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Regulating unmanned aircraft systems in Antarctica: challenges and collaborative solutions

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The increasing use of unmanned aircraft systems (UAS) globally presents significant opportunities and challenges for Antarctic governance, particularly in terms of operational safety and environmental protection. This study investigates the challenges faced by various stakeholders in regulating UAS operations in Antarctica and identifies collaborative solutions, employing both empirical and comparative research methodologies. Data on domestic UAS regulations and Antarctic-specific rules from Antarctic Treaty Consultative Parties (ATCPs) were obtained through their official civil aviation websites, while the involvement of non-state actors in the Antarctic Treaty Consultative Meeting (ATCM) was assessed using information provided by the Antarctic Treaty Secretariat. The findings reveal that ATCPs have developed guidelines, manuals, and other regulatory tools and contribute actively to ATCM discussions. Non-state actors, leveraging their interdisciplinary expertise and research capabilities, also play a critical role in shaping UAS regulatory frameworks. Nevertheless, current rules governing UAS operations in Antarctica remain fragmented, underscoring the need for a more cohesive and comprehensive regulatory framework. As UAS regulations in Antarctica continue to evolve, effective rulemaking will require collaboration among diverse actors, integrating practical expertise, global regulatory standards, and the unique operational conditions of the Antarctic region. A comprehensive legally binding Measure or at least a resolution adopted by ATCM may be good start for this integrated regulatory process.

KEYWORDS

Antarctic Treaty Consultative Parties (ATCPs), non-state actors, regulation, unmanned aircraft systems (UAS), Antarctica

1 Introduction

Technological advancements have driven the global expansion of unmanned aircraft systems (UAS) usage. Current applications and existing legal regulations for UAS provide a valuable research framework for shaping UAS regulation in Antarctica. Although universal UAS regulations are lacking and legal frameworks differ significantly across states, the relatively comprehensive and well-established regulations outside of Antarctica offer useful references for developing robust legal standards for UAS operations within the Antarctic region.

Originally developed as training aids for targeting practice during World War II, UAS have since evolved into highly sophisticated systems with various forms of ground control and pre-programming capabilities (Heverly, 2015). The term "drone" is widely used by the media, industry, and the general public. However, states and private entities often employ alternative terminology, such as Unmanned Aerial Vehicles (UAV) (The Canadian Aviation Regulations, 2016), Remotely Piloted Aircraft Systems (RPAS) (ATCM40 WP20, 2017), and Remotely Piloted Aerial Vehicles (RPAV) (ENAC, 2018). In 2015, the International Civil Aviation Organization (ICAO) published a Manual on Remotely Piloted Aircraft Systems to facilitate the integration of UAS regulations into the existing civil aviation framework (ICAO, 2015). As RPAS has emerged as the most internationally accepted term, it has been adopted by numerous national aviation agencies and is frequently used in guidelines and discussions at the Antarctic Treaty Consultative Meeting (ATCM) in recent years.

ICAO currently differentiates between UAS that can be accommodated within airspace and those capable of integration with manned aircraft (ICAO, 2024). The ICAO encourages states to support the development of UAS regulations by contributing experience-based insights (ICAO, 2011). This study adheres to the ICAO's current model standards and predominantly uses the term UAS, while also retaining the term RPAS in alignment with terminology commonly used in international governance platform publications.

To assess the current state of research on UAS in Antarctica, this study conducted a search in the Web of Science database (Web of Science, 2024) using keywords such as "Antarctica," "drones," "Unmanned Aerial Vehicle," "Unmanned Aircraft System," and "Remotely Piloted Aircraft System" for the period spanning 2012 to 2023. Figure 1 illustrates the search results. Over the past decade, there has been a marked increase in studies focusing on UAS in Antarctica. While the number of published papers fluctuated between 2012 and 2016, a consistent upward trend has been observed since 2016.

The findings indicate that the United States, the United Kingdom, China, Australia, Germany, Spain, and New Zealand have published more research on UAS usage in Antarctica than other Antarctic Treaty Consultative Parties (ATCPs). Figure 2 presents these search results. Greater utilization of UAS in Antarctica has allowed these states to accumulate significant practical experience, resulting in a higher volume of research publications. Leveraging this practical experience and research knowledge, these states have enhanced their governance capacity in regulating UAS activities within Antarctica, increasing their influence in Antarctic governance. Additionally, these countries have submitted national proposals for discussion at the ATCM and the Committee for Environmental Protection (CEP), receiving strong engagement and support. This active participation has initiated the regulatory process for UAS activities under a state-led approach within the broader international Antarctic governance framework.

To deepen understanding of Antarctica, states have increasingly focused on researching and applying new technologies and equipment for polar exploration. The use and regulation of UAS have become prominent topics within the Antarctic Treaty Consultative Meeting (ATCM). The growing volume of research publications on Antarctic UAS highlights states' attention to such innovations in polar research. This rising trend in UAS applications underscores the need for more robust legal regulations governing their use in the region.

In polar research, states closely monitor advancements in technology and equipment. The unique characteristics of Antarctica make enhanced regulation of UAS essential. First,

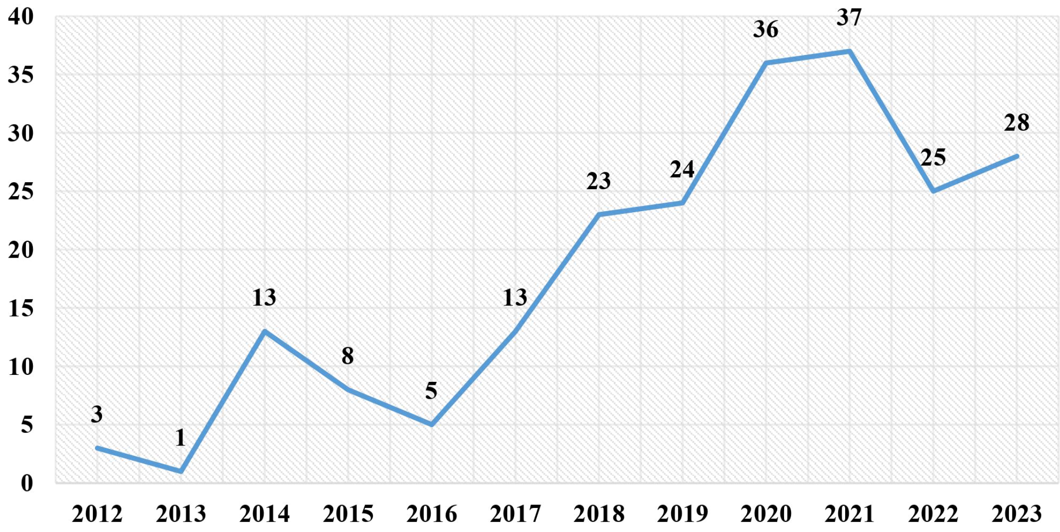

FIGURE 1
Trend in the number of papers related to UAS in Antarctica in the Web of Science Database (2012-2023). Source: Web of Science Database. https://www.webofscience.com/wos/alldb/summary/9dcee866-a1e7-4e31-8552-8d39fa9a2de1-98e3eb44/relevance/1. The figure is made by the author.

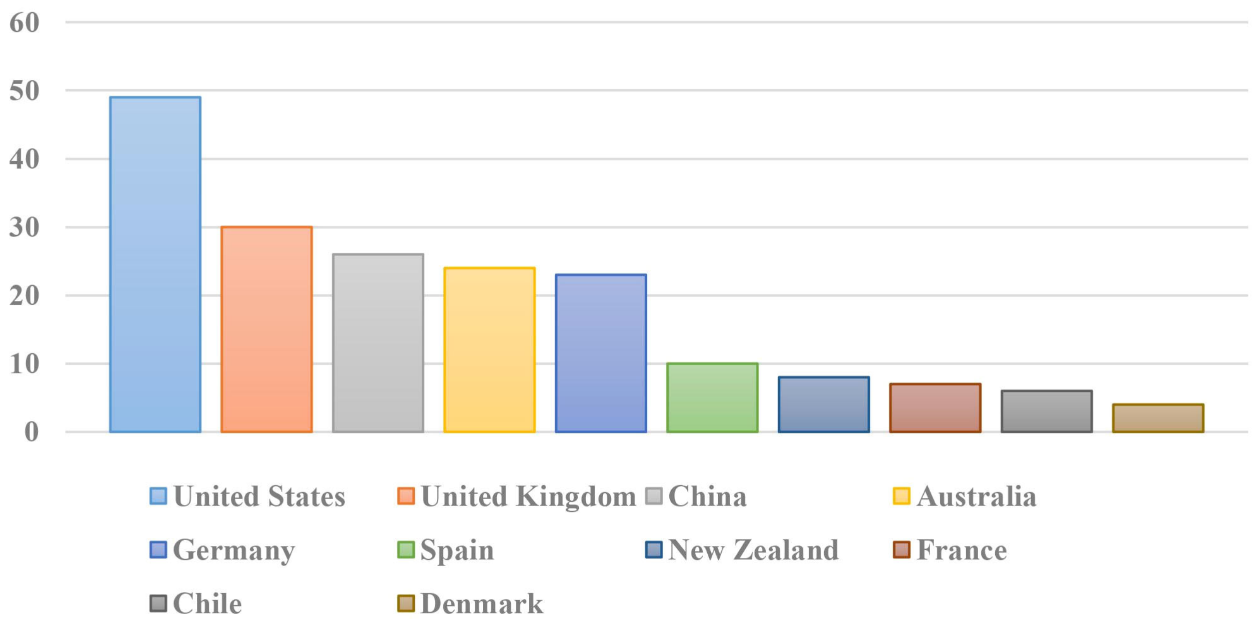

FIGURE 2
The number of papers related to UAS in Antarctica by various states in the Web of Science Database (2012-2023). Source: Web of Science Database. https://www.webofscience.com/wos/alldb/summary/9dcee866-a1e7-4e31-8552-8d39fa9a2de1-98e3eb44/relevance/1. The figure is made by the author.

Antarctica's environment is highly fragile, and UAS operations may disrupt or damage local wildlife and ecosystems. Second, as a key region for scientific study, UAS activities must be carefully coordinated with ongoing research to prevent mutual interference. Third, as an international public domain, UAS operations must be adhered strictly to established rules to ensure the region's peaceful use. Overall, UAS operations in Antarctica call for unified regulatory standards.

