

Bibliometric Analysis of the Research Progress on Cloud Removal of Optical Remote Sensing Images

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Abstract. High-resolution optical remote sensing images are widely used in environmental monitoring, disaster assessment, urban planning, and land use, but cloud cover seriously affects image quality and its application effect. In recent years, as artificial intelligence technology has advanced, cloud removal methods for optical remote sensing images have gradually evolved from machine learning to deep learning, but the development context and research hotspots of this field still lack systematic review. Based on the Web of Science Core Collection database, this paper uses the bibliometric analysis software VOSviewer to conduct a bibliometric analysis of 1,351 related literatures collected from 1999 to 2025, and systematically analyzes the development characteristics of the field of cloud removal of optical remote sensing images from the aspects of publication trend, country, institution, journal, author, and keywords. The results show that the research on cloud removal of optical remote sensing images has entered a rapid development stage since 2016, and the number of publications and citation frequency continue to grow; China and the United States are the most important research forces in this field, and institutions such as the Chinese Academy of Sciences, NASA, and Wuhan University, as well as core journals such as Remote Sensing and IEEE Transactions on Geoscience and Remote Sensing, have played an important role in this field; the keyword co-occurrence analysis identifies three main research directions: remote sensing applications and multi-source data fusion, cloud removal models and image reconstruction, and SAR-assisted cloud removal and multi-source image fusion.

Keywords: optical remote sensing images, cloud removal, bibliometric analysis, VOSviewer

1. Introduction

As satellite remote sensing technology has advanced, high-resolution optical remote sensing images, with rich spatial details and spectral information, have become an important data source in the fields of ecological environment monitoring, resource survey, disaster assessment, and land surface change analysis [1, 2]. Optical remote sensing images usually use passive imaging to obtain surface information, and their observation process is easily disturbed by atmospheric factors such as clouds and cloud shadows. Studies have shown that the observation opportunity under completely cloud-free conditions day and night around the globe is very limited, with an average occurrence frequency of only about 20.7%, while the statistics of the International Satellite Cloud Climatology Project

show that more than 50% of global satellite remote sensing data are affected by cloud cover [3]. The long-term existence of clouds and cloud shadows will block surface target information, weaken the ability of sensors to obtain effective ground object features, cause the attenuation or even loss of ground object information in remote sensing images, and cause spectral feature shift, thereby reducing the reliability of remote sensing data in tasks such as target recognition, classification interpretation, change detection, and quantitative analysis. Therefore, cloud detection and cloud removal technology has become an important research direction to improve the utilization efficiency of high-resolution optical remote sensing data and to ensure the quality of subsequent remote sensing applications [4-6].

At present, some scholars have summarized the cloud removal technology of high-resolution optical remote sensing data. Generally speaking, the cloud removal technology of optical remote sensing images has experienced a development process from traditional image restoration methods to machine learning and deep learning driven methods, and its technical updates mainly focus on the use of image information, auxiliary data fusion, and the improvement of feature expression ability. Shen et al. [7] systematically summarized the traditional restoration methods for missing information in remote sensing images in cloud-covered areas, and found that such methods can achieve missing area reconstruction to a certain extent, but the restoration ability in complex scenes is still limited due to the lack of effective observation information in cloud-covered areas. As machine learning methods have developed, researchers began to use data-driven machine learning models to mine the potential feature relations in remote sensing images and improve the ability of cloud area recognition and surface information restoration. Zhang et al. [8] proposed a "spatial-temporal-spectral" deep convolutional neural network, which completes the missing information in cloud-existing areas by jointly using multi-dimensional remote sensing information and further improves the reconstruction effect of remote sensing images in complex scenes. Subsequently, Enomoto et al. [9] and Grohnfeldt et al. [10] applied conditional generative adversarial networks to cloud removal of optical remote sensing images, and combined multispectral data and synthetic aperture radar (Synthetic Aperture Radar, SAR) data to explore multi-source information fusion methods, providing a new technical path for image restoration under complex cloud cover conditions. Existing researchers have also systematically summarized this method. Xiong et al. [11] focused on the analysis of the generative adversarial network method in multispectral data and synthetic aperture radar assisted cloud removal of optical remote sensing images, and Lee et al. [12] systematically reviewed the development of cloud removal of remote sensing images. Overall, existing research mainly focuses on the specific algorithm design, model performance optimization, and multi-source data fusion strategy in the field of high-resolution optical remote sensing image cloud removal, and still lacks systematic quantitative analysis on the knowledge structure evolution, research hotspot migration, and the correlation between different technical directions in this field.

