

SDGSAT-1: Capabilities for Monitoring and Evaluating SDG Indicators

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Abstract SDGSAT-1, the world's first science satellite dedicated to assisting the United Nations 2030 Sustainable Development Agenda, has been operational for over two and a half years. It provides valuable data to aid in implementing the Sustainable Development Goals internationally. Through its Open Science Program, the satellite has maintained consistent operations and delivered free data to scientific and technological users from 88 countries. This program has produced a wealth of scientific output, with 72 papers, including 28 on data processing methods and 44 on applications for monitoring progress toward SDGs related to sustainable cities, clean energy, life underwater, climate action, and clean water and sanitation. SDGSAT-1 is equipped with three key instruments: a multi-spectral imager, a thermal infrared spectrometer, and a glimmer imager, which have enabled ground-breaking research in a variety of domains such as water quality analysis, identification of industrial heat sources, assessment of environmental disaster impacts, and detection of forest fires. The precise measurements and ongoing monitoring made possible by this invaluable data significantly advance our understanding of various environmental phenomena. They are essential for making well-informed decisions on a local and global scale. Beyond its application to academic research, SDGSAT-1 promotes global cooperation and strengthens developing countries' capacity to accomplish their sustainable development goals. As the satellite continues to gather and distribute data, it plays a pivotal role in developing strategies for environmental protection, disaster management and relief, and resource allocation. These initiatives highlight the satellite's vital role in fostering international collaboration and technical innovation to advance scientific knowledge and promote a sustainable future.

Key words SDGSAT-1, Earth observation, Remote sensing, SDGs

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1 Introduction

In 2015, the United Nations (UN) established an ambitious development roadmap for global society, the 2030 Agenda for Sustainable Development, which contains 17 Sustainable Development Goals (SDGs). To achieve them by 2030, this framework includes a wide

range of broad goals and related targets that promote peace, prosperity, and sustainability for both people and the planet. Lack of data on SDG indicators still remains an important limitation, as only 138 of the 168 SDG indicators have sufficient data for their assessment. It is estimated that approximately 85% of the monitored indicators do not meet their defined schedules or show deterior-

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ration^[1]. Without sufficient data, it has been difficult to understand the full scope of sustainability challenges, and all stakeholders, from governments to NGOs, struggle to make informed decisions and effective policies for the SDGs. For example, the lack of precise data on emissions and environmental changes makes it difficult to gauge the real impact of sustainability initiatives on climate action. Access to accurate, real-time data is therefore important to bridging the data gap and empowering stakeholders to make substantial efforts toward the SDGs.

Over the past several decades, Earth observation (EO) technology has improved the coverage and quality of reliable, structured data, offering critical data beyond the reach of standard ground monitoring methods. Particularly, continuous monitoring of Earth's surface through various satellite observation systems over several decades has proven to be very useful in tracking changes over time and provides continuous temporal data, critical for tracking long-term trends in climate change, urban development, deforestation, and other key indicators required by the SDGs^[2]. The development of Earth observation satellite platforms is a specialized domain. However, research and development efforts aimed at improving spatial, radiometric, and temporal resolutions of these platforms offer cost-effective solutions to global data challenges. These advancements enhance capabilities and opportunities for adding value to datasets through multi-source data integration, providing novel ways to study and understand complex global issues, and facilitating more targeted and realistic sustainability plans^[3].

