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From Security Asset to Shared Infrastructure: Institutional Mechanics and Communicative Effects of Brazil's 2004 CBERS Open-Data Policy

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Abstract. In 2004, Brazil's National Institute for Space Research (INPE) became the first Global South institution to freely distribute medium-resolution satellite imagery from an operational national system, four years before the 2008 USGS Landsat opening widely treated as the originating moment of global open-data norms in Earth observation. Drawing on historical institutionalism and interpretive policy analysis of a documentary corpus of 63 documents, this study reconstructs the institutional mechanics of that decision and traces its communicative effects. Three findings emerge. First, INPE achieved its open-data policy by exploiting a specific bilateral treaty clause that dissociated domestic distribution from international commercial obligations within a military-controlled legal framework, without requiring legislative reform. Second, removing access barriers gradually created the structural conditions for satellite imagery to operate as a boundary-object at the infrastructural level: NGOs, enforcement agencies, journalists, and Indigenous communities each adopted the same open imagery for distinct institutional purposes, shifting environmental contestation toward actionable debates about enforcement and accountability. Third, Brazilian representatives systematically advocated for open-data principles in international forums including GEO, COPUOS, and CEOS, circulating in the institutional spaces where subsequent global open-data norms were contested, though the causal weight of that advocacy on those decisions cannot be established from the available record. The case documents an underexamined Global South contribution to open geoscience governance.

1. Introduction

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In 2004, a developing nation became the first in the Global South to freely distribute medium-resolution satellite imagery from an operational national system over the internet – four years before the United States opened the Landsat archive, which is widely treated in the literature as the originating moment of global open Earth observation norms. Brazil's National Institute for Space Research (INPE) adopted a policy of freely distributing medium-resolution satellite imagery from the China-Brazil Earth Resources Satellite (CBERS) program over the internet, initially to Brazilian users under a domestic clause, with a formal extension to all developing nations following a separate bilateral agreement in 2010 (GEO, 2007b, 2010; CRESDA and INPE, 2010). This represented a deliberate institutional choice to treat publicly funded satellite data as infrastructure for environmental transparency and multi-scalar governance, even within a legal framework that still treated remote sensing as a security matter under military oversight (Câmara, 2006a, 2006b; Câmara, 2007a, 2007b; Ferreira and Câmara, 2008).

The 2004 decision was the product of a specific constellation of pressures: legal tension between military control and civilian science; capacity-building ambitions in the Global South; accelerating deforestation in the Amazon; and strategic calculations about where commercial value could be located within the Earth observation value chain. Beyond its immediate policy outcomes, the CBERS case illustrates how satellite imagery became embedded in terrestrial environmental management, how decisions about data access reflect broader struggles over sovereignty and knowledge authority, and how a Global South nation could systematically advocate for open Earth observation norms in international forums – preceding, and circulating alongside, the policy shifts that the literature has treated as the originating moment of global open-data governance.

The central contribution of this study is to demonstrate how a specific institutional decision about data access – Brazil's 2004 CBERS open-data policy – restructured the conditions under which diverse actors could engage with satellite evidence of environmental change, converting a restricted technical asset into shared geospatial infrastructure for governance and public accountability. The case is significant for geoscience communication research because it represents the first documented instance of a Global South nation doing this for a nationally operated satellite system, and because it allows the communicative mechanisms of that transformation to be reconstructed from a substantial primary document corpus. The analysis addresses two interconnected

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questions: 1) How and why did INPE implement a strategic open-data policy within a formally commercial and security-constrained institutional environment? 2) What does the 2004 decision reveal about the communicative mechanisms through which open Earth observation data becomes actionable evidence for heterogeneous governance actors?

The 2004 pivot was a calculated institutional response to a specific conjuncture of legal, commercial, and political pressures, not a spontaneous act of enlightened governance. By tracing this transition, the study shows how democratization altered the flow of environmental evidence, equipping intermediaries across civil society, enforcement agencies, and Indigenous movements with visual tools for public accountability and knowledge production, and shifting political contestation from whether environmental change was occurring to actionable debates about enforcement and policy response (Litfin, 2002; Rajão and Jarke, 2018).

