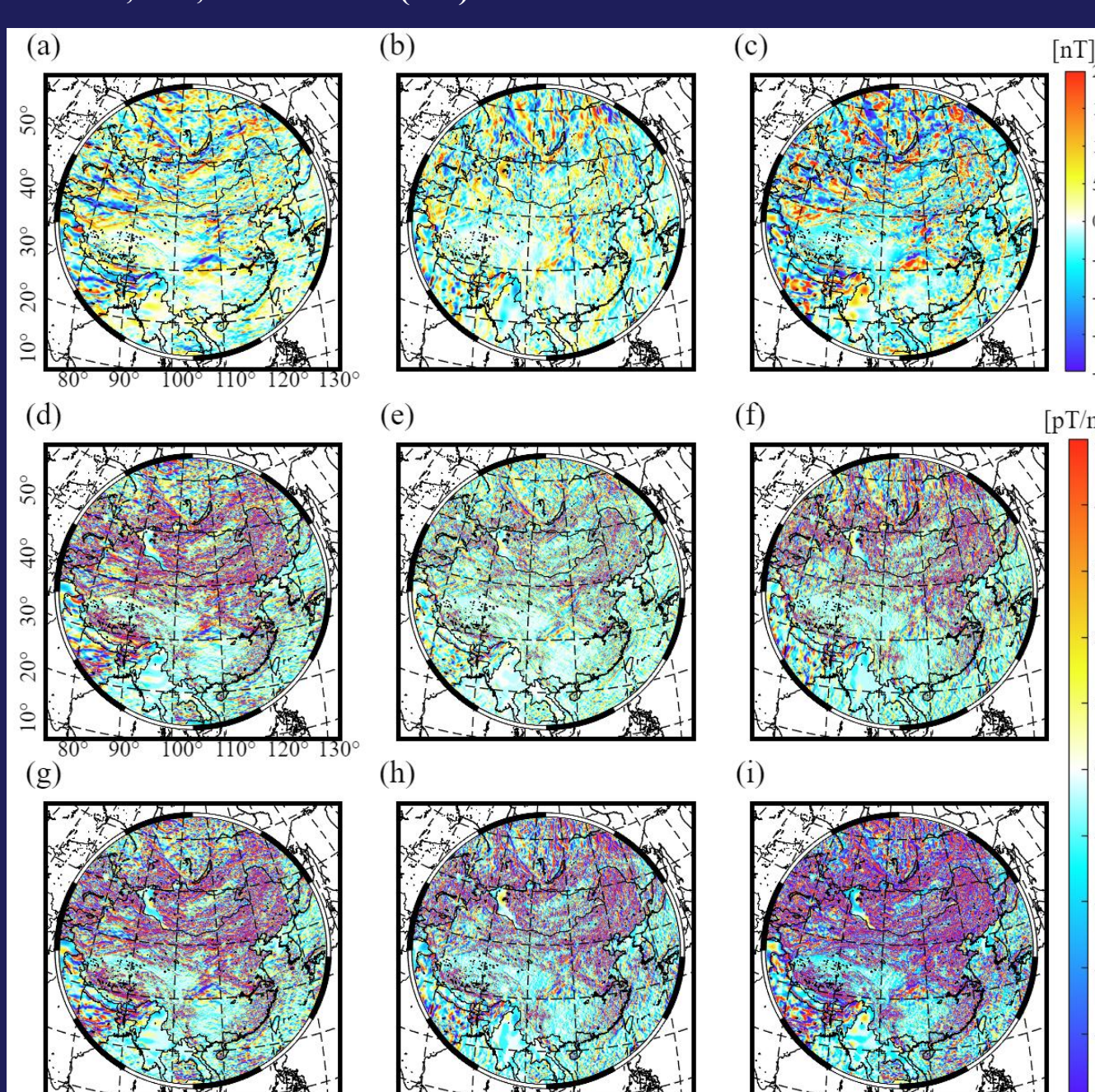
- The spectral analysis reveals that the regional model aligns well with global models up to spherical harmonic degrees/orders of 200 and exhibits higher energy in the medium- to high-frequency range.
- Whereas the global models show a sharp decay at their truncation degrees/orders, indicating no energy beyond the associated wavelengths, the CUG_CLMFM3Dv2 model demonstrates an exponential energy decrease with increasing R-SCH degree, without a sudden cutoff. This continuity suggests a more gradual and comprehensive representation of higher frequency components.