The United Nations General Assembly approved the 2030 Agenda for Space, recognizing the importance of space technology and emphasizing its strategic importance for sustainable development. The Space2030 agenda explicitly emphasizes the importance of EO technology as a critical tool for monitoring and assessing worldwide environmental and development changes^[4]. It encourages countries worldwide to invest in and use these modern tools to fulfill their sustainability goals. China took decisive actions to address data and implementation challenges for SDGs and in November 2021 launched the first science satellite dedicated to serving the 2030 Agenda and SDGs: Sustainable Devel-

opment Science Satellite 1 (SDGSAT-1). China also set up the International Research Center of Big Data for Sustainable Development Goals (CBAS) in September 2021, following its announcement by President Xi Jinping during the 75th Session of The United Nations General Assembly. Building upon these achievements, China also expressed a strong commitment to facilitate global efforts toward developing a constellation of SDG satellites in collaboration with partners. This was highlighted as one of the deliverables of the multilateral High-level Dialogue on Global Development (2022): "Launching a Sustainable Development Satellite Constellation Plan, developing and sharing data and information for Sustainable Development Goal monitoring"

Operating SDGSAT-1, CBAS has been at the forefront of utilizing space-based tools to advance global efforts in deploying modern technology for sustainable development. CBAS has demonstrated successful use cases of SDGSAT-1 to monitor SDGs. Equipped with advanced sensing technology, SDGSAT-1 is tailored to monitor the interaction between human activity and Earth's environment^[2] and has been used to analyze environmental change, urban expansion, agricultural productivity, and other SDG-related issues. CBAS, through its SDGSAT-1 programs and research efforts, has expanded the availability of high-quality data and made significant contributions to support global efforts to accomplish the SDGs by providing stakeholders with the knowledge to make informed decisions and properly monitor their impact.

2 SDGSAT-1 Mission Overview

SDGSAT-1 has maintained a stable operation status since its launch, providing a steady stream of data daily. With a sun-synchronous orbit at an altitude of 505 km and an inclination angle of 97.5°, the revisit period of SDGSAT-1 is approximately 11 days. The swath width of the imagery acquired by all three sensors is 300 km. The spatial resolution for the Thermal Infrared Spectrometer (TIS) is 30 m, while the MSI provides a spatial resolution of 10 m. GLI has three RGB bands at a spatial resolution of 40 m and one high-resolution panchromatic band at a spatial resolution of 10 m. The primary technical parameters of all three SDGSAT-1 sensors are

in Table 1. For a more detailed description of the satellite platform and subsystems, refer to the corresponding chapters by Guo *et al.*^[5,6] in previous Space Science Activities in China National Reports.

The data quality of all three data types has been routinely evaluated and improved after the successful launch of SDGSAT-1 on 5 November 2021. Relying on the accurate imaging of the Earth's surface, MSI has been used for various SDG applications. MSI absolute calibration coefficients for converting Digital Number (DN) data to apparent radiance were derived by a field radiometric calibration experiment conducted at the Dunhuang calibration site. They were cross-validated against Sentinel-2 A Multispectral Instrument and Landsat 8 Operational Land Imager data^[7]. The SDGSAT-1 Data Users Handbook^[8] clearly states the procedures, parameters, and other considerations required to further transform the radiance to apparent reflectance.

Thermal infrared data sourced from SDGSAT-1 can accurately depict the thermal environments of ground cover and is crucial for deriving Land Surface Temperature (LST) and Land Surface Emissivity (LSE). The radiometric calibration conditions of TIS have been systematically evaluated^[9] and measures have been developed to improve the TIS data quality, including on-orbit

image quality evaluation^[10], an enhanced image stitching method that mitigates geometric distortion present in the wide-swath TIS image^[11]. Researchers have also developed an upgraded image restoration method improving its efficiency and standing out among other state-of-the-art methods^[12]. The LSE retrieved from TIS data was empirically proven to have a quality consistent with LSEs retrieved from Landsat 8 and MODIS data^[13]. Considering the well-established applications of thermal infrared data provided by Landsat 8 and MODIS, high-resolution SDGSAT-1 thermal infrared data has the potential to advance the research on regional energy balance, urban heat islands, retrieval of evapotranspiration, and land surface materials analysis.