Beyond Antarctica's unique characteristics, it is crucial to standardize UAS regulations in the region. ATCPs and non-state actors have collaboratively developed a soft law framework for UAS operations in Antarctica, grounded in scientific and practical experience. The ATCM adopted the "Environmental Guidelines for Operation of Remotely Piloted Aircraft Systems in Antarctica" (ATCM41 Final Report Environmental Guidelines, 2018). Additionally, the Council of Managers of National Antarctic Programs (COMNAP) published the Antarctic UAS Operator's Handbook (Handbook, 2022), while the International Association of Antarctica Tour Operators (IAATO) introduced the IAATO Policies on the Use of Unmanned Aerial Vehicles in Antarctica (ATCM38 IP88 IAATO Policies, 2015). The existing UAS regulations in Antarctica are fragmented and lack systematic coherence. It is insufficient for states and non-state actors to independently design and follow their own UAS guidelines. To ensure orderly UAS operations and safeguard the Antarctic environment, it is essential to establish unified regulations as a minimum standard. Various actors, at multiple levels, should take the initiative in developing collaborative solutions for effective UAS governance in Antarctica.

Therefore, this study analyzes the domestic policies and regulations of ATCPs, relevant ATCM documents, normative guidelines from associated organizations, and scholarly literature, utilizing both comparative and empirical research methods. The remainder of the paper is organized as follows: Section 2 examines the practical applications of UAS; Section 3 reviews ATCPs' domestic UAS regulations and their involvement in Antarctic UAS governance; Section 4 analyzes the role of non-state actors in Antarctic UAS regulation; Section 5 offers recommendations for improving UAS regulation in Antarctica; and Section 6 concludes the discussion.

2 Applications and challenges of UAS

UAS were initially developed for military purposes. By the early 21st century, advancements in technologies such as global satellite positioning facilitated the gradual expansion of UAS applications in the civilian sector. Much like the transformative impact of manned aircraft on civil aviation, UAS are now revolutionizing this field (Fiallos, 2016). Their civilian applications parallel those in Antarctica, where their flexibility and cost-effectiveness have led to increased usage. However, UAS operations in Antarctica also pose challenges and risks to the fragile Antarctic environment. Consequently, the regulation of UAS is emerging as a critical issue on the Antarctic governance agenda. This section examines conventional civilian UAS applications and explores their uses and associated challenges in Antarctica to inform the development of effective UAS regulatory frameworks.

2.1 Conventional civilian applications of UAS

Over recent decades, UAS have advanced rapidly, becoming integral to civilian applications such as remote sensing, logistics, emergency rescue, environmental monitoring, and precision agriculture. Their advantages—accuracy, efficiency, and flexibility—make UAS well-suited for these diverse uses (Hayat et al., 2016). To provide a clear overview of UAS applications, this section examines their role in the civilian sector across three key areas: remote sensing, logistics, and emergency rescue.

2.1.1 Remote sensing

UAS-based remote sensing provides automated, intelligent, and specialized capabilities for rapidly acquiring spatial information on land, resources, environmental conditions, and specific events. It integrates advanced technologies, including unmanned aerial vehicle systems, remote sensing sensors, telemetry and telecontrol, communication systems, and GPS differential positioning to enable real-time data processing, modeling, analysis, and actionable insights (Li and Li, 2014). UAS remote sensing applications encompass meteorological monitoring (Sziroczak et al., 2022), environmental observation (Zhang and Zhu, 2023), maritime information infrastructure, and disaster forecasting (Mohd Daud et al., 2022).

For instance, during the monitoring of Antarctic glaciers in 2017, a collapse event occurred at the Darke Glacier near Zhongshan Station, forming a new ice-pit landform. UAS remote sensing was deployed for emergency aerial imaging, surveying the ice surface from Eagle's Nest Rock to the inland departure base and conducting three-dimensional modeling and data processing. This operation provided valuable high-resolution UAS remote sensing data essential for studying ice-pit landforms (Zhang et al., 2019).

As an innovative remote sensing tool, UAS overcomes limitations inherent in traditional satellite remote sensing, manned aerial sensing, and ground-based monitoring. UAS remote sensing images offer a resolution as fine as 0.1 meters—significantly higher than satellite images—and flight endurance exceeding 16 hours. With high mobility, cost-effectiveness, and efficiency, UAS remote sensing is poised to become a vital information source for the dynamic monitoring and management of national marine areas in the future (Li and Li, 2014).

2.1.2 Logistics

The rapid growth of e-commerce has driven increasing demand for UAS in logistics and distribution, with the potential to revolutionize logistics systems. Amazon was one of the first e-commerce companies to utilize UAS for paid deliveries, launching Prime Air in 2015. Prime Air's advanced detection and avoidance system allows it to fly longer distances without a visual observer, while safely avoiding other aircraft, people, pets, and obstacles (Amazon, 2022). In contrast to Amazon's delivery drones, WING employs a unique system that lowers packages to the ground via a tether without the need to land (Wing, 2021). JD.com, capitalizing on its global logistics and warehousing network, is developing a "feeder and terminal" drone logistics ecosystem. This system covers all logistics orders within a 500-kilometer radius and establishes an intelligent "skyway network" (JD, 2024).

In addition to safety and flexibility, the cost of drone delivery is a crucial factor in logistics. Drone delivery costs approximately $0.30 per parcel, which is one-third or less of the cost of traditional ground transportation (Sudbury and Hutchinson, 2016). In 2019, Air Cargo Canada and Drone Delivery Canada partnered to use UAS for air cargo transport, planning 150,000 drone transport routes. These drone-based air transport services are expected to offer cost-effective solutions for cargo delivery, especially in reaching remote communities across Canada. This agreement is also likely to advance the development of regular international air transport operations for UAS (DDC, 2019).

In logistics applications, the advantages of UAS in terms of safety, flexibility, and low cost are fully realized. UAS are commonly used to transport daily necessities and work equipment for scientific expeditions in Antarctica, proving highly effective in logistics support. The experience gained from UAS applications in logistics can offer valuable insights for their use in Antarctica. For instance, optimizing cargo transportation routes can reduce costs, allowing scientific research funds to be allocated more effectively to other key areas of research.

2.1.3 Medical and rescue

States with underdeveloped infrastructure have a high demand for UAS in medical supply delivery and rescue operations. In areas with limited transportation options, such as mountainous regions, traditional methods can be hindered by infrastructure challenges, leading to delayed medical deliveries and missed rescue opportunities. In contrast, UAS are not impacted by such limitations. Their versatility and maneuverability make them ideal for emergency situations. Since 2016, Zipline, a drone operator, has saved lives in Rwanda by delivering medical supplies, including blood, via drones (Zipline, 2018a). While traditional transportation can take hours to deliver medical supplies, Zipline's drones can transport blood samples to hospitals within 75 kilometers of Rwanda's Muhanga distribution center in just 30 minutes, reducing delivery time by at least four hours (Zipline, 2018b).

Geographic dispersion and limited medical services in the Caribbean pose significant challenges for timely medical emergency responses. UAS are increasingly being used in the region to deliver critical medical supplies, such as intravenous injections, sodium chloride infusions, hypertonic solutions, antiepileptic drugs, antihypertensive medications, painkillers, sedatives, and blood products (Ramsewak et al., 2022). Additionally, UAS utilize advanced computer vision technologies for dynamic monitoring (Mishra et al., 2020). For instance, rescue drones are deployed for coastal monitoring and search-and-rescue operations (Del-Real and Díaz-Fernández, 2021), offering timely and efficient assistance to individuals stranded on beaches.

UAS applications contribute to public welfare by stimulating economic growth and enhancing social benefits (Intelsat, 2024). Their high safety, flexibility, and low cost make them valuable not only for daily operations but also for scientific research and exploratory activities in Antarctica. UAS have become increasingly essential for Antarctic scientific research, logistical support, and emergency search-and-rescue operations.

2.2 UAS applications in Antarctica

UAS offer significant advantages in the harsh and sparsely populated conditions of Antarctica, which present unique challenges compared to other regions of the world. Currently, UAS are widely used in Antarctica for scientific research, logistical support, tourism, and journalism.

In scientific research, UAS have been utilized to gather data on the impacts of climate change, monitor sea ice, track penguin populations, map fine-scale vegetation, study ecosystem functioning (ATCM40 WP20, 2017), monitor marine mammals (ATCM40 IP75, 2017), and conduct surveys of Antarctic Specially Protected Areas (ATCM40 IP86, 2017). These applications align with UAS use in remote sensing. For logistical support, UAS are employed to transport scientific equipment and small items to designated locations (ATCM38 IP22, 2015), a role similar to their function in general logistics.

Travel agents and tourists can also use UAS for Antarctic tours, with proper permissions. In the future, UAS could play key roles in various emergency situations, such as search and rescue, firefighting, medical assistance, and the rapid detection of crevasses in sea ice and glaciers, similar to their applications in medical rescue. Furthermore, UAS are revolutionizing conservation efforts and enabling more informed management decisions (Jesús and Mulero-Pázmány, 2019). They can address environmental issues that threaten biodiversity in protected areas by providing continuous monitoring of environmental biophysical indicators. Traditionally, conservation actions combine field visits with satellite remote sensing, but these methods can disrupt the environment in protected areas. UAS offer a less invasive, non-disruptive, and reliable alternative for monitoring species abundance and distribution, as well as documenting wildlife behavior and health status (Jewell, 2013).

Under the harsh conditions of Antarctica, UAS offer several advantages (Li et al., 2021). First, they are cost-effective, with lower acquisition, training, and operational expenses. Second, UAS are highly flexible, lightweight, portable, and easy to operate. Third, they enhance safety by eliminating the risks associated with onboard personnel. Finally, UAS have a minimal impact on wildlife and the environment (ATCM41 WP29, 2018). Excessive human activity in Antarctica can disrupt wildlife habitats and disturb the ecological balance, significantly impacting the local ecosystem. Compared to manned aircraft, UAS are less intrusive when collecting data and conducting missions, making them a more environmentally friendly option for protecting the Antarctic region.

The aforementioned characteristics of UAS allow for the overcoming of human limitations, enabling the collection of scientific data across a wide range of natural conditions and scenarios, while minimizing environmental impact in Antarctica. This significantly enhances the effectiveness of scientific research in the region.

2.3 Challenges of UAS in Antarctica

However, the extreme and complex geography of Antarctica presents significant challenges for UAS operations. First, risks such as extremely low temperatures, strong winds, and rugged terrain can impede UAS flights, leading to potential damage or loss due to accidents, system failures, or unplanned landings. Additionally, UAS may collide with other aircraft or infrastructure, posing safety risks to personnel (ATCM38 IP22, 2015). Second, UAS operations can impact Antarctic wildlife, causing collisions, injuries, or even fatalities (ATCM37 WP51, 2014). The fragile vegetation and soil on the Antarctic surface can take years to recover from damage. Finally, UAS can threaten Antarctic wilderness values and protected areas, potentially harming unique ecosystems, as well as special areas such as Antarctic Specially Protected Areas, Antarctic Specially Managed Areas, and Historical Sites and Monuments (Secretariat of the Antarctic Treaty, 2024a). Thus, UAS operations in Antarctica pose both safety risks and potential environmental harm.

