A time variation of the lithospheric magnetic field and tectonic interpretations of a vertically-integrated magnetic susceptibility

Abstract

The Earth lithospheric magnetic field is one of the main objectives of ESA's ongoing satellite constellation mission Swarm (in orbit since 2013, Friis-Christensen, 2006). Excluding the oceanic remanent part from this field, a continental lithospheric field can be represented by two quantities - the vertically-integrated susceptibility (VIS) and the inducing core field. The inducing core field acting on magnetically susceptible rocks of the lithosphere necessarily produces a subtle time variable component of the lithospheric field. Thus, the lithospheric field can be considered static only over a certain period. An increasing accuracy and length of satellite magnetic time series may make this subtle signal observable soon. In this contribution we focus on two applications of VIS: the time variation of the induced lithospheric magnetic signal over the period of 25-30 years.

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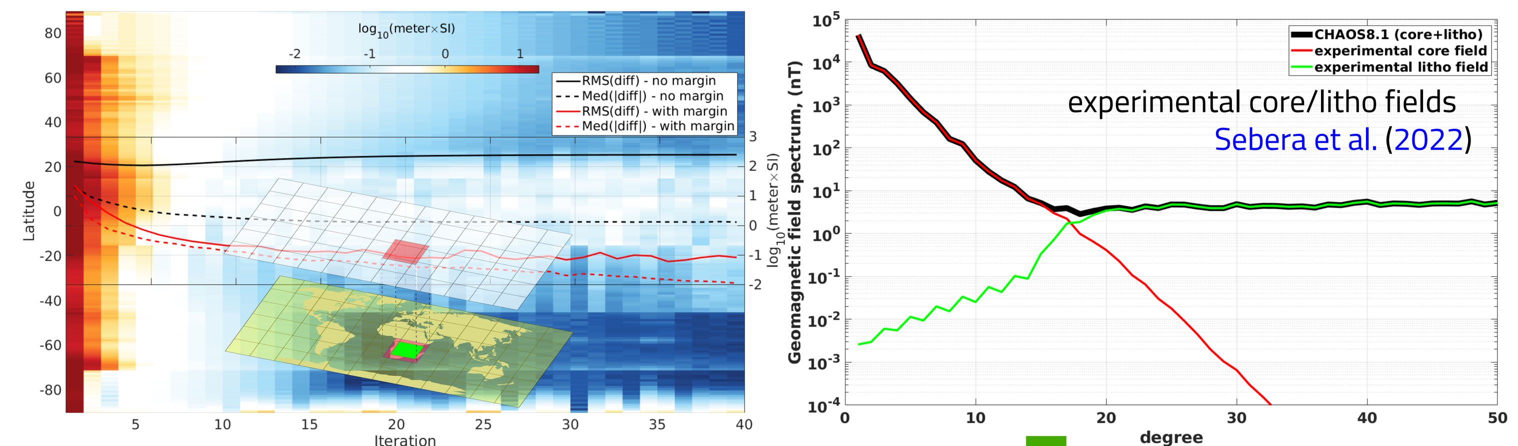
Motivation

* To represent magnetic (vector) field of the lithosphere with a rock-related quantity - vertically integrated susceptibility (VIS)
* Geologic/tectonic applications/interpretations of satellite magnetic data
* To evaluate a slow/tiny variation of the induced lithospheric field

Inversion strategy (Sebera et al., 2019)