Bibliometrics is a research method based on mathematical statistics and visual analysis, which can reveal the development law and knowledge structure characteristics of a specific research field by quantitatively analyzing the quantitative characteristics, cooperation relations, knowledge associations, and topic evolution in scientific literatures [13, 14]. Different from the traditional review method which mainly relies on the experience induction of researchers, bibliometric analysis can use large-scale literature data to identify the changes of research hotspots, knowledge evolution process, and the correlation between different research directions, so it has been widely used in the analysis of research progress in ecology, agriculture, environmental science, remote sensing, and other fields [15-18]. Bibliometric research mainly includes two aspects: performance analysis and scientific knowledge map analysis. Among them, performance analysis evaluates the contribution of

different research subjects by counting the information of country, institution, author, journal, and keyword, while scientific knowledge map analysis depicts the knowledge structure of the field and its development path by revealing the correlation between literatures [19]. Therefore, this paper adopts the bibliometric method to systematically analyze the related research in the field of cloud removal of high-resolution optical remote sensing images. Combined with the methods of publication trend, keyword co-occurrence, topic evolution, and cooperation network analysis, this paper reveals the development trend, knowledge structure characteristics, and research hotspot evolution law of this field, and provides a reference for the development of cloud removal technology of high-resolution optical remote sensing images and subsequent research.

2. Methods

2.1. Data retrieval

The data of this study come from the globally authoritative citation database Web of Science Core Collection (retrieval time: January 23, 2026). This database has high data quality control standards, a standardized citation index system, and a wide subject coverage, and has been widely used in bibliometric analysis research [20]. In order to systematically obtain the related research results in the field of cloud removal of optical remote sensing images, this paper constructs a retrieval strategy based on the terms related to cloud removal and image information restoration, and uses the topic field (Topic, TS) for literature retrieval. The specific retrieval formula is: TS = ((cloud* AND (remov* OR free OR gap* OR reconstruct* OR restor*)) AND ("optical remote sens*" OR "optical satellite image*")). Based on the above retrieval results, this study further carried out literature screening, limited the literature type to "article", and finally determined 1,351 English research papers as analysis samples, and exported the title, abstract, keywords, author, institution, journal name, and citation frequency of the sample literatures and other related data, saved in plain text format, to provide a data basis for the subsequent bibliometric analysis.

2.2. Bibliometric methods

Bibliometric analysis is a research tool based on quantitative methods, which mainly identifies, describes, and evaluates existing scientific research results through performance evaluation and scientific knowledge map construction. Performance analysis focuses on measuring the research output and academic influence of research individuals or institutions with quantitative indicators such as the number of published literatures and citation frequency [13]; while the scientific knowledge map aims to reveal the synergy and structural characteristics between research objects, and then depicts the development and evolution process of scientific knowledge [21]. In order to ensure the accuracy and comparability of the analysis results, before the formal analysis, this study standardized and preprocessed the raw data exported from the Web of Science Core Collection. First, this study used VOSviewer (Version 1.6.18) to extract the basic elements such as country, institution, source journal, and author keywords, and uniformly set the minimum occurrence frequency threshold to 0 to ensure full information coverage. Then, through manual correction, the spelling differences, synonyms, abbreviations, and singular and plural forms in keywords were processed. For example, "Peoples R China" and "Taiwan" were uniformly classified into the "China" category to eliminate statistical errors caused by semantic deviation. After the data cleaning was completed, combined with VOSviewer (Version 1.6.18), the quantitative statistics of the number of publications and citations of major countries, institutions, authors, and journals in different years

were carried out to identify their research contribution and influence distribution. At the same time, the author keyword co-occurrence network was further constructed to analyze the keyword co-occurrence relationship of author keywords (that is, the number of times two keywords appear in the same literature at the same time) and the average occurrence time of keywords (that is, the average publication year of the literatures containing the keyword), so as to reveal the evolution track of machine learning related research topics and the time-series change trend of research hotspots in the drought prediction field.