These concerns have not been adequately addressed by existing international regulations, including the Antarctic Treaty, the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) (Madrid Protocol, 1991), and its accompanying annexes. Given its urgency, the regulation of UAS is swiftly becoming a key issue on the Antarctic governance agenda.

In summary, while the applications of UAS in Antarctica offer significant benefits, they also present substantial challenges. Many states have incorporated UAS into their Antarctic programs as part of their logistical and operational plans for scientific research, and non-governmental organizations and individuals are increasingly using UAS in the region. To fully harness the advantages of UAS and ensure safe operations while safeguarding the environment, it is essential to establish and enhance regulatory frameworks for UAS activities in Antarctica.

3 Engagement of ATCPs in regulating UAS operations in Antarctica

Advancements in science and technology have significantly expanded human understanding of Antarctica and have had a profound impact on its governance. The development of UAS regulations in Antarctica is a prime example of this influence. Currently, UAS operations in the region are governed by a set of frameworks, including the *Environmental Guidelines*, the *Handbook*, and the *IAATO Policies*. These regulations have been shaped through collaboration between ATCPs and non-state actors. According to Article 38 of the Statute of the International Court of Justice (Statute of the International Court of Justice, 1946), states are the principal subjects of international lawmaking. As such, states remain central to the creation of UAS regulations in Antarctica (Rebecca and Saleem, 2015), while non-state actors, such as non-governmental organizations (NGOs), play complementary and interdependent roles (Sands et al., 2012).

There is currently no universally accepted, harmonized regulatory standard for UAS, and national regulatory practices differ significantly. However, the domestic technical practices and regulatory experiences of the ATCPs provide valuable models for UAS regulation in Antarctica. Based on their existing UAS practices, ATCPs have assessed the operational benefits, potential risks, and environmental impacts of UAS. The ATCM, the primary deliberative platform of the Antarctic Treaty System (ATS), facilitates the participation of signatories in Antarctic governance through active involvement, speaking opportunities, and the submission of meeting documents (ATCM Rules, 2022). Some ATCPs, drawing on their domestic regulatory experience and high-quality proposals, have made substantial contributions to shaping the UAS regulatory agenda within Antarctic governance. This section examines the domestic UAS regulations of ATCPs and their application to UAS in Antarctica, offering a comparative analysis of UAS regulations both within and outside the Antarctic region (Tsiamis et al., 2019).

3.1 Comparison of domestic UAS regulations in ATCPs

This section analyzes the domestic regulatory documents of 29 ATCPs to provide a comprehensive understanding of UAS regulations. By examining the varied regulatory practices among ATCPs, this study seeks to draw valuable insights and lessons for the development of UAS regulations in Antarctica.

National civil aviation or transport authorities are responsible for establishing UAS regulations to ensure safe operations and the organized development of the aviation sector. The data for this section were primarily sourced from the official websites of national government departments, civil aviation authorities, and the global drone regulations database (Global Drone Regulations Database, 2024). Table 1 presents the ATCPs and the relevant agencies responsible for regulating UAS. The national UAS regulations discussed in this section were published before March 2024, with the understanding that regulations are part of an evolving legislative process, and new updates are likely to emerge.

An analysis of UAS regulations across various ATCPs reveals that most countries have established specific criteria, including registration requirements, flight distance limitations, weight classifications, restrictions on flying over sensitive areas, proximity to airports, flight prohibitions in densely populated regions, flight time limits, and safety insurance mandates. In addition, some ATCPs emphasize additional factors such as pilot qualifications, age limits, weather conditions for UAS flights, and privacy regulations. Upon reviewing the domestic UAS regulations of 29 ATCPs, it is evident that these criteria appear frequently, indicating a level of commonality across the regulations. This study summarizes these twelve key criteria in Table 2. The black dots in the table indicate the presence of these criteria in the respective ATCPs' regulations, while a slash signifies their absence.

In the left column of Table 2, the ATCPs are listed in alphabetical order. The horizontal header presents the legislative criteria, ranked in descending order based on the number of ATCPs that govern them. All ATCPs regulate UAS registration and flight distance limitations, while only about half address weather conditions and privacy guidelines. This suggests that registration and flight distance limitations are fundamental aspects of UAS operations. The next section will further analyze these two elements.

TABLE 1 Authorities of UAS regulations in ATCPs.

State	Authority
Argentina	National Common Aeronautics Organization of Argentina
Australia	Civil Aviation Safety Authority
Belgium	Civil Aviation Authority
Brazil	National Civil Aviation Agency
Bulgaria	Bulgarian Air Traffic Services Authority
Chile	Directorate General of Civil Aviation
China	Civil Aviation Administration of China
Czech Republic	Civil Aviation Authority of Czech Republic
Ecuador	General Directorate of Civil Aviation of Ecuador
Finland	Finnish Transport Safety Agency
France	Ministry of Ecological and Solidarity Transition
Germany	Federal Minister of Justice and Consumer Protection of Germany
India	Directorate General of Civil Aviation (DGCA) Site for RPAS
Italy	The Italian Civil Aviation Authority
Japan	The Ministry of Land, Infrastructure, Transport and Tourism of Japan
Korea	Ministry of Land, Infrastructure and Transport of South Korea
Netherlands	The State Secretary for Transport, Public Works and Water Management of Netherlands
New Zealand	The Civil Aviation Authority of New Zealand
Norway	The Civil Aviation Authority of Norway
Peru	Peru's Directorate General of Civil Aeronautics
Poland	The Civil Aviation Office of Poland
Russian Federation	Russian Federal Space Agency
South Africa	South African Civil Aviation Authority
Spain	The Safety Aviation Agency of Spain
Sweden	The Transport Agency of Sweden
Ukraine	State Aviation Administration of Ukraine
United Kingdom	Civil Aviation Authority of United Kingdom
United States	Federal Aviation Administration of United States
Uruguay	National Directorate of Civil Aviation and Aeronautical Infrastructure of Uruguay

The table was made by the author based on the official website data from UAS authorities of ATCPs.

TABLE 2 Main legislative criteria in the national legal regulations.

State	Registration	Flight distance limitation	Weight classification	Sensitive area restriction	Distance from the airport	Security Insurance	Prosperous areas Restrictions	Flight time	Pilot qualification	Age limitation	Privacy	Climatic condition	Total
Argentina	•	•	•	•	•	•	•	•	•	•	•	•	12
Australia	•	•	•	•	•	•	•	•	•	•	•	•	12
Belgium	•	•	•	•	•	•	•	•	•	•	•	•	12
Brazil	•	•	•	•	/	•	/	/	•	•	/	/	7
Bulgaria	•	•	•	•	•	•	•	•	•	•	•	•	12
Chile	•	•	•	•	•	•	/	•	•	•	•	•	11
China	•	•	•	•	•	•	•	•	•	•	•	•	12
Czech Republic	•	•	•	•	•	•	•	•	•	/	•	•	11
Ecuador	•	•	•	•	•	•	/	•	•	•	•	•	11
Finland	•	•	•	•	•	•	•	•	•	•	/	/	10
France	•	•	•	•	•	•	•	•	•	•	/	•	11
Germany	•	•	•	•	•	•	•	•	•	/	•	•	11
India	•	•	•	•	•	•	•	•	•	•	/	/	10
Italy	•	•	•	•	•	•	•	•	•	•	•	/	11
Japan	•	•	•	•	•	•	•	•	•	/	/	/	9
Korea	•	•	•	•	•	•	•	•	/	/	•	•	10
Netherlands	•	•	•	•	•	•	•	•	•	•	•	•	12
New Zealand	•	•	•	•	•	•	•	•	•	/	/	/	9
Norway	•	•	•	•	•	•	•	•	•	•	/	/	10
Peru	•	•	•	•	•	/	•	•	/	/	•	/	8
Poland	•	•	•	•	•	•	•	•	•	•	•	•	12
Russian Federation	•	•	•	•	•	•	•	•	/	/	•	•	10
South Africa	•	•	/	/	•	/	/	•	•	•	•	•	8
Spain	•	•	•	•	•	•	•	•	•	•	•	•	12
Sweden	•	•	•	•	•	•	•	•	•	•	•	•	12
Ukraine	•	•	•	•	•	/	•	/	/	/	/	/	6
United Kingdom	•	•	•	•	/	•	•	/	•	•	/	/	8
United States	•	•	•	•	•	/	•	•	/	•	/	/	8
Uruguay	•	•	•	/	/	•	•	/	/	/	/	/	5
Total	29	29	28	27	26	25	25	25	23	20	18	17	

The table is made by the author based on the domestic UAS regulations of ATCPs.

In addition to the total number of criteria, Table 2 outlines the primary legislative criteria for domestic UAS regulations in the ATCPs. Figure 3, created using data from Table 2, provides a graphical representation of ATCPs' UAS regulations at the domestic law level. It illustrates the global distribution of ATCPs, with different colors representing varying numbers of criteria. States depicted in dark blue, such as Australia, have 12 criteria, while those in light blue, such as the United States, have 11 criteria. States shown in green, like Finland, possess 10 criteria; those in yellow, such as Japan, have 9 criteria; and states in orange, like Peru, have 8 criteria. States with skin tones, like Brazil, utilize 7 criteria, while those in red, such as Ukraine, have 6. States depicted in brown, such as Uruguay, possess 5 criteria. Figure 3 thus serves as a graphical representation of the data presented in Table 2.

ATCPs with comprehensive domestic UAS regulations have gained substantial experience in UAS scientific experiments and regulatory frameworks. By combining domestic legislative developments with international rules in Antarctica, it becomes evident that ATCPs with well-established UAS regulations are playing an active role in shaping the Antarctic UAS regulatory agenda. This highlights the fact that domestic experience provides a technical and regulatory foundation for the application of UAS by ATCPs in Antarctica. While the domestic practices and experiences of ATCPs cannot be directly applied to Antarctica due to its unique geography and special governance structure, they offer valuable lessons and insights. The following section compares and analyzes the main legislative criteria of ATCPs, explores their similarities and differences, and investigates how ATCPs' domestic regulations can be adapted for use in Antarctica.

UAS registration is a crucial criterion in the domestic regulations of all ATCPs and should be an essential component of the Antarctic UAS rules. Under Article 17 of the Chicago Convention, aircraft are assigned the nationality of the state in which they are registered (Chicago Convention, 1944). The state of registration bears several responsibilities concerning the aircraft under its jurisdiction. As Professor Cooper notes, "each State has a reciprocal responsibility for the international behavior of an aircraft having its nationality" (Cooper, 1965).