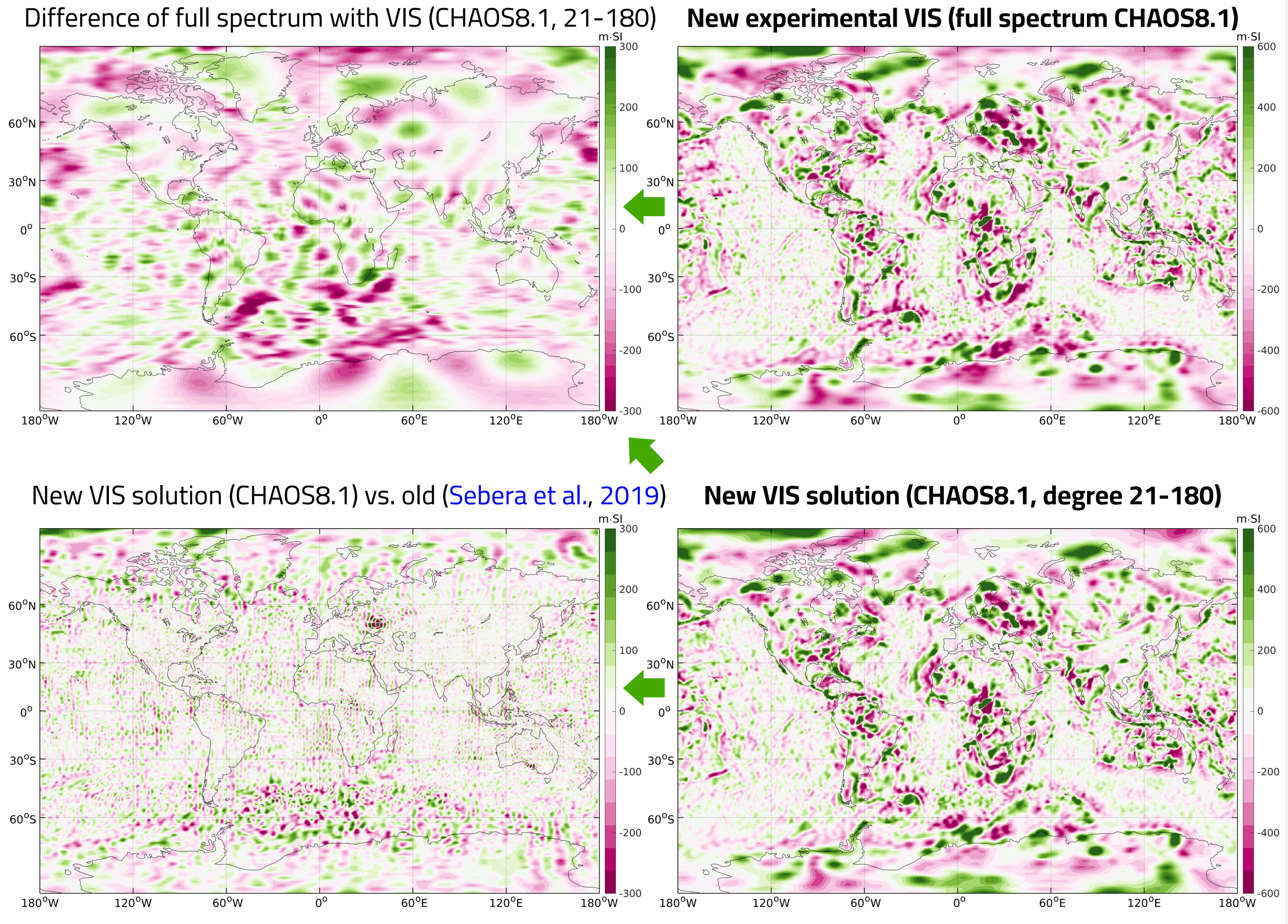
$$\phi_{\mathrm{litho}}(t) = \underbrace{\frac{1}{4\pi}\int\left[\vec{B}^{t}_{\mathrm{core}}\cdot\vec{G}\right]\mathrm{Susc}\,\mathrm{d}S}_{\substack{\text{induced}\\ \text{(follows the main field)}}} + \underbrace{\frac{1}{4\pi}\int \mu_0 I_0\left[\vec{\nu}\cdot\vec{G}\right]\mathrm{d}S}_{\substack{\text{remanent}\\ \text{(geologically slow variation)}}}$$

1a. CHAOS8 (21-180) => $\mathbf{B}_{\mathrm{litho}}$={Bx, By, Bz} (Kloss et al., 2024)
1b. CHAOS8 core (1-20) => **B**core={Bx, By, Bz}
2. Remove remanent signal $\mathbf{B}_{\mathrm{input}} = \mathbf{B}_{\mathrm{litho}} - \mathbf{B}_{\mathrm{remanent}}$
3. Determine VIS (iterative tile-wise inversion)