Researchers have also thoroughly structured the calibration of DN values of GLI data into radiance, leading to a good correlation between GLI data and the Day-Night Band (DNB) data of the Visible Infrared Imaging Radiometer Suite (VIIRS)^[14]. GLI data provides an important source of observations for nighttime human activity. Furthermore, de-noising and de-stripping algorithms were proposed to address the high background noise and stripes in the GLI data^[15–17]. Additionally, selecting an appropriate pan-sharpening method for GLI data has also been in development^[18].

Table 1 Technical parameters of three instruments onboard SDGSAT-1

Instrument	Parameter	Specification and unit
Multispectral imager	Swath width	300 km
	Spatial resolution	10 m
	Bands and central wavelengths	Band 1 (deep blue): 400.63 nm Band 2 (deep blue): 438.47 nm Band 3 (blue): 495.10 nm Band 4 (green): 553.23 nm Band 5 (red): 656.75 nm Band 6 (red edge): 776.12 nm Band 7 (near-infrared): 854.02 nm
Thermal infrared spectrometer	Swath width	300 km
	Spatial resolution	30 m
	Bands and central wavelengths	Band 1: 9.35 μm Band 2: 10.73 μm Band 3: 11.72 μm
Glimmer imager	Swath width	300 km
	Spatial resolution	Panchromatic: 10 m. RGB: 40 m
	Bands and central wavelengths	Blue band: 478.87 nm Green band: 561.20 nm Red band: 734.25 nm Panchromatic band: 680.72 nm

3 Advancing SDG Applications through the SDGSAT-1 Open Science Program

3.1 SDGSAT-1 Open Science Program

In September 2022, CBAS launched the SDGSAT-1 Open Science Program (www.sdgsat.ac.cn), offering free access to SDGSAT-1 data to support global progress toward the SDGs. The program fosters multi-disciplinary SDG research and addresses data gaps that hinder the implementation of the SDGs. As of April 2024, the program has accumulated 1500 data users across 88 countries, resulting in over 16000 image downloads. In addition to accessing archived data of past

missions, users can submit observation plans corresponding to specific mission needs, with the SDGSAT-1 operation team adjusting the satellite operation accordingly.

As shown in Figure 1, the SDGSAT program has produced numerous publications in various areas of sustainable development, which aligns with the satellite's broad impact on academic research. As of the end of April 2024, there are 72 articles related to SDGSAT-1, including 28 articles on data processing and 44 on SDG monitoring and evaluation applications. More than half of the articles were published in “Remote Sensing”, “Remote Sensing of Environment”, and “International Journal of Digital Earth”. Among the data processing articles, over 50% focus on data preprocessing tech-