For example, in Argentina, the registration process for all unmanned aerial vehicles (UAVs) purchased from domestic suppliers must be initiated by the buyers (UAV regulations in Argentina, 2020). In Japan, the Civil Aviation Law mandates the registration of UAS weighing over 100 grams (Flight rules in Japan, 2024). Similarly, China's Interim Regulations on the Administration of Unmanned Aerial Vehicle Flights require owners to register their UAS under their real name, with penalties for operating without proper registration (UAS regulations in China, 2024).

The registration of UAS has become a global trend, facilitating both domestic management and adherence to international aviation regulations. Registration ensures that UAS operations are subject to government oversight and the legal framework of the state of registration, offering an effective mechanism for ensuring safe operations. This principle is equally applicable to UAS in Antarctica. Given that the airspace above Antarctica is considered international public airspace, registration is essential for establishing aircraft ownership and assigning responsibilities. UAS operating in Antarctica should be registered to maintain order and stability in the Antarctic airspace and ensure compliance with the regulations and standards of their respective states.

Additionally, all ATCPs' domestic regulations impose restrictions on flying distances, though the specific limits vary between states. Figure 4 illustrates the data on maximum vertical and horizontal distance limits in the domestic UAS regulations of the 29 ATCPs.

For vertical distance, most ATCPs regulate flight ceilings, with limits ranging from 50 meters to 150 meters. Notably, 66% of ATCPs, including countries such as Australia and the United States, specify a maximum height of 120 meters. However, Japan, Italy, South Korea, and Peru permit flights up to 150 meters, while

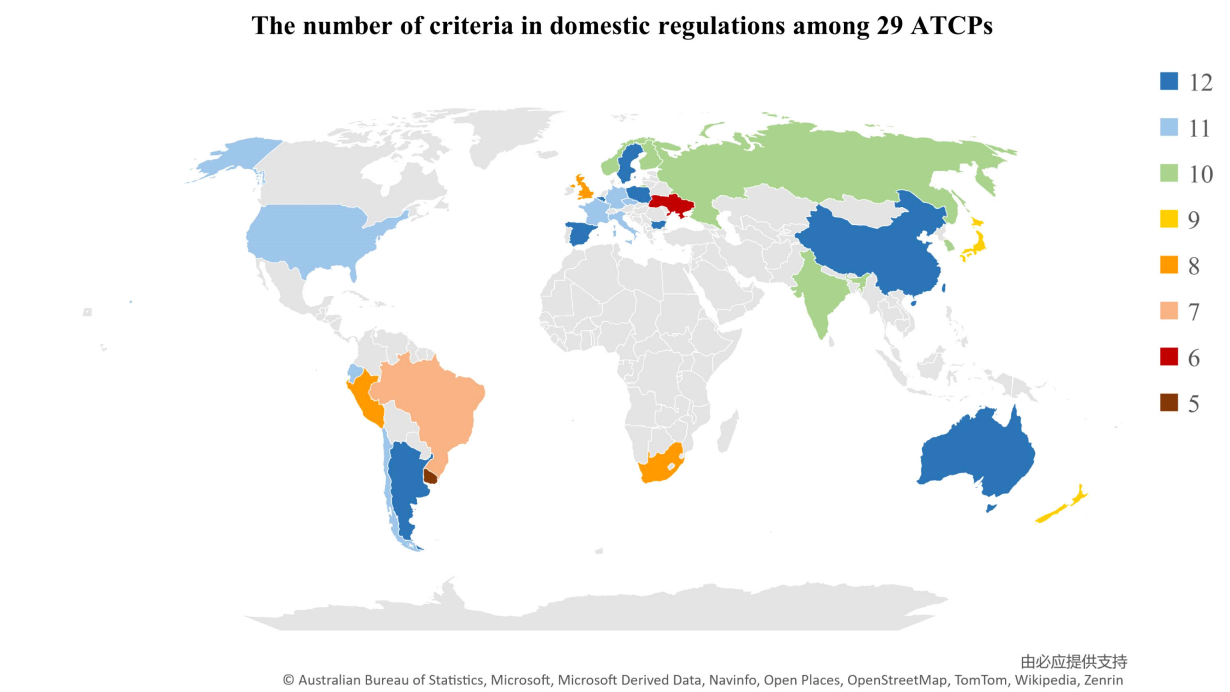

FIGURE 3
The number of criteria in domestic regulations among 29 ATCPs. The figure is made by the author based on the domestic UAS regulations of ATCPs.

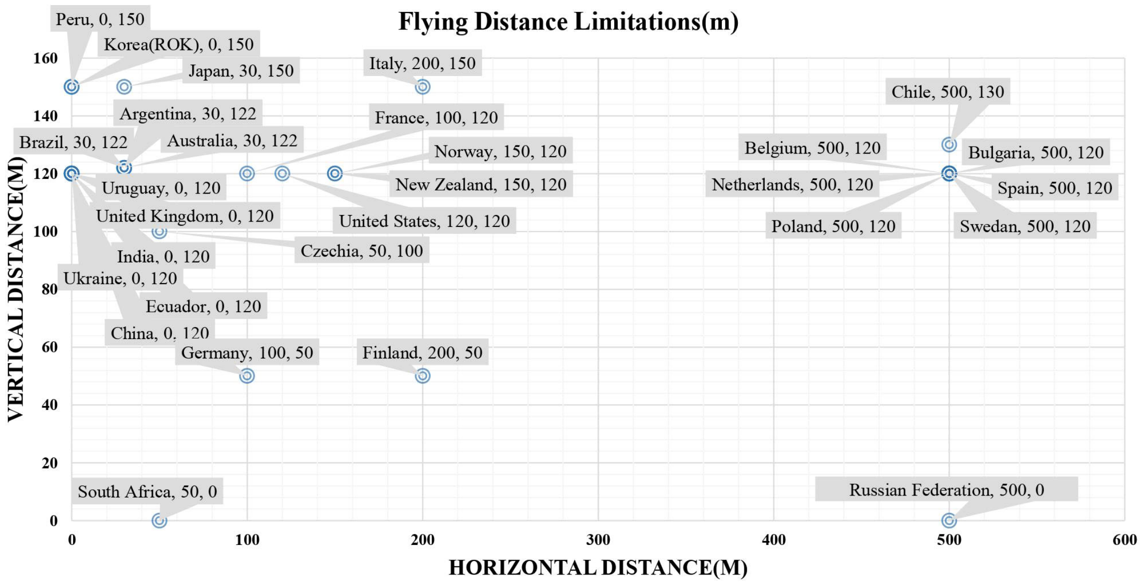

FIGURE 4
Limitations on the vertical and horizontal distance of UAS in the domestic regulations of ATCPs. The figure is made by the author based on the domestic UAS regulations of ATCPs.

Germany and Finland enforce a minimum flight height of 50 meters. By contrast, South Africa and the Russian Federation do not currently regulate maximum vertical distances.

In contrast to vertical distance regulations, the maximum horizontal distance permitted for UAS operations varies significantly among ATCPs, ranging from 30 meters to 500 meters. As shown in Figure 4, eight states, including Russia and Spain, have established a maximum horizontal distance of 500 meters, representing the higher end of the spectrum. Conversely, many other ATCPs impose stricter limits, allowing UAS to operate within a horizontal distance of less than 200 meters. Additionally, eight states, including China and the United Kingdom, do not define a specific horizontal distance but instead require that UAS remain within the visual line of sight (VLOS) of the operator. This approach emphasizes the operator's direct control and situational awareness during flight, potentially enhancing safety.

The emphasis on flight distance limitations in ATCPs' domestic regulations reflects a commitment to multiple priorities: ensuring flight safety, avoiding collisions with other aircraft or ground facilities, minimizing interference with the natural environment and wildlife, and protecting Antarctica's delicate ecosystems. For instance, both the United States and New Zealand extend their domestic standards to Antarctic operations, requiring UAS to operate strictly within the VLOS. Furthermore, they mandate a maximum flight altitude of 120 meters, aligning with safety and environmental protection principles. These measures stem from their broader domestic regulatory frameworks and demonstrate how established national practices can influence Antarctic governance (US Antarctic Program, 2016; ATCM40 ATT36, 2017).

The *Environmental Guidelines* explicitly mandate that UAS pilots and observers maintain operations within the VLOS and uphold constant communication unless explicitly authorized by a competent authority. Additionally, the guidelines emphasize keeping UAS at a precautionary distance from wildlife to minimize disturbances (ATCM41 WP29, 2018). These stipulations highlight the priority of flight distance limitations within the Antarctic UAS regulatory framework (Harris et al., 2019). However, a significant challenge persists: the lack of uniformity in the specific distance rules across ATCPs. For instance, while all ATCPs emphasize flight distance limitations domestically, the permitted distances vary widely.

Regarding the distance from airports during UAS operations (see Figure 5), Brazil, the United Kingdom, and Uruguay currently lack specific regulations, while the remaining 26 ATCPs mandate distances ranging from 1 km to 15 km. Among these, 72% require a minimum distance of 5 km or more. Most regulations fall within the 5–8 km range, with seven states stipulating distances exceeding 8 km. Generally, UAS are prohibited from approaching airports, particularly near take-off and landing paths, to ensure safety and reduce the risk of interfering with manned aircraft operations.

If UAS distances from airports are not effectively regulated, they can disrupt aviation operations, interfere with flight schedules, and even lead to aviation accidents. This issue is equally relevant in Antarctica, where aviation bases are vital infrastructure. Incomplete statistics indicate that over 50 airports exist in and around Antarctica, with more than 40 assigned ICAO airport codes (CAAC News, 2018). The region's unusually complex magnetic fields can cause compass errors, affecting aircraft navigation. The operation of UAS introduces an additional layer of complexity to Antarctic aviation. To ensure aviation safety, UAS should comply with distance limitations from airports, tailored to the unique conditions of Antarctica for safe and effective operations.

