

# Towards intelligent digital ecological civilization: The rise of geospatial foundation models

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The rapid advancement of artificial intelligence (AI), particularly the emergence of large-scale foundation models, is driving a paradigm shift in economic and social development as well as governance, further fueling humanity's pursuit of a better life and a more sustainable future. In January 2025, under the leadership of Dr. Jixian Zhang, our team launched the Mogan Xuanyan Geospatial Foundation Model, a landmark achievement with tens of billions of parameters. This model was trained over four months using more than 100 million high-quality industry-specific tokens and nearly ten million remote sensing visual samples, leveraging a combination of pre-training and full-parameter fine-tuning on proprietary, domain-specific data. The release of Mogan Xuanyan 1.5 in July 2025 further enhanced the model's capabilities and broadened its application scope.

Coinciding with the 20<sup>th</sup> anniversary of the "Lucid waters and lush mountains are invaluable assets" philosophy and the 10<sup>th</sup> anniversary of the United Nations Sustainable Development Goals (SDGs), the year 2025 marks a critical juncture for ecological civilization and global sustainability. Against this backdrop, this commentary explores how geospatial foundation models (GFM), as a new generation of enabling technologies, can empower the construction of digital ecological civilization in China and beyond. Figure 1 presents the GFM-enabled framework, which outlines a potential pathway for GFMs to support digital ecological civilization.

## DIGITAL ECOLOGICAL CIVILIZATION: CHINA'S ACTION FOR AND BEYOND THE SDGS

The relentless pursuit of development in human society has brought about unprecedented advancements; yet, it has also precipitated a series of acute global challenges, including climate change, ecosystem degradation, and resource scarcity. Recognizing the imperative to address these multifaceted crises, the international community established the 2030 Agenda for Sustainable Development, which sets forth 17 SDGs as a blueprint for achieving social, economic, and environmental sustainability. Notably, even before the SDGs were articulated, China had already prioritized the concept of ecological civilization as a national priority, envisioning a path to modernization predicated on the harmonious coexistence of humanity and nature.<sup>1</sup> This forward-looking vision has been foundational to China's development

philosophy, shaping a distinctive trajectory toward sustainability that is deeply rooted in its own historical and cultural context.

Within this conceptual framework, ecological conservation has emerged as the cornerstone of China's high-quality development. The pursuit of a "Beautiful China" has not only become a guiding principle of national policy but also serves as a symbol of the country's enduring commitment to sustainable development.<sup>2</sup> Ecological civilization, as a strategic imperative, integrates environmental protection into every facet of economic and social progress. In the current digital era, this vision has evolved into the paradigm of digital ecological civilization, characterized by the profound integration of digital technologies with ecological governance. Digital ecological civilization leverages the capabilities of artificial intelligence, big data, and digital platforms to enhance the precision, efficiency, and adaptability of environmental management. Through digital empowerment and systemic integration, China is pioneering a shift from traditional management approaches to intelligent, data-driven governance, delivering robust solutions for resource optimization, ecosystem protection, and spatial planning.

However, building digital ecological civilization faces persistent challenges, including data silos, limited integration of intelligent platforms, and the demand for scalable, robust models that can capture the complexity of natural and social systems. Overcoming these obstacles requires a new generation of transformative digital tools – most notably, GFMs – which promise to unlock unprecedented capabilities for large-scale, intelligent ecological governance.

## GEOSPATIAL FOUNDATION MODELS: CAPABILITIES AND TRANSFORMATIVE POTENTIAL

Geospatial information, which encompasses structured knowledge of the properties, characteristics, and dynamics of geographic entities, serves as an essential foundation for digital ecological civilization. By precisely delineating the location, shape, scale, and spatial associations of real-world objects, geospatial data provides a unified spatial framework and an integrated data platform for ecological governance, scientific analysis, and sustainable development.<sup>3</sup> The rapid expansion of multi-source Earth observation systems, including satellite constellations, unmanned aerial vehicles (UAVs), and