Convergence wrt latitude

VIS maps and the differences



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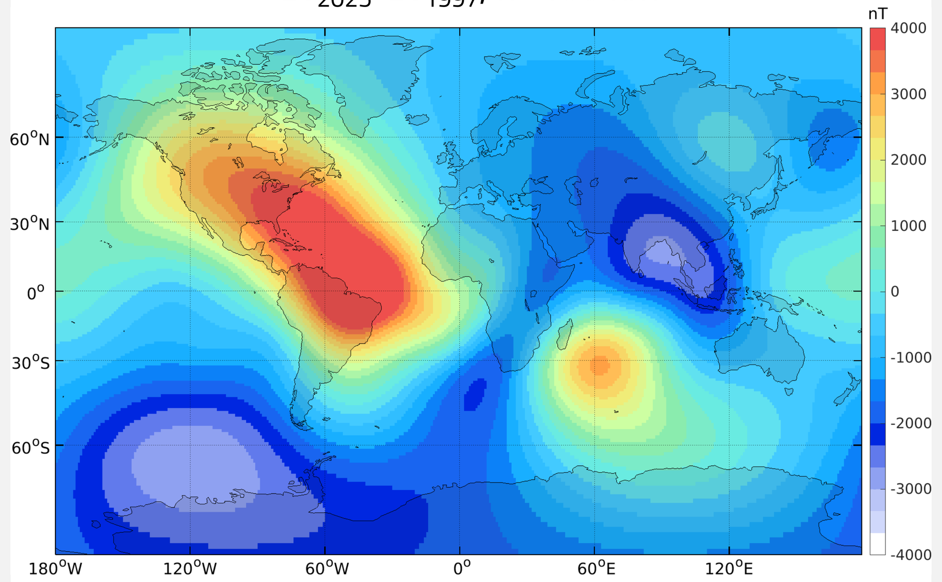
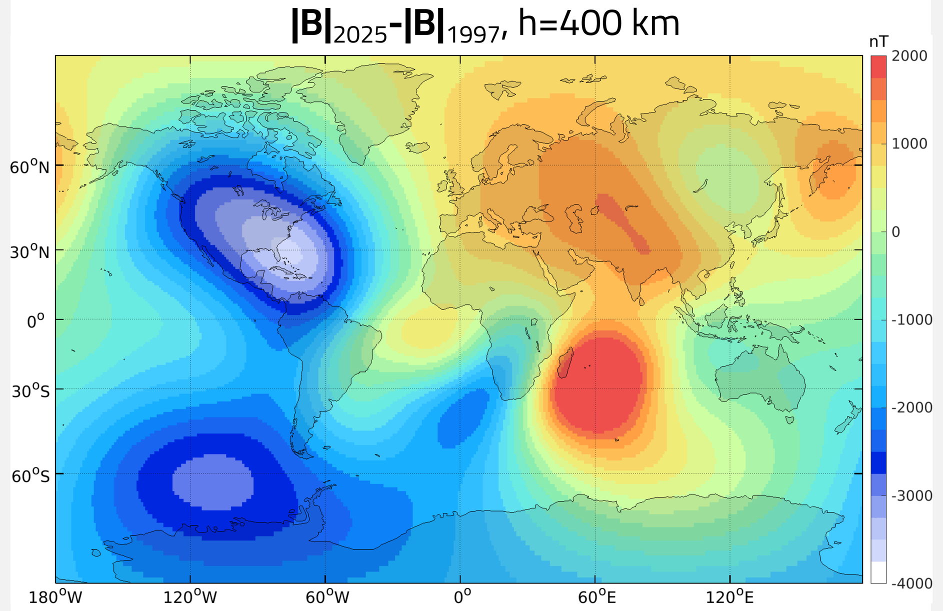
Time variation

Core field time change (2025-1997)