Flight time and weather conditions are critical factors influencing UAS operations. For instance, ATCPs like Australia

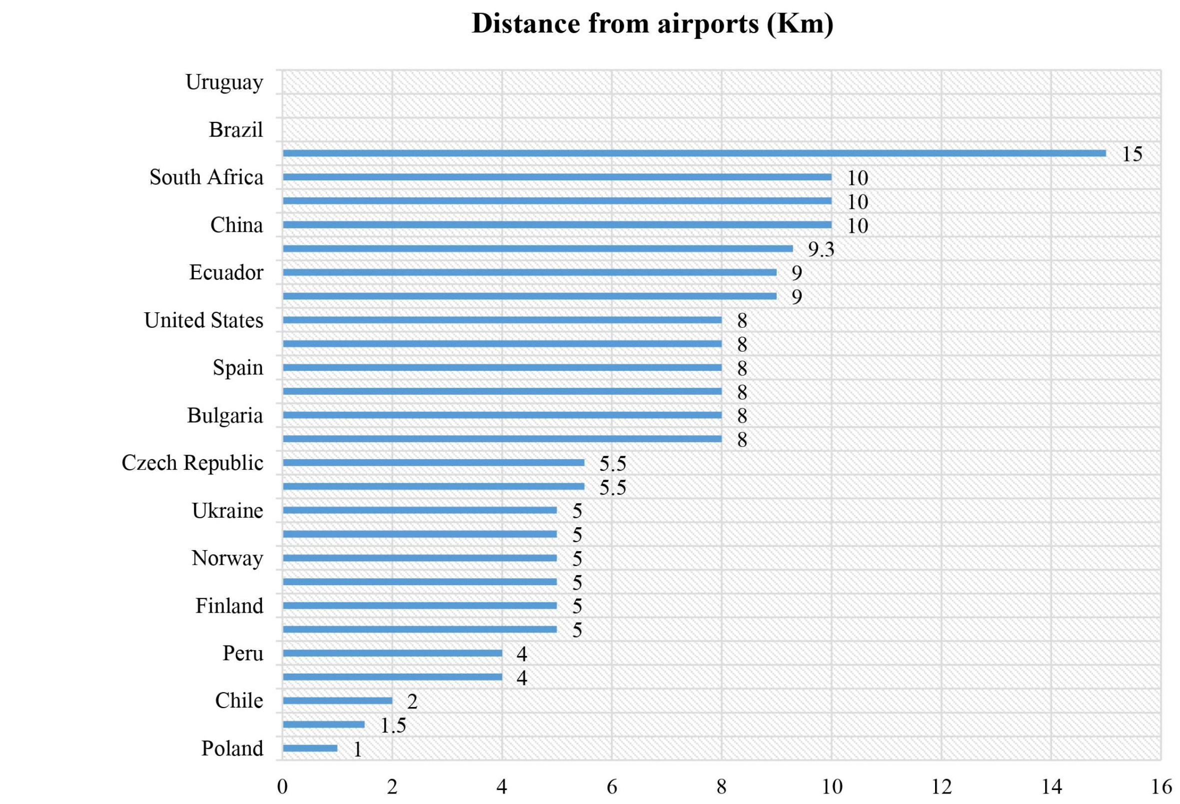

FIGURE 5
Limitations on the distance from airports. The figure is made by the author based on the domestic UAS regulations of ATCPs.

and New Zealand restrict UAS flights to daylight hours, explicitly prohibiting night flights. Conversely, the United States allows UAS to operate at night under certain conditions, such as the absence of exposed rotors and the use of anti-collision lights (Federal Aviation Administration, 2021). Restrictions on night flights are primarily due to reduced visibility, which hinders operators' ability to track UAS trajectories accurately and respond effectively to emergencies. Additionally, adverse weather conditions pose significant risks to UAS performance and safety, underscoring the need for clear regulatory provisions to ensure safe and effective operations.

Most ATCPs mandate that UAS operate only under favorable weather conditions. In Australia, for example, UAS flights are prohibited, unless approved by the Civil Aviation Safety Authority, in adverse conditions such as under clouds, in thick fog, at night, or with visibility less than 5 km. All drones are subject to environmental factors like wind and temperature and must adhere to the manufacturer's operational limits (CASR Part 101, 2023). Similarly, China's regulations have evolved, initially restricting UAS operations to daytime and continuous visual line-of-sight unaffected by weather. Recent updates now permit night flights or operations within the legal line of sight, provided the lighting system is activated (UAS regulations in China, 2024).

As technology advances, UAS are expected to adapt to increasingly complex scenarios, leading to the gradual relaxation of regulations concerning flight time and weather conditions. However, Antarctica's distinctive environment—marked by extreme cold, vast ice caps, frequent blizzards, and unpredictable weather—continues to present substantial challenges to UAS operations. To ensure safety, it is imperative to establish stringent regulations on flight time and weather conditions in Antarctica, mitigating economic losses and minimizing environmental risks.

Finally, security insurance and pilot qualifications are crucial factors influencing UAS operations. With the exceptions of Peru, South Africa, Ukraine, and the United States, all ATCPs have established insurance mechanisms to manage UAS-related accidents. Insurance requirements differ by state, with some regulations mandating coverage while others make it voluntary. For example, Brazil requires insurance for non-recreational UAS weighing ≥ 250 g (ANAC Resolution 419, 2017). In Australia, while public liability insurance is not mandatory, operators may face substantial financial liability in case of damage or injury, making liability insurance highly advisable (CASR Part 101, 2023). Some states, such as Argentina, have a mix of mandatory and voluntary insurance requirements. Operators of class C, D, and E recreational UAS must have liability insurance for damages caused by their operations, while those operating class A and B UAS are exempt but remain liable under general liability rules (UAV regulations in Argentina, 2020). Given the varying approaches, liability insurance should be considered for UAS operations to cover potential damage and accidents.

It is essential to address the issue of civil liability for damages caused by UAS operations (Konert and Kotliński, 2020). Insurance serves to protect UAS operators from accidental damage or liabilities incurred during flight activities. Given the harsh

Antarctic environment and the unpredictable nature of UAS operations in this region, mandatory insurance for UAS operations in Antarctica is crucial. This requirement would provide financial compensation for losses in the event of an accident, ensuring that operators are protected and that responsibilities are clearly defined.

Qualifications and age limits for UAS pilots are critical for ensuring the safe operation of UAS. Remote pilots must be trained, experienced, and competent, with their qualifications verified by the licensing authority in the state of registration, akin to the requirements for manned aircraft pilots (Pazmiño, 2021). According to Annex 2 of the Rules of the Air, remote pilots bear the same responsibilities as pilots of manned aircraft (Annexes of the Chicago Convention, 1944).

Statistically, 24 ATCPs have established requirements for UAS pilot qualifications. For instance, Japan (Flight rules in Japan, 2024) and Poland (Konert and Kotlinski, 2018) mandate that UAS pilots be certified, demonstrating the necessary skills, knowledge, and competence to operate UAS safely. Furthermore, 25 states have set age requirements for pilots. Argentina and Australia stipulate a minimum age of 16, while Brazil, Italy, South Africa, and Spain require pilots to be at least 18 years old.

China has classified personnel requirements for operating UAS based on their size and type. Operators of small, medium, or large civil UAS must possess full legal capacity, complete safe operation training, pass a civil aviation authority assessment, and have no medical history or record of drug abuse that could impair their ability to operate drones (UAS regulations in China, 2024). These requirements ensure that UAS pilots are adequately equipped to handle the responsibilities and challenges of UAS operations, thereby improving safety and reliability.

Individuals with a certain level of cognitive ability and knowledge are permitted to operate UAS. Overall, more than 83% of ATCPs have specific regulations for UAS pilots, highlighting the importance of operator proficiency in ensuring the safety of UAS operations. The challenging natural environment of Antarctica imposes even greater demands on pilots. Therefore, the competence of UAS operators must be thoroughly assessed to ensure their knowledge, skills, and age are suitable for Antarctic conditions, ensuring the safe and effective deployment of UAS in this harsh and unpredictable environment.

After an in-depth analysis of the domestic UAS regulations of ATCPs, this section finds that many ATCPs have already established relatively comprehensive UAS management systems. The regulations and practices of these states can serve as valuable references for the legal regulation of UAS in Antarctica. By drawing on the diverse domestic practices and expertise of ATCPs, Antarctic UAS regulations could benefit from more standardized and refined criteria. These practices can provide a foundation for harmonizing operational safety and environmental protection measures in the unique context of Antarctic governance. Given Antarctica's distinctive natural environment, it is likely to impose more stringent restrictions on UAS than other regions. Therefore, international regulation of UAS in Antarctica could build on the domestic regulations of ATCPs to establish more rigorous flight access regimes and operational rules. The next section will continue to examine UAS regulation practices of some ATCPs in Antarctica to inform the regulation of UAS activities in the region.

3.2 ATCPs' UAS regulations in Antarctica

To ensure compliance with the Antarctic Treaty, Article 7 establishes an inspection mechanism. This allows ATCPs to designate observers who are authorized to carry out inspections across all areas of Antarctica. These inspections encompass stations, installations, and equipment, as well as ships and aircraft involved in the disembarkation or embarkation of cargo and personnel. Additionally, aerial observations can be conducted at any time over any area of Antarctica by any Contracting Party authorized to designate observers.

In a joint report on Antarctic Treaty inspections conducted by the United Kingdom, Australia, and Peru, helicopters were identified as the primary tool for inspections, though their limitations were also highlighted. The report noted that most inspections were carried out using two Lynx helicopters, which facilitated flexible and efficient logistics, enabling more inspections to be completed within the available timeframe. However, during these inspections, five unoccupied stations were only overflown by helicopter but not visited due to the presence of large numbers of penguins or fur seals around the stations. Landing the helicopter in these areas would have caused significant disturbance to wildlife, violating Annex II of the Environmental Protocol (Antarctic Treaty inspections, 2005). In contrast, UAS are less invasive to the environment and can be used in situations where helicopter landings would be impractical or disruptive. This underscores a clear trend toward UAS being increasingly employed by ATCPs to fulfill their inspection obligations under the Antarctic Treaty System.

Supporting scientific research is the primary use of UAS in Antarctica, with ATCPs regulating UAS activities mainly through regulations established by their National Antarctic Programs (NAPs). A survey by COMNAP revealed that, as of March 31, 2017, 26.4% of the 30 member states had UAS regulations specifically applicable to the Antarctic region. Additionally, 56.7% of these states were in the process of developing national UAS guidelines, regulations, or manuals.

As illustrated in Table 3, there are commonalities across the UAS regulations of several ATCPs in Antarctica. These regulations are managed by the relevant Antarctic authorities in each state, which have established approval and licensing procedures. While UAS regulations in Antarctica are largely based on the domestic UAS frameworks of each ATCP, they are also adapted to account for the unique environmental conditions of the continent.

However, there are distinct differences in the form of regulation, scope of application, and specific content. Firstly, the types of normative documents issued by ATCPs to govern UAS in Antarctica vary across states. These include both non-binding instruments, such as operational manuals, guidelines, and usage policies, as well as legally binding measures that involve formal approval and licensing procedures.