The analysis proceeds through the following sections. Section 2 situates the 2004 decision within literature on satellites as environmental infrastructure, Brazil's remote-sensing legal history, PRODES and DETER development, and identifies the key gap this study addresses. Section 3 presents the theoretical framework, outlining three analytical lenses and their operationalization through the boundary-object concept. Section 4 details the research design and methods. Section 5 reconstructs the institutional context, strategic rationales, and implementation of the 2004 pivot. Section 6 examines its transformative effects on capacity building, transparency, accountability, and cross-disciplinary collaboration. Section 7 discusses contemporary implications for geosciences communications and open Earth observation governance, clearly distinguishing between historically documented findings and analytically informed implications. The conclusion synthesizes the study's contributions and outlines directions for future research.

2. Literature Review and Contextual Background

2.1 Satellites as Environmental Governance Infrastructure

Satellite Earth observation has become foundational to contemporary environmental governance, providing near-real-time data on forest cover, water resources, agricultural productivity, and disaster impacts – information prohibitively expensive to gather through ground surveys alone (Tatem et al., 2008; Wulder et al., 2022; Boscolo et al., 2024). Yet the scientific and governance value that satellite data can generate depends critically on

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whether that data is accessible: where open access has been established, research demonstrates accelerated environmental threat detection, rapid policy response, and a fundamental shift in environmental science's epistemic foundations (Wulder et al., 2022). How that access came to exist, and who drove it, is less well understood than the benefits it produced.

Within this landscape, the 2008 decision by the United States Geological Survey (USGS) to open the full Landsat archive at no cost is widely treated in the literature as the definitive catalyst for global open Earth observation norms. Wulder et al. (2012) document how annual data distributions rose from 25,000 to 2.5 million within two years of that decision, and subsequent analyses confirm that the social and economic value generated by Landsat-derived knowledge substantially exceeded the historical cost of the satellite systems themselves (Wulder et al., 2022). As the canonical sources acknowledge in passing, however, this account of origins is incomplete: a Global South nation had already established a comparable policy four years earlier, a precedent whose institutional mechanics and broader significance remain underexamined.

Prior to 2004-2008, satellite Earth observation remained bifurcated and exclusive. Commercial high-resolution imagery (e.g., Ikonos, QuickBird) remained accessible primarily to wealthy institutions, while even medium-resolution public datasets like US Landsat were controlled by cost-recovery mandates, charging up to $4,000 per image (Wulder et al., 2022). This commercial logic extended to the Global South: medium-resolution imagery from developing countries was initially envisioned as a commercial product whose revenue would offset satellite costs (Câmara and Ning, 2004; MCTI, 2004; Borowitz, 2020), resulting in fewer than 1,000 CBERS image sales annually prior to any open-data transition, a commercial underperformance that would become one of INPE's central justifications for abandoning the fee-based model entirely (Câmara, 2006a, 2006b; Ferreira and Câmara, 2008).

In this fragmented landscape, Brazil's 2004 decision occupied a position the existing literature has not sufficiently examined, reached under institutional conditions including military-era legislation, commercial bilateral obligations, and acute resource constraints that made such a decision far from inevitable. Understanding how and why that decision was made, and what it set in motion for environmental governance and geoscience communication in Brazil and beyond, is the gap this study addresses.

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2.2 Brazil's Remote Sensing Legal History

To understand why the 2004 pivot was strategically significant requires situating it within Brazil's decades-long institutional struggle over remote-sensing technology control. This legal history is not merely contextual background; it establishes why the 2004 decision constituted a communicative restructuring rather than a routine policy update, and why its effects on who could access and act upon satellite evidence were as consequential as they were. During military dictatorship (1964-1985), aerial photography and remote sensing were classified as sensitive technologies under military control, reflecting widespread Cold War anxiety that detailed satellite imagery could reveal military bases, infrastructure, or resource vulnerabilities. When Brazil began developing local Earth observation capabilities in the 1980s, this legal and institutional logic persisted (Ferreira and Câmara, 2008).

