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Mapping the research landscape of artificial intelligence in geosciences : A bibliometric analysis

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With the rapid expansion of scientific data and the transformative potential of artificial intelligence (AI), Geosciences have increasingly adopted AI-based approaches for modeling, prediction, and data-driven discovery. This study presents a comprehensive bibliometric analysis of AI research in Geosciences between 2003 and 2023, drawing on 7,032 publications indexed in Scopus. Using bibliometric tools such as VOSviewer, BibExcel, and Biblioshiny, we analyzed publication trends, authorship patterns, collaboration networks, leading journals, and keyword co-occurrences. Results show an average annual growth rate of 14.71% and 16.12 citations per paper. China leads in publication volume (2,044 papers), while the United States demonstrates the highest citation impact (21.6 citations per paper). Neural networks, machine learning, and remote sensing emerged as dominant research themes. Keyword co-occurrence analysis revealed growing emphasis on deep learning, data mining, and environmental applications. Despite progress, significant gaps remain in hydrology, volcanology, and seismology, highlighting directions for future research. This analysis contributes to scientometrics by mapping a rapidly evolving interdisciplinary field and identifying research gaps, collaboration dynamics, and thematic shifts that will inform researchers, policymakers, and funding bodies.

Keywords: *Artificial intelligence, Bibliometric analysis, Geoscience, Network visualization, Research trends, Scientometrics.*

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Introduction

Artificial intelligence (AI), first formally introduced by John McCarthy in 1956 [1], has evolved into one of the most impactful domains in computational science. Early AI applications focused on expert systems, but limitations

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such as adaptability and scalability led to the development of machine learning (ML) and deep learning (DL). These methods, rooted in neural networks, now drive major advancements across disciplines, including Geosciences. Geoscientists rely on AI for data interpretation, forecasting geophysical events, and enhancing simulation models.

The Geosciences generate large and complex datasets from remote sensing, seismic imaging, hydrology, ecology, and planetary studies. AI enables the transformation of these datasets from qualitative descriptions to quantitative insights, offering new pathways for discovery. Previous bibliometric studies have assessed AI in computer science, engineering, and medicine, but systematic evaluations of AI applications in Geosciences remain limited. This creates an opportunity to map how AI has shaped Geosciences research and to highlight research gaps.

Objectives of the study

The objectives of this study are:

1. To analyze the growth and citation trends of AI-related publications in Geosciences (2003–2023).
2. To identify the most productive authors, institutions, and countries.
3. To map international collaboration patterns and keyword co-occurrences.
4. To assess the influence of leading journals and highly cited documents.
5. To highlight underexplored domains and provide implications for future research.

Literature Review

Bibliometric methods have been widely applied to evaluate research landscapes across domains. Prior studies on AI in Geosciences remain scarce, though related efforts exist in earth sciences and environmental monitoring. For instance, Dramsch [2] reviewed 70 years of machine learning in geoscience, while Binetti, Massarelli, and Uricchio [21] examined ML applications in environmental monitoring. Karpatne et al. [25] highlighted challenges of integrating ML in Geosciences, and Sun et al. [19] presented a broad review of Earth AI. Many scientists and researchers focused on computational methods to solve algebraic problems and prove mathematical concepts [2]. However, none of these studies employed a systematic scientometric framework.

In the 1980s, artificial intelligence (AI) experienced a spike in popularity as several research centers and academic institutions created a class of AI systems that aids non-experts in drawing conclusions by summarizing some crucial guidelines from expert expertise [3]. They go by the name of "expert systems" [4]. The information that enabled machines to become "smarter" at this period became the basis for AI research. However, as time passed, the expert system's shortcomings—privacy concerns, poor versatility, lack of adaptation, expensive maintenance costs, and more—became increasingly evident [5].

According to Agwu et al. [6] there are numerous definitions of artificial intelligence, but each one only considers one aspect of the concept. Two requirements must be met for artificial intelligence to be accepted: few definitions and many definitions. Artificial intelligence is the capacity to comprehend and remember information in the context of one's surroundings. Artificial intelligence is the ability of machines and computer systems to simulate human intelligence [7], [8], [9].

The study of theories, techniques, and applications related to emulating, augmenting, and expanding human intelligence with the aim of problem-solving is known as artificial intelligence (AI) [10]. AI is a branch of computational science that builds machines that can simulate psychological processes such as learning, memory continuation, making choices, and finding solutions [11].

According to Gharbi and Mansoori [12], artificial networks (ANNs) and standard artificial intelligence are the two main subcategories of artificial intelligence research. Artificial intelligence is a specific kind of engineering that provides computers and other devices with the same capabilities as people's minds [13]. The foundation of artificial intelligence technology is the cognitive functions of humans, alike learning and thinking. As the data becomes more complex and repetitive, the reasoning becomes more and more

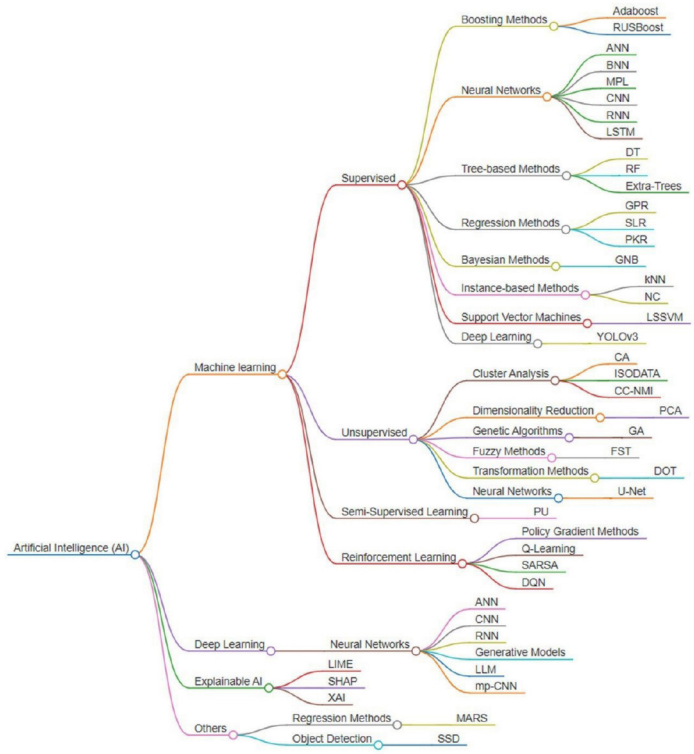


Figure 1

Algorithms for artificial intelligence (AI) classification [20]

practical. The topic of artificial intelligence is complicated. It has to do with both human intelligence and concepts beyond human comprehension [14].