Secondly, in terms of the scope of application, some states, such as the United States (US Antarctic Program, 2016), Germany

(ATCM40 IP38, 2017), New Zealand (ATCM40 ATT36, 2017), Australia (Australian Antarctic Program, 2016), and the United Kingdom, have extended their regulations to cover all activities conducted in Antarctica, including non-scientific activities. In contrast, countries like Spain (ATCM39 IP28, 2016) and Poland (ATCM40 IP46, 2017) have limited their regulations to specific categories of UAS activities.

Finally, regarding regulatory content, the regulations issued by the United States and New Zealand are the most systematic and comprehensive. They cover various aspects, including UAS operations and environmental rules, pilot qualification and licensing, drone airworthiness certification, application-approval mechanisms for drone activities, operation plans, risk assessment and management, liability, and specific operational requirements and restrictions for the Antarctic environment. In contrast, Germany, Australia, the United Kingdom, Spain, and Poland have only partially addressed the issues covered by the United States and New Zealand in their regulations.

In summary, the regulation of UAS in Antarctica has increasingly garnered attention from the ATCPs. In addition to their own national Antarctic UAS regulations, ATCPs submit proposals in the form of working papers, sharing their domestic practices and regulatory experiences on the ATCM and CEP platforms. This process has initiated a driven approach to regulating UAS activities within the Antarctic governance framework, with national precedents paving the way for international governance efforts.

TABLE 3 Regulations of UAS in Antarctica from some ATCPs.

State	Authority	Formality
United States	Office of Polar Programs, U.S. National Science Foundation	Air Operations Manual
New Zealand	Antarctica New Zealand	Antarctica New Zealand Unmanned Aerial System Operations Manual
Australia	Australian Antarctic Program	Unwritten operational requirements and environmental policies
Germany	German Environment Agency	Use of UAVs in Antarctica
Spain	Spanish Polar Commission	Regulations
Poland	Polish Antarctic Program	Criterion
United Kingdom	British Antarctic Survey	unwritten rules

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e; (ATCM, 2024).
The table is made by the author.

4 The role of non-state actors in the regulations of UAS in Antarctica

The ATS plays a crucial role in maintaining peace and stability in the region while fostering international scientific cooperation. Since the Antarctic Treaty entered into force in 1961, 57 states, including 29 ATCPs, have acceded (Secretariat of the Antarctic Treaty, 2024b). As illustrated in Figure 6, both ATCPs and non-state actors collaborate in shaping the Antarctic UAS regulatory agenda. With the expanding use of UAS in Antarctica, ATCPs have actively participated in agenda-setting, drawing from their national experience in UAS operations and regulation.

Currently, the international framework for UAS operations in Antarctica includes the *Environmental Guidelines*, the *Handbook*, and *IAATO Policies*, all of which contribute to a soft law regime governing UAS activities. The development of formal international legal regulations for UAS in Antarctica has been largely driven by the proactive involvement of ATCPs. Furthermore, non-state actors have become increasingly influential in shaping international legislation, thereby complementing the traditional role of states in the regulatory process.

"Non-state actors" typically refer to entities other than sovereign states that play an independent role in international

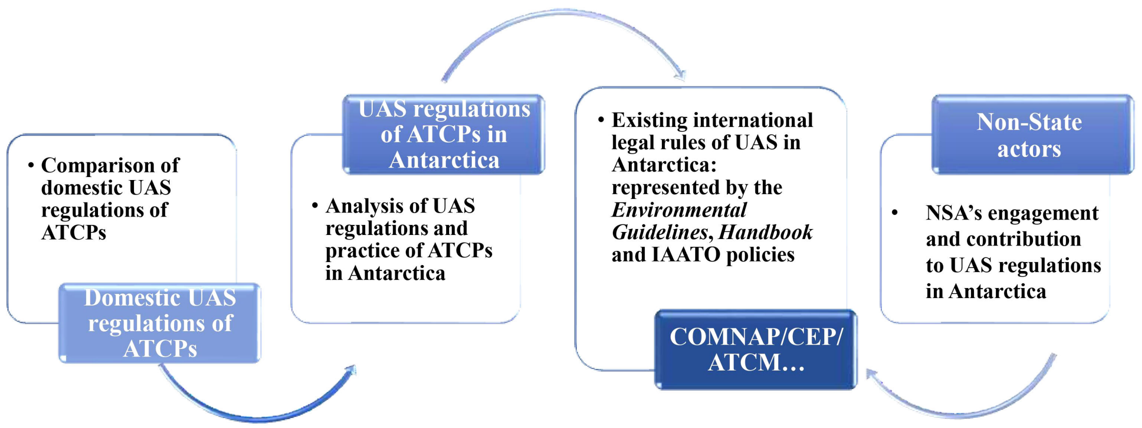

FIGURE 6
Joint engagement in the Antarctic UAS regulations agenda of ATCPs and Non-state actors. The figure is made by the author.

affairs and contribute to global governance through unified actions. These actors include civil society organizations, NGOs, and transnational entities (Naghmeh et al., 2016). In the context of UAS regulation in Antarctica, non-state actors have made substantial contributions. Their involvement has been particularly influential in agenda-setting and rule-setting processes, helping shape the evolving framework for UAS operations in the region.

4.1 Modalities of non-state actors' participation in the regulation of UAS in Antarctica

4.1.1 Through ATCM and CEP

The ATCM serves as the primary platform for deliberation within the ATS. According to the ATCM Rules of Procedure, Antarctic Treaty Contracting Parties, Observers, and invited experts from international organizations with scientific or technical interests in Antarctica are entitled to participate in Antarctic governance by submitting documents for consideration (ATCM Rules, 2022). Key document types include Working Papers (WPs), which propose substantive discussions and actions, and Information Papers (IPs), which offer supporting materials for these proposals. The content of WPs and IPs is often incorporated into legally binding measures or non-binding but influential soft laws. The conference papers submitted by ATCPs offer insight into their priorities and engagement in Antarctic matters (Chen, 2023).

As shown in Figure 7, from 2011 to 2023, the four non-state actors most actively involved in Antarctic governance were the Scientific Committee on Antarctic Research (SCAR), the Antarctic and Southern Ocean Coalition, IAATO, and COMNAP. Notably, the top three of these non-state actors submitted more proposals than France, one of the Antarctic territorial claimants, and Russia, a state that retains territorial claim rights. This underscores the significant role that non-state actors play in Antarctic governance. These organizations have effectively applied their expertise in science, technology, and environmental protection to influence proposals submitted to the ATCM/CEP, addressing specific governance issues, advancing the governance agenda, and providing recommendations for future resolutions.

The number and nature of documents submitted by non-state actors on the ATCM/CEP platform reflect both their willingness and capacity to contribute to Antarctic governance. A study of UAS-related issues at the ATCM (Table 4) reveals that ATCPs have leveraged their scientific and technological strengths to enhance their deliberative capacity within the ATCM (Chen and Gao, 2022). While ATCPs have submitted 21 papers on UAS issues, non-state actors have contributed 8 papers. This demonstrates that although states continue to dominate agenda-setting, non-state actors, particularly those oriented toward scientific and technological concerns, have made significant contributions to the process of regulating UAS in Antarctica.

The Committee for Environmental Protection (CEP) plays a significant role in the regulatory process for UAS in Antarctica, and it is highly inclusive of non-state actors. The Madrid Protocol allows relevant scientific, environmental, and technical organizations that contribute to the CEP's work to participate as observers in its meetings. According to the CEP Rules of Procedure, organizations such as SCAR, CCAMLR, and COMNAP can submit Working Papers (WPs), while other observers are restricted to submitting

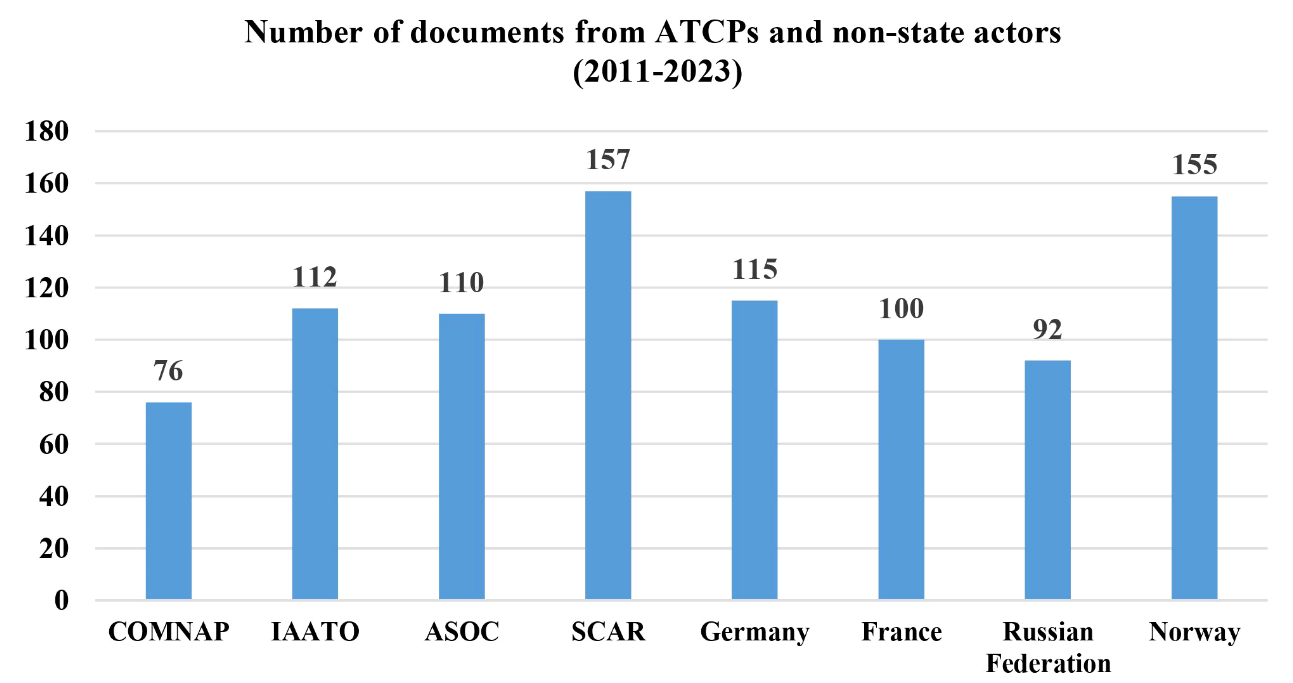

FIGURE 7
Number of documents from ATCPs and non-state actors (2011-2023). Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e. The table is made by the author.

TABLE 4 Number of ATCM documents relating to the topic of UAS in Antarctica (2004-2023).