3. Results and discussion

3.1. Publication volume trend

The number of publications can reflect the development activity of a research field, while the citation frequency can measure the academic influence of research results and its promoting effect on subsequent research to a certain extent [13]. Figure 1 shows the change trend of the annual publication number and total citation frequency of related research in the field of cloud removal of optical remote sensing images in different years. Overall, the research results in this field show a continuous growth trend, and show a more obvious development transition around 2016. Before 2016, a total of 232 literatures were published in this field, with an average annual publication of 3.65; after 2016, the research scale expanded rapidly, and the cumulative publication volume reached 1,119 in 10 years, with the average annual publication increasing to 111.9, which is 8.2 times the average level before 2016. At the same time, the citation frequency of literatures in this stage also shows a significant growth trend, indicating that the academic influence of this field continues to improve.

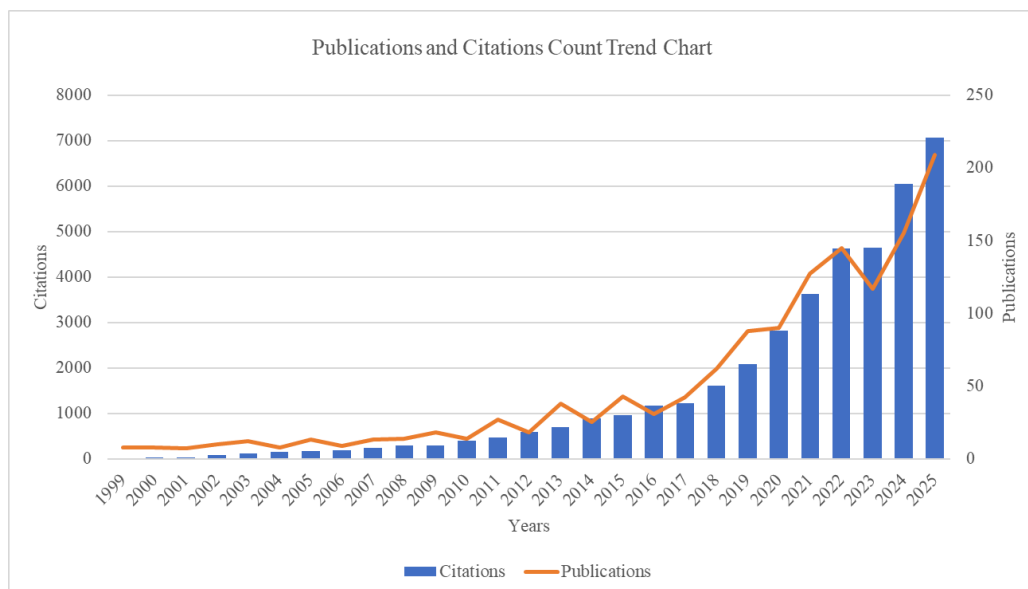


Figure 1. Annual publication volume and citation frequency changes of related research on cloud removal of optical remote sensing images

3.2. Country and institution analysis

This study uses the bibliometric method to analyze the publication of countries and institutions of related literatures in the field of cloud removal of optical remote sensing images, and uses the

number of publications and average citation frequency to judge the research output and academic influence of each country and each institution. Figure 2(a) shows the top 15 countries in terms of publication volume. China and the United States rank the top two with 649 and 429 literatures respectively, and their publication volume is significantly higher than that of other countries, making them the most important research forces in this field; Germany, France, and Italy form the second echelon and maintain a high research output. In terms of average citation frequency, Canada (83.70 times/article) ranks first, and Spain, France, and the United Kingdom all exceed 48 times/article, showing a high international academic influence. In contrast, although China ranks first in publication volume, its average citation frequency is only 23.21 times/article, lower than that of the United States and several European countries, indicating that the international influence of research results still has room for further improvement.

Figure 2(b) shows the distribution of the top 15 research institutions in terms of publication volume. The Chinese Academy of Sciences (CAS) ranks first with 169 literatures, followed by NASA (111) and Wuhan University (WHU, 106), reflecting the significant research advantages of Chinese research institutions in this field. In terms of average citation frequency, the University of Maryland (UMD) ranks first with 92.25 times/article, and Caltech (67.93 times/article) and NASA (45.23 times/article) also have high academic influence. In contrast, although CAS has the highest publication volume, its average citation frequency is only 21.74 times/article. Overall, Chinese research institutions occupy a dominant position in the research of cloud removal of optical remote sensing images, while some research institutions in the United States show higher academic influence, jointly promoting the development of this field.