Hinton, Osindero, and Teh [15] and associates made significant advances in AI when they developed a method to prevent variations disappearing all through training and to build deeper neural networks. Deep Learning (DL) algorithms are among the utmost prevalent grounds of AI research as a result of this renewed interest [16]. Machine Learning (ML), which is founded on many layers of neural systems [17] with learning representations [18], includes Deep Learning (DL) as a subclass. A subclass of artificial intelligence called machine learning (ML) allows computers or software to accumulate knowledge and become intelligent with no requiring human involvement [19]. Therefore, the watchword for AI research at this time is "learn." As seen in Figure. 1, machine learning (ML) approaches include explainable artificial intelligence (AI), deep learning, reinforcement learning (LR), supervised, semi-supervised, unsupervised learning, and other algorithms [20]. Table 1 lists the naming conventions adopted worldwide to distinguish between the various machine learning algorithms [21].

Table 1

The nomenclature of algorithms [21]

Acronym	Connotation	Acronym	Connotation
Adaboost	Adaptive-Boosting	ANN	Artificial Neural Network
BNN	Bayesian Neural Network	CA	Cluster Analysis
CC-NMI	Cluster Confusion-Normalized Mutual Information	CNN	Convolutional Neural Network
DL	Deep Learning	DOT	Discrete Orthogonal Transformations
DR	Dimensionality Reduction	DT	Decision Tree
Extra-Trees	Extremely Randomized Trees	FF	Futures Filtering
FPN	Feature Pyramid Network	FST	Fuzzy Set Theory
GA	Genetic Algorithm	GANs	Generative Adversarial Networks
GNB	Gaussian Naive Bayes	GPR	Gaussian Process Regression
ISODATA method	Iterative Self Organizing Data Analysis Technique	kNN	k Nearest Neighbors
LIME	Local Interpretable Model Agnostic Explanations	LLMs	Large Language Models
LSSVM	Vector Support Machines for Least Squares	LSTM	Long Short-Term Memory
MARS	Multivariate Adaptive Regression Splines	ML	Machine Learning

Contd...

mp-CNN	Multipath Convolutional Neural Network	MPL	Multilayer Perceptron
NC	Nearest Centroid	NN	Neural Network
OD	Object Detection	PCA	Principal Component Analysis
PKR	Polynomial Kernel Regression	PU	Positive-Unlabeled Learning Algorithm
RF	Random Forest	RNN	Recurrent Neural Network
RUSBoost	Random Under Sampling Boosting	SHAP	Shapley Additive Explanations
SLR	Step-wise Linear Regression	SSD	Single-Shot Detector Algorithm
SVM	Support Vector-Machine	U-Net	Unique Architecture- Network is a "U" Shape (CNN)
XAI	Explainable Artificial Intelligence	YOLOv3	You-Only Look-Once, Version 3

Geoscientists are constantly trying to improve their techniques to simulate the existing scenario of the ecosystem (for instance- the amount of carbon dioxide that is put out into the surrounding environment) and the relationships within and between its component systems (for instance- the effects of elevated temperatures on the ocean ecology) [22]. From a geoscientific perspective, these difficulties in the use of geoscience are perfectly served by newly emerging approaches that use artificial intelligence (AI): (1) characterizing objects and events [23]; (2) utilizing evidence to estimate geoscience variables [24]; (3) using observations over time to forecast geophysical parameters [25]; (4) exploring relationships between geoscience data [26]; and (5) causal exploration and the process of attribution [27].

With AI techniques improving geoscientists' capacity to understand, evaluate, and forecast geological events, the fields of geoscience and AI are becoming increasingly complementary. Applications of AI, which is essential to geoscience, include natural language processing, machine learning, voice recognition, robotics, picture recognition, and expert systems [28]. In numerous distinct geoscience domains, including remote sensing, rock physics, marine geoscience, ecology, geology, environment, seismic activity, hydrology, planetary science and Arc GIS; technologies powered by AI, like image visualization, smart sensors, and intelligent inversion, have been proactive investigated alongside diversified data [21].

Furthermore, AI facilitates the creation of models driven by data as opposed to theoretical ones that are challenging to validate against actual data. More precisely, as Figure. 2 illustrates, AI can assist geoscientists in their work [29].

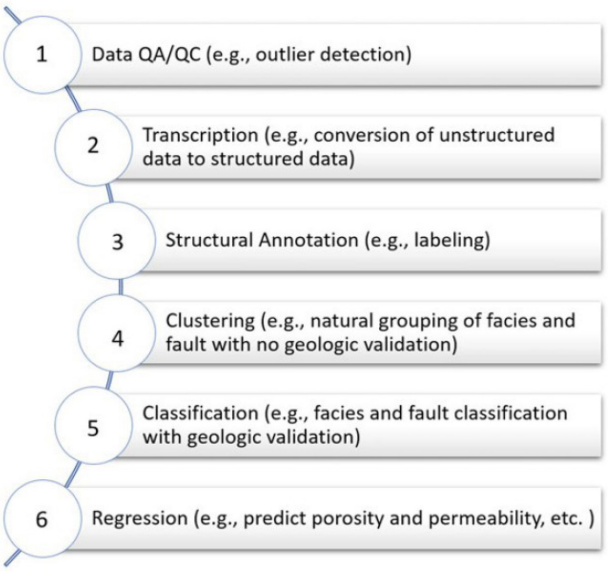


Figure 2

An example of a common set of geoscience activities that artificial intelligence can do [29].

Perhaps creating "new" samples to train AI-based models is the most natural application. This is helpful in situations such as reservoir modeling, where geoscientists frequently have to work with several subsurface samples and create probabilistic models to facilitate the process of making decisions that follows. Instances of recent attempts to use AI in geoscience incorporates the restoration of 3D fluids [30], the development of scientifically pragmatic 3-dimensional reservoirs appearance through the use of deep learning of fossilized structure [31], and the augmentation of seismic data [32] using earthquake waves synthesis and generative adversarial networks (GANs) [33].

Though they are by no means all-inclusive, the difficulties, issues, and encouraging paths that artificial intelligence has to offer show how much room there is for more AI study in this crucial area. The expansion, advancement, and popularity of AI methodologies in the geological sciences are frequently inspired by a stated scientific topic, and the best means for AI scientists to thrive is to work collaboratively with scientists in the earth sciences at every stage of the investigation process [34]. According to Kates et. al [35], geoscientists are better equipped to identify which scientific doubt is new and significant, which specimen recuperation method can reasonably demonstrate its intrinsic abilities, what sets of data and elements are likely to be utilized for addressing that query, as well as what preparatory processing procedures such as smoothing or seasonal cycle removal are performed.

Accordingly, researchers studying artificial intelligence have a stronger ability to identify the statistical techniques that are available and appropriate for the information

being analyzed, as well as the strengths and shortcomings of these methods alongside what they really learn [36]. In the field of geoscience, interpretability holds significant value as it allows for the use of models, patterns, or correlations generated from data as building blocks for scientific knowledge acquisition, provided that the core rationale behind them can be comprehended [37]. Thus, regular contact between the researchers guarantees that analytic results are useful to both geoscientists and AI researchers, and prevents lengthy detours [38].