ATCPs/ Institutions	WP	IP
Germany	4	4
United States	1	3
Poland	1	4
New Zealand	0	2
South Africa	0	1
Spain	0	1
COMNAP	2	2
SCAR	2	0
IAATO	0	2

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

Information Papers (IPs). However, observers do not possess decision-making authority. Additionally, experts and consultants are welcome to participate and provide expert advice tailored to the Committee's needs (CEP Rules, 2022). These WPs and IPs from non-state actors can influence UAS regulation in Antarctica, thereby contributing to the regulatory framework.

In addition to the ATCM, the annual CEP meetings are a central forum for discussing UAS regulations. The CEP focuses on the environmental impact of UAS activities in Antarctica, and UAS was incorporated into its five-year plan (CEPXVII Report, 2014). One notable contribution of the CEP is its role in advancing the development of Environmental Guidelines for UAS operations. In 2018, at its 21st session, the CEP adopted the draft Environmental Guidelines developed by the German-led Intersessional Working Group. These guidelines were then submitted to the 41st session of the ATCM for further consideration and were subsequently adopted as a resolution (CEP XXI Report, 2018). This highlights the CEP's important role in shaping the environmental standards that govern UAS operations in the Antarctic region.

4.1.2 Through CCAMLR

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is a key law-making and decision-making body within the ATS, established under the Convention on the Conservation of Antarctic Marine Living Resources (CAMLR Convention, 1980). The CCAMLR includes a permanent Scientific Committee that provides scientific advice and programs to support its decision-making processes.

The CCAMLR's website features numerous studies on the use of UAS, reflecting their increasing importance in Antarctic research. For example, UAS have been identified as valuable tools for studying the distribution and abundance of predator populations, providing detailed data that would be difficult to obtain through traditional methods (WG-EMM-15, 2015). Additionally, UAS have become essential for wildlife monitoring, offering a less intrusive and more efficient way to track and observe wildlife in Antarctica without causing disruption to sensitive ecosystems (WG-EMM-2019, 2019). These developments demonstrate the growing role of UAS in advancing scientific research and environmental monitoring in Antarctica, which aligns with the broader goals of the CAMLR Convention and the protection of the region's marine and terrestrial ecosystems.

4.1.3 Through ICAO

As international legal frameworks for UAS continue to evolve, it is essential to monitor and integrate regulations established by global bodies such as the International Civil Aviation Organization (ICAO). The ICAO has made significant strides in the development of international UAS regulations, with a particular focus on ensuring the safe and coordinated use of drones worldwide.

In 2015, the ICAO introduced the Remotely Piloted Aircraft Systems Manual, which provides a comprehensive framework based on the latest drone technology. This manual addresses critical aspects such as drone airworthiness, technical requirements, operational limitations, and human resource qualifications (ICAO, 2015). The goal was to establish a standardized approach for the safe integration of UAS into global airspace.

Further accelerating the regulatory development process, the ICAO issued Model UAS Regulations in 2020. These guidelines, derived from the existing UAS regulations in countries like New Zealand, Australia, Canada, and the United States, also incorporate elements of international best practices. Although non-mandatory, these model regulations offer member states a standardized reference to guide the creation of their own national UAS regulations, providing flexibility while promoting international consistency (ICAO Model UAS Regulations, 2020). As these international standards evolve, they will likely influence the regulation of UAS in Antarctica, especially as the use of drones expands for scientific research, environmental monitoring, and logistical operations.

In recent years, the ICAO has made significant strides in UAS regulation. In 2021, the ICAO Council revised its Standards and Recommended Practices, improving international safety and interoperability of RPAS (ICAO News, 2021). In 2022, the ICAO launched the "Drone Enable" initiative, inviting innovative organizations from both the public and private sectors to contribute to advancements in drone airspace management and global UAS standards (ICAO News, 2022). As UAS regulations evolve, the ICAO is expected to amend the 19 annexes of the Chicago Convention to integrate UAS into the global aviation system in a safe and efficient manner.

UAS regulations in Antarctica are part of the broader framework of international UAS rules, and there are strong connections between them. Antarctic UAS regulations will not be entirely separate from global regulations and can therefore draw on the experiences of UAS regulation in other regions. In 2019, the ICAO presented a paper at the 42nd ATCM, suggesting that Antarctic UAS regulation could benefit from the Arctic's regulatory experiences (ATCM42 IP163, 2019). Given the faster pace of global UAS regulation compared to Antarctic developments, the expertise and experience of the ICAO in regulating UAS can serve as a valuable reference for shaping UAS regulations in Antarctica.

4.2 Non-state actors' engagement of UAS regulation in Antarctica

Non-state actors play a key role in the agenda-setting and rule-making phases of UAS regulation in Antarctica. Their involvement is exemplified by the development of the *Environmental Guidelines*. As shown in Table 5, during the agenda-setting phase, COMNAP and SCAR contributed significantly by submitting proposals to the ATCM and CEP platforms. SCAR provided current scientific insights into the impacts of UAS on Antarctic wildlife, while COMNAP shared practical experience regarding the use of UAS in scientific research, logistics, and other Antarctic activities. This collective expertise enriched the understanding of UAS's environmental effects, ultimately facilitating consensus among ATCPs on the *Environmental Guidelines*.

At the specific rule-making stage, non-state actors, especially SCAR and COMNAP, played a significant role in shaping the content of the *Environmental Guidelines*. The working group referred to previous Working Papers (WPs) submitted by these organizations and also distributed a questionnaire to all ATCPs, observers, and experts on issues related to the rules' content. The feedback, including contributions from SCAR and COMNAP, informed the draft text. For instance, the issue of maintaining separation distances between UAS and Antarctic wildlife, addressed in the guidelines, can be traced back to a WP submitted by SCAR (ATCM41 WP29, 2018). This process illustrates how non-state actors have influenced the regulatory framework for UAS in Antarctica.

The documents adopted by the ATCM, COMNAP, and IAATO in addressing UAS governance in Antarctica exhibit varying effectiveness, as shown in Table 6. While each document plays a distinct role in different contexts, they also have shortcomings. One key issue is the lack of clear definitions for different categories of UAS activities. For instance, the *Environmental Guidelines* apply to all UAS activities, potentially allowing recreational ones, while the *IAATO Policies* explicitly prohibit recreational UAS operations. This creates a conflict, as the *Environmental Guidelines* and *IAATO Policies* are not aligned on the matter of recreational UAS. The inconsistencies in scope and application across these documents may lead to practical challenges and highlight a need for clearer, more cohesive regulations.

The three documents—*Environmental Guidelines, IAATO Policies*, and the *Handbook*—overlap in regulatory content, but each focus on different aspects. The *Environmental Guidelines* provide detailed environmental impact assessment procedures based on the Madrid Protocol and emphasize the protection of wildlife, ASPAs, and sensitive areas during UAS operations. The

TABLE 5 Process leading to the *Environmental Guidelines*.

Time of session	Subject of the proposal	Main elements of the motion	Outcome of ATCM discussions/considerations
37	Germany, Poland; The United States	(1) Recommended that establish an intersessional working group to advance the discussions and conduct further work; (2) Discuss the possibility of developing a guide for the operation of UAS in Antarctica; (3) COMNAP and SCAR review the safety risks and environmental impacts of UAS activities in Antarctica;	(1) Determine the potential environmental impacts of UAS in Antarctica; (2) Adopt the US proposal that request COMNAP and SCAR to report the utility and risks of UAS activities in Antarctica at the next meeting.
38	COMNAP	Recommended states and other operators to share information on UAS practices in Antarctica	(1) Consider to develop operational guidance on environment aspects of UAS in Antarctica; (2) Consider to establish an intersessional working group
	SCAR	Reported on the impacts of anthropogenic disturbance on Antarctic wildlife	
39	Germany	Recommended minimum distances between UAS and Antarctic wildlife	(1) Agreed to develop operational guidance on environment aspects of UAS in Antarctica; (2) Agreed to establish an intersessional working group
	COMNAP	Reported on the UAS Operator's Guide: The *Handbook*	
40	SCAR	Reported on the latest scientific knowledge on the response of Antarctic wildlife to UAS	Agreed to establish an intersessional working group led by Germany to develop operational guidance on environment aspects of UAS in Antarctica
41	Germany	Reported on the draft *Environmental Guidelines* developed by the German-led intersessional working group	Adopted *Environmental Guidelines* in the form of a resolution
44	Germany	(1) Improve the content and structure of the *Environmental Guidelines*	Agreed to revise the *Environmental Guidelines*

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

TABLE 6 Comparison of *Environmental Guidelines, Handbook, IAATO Policies*.

Name of the document	Scope of application	Content
Environmental Guidelines	All types of UAS activities	Environmental guidance
Handbook	Require that any deployment of drones in the Antarctic Treaty area is subject to notification. In fact, it applies mainly to drone activities of a scientific, logistical and operational nature that fall within the scope of COMNAP's responsibilities.	Operational guidelines, and environmental guidance
IAATO Policies	Apply to UAS activities in Antarctic tourism. Commercial and scientific UAS activities are conditionally permitted; recreational UAS activities are explicitly prohibited. In practice, there are also operational UAS activities in Antarctic.	Operational guidelines, with a small amount of environmental guidance

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

IAATO Policies address environmental concerns more briefly, particularly regarding UAS use near wildlife and in special areas like ASPAs. The *Handbook* offers both operational and environmental guidance, including procedures for communication, record-keeping, and pre-flight environmental assessments. However, this overlap raises the question of which document should serve as the primary reference for practical issues. Given the increasing frequency of UAS operations in Antarctica, it is crucial to resolve inconsistencies in these regulations to ensure effective and coherent governance.

Efforts by non-state actors to regulate drones in Antarctica have been ongoing. Since the release of the *Handbook* in 2016, COMNAP has regularly reviewed and updated it to reflect the latest developments in the Antarctic region. The most recent edition, the 8th edition, was released in December 2023. This update includes a document catalog that incorporates relevant content from the 2023 ATCM Resolution and CEP Recommendations. It also features a separate annex listing information shared by states on national Antarctic plans and operational programs, including details on the operation of large UAS over 25 kg and examples related to Beyond Visual Line of Sight (BVLOS) flights (COMNAP Handbook, 2022).

The international regulations for UAS in Antarctica are not yet comprehensive, and the decentralized rules lack clear and straightforward guidance for current and potential UAS users. Improvements in operational and environmental regulations continue to rely heavily on the involvement of non-state actors, primarily COMNAP, SCAR, and IAATO. While non-state actors play a crucial role as experts, their influence remains non-determinative in shaping the legal framework. Their interdisciplinary expertise, scientific research capabilities, and long-term field experience provide essential input for the formulation of policies and the achievement of legally accepted outcomes (Secretariat of the Antarctic Treaty, 2024b). Submissions from non-state actors are often incorporated into binding measures or non-legally binding resolutions. This study argues for strengthening the interaction between ATCPs and non-state actors to enhance current UAS regulations and establish a more comprehensive, detailed, and operational regulatory system for UAS in Antarctica. This collaborative approach would help create a more cohesive and effective framework for UAS operations in this unique and sensitive environment.