$\mathbf{Br}_{2025}$-$\mathbf{Br}_{1997}$, h=400 km

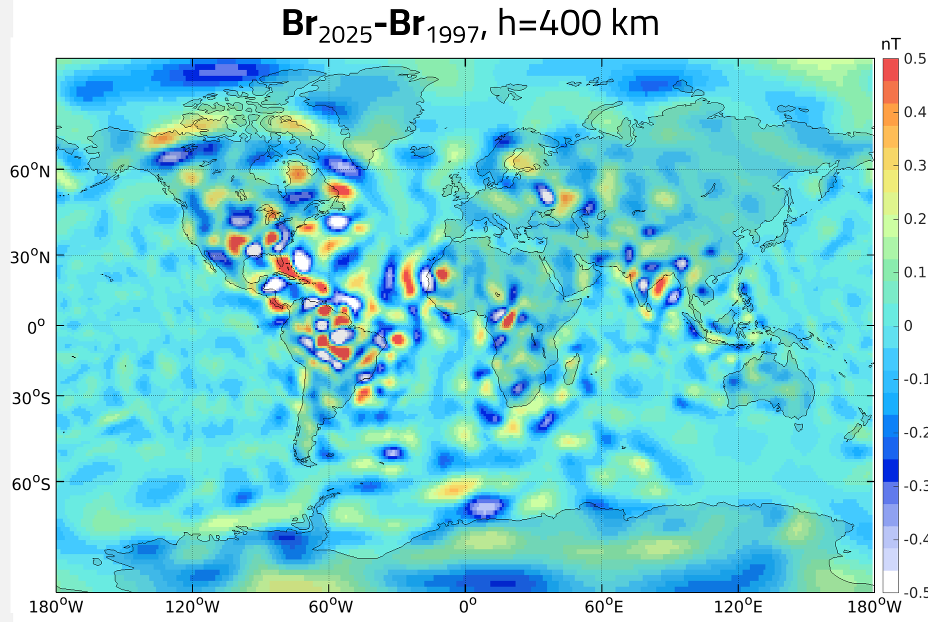


$|\mathbf{B}|_{2025}$-$|\mathbf{B}|_{1997}$, h=400 km

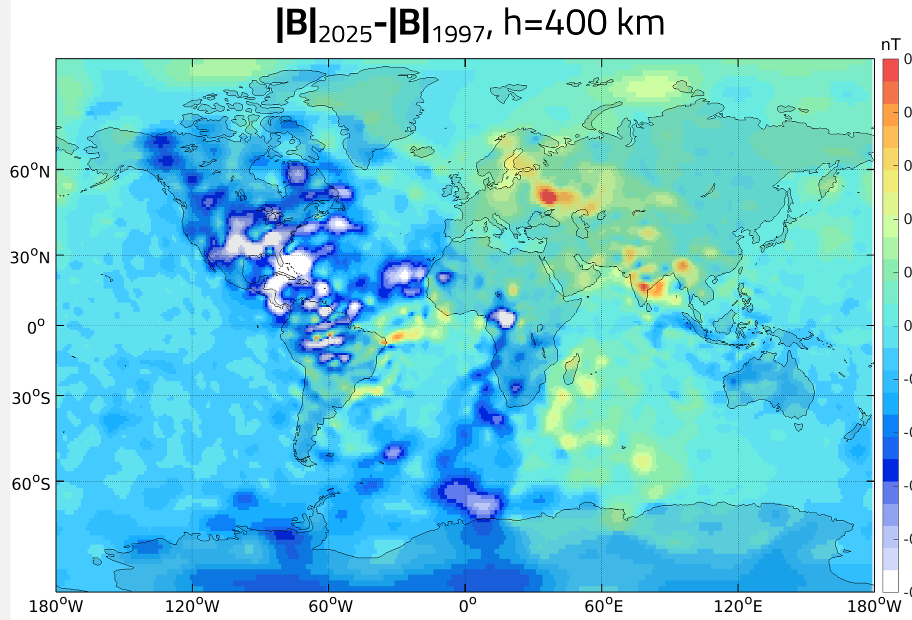


Lithospheric field time change (2025-1997)