On the AI side, numerous bibliometric studies have been conducted in computer science and healthcare, emphasizing the utility of keyword mapping, citation analysis, and collaboration networks. Yet, a consolidated bibliometric assessment targeting the intersection of AI and Geosciences is absent. This study addresses this gap by systematically analyzing publication and citation patterns, keyword evolution, and collaboration structures to provide new insights for both scientometrics and Geosciences communities.

Methodology

This study adopted a bibliometric design to analyze AI research in Geosciences between 2003 and 2023. Data were collected from Scopus using a comprehensive query combining AI-related terms (e.g., machine learning, deep learning, neural networks) with geoscience-related terms (e.g., geology, hydrology, geophysics). The search returned 8,685 records, which were refined to 7,032 relevant documents after screening. The dataset included metadata on authors, affiliations, publication sources, citations, and keywords.

Bibliometric analysis was performed using VOSviewer, BibExcel, and Biblioshiny to generate co-authorship maps, keyword networks, and productivity metrics. Indicators included total publications, total citations, average citations per paper, and annual growth rate.

For this research impact analysis, the search term that was utilized was: TITLE-ABSTRACT-KEYWORD (“Artificial intelligence*” OR “AI” OR “Deep learning” OR “Machine learning” OR “Expert systems” OR “Neural networks” OR “Natural language processing” OR “Cognitive computing” OR “Smart technology” OR “Intelligent systems” OR “Computer vision” OR “Computational intelligence” OR “Data mining” OR “Decision trees” OR “Big data analytics” OR “Pattern recognition” OR “Cognitive automation” OR “Knowledge engineering” OR “Predictive analytics”) AND TITLE-ABSTRACT-KEYWORD (“Geoscience*” OR “Earth Science” OR “Geology” OR “Environmental Science” OR “Geophysics” OR “Geochemistry” OR “Earth Systems Science” OR “Geotechnology” OR “Geological Sciences” OR “Earth and Planetary Sciences” OR “Hydrology”) AND NOT PUBYEAR = 2024.

Artificial intelligence (AI), machine learning, deep learning, expert systems and neural networks, along with other associated concepts are used in the Geosciences; like Earth Science, Geology, Environmental Science, Geophysics, Geochemistry, Earth Systems Science, Geotechnology, Geological Sciences, Earth and Planetary Sciences, and Hydrology was the focus of this search query. The fields for author, keywords, abstract, and title all

had searches done in them. Moreover, the search results did not include any articles from 2024.

Limitations: The study relied solely on Scopus, which, while comprehensive, may omit relevant works indexed in Web of Science or Google Scholar. Thus, results should be interpreted with this limitation in mind.

Data extractions

The information was acquired for the research impact study on the use of artificial intelligence in the Geosciences: "titles of studies, affiliations, names, and keywords of the authors; years since the publication; total citations (TC); cited paper (CP), not cited paper (NCP), average citation per paper (ACPP), and type of study (inventive investigation paper)." In keeping with the primary objective of the research, which was to guarantee that lone pertinent publications were included in the statistical evaluation, these data were gathered following the application of the criteria for incorporation and elimination.

The development of research, well-known sources, prodigious authors, significantly referenced papers, and collaborative publications initiatives by countries, organizations, and geoscientists were all assessed using bibliometric approaches. 1,653 entries were removed from the study after all the publications had been screened and determined to be unrelated to the subject. The remaining 7,032 entries were then stored in Microsoft Excel format, as Figure 3 illustrates.

This section includes Figure 3, from author research work.

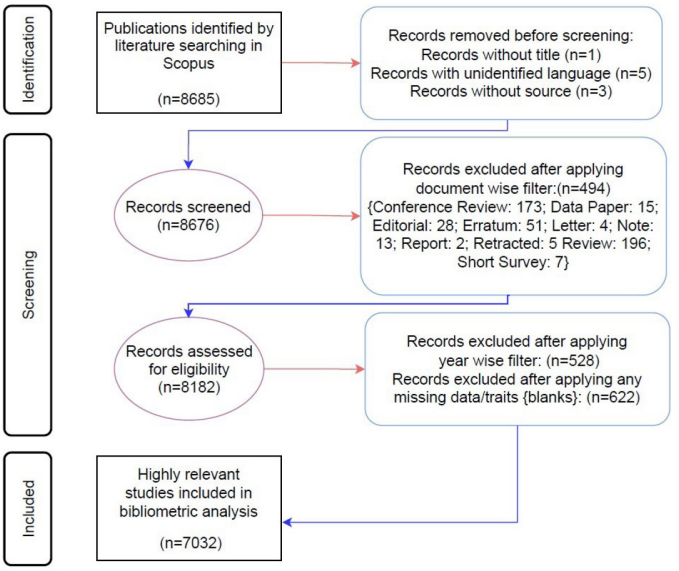


Figure 3

Diagram showing the three stages of the data extraction and filtering process

Data Interpretation and Outcomes

Key Details

A collection of 7,032 academic publications highlights the application of AI in the Geosciences. Between 2003 and 2023, an incredible 17,240 authors from 1,056 different sources contributed to the writing of this study. A single author appeared in 381 of the publications. The analysis indicated a yearly percentage of growth of 14.71% and 16.12 citations on average per document. 13,908 were the overall keywords (ID) and 30,038 were the author keywords (DE). After the 7,032 papers were examined, the analysis revealed that they had appeared in a range of journals, books, book chapters, and conference proceedings. Articles made up 54.78% (3,852) of the publications, followed by conference papers 43.10% (3,031) and book chapters 1.45% (102).

Publication and citation trends

Figure. 4 illustrates the productivity of AI research in the Geosciences from 2003 to 2023. In comparison to the study's beginning year, the graph shows a progressive increase in the first three years (2003–2005) and a minor reduction in the next two years (2006 & 2007).

Over the course of the investigation, there was a publications' steady upward and decrease trend. 2020 saw the highest number of publications (1,054, or 15%) ever recorded. 2019 and 2023 (12.18%, 857 & 12.17%, 856) came after this. 2020 had the highest number of citations with 13,236 overalls, followed by 2019 and 2021 (TC-11,942 & 11,843). The fact that the incredibly productive years 2020 (NCP-143), 2019 (NCP-125), and 2023 (NCP-277) were not extensively cited.