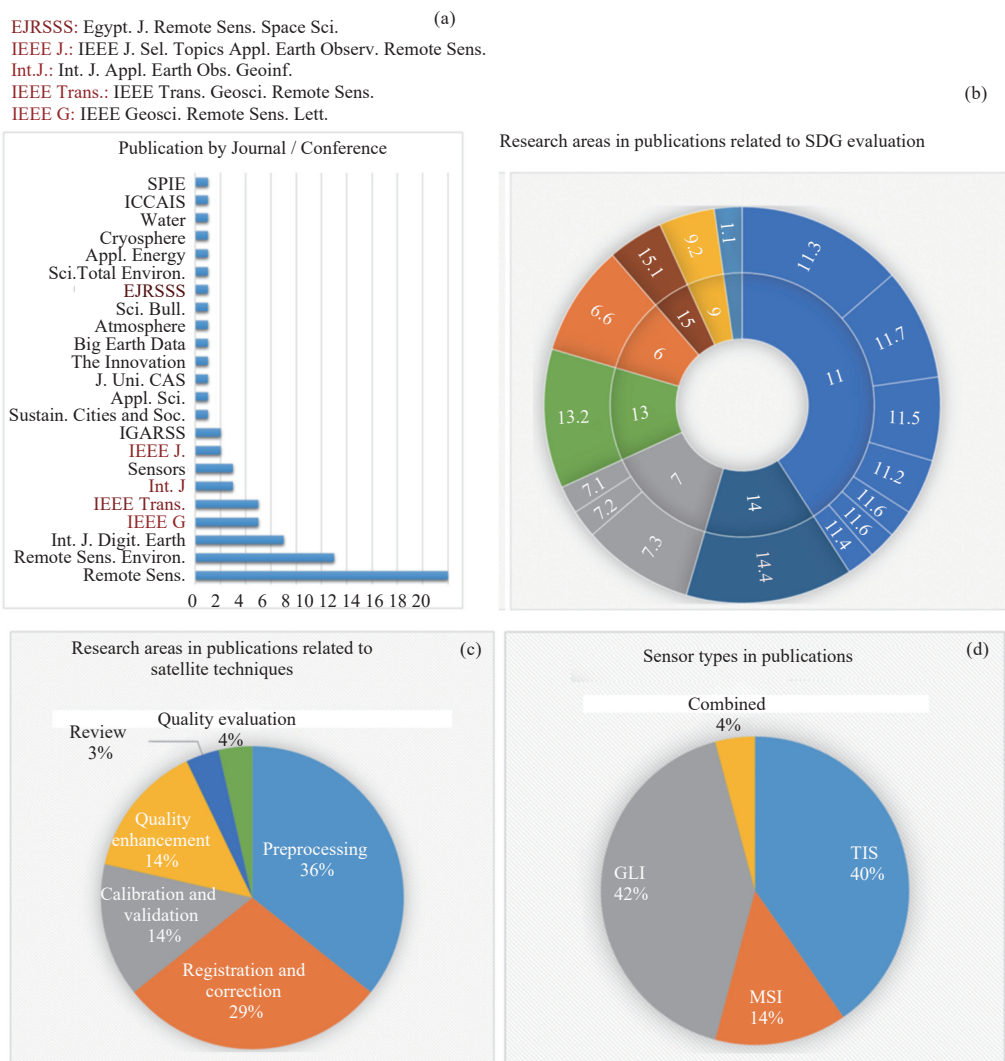


Fig. 1 Statistics of public articles

niques, registration, and correction techniques, followed by data calibration and validation, as well as quality enhancement. In the SDG monitoring and evaluation articles, research on SDG 11 receives the most attention. It covers the broadest range of objectives, followed by studies on SDG 7 and SDG 14, with SDG 13 and SDG 6 closely following. In terms of payload usage in published articles, the GLI sensor receives the most attention, accounting for 57%, which underscores its potential for sustainable cities (SDG 11), clean energy (SDG 7), and underwater life (SDG 14). Next is the thermal infrared sensor, primarily showcasing its ability to finely characterize heat sources.

3.2 Emerging SDG Applications

As of April 2024, research projects utilizing SDGSAT-1 imagery are gaining increasing influence in the study of SDGs, particularly within the research communities focused on SDG 6 (Clean water and sanitation), SDG 9 (Industry, innovation, and infrastructure), SDG 11 (Sustainable cities and communities), and SDG 13 (Climate action).

3.2.1 SDG 6 Clean Water and Sanitation

SDGSAT-1 MSI and TIS data have proven valuable proxies for water quality analysis, supporting the implementation of SDG target 6.1 (Safe and affordable drinking water). Figure 2 depicts the red tide near the coast of

Huizhong City from a study on red tide index using SDGSAT-1 MSI data conducted by Wang *et al.*^[19]. Additionally, MSI-based studies on water quality parameters such as Suspended Sediment Concentration (SSC)^[20], Optical Water Type (OWT)^[21], and suspended matter concentration (C_{tsm})^[22], along with TIS-based sea surface temperature retrieval^[23], have introduced methods for water quality analysis using SDGSAT-1 data.