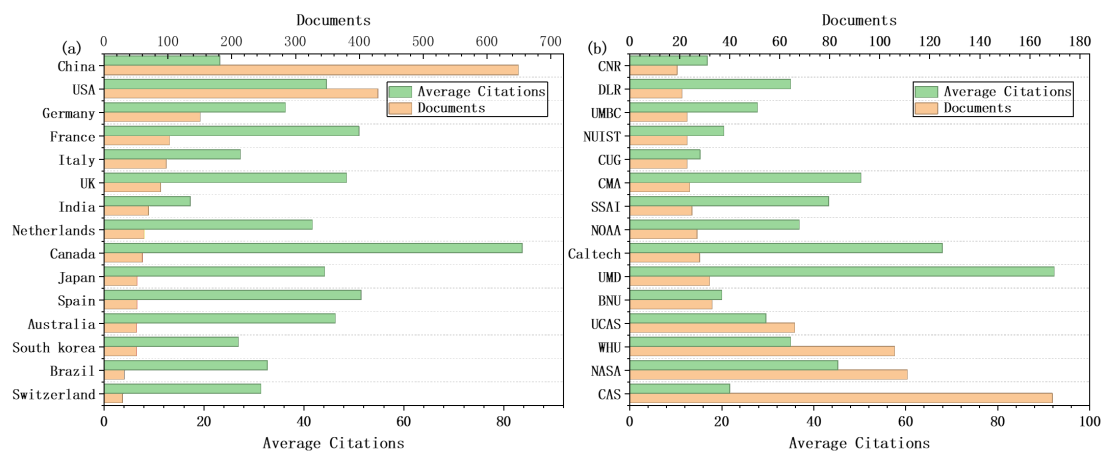


Figure 2. The top 15 countries (a) and research institutions (b) in terms of publication volume and average citation frequency in the field of cloud removal of optical remote sensing images

3.3. Journal and author analysis

This study uses the bibliometric method to systematically analyze the publication of journals and authors in the field of cloud removal of optical remote sensing images, so as to reveal the core publishing platform of this field and the change characteristics of the main research forces (Figure 3). Figure 3(a) shows the top 20 journals in terms of publication volume and their publication in different stages. Among them, *Remote Sensing* (RS) has the highest publication volume, with a total of 232 related papers published, followed by *IEEE Transactions on Geoscience and Remote Sensing* (TGRS, 109), *Remote Sensing of Environment* (RSE, 99), and *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* (JSTARS, 66), which constitute an important

communication platform for the research of cloud removal of optical remote sensing images. 2021-2025 is a key stage for the rapid development of this field, and the related research of most core journals shows an obvious growth trend. 2021-2025 is an important stage for the rapid development of the field of cloud removal of optical remote sensing images. Among the top 20 journals in terms of publication volume, the publication volume of 3 journals in the recent five years accounts for more than 70% of their total publication volume, among which *Acta Optica Sinica* (AOS, 94.1%), *GIScience & Remote Sensing* (GISRS, 76.9%), and *International Journal of Applied Earth Observation and Geoinformation* (JAG, 74.4%) are particularly prominent, reflecting that the research hotspots in this field have been continuously expanding to the directions of remote sensing image processing, earth observation, and computer vision in recent years.

Figure 3(b) shows the top 20 prolific authors in terms of publication volume and their research contributions in different stages. Among them, Shen, Huan Feng (22), Zhang, Lian Gpei (18), and Zhu, Xiao Xiang (12) rank the top three in publication volume, and are the representative core researchers in this field. In addition, Ansmann, Albert, Zhang, Yu, Zhang, Wenjuan, Li, Jun, Chen, Jin, and Zhang, Hongyan all have more than 70% of their total publication volume in the recent five years, and these scholars are the emerging research forces active in the field of cloud removal of optical remote sensing images in recent years, and their continuous research potential is worthy of attention. In addition, among the top 20 authors in terms of publication volume, 14 are from China, accounting for 70%, indicating that Chinese scholars have formed a relatively stable core research group in this field.