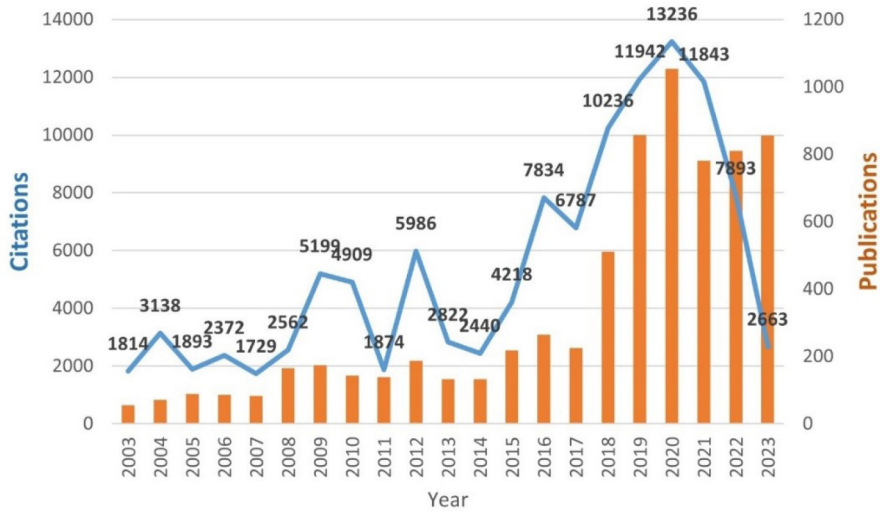


Figure 4

Publications and citation trends

Document type information

Table 2 summarizes the quantity and diversity of publications about the application of AI in Geosciences from 2003 to 2023. The data has been classified using publication types, including books, conference papers, articles, and chapters in books. The results show that articles (54.78%) and conference papers (43.10%) were the most frequently published types. Conversely, books, although having the fewest publications (47), obtained the most citations on average for each work (56.36). Articles garnered the greatest number of citations overall (96,289) and each manuscript had a mean of 25 citations, which was the second-highest. The next-highest total number of citations (13,552) were found in conference papers.

Table 2

Details of the document type

Document Type	Total Citations	Total Publications	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
Article	96289	3852	25.00	305	3547	54.78	2003	2023
Conference Paper	13552	3031	4.47	879	2152	43.10	2003	2023
Book Chapter	900	102	8.82	28	73	1.45	2005	2023
Book	2649	47	56.36	9	38	0.67	2003	2023

Based on citation counts, articles and conference papers appear to be the most prevalent forms of AI-related publications in Geosciences. Books, however, compared to papers, had a higher average citation per publication (ACPP).

Leading Ten Contributing Nations

Table 3 presents an examination of the effects of the leading 10 nations that have impacted to the field of research on AI applications in the Geosciences. Interestingly, only one country from Oceania, two from North America, and three from Asia, with four of the ten being in Europe. Compared to other countries, China published the most publications (2,044) between 2003 and 2023. In the top ten, eight other nations had three-digit publications, with the United States publishing the second-highest number (1,132).

Table 3

Leading ten contributing nation

Nations	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
China	2044	25681	12.56	339	1701	41.62	2003	2023

Contd...

United States	1132	24449	21.60	161	909	23.05	2003	2023
Italy	218	3189	14.63	39	171	4.44	2003	2023
Germany	247	4039	16.35	23	220	5.03	2004	2023
France	212	4071	19.20	29	172	4.32	2003	2023
Canada	232	5465	23.56	33	187	4.72	2003	2023
Australia	221	4967	22.48	33	181	4.50	2004	2023
India	233	3250	13.95	35	188	4.74	2003	2023
United Kingdom	201	4485	22.31	32	159	4.09	2003	2023
Iran	171	3497	20.45	27	133	3.48	2007	2023

The China leads the world in citations (25,681), followed by United States (24,449), Canada (5,465), and Australia (4,967). With an average citation per publication (ACPP) of 22.48%, Australia led the world, while India had the lowest, at 13.95%. Furthermore, with a proportion of 41.62%, China leads all contributing countries in AI in the Geosciences, followed by the US with 23.05%.

Top Ten Author Keywords

The most widely used author terms in relation to AI in Geosciences from 2003 to 2023 are listed in Table 4. With 16,163 citations, neural networks were the most frequently cited keyword. Machine learning (13,314) and remote sensing (12,220) were the next most often cited keywords. Moreover, from 2003 to 2023, the most often used keyword in articles was data mining; from 2008 to 2023, it was machine learning; and from 2016 to 2023, it was deep learning. The highest median number of citations per publication (ACPP) was found in deep learning (10.32%), neural networks (14.94%), and artificial neural networks (11.87%).

Table 4

The top ten keywords for authors

Topics	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
Neural Networks	1082	16163	14.94	51	490	9.03	2003	2023
Machine Learning	1511	13314	8.81	99	746	12.62	2008	2023
Remote Sensing	2245	12220	5.54	45	421	18.75	2003	2023
Deep Learning	1143	11794	10.32	61	585	9.54	2016	2023

Contd...

Artificial Neural Network	948	11250	11.87	31	265	7.92	2003	2023
Geology	2501	2657	1.06	25	171	20.88	2003	2023
Data Mining	667	1693	2.54	16	101	5.66	2003	2023
Forecasting	666	1370	2.06	16	71	5.56	2003	2023
Algorithm	439	561	0.78	24	181	4.68	2006	2023
Decision Trees	652	295	0.45	1	13	5.44	2006	2023

Citations were highest for machine learning (99) among the not cited papers (NCP), with deep learning coming in second (61). When it comes to cited papers (CP) count, machine learning had the most citations (746), while the least cited publication was CP-13, which dealt with decision trees.

Top 10 most pertinent affiliations

Taking into account the total quantity of articles and citations obtained, the study in Table 5 highlights the most productive affiliations in the Geosciences with regard to AI in the Geosciences. Nine of the ten most productive affiliations were from China, and there was only one from the United States. The China University of Geosciences, China (TP-298), Wuhan University, China (TP-143), and China University of Petroleum, China (TP-142) had the most articles. China University of Geosciences (TC-5,532), Wuhan University (TC-4,941), and University of California, USA (TC-2,176), ranked first, second and third, respectively, in relation to the total sum of citations obtained. The Chinese universities Jilin University (TC-485), Sun Yat-Sen University (TC-626), and the University of Electronic Science & Technology (TC-676) had the fewest total citations.

Table 5

Top ten pertinent affiliations

Affiliations and Country	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
China University of Geosciences, China	298	5532	18.56	36	262	30.69	2004	2023
Wuhan University, China	143	4941	34.55	11	143	14.73	2006	2023

Contd...

China University of Petroleum, China	142	1823	12.84	23	119	14.62	2006	2023
University of California, USA	79	2176	27.54	9	70	8.14	2003	2010
University of Electronic Science & Technology, China	72	676	9.39	6	66	7.42	2008	2023
Chengdu University of Technology, China	62	789	12.73	5	57	6.39	2006	2023
Jilin University, China	57	485	8.51	7	50	5.87	2007	2023
Sun Yat-Sen University, China	45	626	13.91	4	41	4.63	2017	2023
Central South University, China	42	688	16.38	6	36	4.33	2006	2023
Ocean University of China, China	31	1167	37.65	1	30	3.19	2006	2023

Authorship patterns

Table 6 presents the writer distribution of the geoscience articles in AI. There was a total of 415 papers (5.90%) by single authors had a total of 9,424 citations. There were 1,101 papers (15.66%) with two authors, which received 16,652 citations.