3.2.2 SDG 9 Industry, Innovation, and Infrastructure

To address the significant environmental challenges posed by industrial activities, SDG target 9.4 (Upgrade all industries and infrastructures for sustainability) appeals to the monitoring of industrial processes and emissions. However, in-situ surveillance of factories may encounter challenges such as high costs of materials and human resources and inconclusive or false results due to deliberate evasion of inspection. SDGSAT-1 offers an effective alternative for capturing distinctive industrial thermal signals using its TIS. Figure 3 shows a cluster of factories in Tangshan City, China, which have high thermal signals compared with the landmass and the sea surface. In a study locating industrial heat sources in the Beijing–Tianjin–Hebei Region, high-resolution TIS data helps identify industrial heat sources with low heat emis-

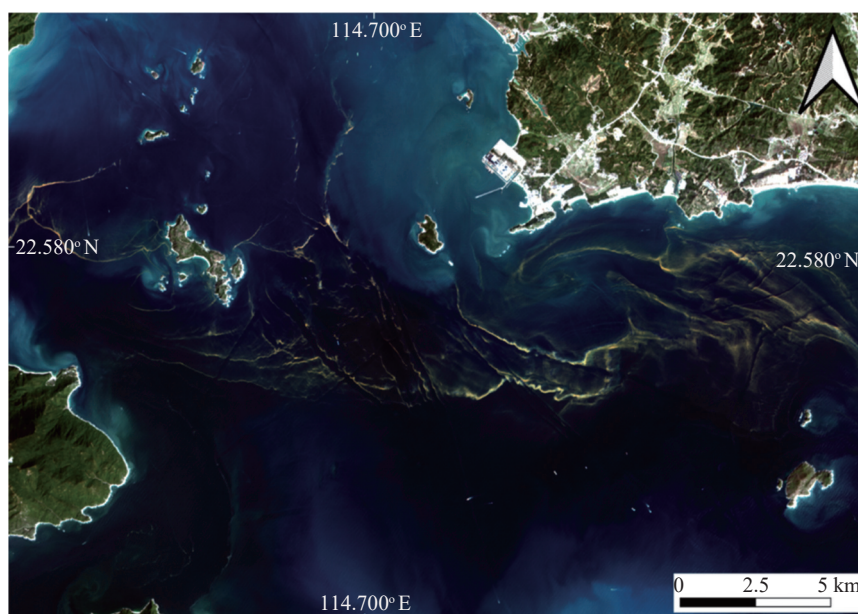


Fig. 2 SDGSAT-1 MSI true RGB image (band combination: 5-4-3) of the red tide observed off the coast of Huizhou City, Guangdong Province, China, captured on 11 March 2022