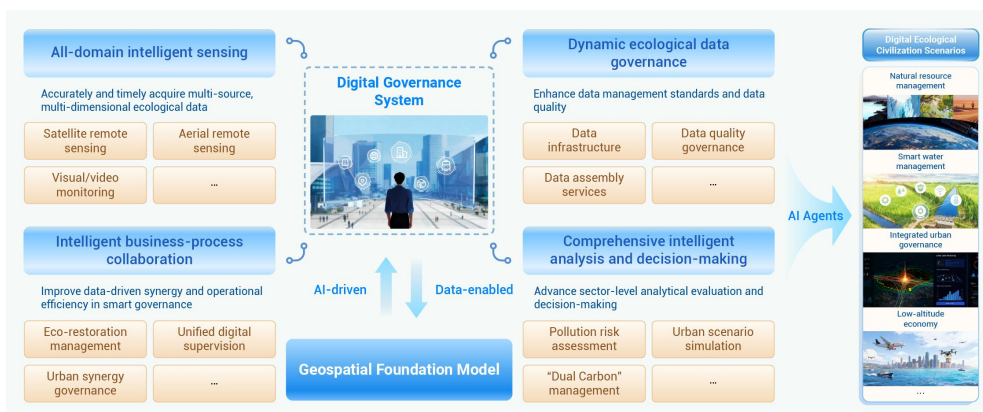


**Figure 1. Schematic framework proposed in this work illustrating how geospatial foundation models (GFMs) empower intelligent digital ecological civilization.** GFMs underpin core functional modules, including spatiotemporal perception, ecological data governance, business-process collaboration, and intelligent decision-making, which collectively enable a wide range of ecological civilization applications. Intelligent Agents bridge GFMs and real-world scenarios, facilitating adaptive, scenario-specific solutions across domains such as natural resource management, integrated urban governance, the low-altitude economy, and beyond.

IoT-enabled ground sensors, has dramatically enhanced the scope, granularity, and timeliness of geospatial data collection. This

abundance of spatiotemporal data holds substantial potential to fundamentally transform ecological governance by delivering a comprehensive, dynamic, and high-resolution representation of Earth's systems.

However, significant challenges remain. Current geospatial information technologies and service models are often constrained by data silos, fragmented analytical capabilities, and insufficient automation, rendering them inadequate for addressing the complexity, scale, and real-time requirements of modern ecological governance.<sup>4</sup> This evolving context necessitates a paradigm shift from traditional data processing toward intelligent, scenario-driven, and adaptive decision-making. At the forefront of this transformation are geospatial foundation models (GFM). Unlike general-purpose foundation models trained primarily on text or generic imagery, GFMs are pre-trained specifically on vast, heterogeneous Earth observation datasets, encompassing remote sensing imagery, vector topologies, and climate archives, allowing them to learn intrinsic spatiotemporal dependencies and geographic context. These large-scale models, powered by advances in machine learning and reasoning algorithms, are able to integrate vast volumes of heterogeneous spatiotemporal data and automate certain processes of extraction, interpretation, and reasoning across multiple ecological domains.<sup>5</sup> Early implementations of GFMs show promise in simulating ecological processes, anticipating dynamic changes, and facilitating proactive responses to emerging environmental risks. The end-to-end intelligence supports applications ranging from real-time ecological monitoring and intelligent early warning to precision assessment, scenario simulation, and optimal resource allocation.

The transformative potential of GFMs lies in their ability to break through the limitations of conventional geospatial intelligence by offering unified, scalable, and adaptive solutions for digital ecological civilization. By serving as the intelligent engine for high-level ecological governance, GFMs address persistent challenges such as fragmented data, low analytical efficiency, and limited automation. As the backbone of next-generation ecological management, GFMs are poised to drive innovation, enhance sustainability, and unlock new pathways for the construction of digital ecological civilization.

## EMPOWERING DIGITAL ECOLOGICAL CIVILIZATION: FRAMEWORK AND APPLICATIONS

This section presents our proposed conceptual framework for empowering digital ecological civilization, highlighting a visionary approach that integrates a digital governance system – supported by GFMs – with scenario-specific intelligent agents, as illustrated in Figure 1. This framework is designed as a forward-looking architecture, intended to guide future research and development in this emerging field.

At the core of this vision is the synergy between GFMs and intelligent agents. GFMs supply essential capabilities for advanced spatiotemporal perception, cognition, and reasoning, ensuring that the governance framework rests on a robust and adaptive technological foundation. The ongoing evolution of GFMs guarantees that the technological infrastructure remains at the forefront of innovation. The digital governance system is structured around four core functional modules; together, these modules enable the real-time acquisition, standardized management, efficient coordination, and smart utilization of multi-source ecological information.