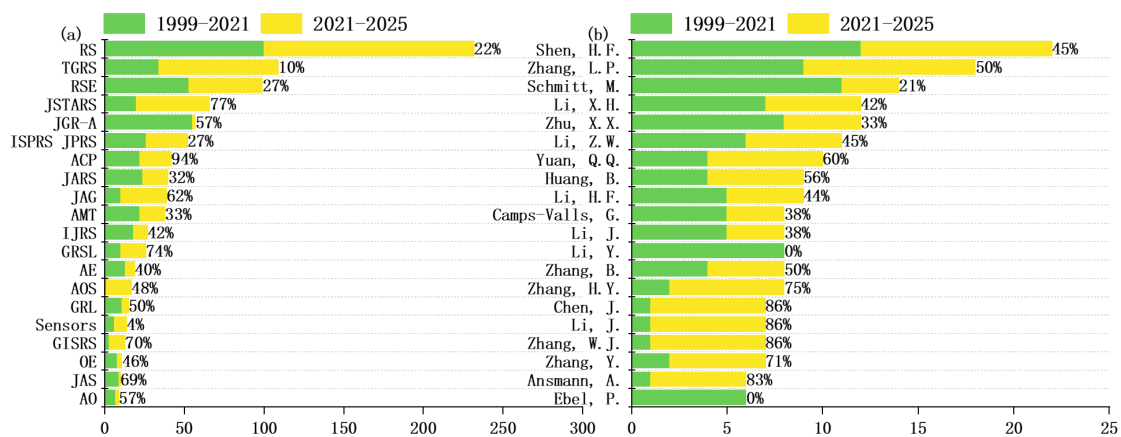


Figure 3. The top 20 journals (a) and authors (b) in terms of publication volume in the field of cloud removal of optical remote sensing images

3.4. Author keyword analysis

Author keywords can intuitively reflect the research hotspots and evolution trend of the field of cloud removal of optical remote sensing images [22]. In order to improve the accuracy of keyword analysis, this study first standardized the author keywords, including synonym merging, singular and plural unification, and common abbreviation standardization. After processing, the keywords with occurrence frequency no less than 10 times were identified, and the keyword co-occurrence network was constructed by using VOSviewer. Figure 4(a) shows the keyword co-occurrence relationship, in which the node size represents the keyword occurrence frequency, the node color represents the topic cluster formed based on the co-occurrence relationship, and the line between nodes reflects the

correlation strength between keywords; Figure 4(b) further shows the time evolution characteristics of keywords, in which purple represents the research hotspots that appeared earlier, and yellow represents the emerging directions that have gradually emerged in recent years. Based on the keyword co-occurrence relationship, a total of three closely related and distinctive research clusters were formed, namely Cluster 1 (Red): remote sensing application and multi-source data fusion; Cluster 2 (Green): cloud removal model and image reconstruction; Cluster 3 (Blue): SAR-assisted cloud removal and multi-source image fusion. The three clusters jointly constitute the main knowledge structure of the field of cloud removal of optical remote sensing images, and reflect the development trend of research hotspots continuously evolving from traditional remote sensing applications to intelligent cloud removal technology.