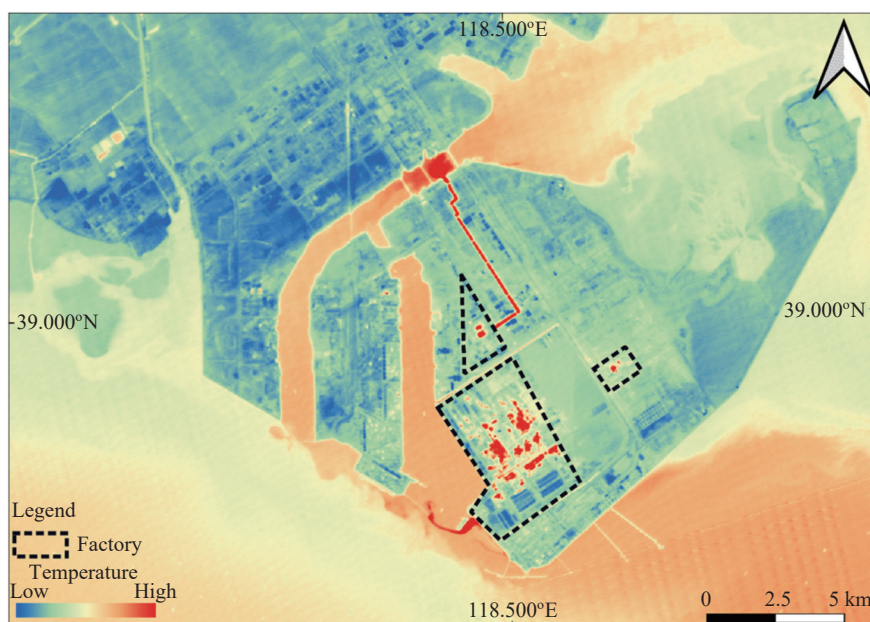


Fig. 3 SDGSAT-1 TIS Band 2 nighttime imagery showing coastal factories in Tangshan City, Hebei Province, China on 10 January 2024. Heat sources within the factory perimeters are visible in the imagery. Water bodies around factories also have an elevated temperature relative to their surrounding environment

sions and small spatial coverage^[24]. Furthermore, the sensitivity of TIS data to heat anomalies has facilitated its application in detecting thermal discharge from nuclear power stations^[23].

3.2.3 SDG 11 Sustainable Cities and Communities

With more than half of the global population residing in cities and the concentration of socioeconomic activities in urban centers, it is crucial to trace human activity within these areas accurately. Disasters, air and light pollution, and climate changes can have disproportionately large impacts on the urban population, underscoring the importance of SDG target 11.5, “Reduce the adverse effects of natural disasters”.

Damage to power grids and buildings caused by earthquakes, flooding, and other natural disasters can be assessed by comparing pre-disaster and post-disaster glimmer images. Previous generations of nighttime light sensors, such as the VIIRS with a spatial resolution of 500 m, cannot capture nighttime light dynamics at a fine scale. In contrast, SDGSAT-1 GLI has a maximum resolution of 10 m, the highest among contemporary freely available data sources, enabling it to capture the status of nighttime light at a neighborhood level. The ability of SDGSAT-1 glimmer data to assess the destruction of disasters has been proven in damage assessment re-

search and reports of the 2023 Turkey-Syria earthquake^[25,26], the 2023 Libya flooding^[27], the 2023 Sudan conflicts^[28], and the 2023 Gansu earthquake^[29]. For example, Figure 4 shows that Antakya, Turkey, experienced a significant light loss after the 2023 Turkey-Syria earthquakes that occurred on 6 February 2023.

The RGB band configuration of the GLI facilitates in-depth analysis of the distribution of different artificial light sources and Correlated Color Temperature (CCK). Thus, extensive applications of SDGSAT-1 for light pollution and light source studies^[30–33] have been conducted, and a light pollution map of the Iberian Peninsula, Canary Islands, Balearic Islands, and Madeira has been published through cooperation between the Complutense University of Madrid and CBAS^[34].

3.2.4 SDG 13 Climate Action

The accumulation of greenhouse gases has warmed and altered Earth’s climate significantly over the course of a century. As temperature and climate become increasingly unpredictable, the disasters associated with climate change, such as wildfires and flooding, become more frequent and severe^[35,36]. Building a comprehensive mechanism to record the severity of climate-related disasters, climate change phenomena, and their impacts on population can contribute to SDG targets 13.1 (Strength-