5 Strengthening collaboration among multiple actors for a comprehensive UAS regulatory framework in Antarctica

Currently, the domestic operating standards and technical specifications for UAS among ATCPs are not fully harmonized. The number of ATCPs using UAS in Antarctica remains limited, resulting in insufficient practical experience in drone operations. Regulations by non-state actors are fragmented, lacking universality and certainty. The process of international lawmaking for UAS in Antarctica is still in the agenda-setting phase, with most relevant rules primarily taking the form of soft law. As the demand for UAS increases, the lack of uniform regulation will create uncertainty for their application in the region. ATCPs and non-state actors must promote the integration of technology and legal regulation for UAS in Antarctica. Based on existing UAS practices, the Environmental Guidelines should be revised. To establish a preliminary legal regulatory system, a comprehensive legally binding Measure, or at least a resolution adopted by the ATCM, could serve as a strong starting point for this integrated regulatory framework. As the principal international forum for Antarctic affairs, the ATCM is uniquely positioned to harmonize the interests of all parties, facilitate the development of minimum UAS standards, and establish a consistent regulatory framework for all stakeholders.

5.1 Promote the integration of technology and legal regulation of UAS

UAS regulations in Antarctica are evolving in tandem with advancements in UAS technology. As UAS technology continues to develop, operational standards and procedures are also subject to change. Legal regulation of UAS in Antarctica should be grounded in practical experience at the current level of scientific and technological development. It should also incorporate information on UAS operations and certifications from the ATCPs' National Antarctic Programs, as well as insights from existing Antarctic documents. This approach will ensure that the regulations are both relevant and responsive to the fast-paced changes in UAS technology while maintaining alignment with the unique environmental and operational context of Antarctica.

Firstly, ATCPs and non-state actors should prioritize innovation and collaboration in UAS technology development. For instance, advancing sense-and-avoid technology to ensure safe drone operations and improving battery technology for cold-weather adaptability are key areas for progress (Sharma, 2019). These technological advances offer a crucial scientific foundation for legal regulations. By integrating the latest UAS technology into Antarctic operations, practical experience can be accumulated to inform the regulatory framework. Non-state actors, through their expertise, research, and perspectives, can significantly contribute to the regulatory process. Their scientific input can enhance the decision-making process, helping shape UAS regulations in Antarctica more effectively (Chen and Liu, 2023). In turn, ATCPs should foster greater exchange of cutting-edge UAS technology with non-state actors, taking into account Antarctica's unique environmental conditions.

Secondly, multiple actors should collaborate to establish an Antarctic UAS database to consolidate operational experience. We recommend adding an Antarctic UAS module to the official website of the Antarctic Treaty Secretariat. This database could categorize UAS in Antarctica into five types: scientific research, environmental protection, emergency rescue, commercial use, and recreational use. Each UAS operation would be registered, with flight details submitted before and after operations, ensuring compliance with environmental protection standards and flight restrictions in Antarctica (Jesús and Mulero-Pázmány, 2019). Such a database would promote transparency in UAS technology and operations, providing valuable data to inform the development of more effective legal regulations.

Finally, a robust science-policy communication mechanism should be established in Antarctica. Multiple actors must stay informed about the latest developments in UAS regulations, both in Antarctica and globally. This includes monitoring the ATCM and CEP's priorities regarding UAS issues, as well as changes in international UAS regulations. Through deliberative platforms such as the ATCM, CEP, and CCAMLR, actors can actively submit proposals and share scientific, technical, and regulatory expertise. Such collaborative exchanges would help drive the process of UAS legal regulation in Antarctica, ensuring a more coordinated and informed approach.

In general, the interaction between technology and regulations promotes polar research. The coordinated use of UAS enhances ongoing scientific activities, minimizing interference and ensuring the uninterrupted progress of crucial studies. This leads to more efficient and productive polar research. Additionally, the establishment of an Antarctic UAS database and a science-policy communication mechanism would strengthen international cooperation. Such collaboration in regulating Antarctic UAS would facilitate a unified approach, supporting the peaceful and sustainable use of UAS in the region.

5.2 Revising the *Environmental Guidelines* and establishing a preliminary legal regulatory system for UAS in Antarctica

At the 44th ATCM, Germany proposed improvements to the content and structure of the *Environmental Guidelines*, recommending the establishment of an informal international coordination group to revise them promptly. Germany also encouraged the Parties to gather data on the impacts of UAS on Antarctic wildlife. After deliberation, the ATCM agreed that the *Environmental Guidelines* should be revised but did not reach a consensus on the immediate revision. The Parties were urged to continue discussions during the intersessional period (ATCM44 Final Report, 2022).

The revision of UAS environmental rules should be grounded in the latest scientific and technological advancements regarding their environmental impacts on Antarctica. To facilitate this process, all Parties can exchange and share relevant information through proposals at the ATCM, based on the data collected on UAS' environmental effects in the region.

Additionally, as a deliberative platform, the ATCM should enhance efforts to promote awareness and deepen the scientific understanding of UAS' environmental impact in Antarctica among multiple actors. This could involve organizing workshops, distributing research findings, and sharing expertise through various channels. Based on this improved scientific knowledge, the ATCM should drive the updating of environmental rules for UAS in the region.

The global legal regulation of UAS is progressing toward greater uniformity but remains in an evolving state. Thus, the international legal framework for UAS in Antarctica will necessarily develop gradually, not through immediate comprehensive solutions. Both global UAS regulations and existing Antarctic regulatory experiences can provide useful references for this process. For instance, establishing an intersessional working group on Antarctic UAS, similar to the one led by Germany, could bring together UAS technology experts, environmental scientists, and legal professionals to manage Antarctic UAS operations, conduct environmental impact assessments, and refine legal frameworks. Strengthening cooperation and interaction among states and organizations in Antarctica is essential for advancing these regulatory efforts.

By integrating existing UAS regulations, a more comprehensive, detailed, and operational regulatory framework can be developed, gradually establishing a legal system for UAS in Antarctica. Strengthening Antarctic UAS rules is crucial for environmental protection, flight safety, and regulatory compliance. Uniform standards would help minimize disturbances and damage to the delicate Antarctic ecosystem and wildlife caused by UAS operations, ensuring the preservation of the environment for scientific research and ecological conservation. Additionally, unified rules can reduce the risks associated with UAS flights in the harsh Antarctic climate, improving overall safety. In sum, a well-developed legal and regulatory system would provide a clear management framework for the sustainable use of UAS in Antarctica, guiding the operations of multiple actors in the region.

6 Conclusion

As States increasingly focus on advancing polar research through new technologies and equipment, there is growing attention to the regulation of UAS activities in Antarctica. With the continued innovation and maturation of UAS technology, more states and non-state actors are likely to deploy UAS for scientific research and commercial activities. This increasing use of UAS could spur scientific and technological competition in Antarctica, potentially leading to more complex legal challenges and the need for stronger regulatory frameworks to manage these activities effectively.

Many states have successfully translated their scientific and technological innovation capabilities into agenda-setting and rule-making powers, significantly shaping the development of UAS regulations. Non-state actors, such as scientific organizations and experts, have also played a crucial role by contributing field experience and providing scientific advice. To improve air safety in Antarctica, the ATCM and COMNAP have organized collaborative efforts, bringing together various stakeholders to reach an agreement on the Antarctic Flight Information Manual (Air Safety in Antarctica, 2022). Both state and non-state actors are actively involved in the legal regulation of UAS in Antarctica, underscoring the importance of collective efforts in addressing the challenges of regulating emerging technologies in this unique and environmentally sensitive region.

Currently, the legal regulation of UAS in Antarctica remains fragmented, with no unified framework in place. Nevertheless, all actors are obliged to minimize the environmental impacts of their activities, including UAS operations, and they already bear the responsibility to regulate such activities under the ATS. Regulating and limiting UAS use is essential to the exercise of personal jurisdiction by Parties in fulfilling their ATS obligations. For instance, Article 13 of the Madrid Protocol mandates each Party to take appropriate measures within its jurisdiction to ensure compliance with the Protocol, including adopting relevant laws and regulations. Similarly, Article 21 of the CAMLR Convention obligates Contracting Parties to implement measures ensuring compliance with conservation provisions and measures adopted by the Commission.

Therefore, UAS regulations in Antarctica must be further developed and refined to safeguard areas of special environmental, scientific, historic, aesthetic, and wilderness significance. To ensure a more standardized and effective approach, all relevant actors, including states and non-state actors, must collaborate to create a comprehensive and cohesive legal framework for UAS regulation in Antarctica as a minimum standard. The concept of a minimum standard has been implemented in various international governance regimes. For instance, in the development of Environmental Impact Assessments mechanism related to Marine Biological Diversity in Areas beyond National Jurisdiction (BBNJ), the draft of BBNJ Agreement has attempted to establish a "global minimum standard" (Revised draft text of BBNJ Agreement, 2019). Similarly, the United Nations Convention on the Law of the Sea (UNCLOS) requires coastal State, under Article 61(3), to consider "any generally recommended international minimum standards, whether subregional, regional or global" when formulating conservation and management measures within their Exclusive Economic Zones. A notable precedent is the 1946 International Convention for the Regulation of Whaling (ICRW), which sets minimum standards for whale protection while allowing states to adopt stricter regulations within their jurisdiction which give additional protection to whales, provided they do not conflict with ICRW provisions (Proelss, 2017). Additionally, the Port State Measures Agreement (PSMA), the first legally binding international agreement to combat illegal, unreported, and unregulated (IUU) fishing, also provides minimum standards for port state measures while permitting states to implement more stringent measures (PMSA Agreement, 2009). The proposed unified legal framework for UAS regulation in Antarctica aligns with these examples, serving as an international minimum standard to guide governance while allowing for further tailored and stricter measures.

This study does not suggest that unified UAS regulations should be the sole framework for compliance in Antarctica. Instead, it acknowledges and respects the diverse regulatory efforts by multiple actors. These actors remain free to develop more specific and stringent rules. For instance, ATCPs can regulate UAS operations conducted by their nationals in Antarctica under the principle of personal jurisdiction and propose higher standards tailored to their technical capabilities and governance frameworks. Similarly, non-state actors, such as IAATO, could implement stricter measures to manage private UAS usage. Such collaborative approaches will contribute to enhancing the safety, efficiency, and environmental stewardship of UAS operations in this unique and sensitive region.

Author contributions

YC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. SW: Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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