3.4.1. Cluster 1: remote sensing application and multi-source data fusion

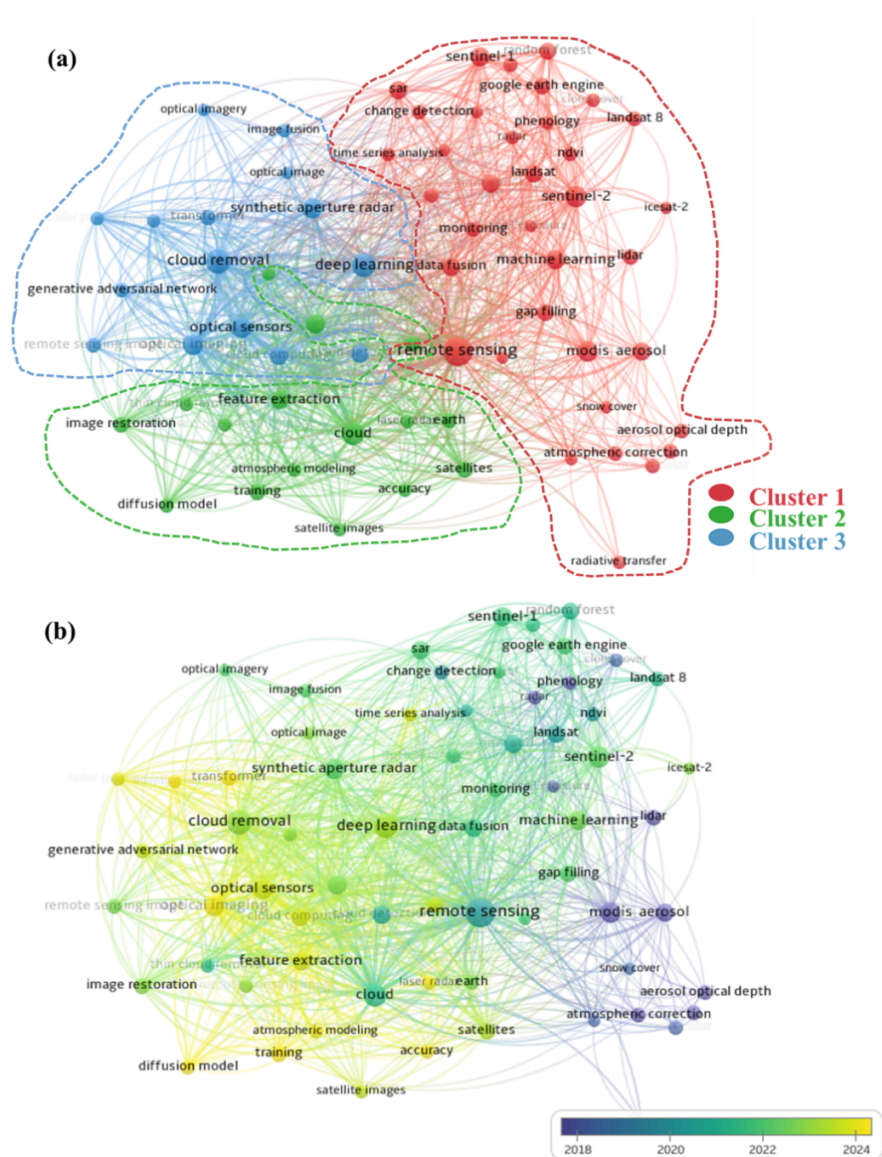


Figure 4. The author keyword co-occurrence network (a) with occurrence frequency no less than 10 times and the overlapped visualization of the average publication year of keywords (b)

Cluster 1 takes "remote sensing" as the core node, and forms a close relationship with keywords such as "machine learning", "Sentinel-2", "Landsat", "Google Earth Engine", "monitoring", "change detection", "data fusion", and "gap filling". This cluster mainly focuses on the application of multi-source remote sensing data in scenarios such as environmental monitoring, land surface change detection, and resource survey, and focuses on the fusion application of machine learning methods and satellite remote sensing data. The keywords such as Sentinel series, Landsat series, and Google Earth Engine all have high node connection degrees, indicating that open remote sensing data platforms and cloud computing technology have become an important data basis and application support for the research of cloud removal of optical remote sensing images [23]. Combined with Figure 4(b), it can be found that keywords such as "machine learning" and "Google Earth Engine" are mainly active after 2020, indicating that multi-source data fusion and intelligent remote sensing applications have gradually become important research directions in recent years.

3.4.2. Cluster 2: cloud removal model and image reconstruction

Cluster 2 takes "cloud" and "cloud removal" as the core, and mainly includes keywords such as "feature extraction", "image restoration", "optical sensors", "training", "accuracy", "atmospheric modeling", and "diffusion model". This cluster mainly focuses on cloud removal model construction, image reconstruction, and model performance optimization, and is the most active direction of algorithm research in recent years. The time evolution results show that early research mainly focused on image restoration and feature extraction, while in recent years the activity of keywords such as "training", "accuracy", and "diffusion model" has increased significantly, reflecting that the research focus has gradually shifted from traditional image processing methods to deep learning model training, model generalization ability, and generative artificial intelligence methods. In particular, the diffusion model, as an emerging keyword appearing in recent years, has become an important research direction for optical remote sensing image restoration [23-25].

3.4.3. Cluster 3: sar-assisted cloud removal and multi-source image fusion

Cluster 3 takes "synthetic aperture radar" and "cloud removal" as the core, and is closely related to keywords such as "optical imagery", "optical image", "image fusion", "deep learning", "transformer", and "generative adversarial network". This cluster mainly focuses on the collaborative application of SAR and optical remote sensing images, and restores the surface information of cloud-covered areas through multi-source data fusion and deep learning methods. SAR images have the advantage of all-time and all-weather observation, and can form a complement with optical remote sensing data, providing reliable information support for cloud removal in complex scenes [23, 24]. Combined with Figure 4(b), it can be seen that SAR data fusion runs through the whole research period, while deep learning models such as Transformer and generative adversarial network are mainly concentrated in recent years, indicating that the research focus is gradually developing from traditional deep learning methods to multimodal fusion and a new generation of generative models [23, 24].

Based on the comprehensive keyword clustering and time evolution results, it can be found that the research on cloud removal of optical remote sensing images has gradually developed from traditional remote sensing data processing to a comprehensive research system integrating multi-source remote sensing data, deep learning, and generative artificial intelligence. Among them, Transformer, Diffusion Model, and SAR-optical collaborative reconstruction are emerging topics

with high occurrence frequency in recent years, reflecting the latest research hotspots and development trends in the field of cloud removal of optical remote sensing images.