In 1997, the Brazilian government formalized this through Decree 2278/97[1], establishing remote sensing as national-security matter and placing operational control over all satellite imagery and data dissemination under military authority (Brasil, 1997). This codified Cold War-era assumptions well into the civilian period. By the late 1990s, however, the framework was becoming technologically and politically untenable: commercial satellite companies were proliferating, international scientific collaboration increasingly required data sharing, and scientists recognized that restriction hampered Brazil's own remote sensing capacity (Litfin, 2002).

Between 2000 and 2003, proposed amendment to Brazilian law – Project of Law 3587/00[2] – sought to revise remote-sensing governance (Câmara dos Deputados, 2000). Rather than opening access outright, however, the draft threatened to expand military oversight. INPE, as a civilian scientific institution under the Ministry of Science, Technology and

[1] Decree 2278/1997 classified orbital remote sensing as a national security activity, subjecting the dissemination of satellite imagery of Brazilian territory to the prior authorization of the Ministry of Defense (Brasil, 1997). This framework extended military-era regulatory logic into the civilian period, effectively centralizing data control.

[2] Proposed in 2000 by an inter-ministerial working group, Project Law 3587/00 defined remote sensing broadly as "the set of operations of reception, processing, interpretation, or distribution of satellite-collected data" covering Brazilian territory (Câmara dos Deputados, 2000). Ignoring the United Nations Remote Sensing Principles (UNGA, 1986) and the technical reality of global satellite observation, the bill sought to impose strict state control by requiring any citizen or institution to obtain specific government permission to use remote sensing data. This approach treated satellite imagery as equivalent to classified aerial photography, a stance that the scientific community, led by INPE, argued would make the distribution of environmental data practically impossible and legally untenable (Ferreira and Câmara, 2008). The project was finally archived in 2023.

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Innovation (MCTI), faced a critical choice: accept a more restrictive legal regime or reshape what was politically and legally possible through practice. INPE chose the latter, adopting a systematic strategy of releasing remote-sensing data and tools over the internet, beginning in the late 1990s with the SPRING geographic information system, accelerating in 2003 with the publication of open PRODES deforestation data (Sá and Grieco, 2016; Maurano et al., 2019), and culminating with the 2004 CBERS free-data policy (Ferreira and Câmara, 2008).

Thus the 2004 pivot represented more than a technical upgrade; Rajão and Hayes (2009) argue it was calculated resistance against "conceptions of control" inherited from authoritarianism and Cold War days. By unilaterally opening the archive, INPE subverted legal frameworks treating satellite imagery as sensitive intelligence and established remote sensing as a public good, rendering the military-era information control paradigm practically obsolete (Câmara and Fonseca, 2007; Ferreira and Câmara, 2008).

2.3 PRODES and DETER: Transparency as Environmental Governance

Brazil's decision to open CBERS data must be understood within the specific context of its environmental monitoring infrastructure. Two systems, PRODES (Program for Monitoring Deforestation in the Amazon by Satellite) and DETER (System for Detection of Deforestation in Real Time), had established Brazil as a global leader in transparent deforestation monitoring by the early 2000s. PRODES, operational since 1988, provided annual Brazilian Amazon forest loss maps, derived primarily from Landsat imagery supplemented later with CBERS data. DETER, deployed in 2004, offered near-real-time deforestation event alerts to law enforcement agencies, integrating MODIS, CBERS WFI, and other sensors[3] (Soler et al., 2021; Rajão, 2012).

Significantly, INPE committed to publishing its results publicly: annual PRODES maps became freely digitally available from 2003 on, and in 2004, the newly created DETER system began circulating alerts among environmental agencies and the public (Rajão and

[3] MODIS (Moderate Resolution Imaging Spectroradiometer) and CBERS WFI (Wide Field Imager) are satellite sensors characterized by high temporal resolution (frequency of visits) but moderate spatial resolution. While sensors like Landsat provide detailed imagery (approx. 30m resolution) every 16 days, MODIS and CBERS WFI capture data daily or every 3-5 days over much larger swaths of territory (up to 890 km). This 'coarser' (64-260m) but more frequent data is technically optimized for the DETER system, which prioritizes the rapid detection of new deforestation 'alerts' over high-detail annual mapping.