In this regard, mid-sized teams (3-5 authors) remained dominant in the authorship structure of the field, producing 3,900 papers (55.47% of all), 60,555 citations, and achieving a relatively high average citation per paper ratio of 15.53.

Papers with 6-10 authors were the most productive (20.99% of all papers) and received 22,318 citations, making an average of 15.12 citations per paper, having similar productivity and impact as mid-sized (3-5 authors) teams.

These results combined suggest that collaboration, as measured by the number of authors (3-5), is a key aspect in the emergence of geoscience AI applications, with such teams being the most productive and impactful.

Table 6

The top 10 patterns of authorship

Authorship	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
1	415	9424	22.71	127	288	5.90	2003	2023
2	1101	16652	15.12	211	890	15.66	2003	2023
3-5	3900	60555	15.53	678	3222	55.47	2003	2023
6-10	1476	22318	15.12	191	1285	21.0	2003	2023

Most Leading Journals

The top journals for AI in the Geosciences from 2003 to 2023 are covered in Table 7. The most articles were published by the "International Geoscience & Remote Sensing Symposium (IGARSS)," with 1,316 publications. Of them, 1,159 papers were cited, making up 18.17% of all publications between 2003 and 2023. Between 2010 and 2023, the journal Remote Sensing published 248 articles, of which 9 papers were not cited (NCP) and 239 were cited papers (CP). IOP Conference Series: Earth and Environmental Science, which published 242 articles between 2014 and 2023, was the third-most influential publication. Of the 242 publications, a total of 185 papers received citations, while 57 did not, with an average citation per paper of 2.84.

Table 7

Top ten leading journals

The Source	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
International Geoscience & Remote Sensing Symposium (IGARSS)	1316	8380	6.37	157	1159	18.71	2003	2023
Remote Sensing	248	5792	23.35	9	239	3.53	2010	2023
IOP Conference Series: Earth & Environmental Science	242	688	2.84	57	185	3.44	2014	2023
Computer and Geosciences	157	5525	35.19	1	156	2.23	2003	2023

Contd...

SEG Technical Program Expanded Abstracts	130	387	2.98	49	81	1.85	2003	2023
IEEE-Transactions on Geoscience & Remote Sensing	112	3840	34.29	3	109	1.59	2003	2023
IEEE-Geoscience & Remote Sensing Letters	93	1706	18.34	8	85	1.32	2007	2023
Journal of Petroleum Science & Engineering	88	2500	28.41	0	88	1.25	2005	2023
IEEE-Journal of Selected Topics in Applied Earth Observations & Remote Sensing	86	2464	28.65	6	80	1.22	2010	2023
ORE Geology Reviews	79	1413	17.89	3	76	1.12	2009	2023

Regarding citations, the "International Geoscience & Remote Sensing Symposium (IGARSS)" received 8,380 citations. Second place in terms of citation count went to the Remote Sensing with 5,792 citations, closely followed by Computer and Geosciences SEG Technical Program Expanded Abstracts with 5,525 citations.

Top ten Productive Authors

An examination of the top ten writers of AI in the Geosciences is shown in Table 8. With 130 articles between 2006 and 2023, Li, Y. from Shandong University of Technology, China, stood out as the most highly contributing author. With 129 and 98 publications, respectively, Zhang, Y. from China University of Geosciences, China, and Li, X. from Sichuan University, China, stood out as exceedingly contributory writers between 2004 and 2023. Wang, Y. and Wang, X., both affiliated with the Chinese Academy of Sciences in China, published 97 and 74 papers, respectively. Zhang, X. from Yangtze University in China and Wang, J. from Harbin Institute of Technology in China came next with 91 articles apiece.

Table 8

Top ten productive authors

Authorship	Affiliations and Nation	Total Publications	Total Citations	Average Citation per Publication	Not Cited Papers	Cited Papers	Percentage	Year-Start	Year-End
Li, Y	Shandong University of Technology, China	130	1691	13.01	23	107	1.85	2006	2023
Zhang, Y	China University of Geosciences, China	129	1182	9.16	26	103	1.83	2004	2023
Li, X	Sichuan University, China	98	1353	13.81	14	84	1.39	2004	2023
Wang, Y	Chinese Academy of Sciences, China	97	1156	11.92	15	82	1.38	2005	2023
Zhang, L	Wuhan University, China	92	5933	64.49	6	86	1.31	2004	2023
Wang, J	Harbin Institute of Technology, China	91	2184	24.00	11	80	1.29	2004	2023
Zhang, X	Yangtze University, China	91	1237	13.59	19	72	1.29	2003	2023
Li, J	Ocean University of China, China	90	1330	14.78	8	82	1.28	2008	2023
Zhang, J	Shanghai University, China	79	649	8.22	17	62	1.12	2008	2023
Wang, X	Chinese Academy of Sciences, China	74	1070	14.46	12	62	1.05	2008	2023

Table 9

Top ten documents

Citations	Title	Author, Year, Source	Total Citation per Year	Normalized Total Citation
1721	Deep Learning for Remote Sensing Data: A Technical Tutorial on the State of the Art	Zhang L, 2016, IEEE Geoscience & Remote Sensing Magazine	191.22	58.00
1331	Remote Sensing Digital Image Analysis	Richards JA, 2022, Remote Sensing Digital Image Analysis	443.67	136.76
937	Remote sensing of impervious surfaces in the urban areas: Requirements, methods & trends	Weng Q, 2012, Remote Sensing of Environment	72.08	29.27
890	More diverse means better: Multimodal deep learning meets remote-sensing imagery classification	Hong D, 2021, IEEE Transactions on Geoscience & Remote Sensing	222.50	58.69
888	Deep learning in environmental remote sensing: Achievements & challenges	Yuan Q, 2020, Remote sensing of Environment	177.60	70.71
843	Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application	James MR, 2012, Journal of Geophysical Research: Earth Surface	64.85	26.33
830	Rainfall–runoff modelling using long short-term memory (LSTM) networks	Kratzert F, 2018, Hydrology and Earth System Sciences	118.57	41.44
766	Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: a case study from Kat landslides (TOKAT-TURKEY)	Yilmaz I, 2009, Computers & Geosciences	47.88	25.64
765	Machine learning in geosciences and remote sensing	Lary DJ, 2016, Geoscience Frontiers	85.00	25.78
534	Delineation of landslide hazard areas on Penang Island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models	Pradhan B, 2010, Environmental Earth Sciences	35.60	15.56

With 92 publications between 2004 and 2023, Zhang, L from Wuhan University in China has the most citations (5,933), accounting for 64.49% of the average citation per publication (ACPP). With 2,184 citations, Wang, J. from Harbin Institute of Technology in China is the second most cited, and Li, Y. (1,691) from Shandong University of Technology in China is among the top three. To sum up, the data indicates that these ten writers made a substantial contribution to the publication of AI in the Geosciences. Their highly cited research and publications demonstrate their influence on the research community and have advanced the field as a whole.