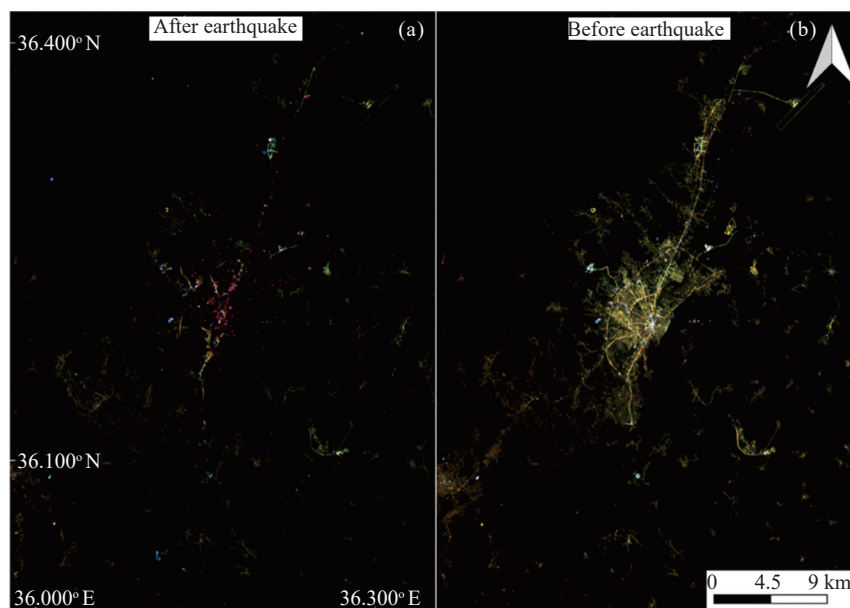


Fig. 4 Comparison between SDGSAT-1 GLI imagery of Antakya, Hatay Province, Turkey, before and after the 2023 Turkey-Syria earthquakes. (a) RGB (band combination: 1-2-3) nighttime GLI imagery captured on 12 February 2023, after the earthquake, (b) RGB (band combination: 1-2-3) nighttime GLI imagery captured on 22 August 2022, before the earthquake, depicting bright nighttime light from roads and urban areas with precise details

en resilience and adaptive capacity to climate-related disasters) and 13.2 (Integrate climate change measures into policy and planning).

Sea ice dynamics in the polar regions are closely associated with global warming in a positive feedback loop^[37]. SDGSAT-1 wide-swath high-resolution TIS data has the capability to detect previously hard-to-trace small ice leads in polar regions, contributing additional insights for monitoring sea ice changes^[38]. In Figure 5, the considerable temperature difference between ice sheets and seawater makes gaps and fractures between sea ice obvious.

CBAS has conducted an experimental study applying synergetic observation of three SDGSAT-1 sensors to observe the spread of a forest fire. Figure 6 illustrates the observation of the 2024 Ganzi forest fire using all three sensors. In the daytime MSI imagery (Figure 6a), burned areas differ from their surrounding environments. The nighttime observation of the regions around Yajiang County on 16 March 2024 (Figure 6b), shows that TIS data is sensitive to high temperatures. GLI images (Figure 6c) captured synchronously with the TIS data were clearly able to delineate fire locations for observing nighttime forest fires.

4 Conclusion

SDGSAT-1 has played a pioneering role in addressing the data gaps that have impeded advancements in the United Nations Sustainable Development Goals (SDGs). Being the first scientific satellite to facilitate progress toward the 2030 Agenda, SDGSAT-1 has showcased the significant capabilities of Earth observation technology in tracking and assessing efforts toward sustainable development across various sectors. The Open Science Program of SDGSAT-1 has cultivated a worldwide network of researchers who are actively employing its data to create new techniques and solutions for different SDG targets and indicators. This initiative has produced numerous scientific papers demonstrating the satellite's adaptability in analyzing water quality, identifying industrial heat sources, evaluating disasters, examining light pollution, and monitoring climate change.

The ability to successfully integrate space technology with sustainable development goals is demonstrated by SDGSAT-1's ongoing success. The information acquired from this mission is essential for developing policies and plans that address disaster risk reduction, environmental preservation, and socioeconomic inequality.