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Jarke, 2018; Sá and Grieco, 2016). The 2004 CBERS open-data policy followed directly from this emerging logic of transparency. If Brazil was now making deforestation maps and alerts public through PRODES and DETER, restricting the underlying satellite imagery seemed contradictory. Consequently, INPE adopted what Ferreira and Câmara (2008) call a "de facto data policy," institutionalizing a commitment to transparent environmental governance rather than waiting for legislative reform.

By making both monitoring products and underlying imagery freely available, this dual transparency directly shifted political contestation from debates over whether deforestation was occurring to actionable discussions about enforcement and policy response (Rajão and Hayes, 2009; Rajão and Georgiadou, 2014).

2.4 Literature Gap

While the existing literature has significantly documented the scientific and economic benefits of open Earth observation data (Turner et al., 2015; Zhu et al., 2019), it predominantly frames the 2008 USGS Landsat opening as the definitive catalyst for global open-data norms (Wulder et al., 2012; Zhu et al., 2019), treating it as the originating moment from which subsequent international policy shifts follow. In doing so, it underemphasizes the political and legal complexities involved in transitioning Earth observation from a military-controlled security asset into a shared geospatial resource – and leaves unexamined the fact that a Global South nation had already navigated precisely those complexities four years earlier.

The pattern is visible throughout different sources. Wulder et al. (2012), the definitive account of how free data enabled Landsat's scientific promise, mentions CBERS only in passing – noting its free availability without examining the institutional decision that made it so, or the precedent it established before 2008. Turner et al. (2015) goes slightly further, acknowledging that the 2008 Landsat policy shift was in line with data policies previously instituted by the United States' National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the Brazilian Government – but devotes no further analysis to what that Brazilian policy was, how it was achieved under restrictive legal conditions, or why it matters for understanding how open-data norms emerge. Zhu et al. (2019) similarly credit the 2008 decision as a catalyst for replication by other national and multi-national observation programs, without examining whether that process had earlier precedents. In each case,

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Brazil is present enough to confirm that a policy existed, but insufficiently examined to establish what that policy was, how it was achieved, or why it matters.

This omission is partly explicable by how existing scholarship has approached the case: as a technical data-policy reform within the history of Earth observation openness (Borowitz, 2020; Wulder et al., 2022), as an institutional input to deforestation enforcement (Rajão and Hayes, 2009; Nunes et al., 2024), or as a transparency mechanism within Brazilian environmental politics (Rajão and Georgiadou, 2014; Rajão and Jarke, 2018). The closest prior study to examine the open-data transition as a governance case in its own right is Sá and Grieco (2016), who trace INPE's shift from a closed to an open model using interview data alongside documents, and demonstrate how political resistance, usability barriers, and the role of intermediaries shaped the process. Their study, however, focuses primarily on PRODES and DETER as monitoring outputs and does not examine the CBERS bilateral treaty mechanism, the geoscience communication dimension, or the international norm-entrepreneurship trajectory that preceded and accompanied the 2004 decision. Each perspective offers genuine insight, but none has systematically integrated these strands to analyze the 2004 decision as a geoscience communication intervention.

This gap has two dimensions. Empirically, it leaves the 2004 CBERS pivot – the first instance of a Global South nation freely distributing medium-resolution satellite imagery from an operational national system – without an adequate institutional reconstruction. Analytically, it means the political and legal mechanisms through which open-data norms are actually forged, particularly outside the context of well-resourced Northern agencies, remain poorly understood. This study addresses both dimensions: by reconstructing the institutional mechanics and strategic rationales of the 2004 decision, it establishes the empirical foundation for what the introduction identifies as an underacknowledged but consequential Global South precedent in the governance of open Earth observation data.