Top ten documents

The top ten papers on artificial intelligence in Geosciences that were published between 2003 and 2023 are shown in Table 9. IEEE Geoscience and Remote Sensing Magazine's article "Deep Learning for Remote Sensing Data: A Technical Tutorial on the State of the Art" has the most articles on AI in the Geosciences, with 1,721 citations overall. Published in the book *Remote Sensing Digital Image Analysis*, the second most popular article is titled "Remote Sensing Digital Image Analysis" and has garnered 1,331 citations. The third most referred article is "Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends," which was published in the journal of *Remote Sensing of Environment*

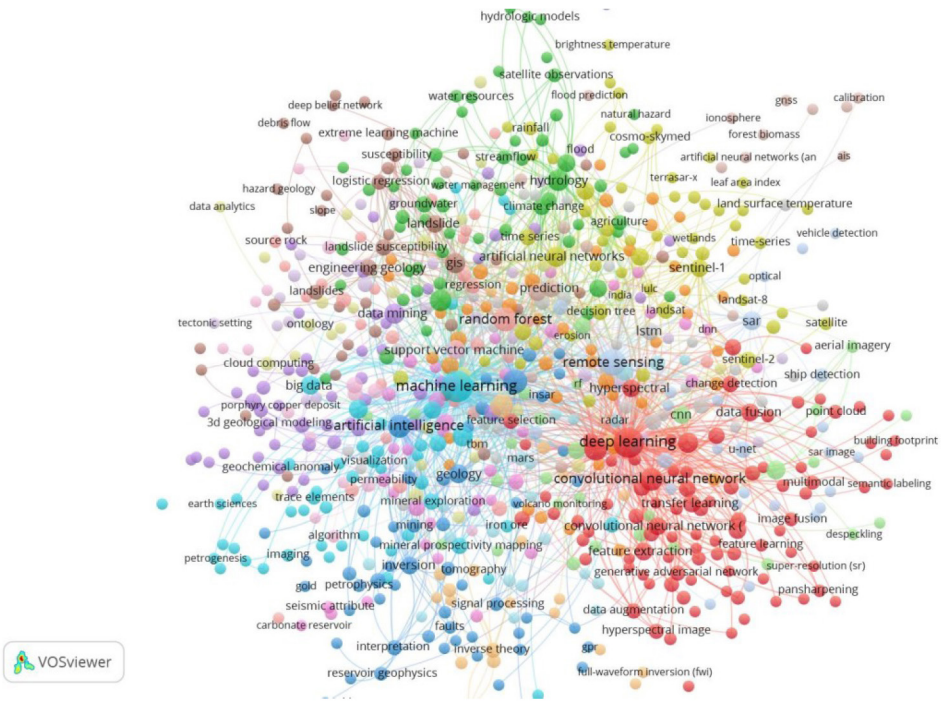


Figure 5

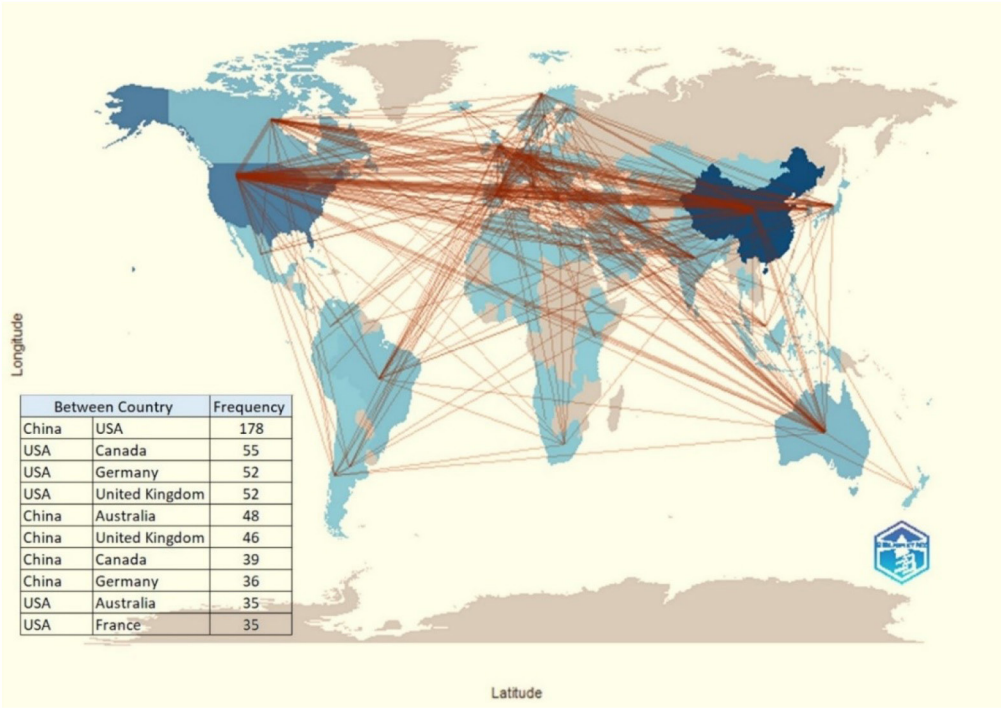
Mapping author keywords' co-occurrences

and has 937 citations. The title "Remote Sensing Digital Image Analysis" was awarded the highest total citation per year, with 443.67. The document with the lowest Normalized TC (15.56) in the top ten is "Delineation of landslide hazard areas on Penang Island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models."

Mapping author keywords' co-occurrences

The most often used terms by AI researchers in Geosciences study are shown in Figure 5. The keywords were visualized using the VOS viewer tool, which required at least five keyword occurrences and a complete counting approach. 739 of the 16,164 keywords were deemed suitable for analysis. The top 739 keywords are shown as colored bubbles or clusters and were chosen based on their total link strength. The bubble size indicated how frequently the keyword was used.

The quantity of research publications that include the given keywords is reflected in the strength of the nodes' correlation. According to the data, terms like "deep learning," "machine learning," "remote sensing," and "neural networks" were frequently employed by researchers. The picture displays various term clusters, each of which represents a distinct field of study.



Between Country		Frequency
China	USA	178
USA	Canada	55
USA	Germany	52
USA	United Kingdom	52
China	Australia	48
China	United Kingdom	46
China	Canada	39
China	Germany	36
USA	Australia	35
USA	France	35

Figure 6

Country collaboration map

Country collaboration map

Figure 6 shows a map of international cooperation between countries in geoscience AI research. With 178 articles between them, China and the USA have the highest level of collaboration; the USA and Canada come in second with 55 publications. USA and the UK as well as USA and Germany with 52 publications each. China and the United Kingdom (46), China and Australia (48), China and Canada (39), and China and Germany (36) come next, while USA-Australia and USA-France each had 35 publications.