4. Conclusion

This study is based on the Web of Science Core Collection database, and uses the bibliometric method and VOSviewer software to systematically analyze the research in the field of cloud removal of optical remote sensing images from 1999 to 2025, revealing the development process, research hotspots, and future development trend of this field. The results show that the research on cloud removal of optical remote sensing images has entered a rapid development stage since 2016, and both the publication volume and citation frequency show a continuous growth trend. China and the United States are the most important research output countries in this field, and institutions such as the Chinese Academy of Sciences, NASA, and Wuhan University have high publication volume, while the University of Maryland, Caltech, and NASA show strong academic influence. *Remote Sensing*, *IEEE Transactions on Geoscience and Remote Sensing*, and *Remote Sensing of Environment* are the core journals in this field, and scholars such as Shen, Huanfeng, Zhang, Liangpei, and Zhu, Xiaoxiang constitute the representative core research forces. The keyword clustering analysis shows that this field has mainly formed three research directions: remote sensing application and multi-source data fusion, cloud removal model and image reconstruction, and SAR-assisted cloud removal and multi-source image fusion, and gradually develops from traditional remote sensing data processing to intelligent reconstruction driven by multi-source data fusion, deep learning, and generative artificial intelligence, and model generalization ability, multimodal fusion, and high-precision cloud removal are expected to become important research hotspots in the future.

References

- [1] Ning, J.; Xie, L.; Yin, J.; Liu, Y. Cloud removal advances: A comprehensive review and analysis for optical remote sensing images. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 18, 15914–15930. doi:10.1109/JSTARS.2025.3580718.
- [2] Peng, Y. A comparative analysis between GAN and diffusion models in image generation. *TCSISR*, 5, 189–195. doi:10.62051/0f1va465.
- [3] Saunders, R. W. An automated scheme for the removal of cloud contamination from AVHRR radiances over Western Europe. *International Journal of Remote Sensing*, 7, 867–886. doi:10.1080/01431168608948896.
- [4] Meraner, A.; Ebel, P.; Zhu, X. X.; Schmitt, M. Cloud removal in Sentinel-2 imagery using a deep residual neural network and SAR-optical data fusion. *ISPRS Journal of Photogrammetry and Remote Sensing*, 166, 333–346. doi:10.1016/j.isprsjprs.2020.05.013.
- [5] Wang, Z.; Zhao, L.; Meng, J.; Han, Y.; Li, X.; Jiang, R.; Chen, J.; Li, H. Deep learning-based cloud detection for optical remote sensing images: A survey. *Remote Sensing*, 16, 4583. doi:10.3390/rs16234583.
- [6] Xie, X., Ma, L., Yao, J., & Mao, W. (2025). Spatiotemporal variability of cloud parameters and their climatic impacts over Central Asia based on multi-source satellite and ERA5 data. *Remote Sensing*, 17, 2724. doi:10.3390/rs17152724.
- [7] Shen, H., Li, X., Cheng, Q., Zeng, C., Yang, G., Li, H., & Zhang, L. (2015). Missing information reconstruction of remote sensing data: A technical review. *IEEE Geosci. Remote Sens. Mag.*, 3, 61–85. doi:10.1109/MGRS.2015.2441912.
- [8] Zhang, Q., Yuan, Q., Zeng, C., Li, X., & Wei, Y. (2018). Missing data reconstruction in remote sensing image with a unified spatial–temporal–spectral deep convolutional neural network. *IEEE Trans. Geosci. Remote Sensing*, 56, 4274–4288. doi:10.1109/TGRS.2018.2810208.
- [9] Enomoto, K., Sakurada, K., Wang, W., Fukui, H., Matsuoka, M., Nakamura, R., & Kawaguchi, N. (2017, July). Filmy cloud removal on satellite imagery with multispectral conditional generative adversarial nets. In *Proceedings of the 2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)* (pp. 1533–1541).