$\mathbf{Br}_{2025}$-$\mathbf{Br}_{1997}$, h=400 km



$|\mathbf{B}|_{2025}$-$|\mathbf{B}|_{1997}$, h=400 km



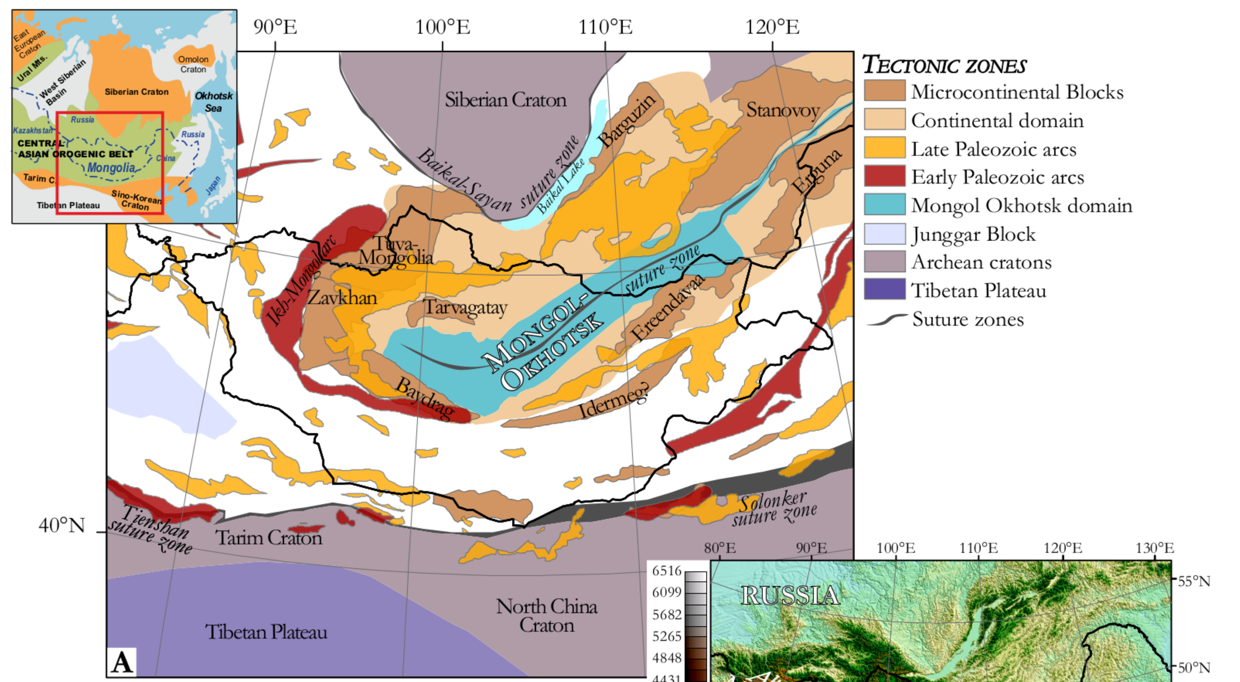
Correlation between VIS and litho-scale structures of Central Asia: tectonic implications

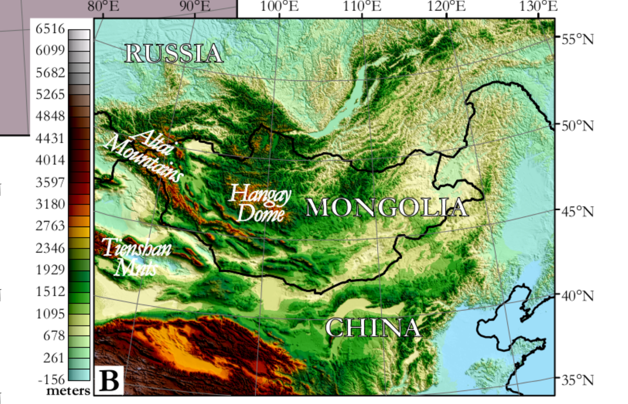
1. Tectonic and geological setting of the Central Asian Orogenic Belt