Within this framework, all-domain intelligent sensing integrates satellite remote sensing, aerial observation, and ground-based monitoring to achieve precise and timely acquisition of multi-dimensional ecological data. Dynamic ecological data governance establishes mechanisms for data integration, quality control, and service provisioning, effectively enhancing the reliability and utility of large-scale environmental datasets. Intelligent business-process collaboration facilitates cross-domain data sharing and automated workflows, which improve both synergy and operational efficiency in ecological management practices. Comprehensive intelligent analysis and decision support employ advanced AI-driven modeling and reasoning to deliver scientific, accurate, and timely policy recommendations for complex environmental scenarios.

Scenario-specific intelligent agents operate as the bridge between the governance system and real-world applications. These agents orchestrate and integrate the system's core functions, dynamically translating foundational capabilities into targeted, actionable solutions tailored to diverse ecological and management contexts. Through intelligent agents, the gover-

nance system achieves adaptive interaction and effective responses to the continuously changing demands of ecological civilization construction.

The potential and feasibility of this framework have been demonstrated through the implementation of the Mogan Xuanyan GFM and its ecosystem of intelligent agents. This deployment has delivered substantial value across a wide range of ecological and administrative domains, including natural resource management, urban governance, flood emergency response, geological disaster prevention, farmland protection, and rural planning. For instance, in natural resource management, the model greatly enhances the automation and intelligence of geospatial data analysis, supporting integrated, one-stop satellite imagery-based law enforcement monitoring. In urban governance, the system facilitates cloud-based, multi-event collaborative tracking, allowing for the simultaneous and precise identification and localization of multiple incidents, which significantly improves the efficiency and responsiveness of city management. During flood emergency exercises, the model can simulate flood scenarios and intelligently coordinate rescue resources, thereby enhancing the effectiveness of early warnings and responses.

Nevertheless, this framework remains at a developmental stage. Key challenges persist, including comprehensive data integration, scalability across diverse scenarios, and the further enhancement of intelligent agents' adaptability and autonomy. Addressing these challenges will be critical to fully realizing the vision of digital ecological civilization and maximizing the practical impact of this framework.

## CONCLUSION

Geospatial foundation models, in concert with scenario-specific intelligent agents, are reshaping the landscape of digital ecological civilization by enabling data-driven, intelligent, and adaptive governance. Looking ahead, sustained innovation and cross-disciplinary collaboration will be vital to unlock new application frontiers and address emerging ecological challenges. The digital ecological civilization initiative pioneered in China provides important insights, while diverse global practices collectively inform sustainable development in the digital era.

## REFERENCES

1. Hansen M., Li H. and Svarverud R. (2018). Ecological civilization: Interpreting the Chinese past, projecting the global future. *Glob. Environ. Change* **53**:195–203. DOI:10.1016/j.gloenvcha.2018.09.014
2. Guan Y., Qiang Y., Qu Y., et al. (2024). Environmental sustainability and beautiful China: A study of indicator identification and provincial evaluation. *Environ. Impact Assess. Rev.* **105**:107452. DOI:10.1016/j.eiar.2024.107452
3. Kavvada A., Metternicht G., Kerblat F., et al. (2020). Towards delivering on the sustainable development goals using earth observations. *Remote Sens. Environ.* **247**:111930. DOI:10.1016/j.rse.2020.111930
4. Koldasbayeva D., Tregubova P., Gasanov M., et al. (2024). Challenges in data-driven geospatial modeling for environmental research and practice. *Nat. Commun.* **15**:10700. DOI:10.1038/s41467-024-55240-8
5. Hong D., Li C., Zhang B., et al. (2024). Multimodal artificial intelligence foundation models: Unleashing the power of remote sensing big data in earth observation. *Innov. Geosci.* **2**:100055. DOI:10.59717/j.xinn-geo.2024.100055

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## AUTHOR CONTRIBUTIONS

Yue Chang: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. Jixian Zhang: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing. Yizhong Ding: Conceptualization, Formal analysis, Methodology, Writing – review & editing. Jingfeng Xiao: Formal analysis, Investigation, Writing – review & editing. Qi Wang: Formal analysis, Investigation, Writing – review & editing. Huan Ni: Formal analysis, Investigation, Writing – review & editing. All authors contributed to the manuscript and approved the final version.

## DECLARATION OF INTERESTS

The authors declare no competing interests.