- [10] Grohnfeldt, C., Schmitt, M., & Zhu, X. (2018, July). A conditional generative adversarial network to fuse SAR and multispectral optical data for cloud removal from Sentinel-2 images. In *Proceedings of the IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium* (pp. 1726–1729). IEEE.
- [11] Xiong, Q., Li, G., Yao, X., & Zhang, X. (2023). SAR-to-optical image translation and cloud removal based on conditional generative adversarial networks: Literature survey, taxonomy, evaluation indicators, limits and future directions. *Remote Sensing*, 15, 1137. doi:10.3390/rs15041137.
- [12] Lee, G. Y., Chen, J., Dam, T., Ferdaus, M. M., Poenar, D. P., & Duong, V. N. (2024). Dehazing remote sensing and UAV imagery: A review of deep learning, prior-based, and hybrid approaches.
- [13] Deng, Z., Wang, H., Chen, Z., & Wang, T. (2020). Bibliometric analysis of dendritic epidermal T cell (DETC) research from 1983 to 2019. *Front. Immunol.*, 11, 259. doi:10.3389/fimmu.2020.00259.
- [14] Fernandes, S., Jit, M., Bozzani, F., Griffiths, U. K., Scott, J. A. G., & Burchett, H. E. D. (2018). A bibliometric analysis of systematic reviews on vaccines and immunisation. *Vaccine*, 36, 2254–2261. doi:10.1016/j.vaccine.2018.02.049.
- [15] Ramírez-Malule, H., Quiñones-Murillo, D. H., & Manotas-Duque, D. (2020). Emerging contaminants as global environmental hazards. A bibliometric analysis. *Emerging Contaminants*, 6, 179–193. doi:10.1016/j.emcon.2020.05.001.
- [16] Şengel, Ü., & Koç, A. (2022). Bibliometric review of studies on sustainable tourism and climate change in 2019. *tursoc*, 31, 161–176. doi:10.18601/01207555.n31.09.
- [17] Su, Y., Yu, Y., & Zhang, N. (2020). Carbon emissions and environmental management based on big data and streaming data: A bibliometric analysis. *Science of The Total Environment*, 733, 138984. doi:10.1016/j.scitotenv.2020.138984.
- [18] Wang, Y., Zhang, B., Zhang, R., Wei, Y., Wang, Y., & Zhu, R. (2023). Microplastic pollution research based on the VOS viewer software: Research trends, ecological effects, and testing methods. *Atmosphere*, 14, 838. doi:10.3390/atmos14050838.
- [19] Lin, W., De, K., Wei, X., Wang, W., Zhang, L., Xiang, X., & Li, F. (2023). Visual analysis of alpine meadow research trends and hotspots based on VOS viewer. *Front. Environ. Sci.*, 11, 1095299. doi:10.3389/fenvs.2023.1095299.
- [20] Xu, G., Li, X., Liu, X., Han, J., Shao, K., Yang, H., Fan, F., Zhang, X., & Dou, J. (2024). Bibliometric insights into the evolution of uranium contamination reduction research topics: Focus on microbial reduction of uranium. *Science of The Total Environment*, 917, 170397. doi:10.1016/j.scitotenv.2024.170397.
- [21] Yu, Y., Wang, S., Yu, P., Wang, D., Hu, B., Zheng, P., & Zhang, M. (2024). A bibliometric analysis of emerging contaminants (ECs) (2001–2021): Evolution of hotspots and research trends. *Science of the Total Environment*, 907, 168116. doi:10.1016/j.scitotenv.2023.168116.
- [22] Oyarzabal, R. S., Santos, L. B. L., Cunningham, C., Broedel, E., De Lima, G. R. T., Cunha-Zeri, G., Peixoto, J. S., Anochi, J. A., Garcia, K., Costa, L. C. O., et al. (2025). Forecasting drought using machine learning: A systematic literature review. *Nat Hazards*, 121, 9823–9851. doi:10.1007/s11069-025-07195-2.
- [23] Shojaezadeh, S. A., Elnashar, A., & David Weber, T. K. (2025). A novel fusion of Sentinel-1 and Sentinel-2 with climate data for crop phenology estimation using machine learning. *Science of Remote Sensing*, 11, 100227. doi:10.1016/j.srs.2025.100227.
- [24] Ge, W., Yang, X., Jiang, R., Shao, W., & Zhang, L. (2024). CD-CTFM: A lightweight CNN-Transformer network for remote sensing cloud detection fusing multiscale features. *IEEE J. Sel. Top. Appl. Earth Observations Remote Sensing*, 17, 4538–4551. doi:10.1109/JSTARS.2024.3361933.
- [25] Hui, M., Xie, H., & Chi, Y. (2024). Deep learning network comparison and validation in Landsat imagery cloud detection. *Advances in Meteorology*, 2024, 9485656. doi:10.1155/adme/9485656.