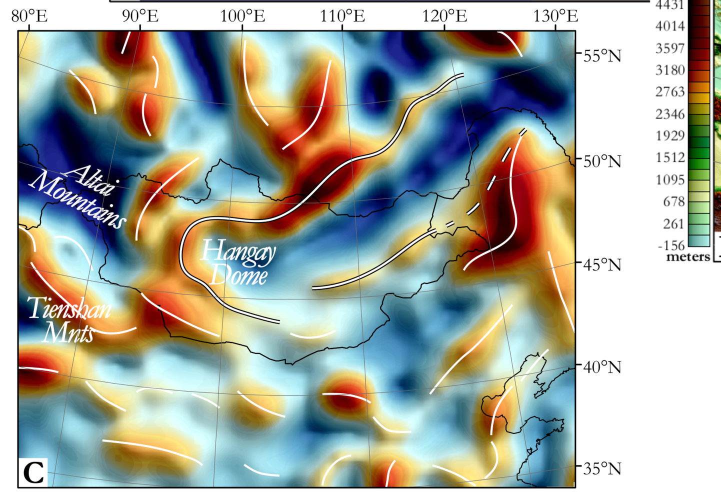
The Central Asian Orogenic Belt (CAOB), the world's largest accretionary orogenic system, is located between the Siberian Craton to the north, and the Tarim and North China cratons to the south (**Fig. A inset**). It is composed of a complicated tectonic mosaic of microcontinental blocks, island arcs, accretionary wedges, back-arc basins and oceanic domains (e.g. Windley et al. 2007) developed during the Neoproterozoic–Mesozoic (e.g. Wilhem et al. 2012). It formed by Neoproterozoic breakup of Rodinia and ended with formation of the eastern tract of the Pangea supercontinent in Triassic (Stampfli et al. 2013). In its eastern part, the CAOB contains a giant orocline formed in the late Palaeozoic–Mesozoic: the Mongolian Orocline (Xiao et al. 2015).

It is characterized by an assemblage of microcontinental blocks, comprising Stanovoy, Barguzin, Tuva-Mongol, Tarvagatay, Zavkhan, Baydrag, Idermeg, Ereendavaa and Erguna (Fig. A), which are composed of Paleoproterozoic–Neoproterozoic high-grade metaigneous and metasedimentary basement covered by Ediacaran to early Cambrian passive margin sequences (e.g. Sengör et al. 1993). These Precambrian blocks wrap around the Mongol-Okhotsk Silurian–Carboniferous oceanic domain thereby forming a distinct U-shape. In this study, we call the entire belt of different Precambrian microcontinental blocks, the "Continental Domain" (**Fig. A**), which comprises both the cratonic blocks and the tectonic units between them, presumably composed of oceanic basin remnants (Yakubchuk 2017). The Mongol-Okhotsk oceanic domain constitutes the center of the Mongolian Orocline. It is dominated by a Silurian to Carboniferous turbidite sequences (Ruppen et al. 2014) intruded by numerous Permian–Triassic plutons (Badarch et al. 2002). It is considered as the embayment of the Paleo-Pacific Ocean presumably closed between Permian–early Cretaceous (Donskaya et al. 2013). The Mongol-Okhotsk suture is usually mapped in the middle of the Mongol-Okhotsk domain or along its periphery from the Hangay Range in Mongolia to the Okhotsk Sea in far east Russia. Moreover, the Mongolian Orocline is bordered on its western and southern sides by Early Paleozoic arcs such as the giant Ikh-Mongol arc (Janoušek et al. 2018) and the entire system was then intruded by various Late Paleozoic arcs (Ruzhentsev et al. 1992).