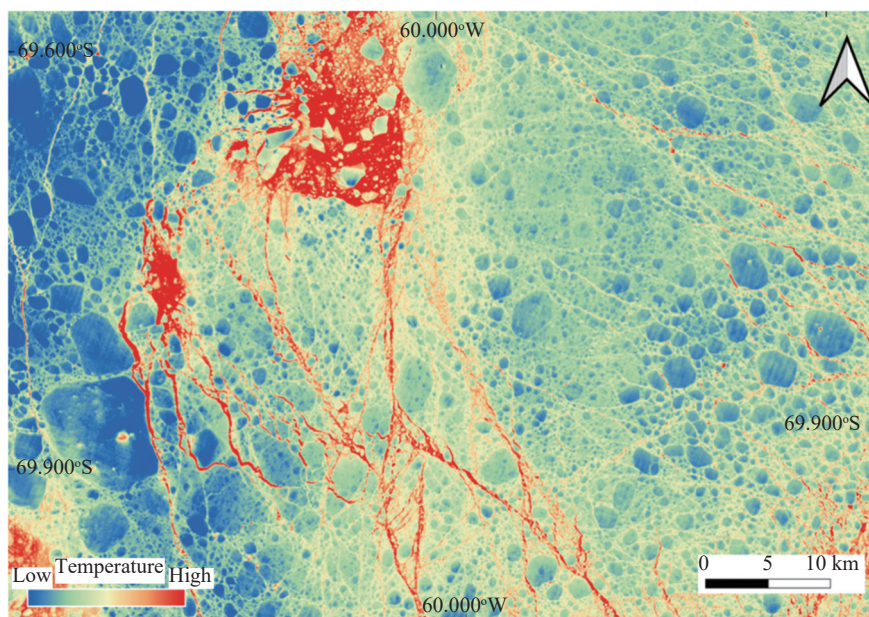


Fig. 5 SDGSAT-1 TIS Band 2 imagery of the sea ice distribution near the Antarctic Peninsula. Imaging date: 16 February 2023

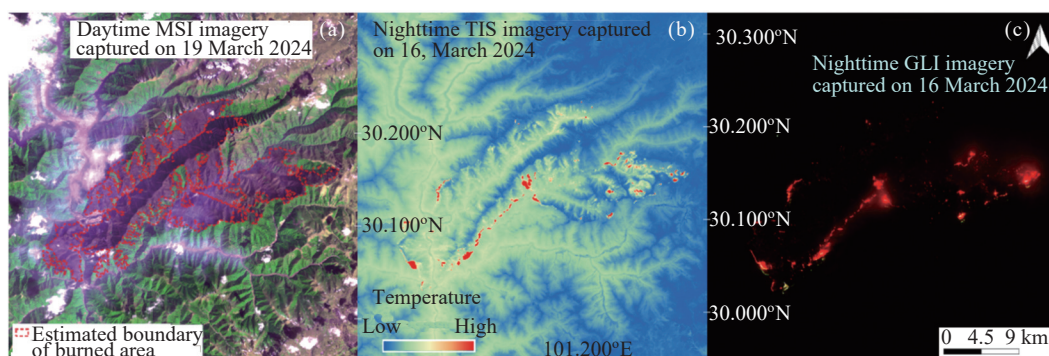


Fig. 6 SDGSAT-1 three-sensor synergetic observation of the 2024 Ganzi forest fire. (a) MSI pseudo-RGB image (band combination: 5-6-3) captured on 19 March 2024, of burned areas near Yajiang County, Ganzi Prefecture, Sichuan Province, China. (b) TIS Band 2 nighttime imagery of the same area was captured on 16 March 2024. (c) GLI nighttime imagery (band combination: 1-2-3) captured on 16 March 2024, of the same location

Moreover, the data and methods developed are critical in supporting international innovation and collaboration, strengthening international efforts to accomplish the SDGs. The ability to improve and broaden these strategies as we use the data supplied by SDGSAT-1 will enable more focused and efficient actions, thereby reinforcing satellite technology's position as a key component in the worldwide effort to achieve sustainability. SDGSAT-1's legacy will be used to demonstrate the advancements in satellite and Earth observation technology and provide guidance for other missions that will deepen our knowledge and improve our ability to man-

age Earth's resources. Developing space-based observational capabilities provides countries worldwide with the essential instruments needed to manage sustainable development challenges in a dynamic world.

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