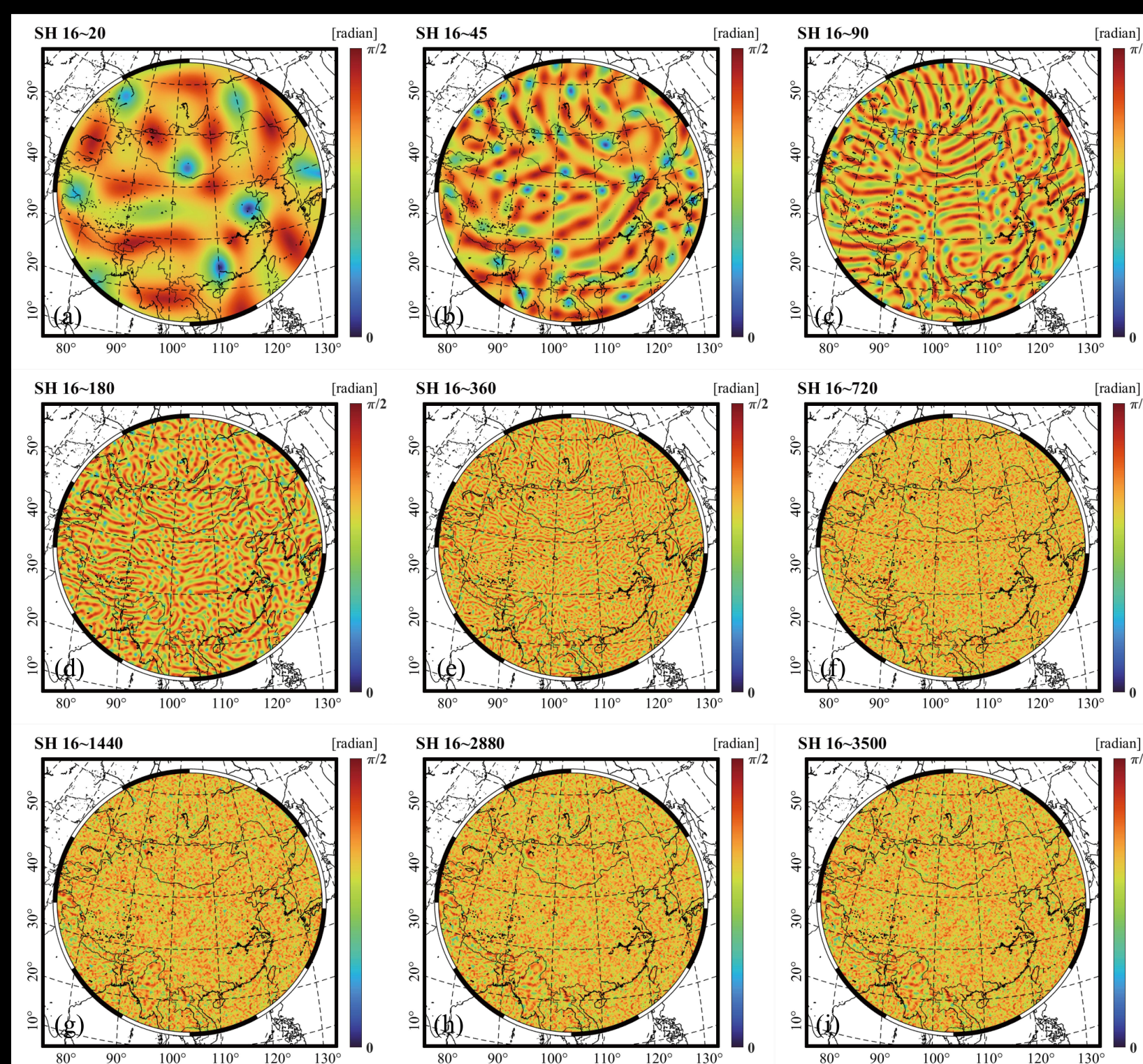
- CUG_CLMFM3Dv2 exhibits a higher resolution. The morphology and amplitude of the small-scale magnetic anomalies in CUG_CLMFM3Dv2 are closer to observed data, capturing finer details with improved accuracy.
- Global models exhibit low-frequency characteristics and small-scale artifact oscillations in data-vacant areas, in contrast, CUG_CLMFM3Dv2 integrates high-resolution near-surface data, which supplements fine details of magnetic anomalies and, like CUG_CLMFM3Dv1, avoids small-scale oscillatory artifacts in regions previously limited to low-resolution data coverage.

Forward predictions at multiple altitudes

- The 1st- and 2nd- rank magnetic tensor components, forward computed by the obtained R-SCHA model at 0 km altitude (right);
- The magnetic vector and module components at altitudes of 50, 100, 200, 300, and 400 km (left).



Magnetic signal boundary detection and tectonic information



Main References
Thébaud, et al., 2006, JGR, Modeling the lithospheric magnetic field over France by means of revised spherical cap harmonic analysis (R-SCHA).
Zhang et al., 2025, IAGLR, A high-resolution lithospheric magnetic field model of China and surroundings by using CHAMP, Swarm, CSES-1, and MSS-1 satellite magnetic measurements and aeromagnetic anomaly data.

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