Discussions

This study highlights several important patterns in AI-geoscience research. First, while global output has grown rapidly, China dominates in volume due to significant national investment in AI and earth sciences, though the U.S. demonstrates higher impact per paper, reflecting established research infrastructure.

The concentration of keywords around machine learning, neural networks, and remote sensing reflects the integration of AI into data-intensive domains. The rise of deep learning aligns with broader AI developments. However, subfields such as hydrology, volcanology, seismology, and climatology remain underrepresented. This may be due to challenges in acquiring large datasets, disciplinary silos, or limited cross-disciplinary training.

Authorship pattern analysis indicates the collaborative nature of the field, with mid-sized teams of 3-5 authors producing the majority of impactful work. National-level collaboration analysis reveals geopolitical drivers of science, with China–U.S. ties shaping much of the knowledge exchange. Institutional collaboration networks were not fully explored in this study but represent an avenue for future scientometric research.

From a scientometrics perspective, this study demonstrates the utility of bibliometric mapping in understanding disciplinary convergence. The findings align with theories of knowledge diffusion and scientific collaboration, showing how emerging technologies restructure traditional scientific fields.

Conclusion

This comprehensive bibliometric analysis of AI research in Geosciences reveals a rapidly evolving field characterized by exponential growth, geographic concentration, and technological sophistication. Key findings include:

i. ***Exponential Growth:*** The field demonstrates sustained growth with 14.71% annual increase, reaching peak productivity of 1,054 publications in 2020.

ii. ***Geographic Concentration:*** China leads with 41.62% of publications, though smaller countries achieve higher citation rates per paper.

iii. ***Technological Evolution:*** Clear progression from basic neural networks to sophisticated deep learning applications.

iv. ***Application Dominance:*** Remote sensing emerges as the primary application domain, while traditional geology maintains strong representation.

v. ***Research Gaps:*** Significant opportunities exist in hydrology, meteorology, volcanology, and seismology.

vi. ***Collaboration Patterns:*** International collaboration represents 21.35% of publications, with China-USA partnerships being most prominent.

Practical implications: For researchers, this study identifies promising directions such as hydrology and volcanology where AI can make significant contributions. For policymakers and funding bodies, the results highlight the importance of supporting international collaboration and cross-disciplinary training.

Limitations: This study relied solely on Scopus data, which may bias coverage. Future work should integrate Web of Science and other sources. Expanding to institutional and individual collaboration networks could yield further insights.

Future research should focus on expanding AI applications into under-represented geoscience domains, developing explainable AI approaches for scientific discovery, and building global research capacity through international collaboration initiatives. The continued evolution of AI technologies promises to further transform Geosciences, requiring sustained attention to methodological rigor, interpretability, and global accessibility.

References

[1] D. T. Pham and P. T. N. Pham, "Artificial intelligence in engineering," *Int J Mach Tools Manuf*, vol. 39, no. 6, pp. 937–949, Jun. 1999, doi: 10.1016/S0890-6955(98)00076-5.

[2] J. S. Dramsch, "70 years of machine learning in geoscience in review," 2020, pp. 1–55. doi: 10.1016/bs.agph.2020.08.002.

[3] P. McCorduck and C. Cfe, *Machines Who Think*. A K Peters/CRC Press, 2004. doi: 10.1201/9780429258985.

[4] A. Hadid, T. Chakraborty, and D. Busby, "When geoscience meets generative AI and large language models: Foundations, trends, and future challenges," *Expert Syst*, 2024, doi: 10.1111/exsy.13654.

[5] G. I. Parisi, R. Kemker, J. L. Part, C. Kanan, and S. Wermter, "Continual lifelong learning with neural networks: A review," *Neural Networks*, vol. 113, pp. 54–71, May 2019, doi: 10.1016/j.neunet.2019.01.012.

[6] O. E. Agwu, J. U. Akpabio, S. B. Alabi, and A. Dosunmu, "Artificial intelligence techniques and their applications in drilling fluid engineering: A review," *J Pet Sci Eng*, vol. 167, pp. 300–315, Aug. 2018, doi: 10.1016/j.petrol.2018.04.019.

[7] M. Desai and M. Shah, "An anatomization on breast cancer detection and diagnosis employing multi-layer perceptron neural network (MLP) and Convolutional neural network (CNN)," *Clinical eHealth*, vol. 4, pp. 1–11, 2021, doi: 10.1016/j.ceh.2020.11.002.

[8] S. Panchiwala and M. Shah, "A Comprehensive Study on Critical Security Issues and Challenges of the IoT World," *Journal of Data, Information and Management*, vol. 2, no. 4, pp. 257–278, Dec. 2020, doi: 10.1007/s42488-020-00030-2.

[9] H. Thakkar, V. Shah, H. Yagnik, and M. Shah, "Comparative anatomization of data mining and fuzzy logic techniques used in diabetes prognosis," *Clinical eHealth*, vol. 4, pp. 12–23, 2021, doi: 10.1016/j.ceh.2020.11.001.

[10] J. McCarthy and P. J. Hayes, "Some Philosophical Problems from the Standpoint of Artificial Intelligence," in *Readings in Artificial Intelligence*, Elsevier, 1981, pp. 431–450. doi: 10.1016/B978-0-934613-03-3.50033-7.

[11] P. Solanki, D. Baldaniya, D. Jogani, B. Chaudhary, M. Shah, and A. Kshirsagar, "Artificial intelligence: New age of transformation in petroleum upstream," *Petroleum Research*, vol. 7, no. 1, pp. 106–114, Mar. 2022, doi: 10.1016/j.ptlrs.2021.07.002.

[12] R. B. C. Gharbi and G. A. Mansoori, "An introduction to artificial intelligence applications in petroleum exploration and production," *J Pet Sci Eng*, vol. 49, no. 3–4, pp. 93–96, Dec. 2005, doi: 10.1016/j.petrol.2005.09.001.

[13] M. Dodiya and M. Shah, "A systematic study on shaping the future of solar prosumage using deep learning," *International Journal of Energy and Water Resources*, vol. 5, no. 4, pp. 477–487, Dec. 2021, doi: 10.1007/s42108-021-00114-8.

[14] Z.-Z. Shi and N.-N. Zheng, "Progress and Challenge of Artificial Intelligence," *J Comput Sci Technol*, vol. 21, no. 5, pp. 810–822, Sep. 2006, doi: 10.1007/s11390-006-0810-5.

[15] G. E. Hinton, S. Osindero, and Y.-W. Teh, "A Fast Learning Algorithm for Deep Belief Nets," *Neural Comput*, vol. 18, no. 7, pp. 1527–1554, Jul. 2006, doi: 10.1162/neco.2006.18.7.1527.

[16] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *Nature*, vol. 521, no. 7553, pp. 436–444, May 2015, doi: 10.1038/nature14539.

[17] M. D. McCormack, "Neural computing in geophysics," *The Leading Edge*, vol. 10, no. 1, pp. 11–15, Jan. 1991, doi: 10.1190/1.1436771.