Central Asia exhibits a distinctive topography characterized by highlands comprising elevated plateaus and mountains, bounded by sedimentary basins and vast plains. The Tibetan Plateau constitutes the most prominent topography high, with its spatial extent and an average elevation of 5000 meters. The Mongolian Plateau, while less elevated—averaging around 1,500 meters—remains a significant physiographic unit, covering roughly 3 million square kilometres, and including the Hangay Dome. It is composed of the Altai and Tien Shan mountain ranges, both active intracontinental orogens, which further contribute to the region's elevated relief. In contrast, northern Siberia is characterized by much lower-altitude landscapes (**Fig. B**).





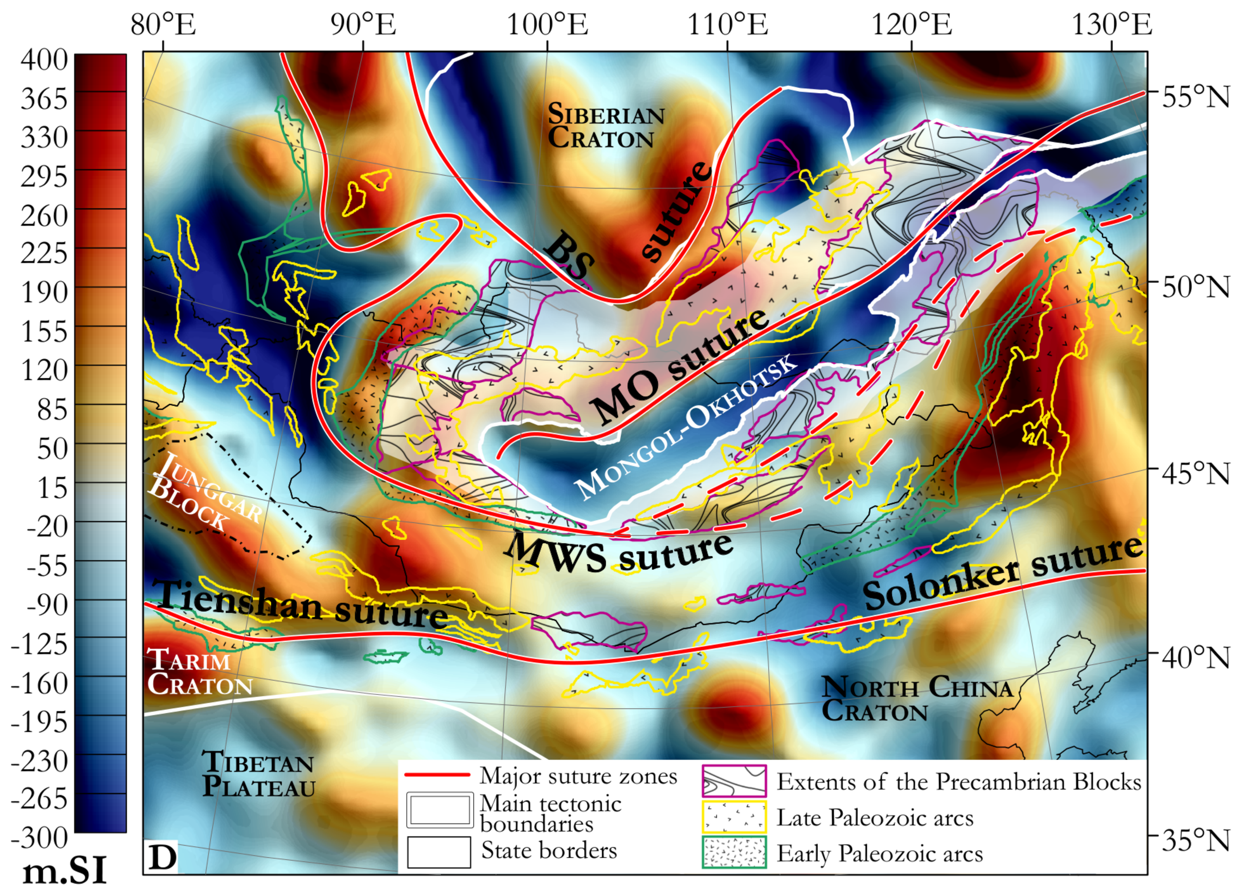


2. Geophysical fabrics and their correlation with main tectonic zones

The VIS data were extracted from the model based on the magnetic field vector from the CHAOS-8.1 model (degrees 21–180) without any further treatment or filtering. Then, the VIS signal was correlated with the large-scale tectonic features and first order lineaments representing the ridges of high susceptibility values were extracted (**Fig. C**).

As expected, no strong and systematic correlation can be observed between the topography and the VIS signal. The Tibetan Plateau does not correspond to any specific VIS highs or lows. The Altai Mountains and the Hangay Dome correlate with a characteristic low VIS signal, whereas the Tienshan Mountains display VIS low to the west and a VIS high to the east. The Siberian "lowlands" show N-S alternations of highs and lows that cannot be linked to a specific signal trend. Similarly, no clear correlation can be established between Archean cratonic units, such as the Siberian, Tarim and North China cratons, the Phanerozoic CAOB and a specific VIS signal. Nevertheless, the correlation of the VIS signal with major tectonic units of the CAOB reveals that the well-identified Precambrian blocks coincide with the VIS lows (**Fig. D**). In addition, there is an overall good correlation between Early and Late Paleozoic arcs and high VIS signals. Another interesting observation concerns the Junggar Block beneath the Junggar Basin. The nature and the composition of the block on which the Junggar Basin sediments were deposited is a matter of debate. Recent geochemical and geophysical studies suggested that the block may be mafic. The Junggar Basin exhibits strong magnetic susceptibilities, which confirms the mafic composition of the Junggar Block (**Fig. D**).

The boundary of the Siberian Craton, which corresponds to the Baikal-Sayan suture zone (BS), and to a lesser extent the northern boundaries of the Tarim and North China cratons (the Tienshan and Solonker sutures, respectively) correlate with a sequence of marked gradient discontinuities. Moreover, the northern part of the Mongol-Okhotsk domain coincide with a prominent and continuous E–W-oriented gradient, whereas the gradient in the southern boundary of the Mongol-Okhotsk domain is weaker with an important offset (**Fig. D**). Thus, the Mongol-Okhotsk suture zone (MO) is likely to be prominent in the northern part and its location and significance can be reassessed using the VIS signal. The southern and more diffuse VIS gradient, which could be attributed to the southern boundary of the Mongol-Okhotsk domain and its related suture, is shifted from the southern boundary defined by the geology and correlate better with the geological contact between the Continental Domain (**Fig. D**). Similarly, the western outer margin of the Mongolian Orocline displays a prominent VIS gradient corresponding to the boundary between the Continental Domain. In the VIS map, the Mongol-West Sayan suture (MWS) coincides with a nearly continuous single magnetic gradient in its western part turning into a series of gradient discontinuities in its eastern part. Therefore, a trace of the Mongol-West Sayan suture can be proposed, challenging previous models. Finally, the most striking observation is in the central part of the area, where a consistent pattern of ridge anomalies is highlighted by the lineaments (**Fig. C**). This reveals an apparent continuity of the VIS highs around the negative susceptibility of the Mongol-Okhotsk domain in the form of a nearly complete U-shaped belt, albeit a bit interrupted in the southern part. This pattern unveils the extent and the shape of the Mongolian Orocline across the entire crustal (not to say lithospheric) thickness. .



3. Conclusions and perpectives

The VIS signal allows the reassessment of large-scale tectonic features in Central Asia, such as the extent of Precambrian blocks, prominent magmatic arcs and their remnants in the continental crust, but also the traces of suture zones. It also highlights the overall shape, extent and importance of the Mongolian Orocline in the structural large-scale pattern of the CAOB.

Thus, we can expect that the analysis of VIS signal may bring significant new indications concerning continental-scale major tectonic structures in other part of the world. It may revise the importance and/or extent of some suture zones, as well as the nature of the deep crust of some major lithospheric-scale tectonic features. For example, doubts emerged concerning the existence of the Idermeg Precambrian Block as the geological evidence are ambiguous and scarce.

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