[18] M. van der Baan and C. Jutten, "Neural networks in geophysical applications," *GEOPHYSICS*, vol. 65, no. 4, pp. 1032–1047, Jul. 2000, doi: 10.1190/1.1444797.

[19] Z. Sun *et al.*, "A review of Earth Artificial Intelligence," *Comput Geosci*, vol. 159, p. 105034, Feb. 2022, doi: 10.1016/j.cageo.2022.105034.

[20] F. Y. Osisanwo, J. E. T. Akinsola, O. Awodele, J. O. Hinmikaiye, O. Olakanmi, and J. Akinjobi, "Supervised Machine Learning Algorithms: Classification and Comparison," *Interna-*

tional Journal of Computer Trends and Technology, vol. 48, no. 3, pp. 128–138, Jun. 2017, doi: 10.14445/22312803/IJCTT-V48P126.

[21] M. S. Binetti, C. Massarelli, and V. F. Uricchio, "Machine Learning in Geosciences: A Review of Complex Environmental Monitoring Applications," *Mach Learn Knowl Extr*, vol. 6, no. 2, pp. 1263–1280, Jun. 2024, doi: 10.3390/make6020059.

[22] Y. Xu, F. Wang, Z. An, Q. Wang, and Z. Zhang, "Artificial intelligence for science—bridging data to wisdom," *The Innovation*, vol. 4, no. 6, p. 100525, Nov. 2023, doi: 10.1016/j.xinn.2023.100525.

[23] D. B. Chelton, M. G. Schlax, R. M. Samelson, and R. A. de Szoeke, "Global observations of large oceanic eddies," *Geophys Res Lett*, vol. 34, no. 15, Aug. 2007, doi: 10.1029/2007GL030812.

[24] M. Sambridge, "Reconstructing time series and their uncertainty from observations with universal noise," *J Geophys Res Solid Earth*, vol. 121, no. 7, pp. 4990–5012, Jul. 2016, doi: 10.1002/2016JB012901.

[25] A. Karpatne, I. Ebert-Uphoff, S. Ravela, H. A. Babaie, and V. Kumar, "Machine Learning for the Geosciences: Challenges and Opportunities," *IEEE Trans Knowl Data Eng*, vol. 31, no. 8, pp. 1544–1554, Aug. 2019, doi: 10.1109/TKDE.2018.2861006.

[26] Q. Qiu, Z. Xie, L. Wu, and W. Li, "Geoscience keyphrase extraction algorithm using enhanced word embedding," *Expert Syst Appl*, vol. 125, pp. 157–169, Jul. 2019, doi: 10.1016/j.eswa.2019.02.001.

[27] A. Perez-Suay and G. Camps-Valls, "Causal Inference in Geoscience and Remote Sensing From Observational Data," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 57, no. 3, pp. 1502–1513, Mar. 2019, doi: 10.1109/TGRS.2018.2867002.

[28] M. I. Jordan and T. M. Mitchell, "Machine learning: Trends, perspectives, and prospects," *Science (1979)*, vol. 349, no. 6245, pp. 255–260, Jul. 2015, doi: 10.1126/science.aaa8415.

[29] S. Bhattacharya, *A Primer on Machine Learning in Subsurface Geosciences*. Cham: Springer International Publishing, 2021. doi: 10.1007/978-3-030-71768-1.

[30] L. Mosser, O. Dubrule, and M. J. Blunt, "Reconstruction of three-dimensional porous media using generative adversarial neural networks," *Phys Rev E*, vol. 96, no. 4, p. 043309, Oct. 2017, doi: 10.1103/PhysRevE.96.043309.

[31] T.-F. Zhang, P. Tilke, E. Dupont, L.-C. Zhu, L. Liang, and W. Bailey, "Generating geologically realistic 3D reservoir facies models using deep learning of sedimentary architecture with generative adversarial networks," *Pet Sci*, vol. 16, no. 3, pp. 541–549, Jun. 2019, doi: 10.1007/s12182-019-0328-4.

[32] T. Wang, D. Trugman, and Y. Lin, "SeismoGen: Seismic Waveform Synthesis Using GAN With Application to Seismic Data Augmentation," *J Geophys Res Solid Earth*, vol. 126, no. 4, Apr. 2021, doi: 10.1029/2020JB020077.

[33] I. J. Goodfellow, J. Pouget-Abadie, M. Mirza, B. Xu, D. Warde-Farley, S. Ozair, A. Aaron Courville, and Y. Bengio, "Generative Adversarial Networks," Jun. 2014, [Online]. Available: http://arxiv.org/abs/1406.2661

[34] J. Pwavodi, A. U. Ibrahim, P. C. Pwavodi, F. Al-Turjman, and A. Mohand-Said, "The role of artificial intelligence and IoT in prediction of earthquakes: Review," *Artificial Intelligence in Geosciences*, vol. 5, p. 100075, Dec. 2024, doi: 10.1016/j.aiig.2024.100075.

[35] R. W. Kates, W. C. Clark, R. Corell, J. M, Hall, C. C. Jaeger, I.Lowe, J. J. McCarthy, H. J. Schellnhuber, B. Bolin, N. M. Dickson, S. Faucheux, G. C. Gallopin, A. Grübler, B. Huntley, J. Jäger, N. S. Jodha, R. E. Kasperson, A. Mabogunje, P. Matson, H. Mooney, B. Moore III, T. O'Riordan, and U. Svedin, "Sustainability Science," *Science (1979)*, vol. 292, no. 5517, pp. 641–642, Apr. 2001, doi: 10.1126/science.1059386.

[36] Y. Xu, X. Liu, X. Cao, C. Huang, E. Liu, S. Qian, X. Liu, Y. Wu, F. Dong, CW. Qiu, J. Qiu, K. Hua, W. Su, J. Wu, H. Xu, Y. Han, C. Fu, Z. Yin, M. Liu, R. Roepman, S. Dietmann, M. Virta, F. Kengara, Z. Zhang, L. Zhang. T. Zhao, J. Dai, J. Yang, L. Lan, M. Luo, Z. Liu, T. An, B. Zhang, X. He, S. Cong, X. Liu, W. Zhang, J. P. Lewis, J. M. Tiedje, Q. Wang, Z. An, L. Zhang, T. Huang, C. Lu, Z. Cai, F. Wang, J. Zhang, "Artificial intelligence: A powerful paradigm for scientific research," *The Innovation*, vol. 2, no. 4, p. 100179, Nov. 2021, doi: 10.1016/j.xinn.2021.100179.

[37] S. Gao, Y. Hu, and W. Li, *Handbook of Geospatial Artificial Intelligence*. Boca Raton: CRC Press, 2023. doi: 10.1201/9781003308423.

[38] F. Press, "Earth science and society," *Nature*, vol. 451, no. 7176, pp. 301–303, Jan. 2008, doi: 10.1038/nature06595.