3. Theoretical Framework

Before presenting the three analytical lenses and the boundary-object framework, it is necessary to situate this study within the field of geoscience communication. Geoscience communication, as defined by Illingworth et al. (2018), encompasses scientific activities at multiple levels that aim to increase attention to and public discussion of geoscientific results – ranging from policy briefings and open-data initiatives to the cultivation of two-

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way dialogues between scientists and non-specialist audiences. Effective geoscience communication is increasingly understood as the construction of shared frameworks through which diverse actors – policymakers, civil society organizations, local communities – can engage with and act upon geoscientific evidence (Illingworth et al., 2018; Stewart and Lewis, 2017).

This study sits at the intersection of two defined areas: open geoscience, understood as the study of how geoscientific results can be made more accessible and how data-sharing practices shape public engagement with scientific knowledge; and geoscience policy, which examines the institutional and political conditions under which geoscientific actions are enabled or constrained (Illingworth et al., 2018). The 2004 CBERS case is a legitimate object of geoscience communication inquiry precisely because its significance lies in how a specific institutional decision about data access transformed the conditions under which varied actors could engage with orbital evidence of environmental change. The satellite data itself was a precondition, but it was the decision to open it that converted a technically specialized asset into shared geospatial infrastructure for governance, accountability, and cross-disciplinary collaboration. Analyzing this case through a geoscience communication lens requires three complementary analytical frameworks, each illuminating a different dimension of how the 2004 pivot simultaneously restructured the political economy of satellite data and the communicative conditions under which that data became accessible.

3.1 Analytical Lenses

The first analytical lens rests on the economic conception of *data as public good*. Traditionally, public goods are defined as resources that everyone can use without significantly reducing their availability to others, and which is impractical or inefficient to prevent people from accessing them (Samuelson, 1954; Kaul and Mendoza, 2003). Satellite Earth observation data from publicly funded systems largely fit this characterization. Once a satellite is operational, distributing additional data incurs almost no extra cost, since the primary expenses are tied to the initial investment. Under these conditions, restricting access through pricing or licensing suppresses downstream social and economic value (Câmara, 2006a, 2006b; Câmara, 2010a).

This public-goods perspective underpins Brazil's 2004 decision and resonates with recent international frameworks – FAIR principles (Findable, Accessible, Interoperable, Reusable) and United Nations Global Geospatial Information Management (UN-GGIM) statements on geospatial data for public good (UN-GGIM, 2025) – explicitly framing environmental and scientific data as foundational infrastructure. Throughout this paper, "public good" implies the economic properties rendering exclusionary pricing of satellite data economically inefficient, and the normative claim that publicly funded data should be openly available when serving collective environmental governance (Câmara, 2010a, 2010b; GEO, 2023; UN-GGIM, 2025).

Geospatial environmental information behind paywalls creates epistemic and material asymmetries: NGOs cannot conduct multi-year deforestation analyses without subscription costs; local governments cannot access baseline imagery for land use planning; university researchers in under-resourced institutions cannot undertake independent monitoring. By establishing satellite imagery as a public goof, Brazil's 2004 policy democratized the capacity to interpret the landscape from orbital perspective, shifting from data scarcity and centralized control to data abundance enabling distributed knowledge production.

The second lens pertains to *institutional politics*, operationalized through historical institutionalism (Mahoney and Thelen, 2010; Thelen, 1999). Where the public-goods lens explains why commercial cost-recovery of satellite data was economically indefensible, this lens explains why economic logic alone was insufficient to produce the 2004 pivot. Legal frameworks, once established, create path dependencies that constrain subsequent actors: the security-control logic embedded in Brazil's remote-sensing legislation (detailed in Section 2.2) did not dissolve simply because it had become economically irrational. Institutional change required active navigation of those constraints.

Historical institutionalism directs analytical attention to how actors exploit ambiguity within existing rules to shift what is politically and legally enforceable, without requiring formal legislative reform. Applied here, it accounts for INPE's incremental strategy of releasing software, monitoring outputs, and ultimately raw satellite imagery in sequence – each step expanding the de facto open-data regime while remaining formally inside the restrictive bilateral and military-controlled framework. This lens thus explains the how of the 2004 decision: the specific institutional moves that converted economic rationale into enacted policy under adverse conditions.

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The third lens extends the analysis beyond the domestic institutional context, situating the 2004 decision within the normative framework that Brazilian actors themselves deployed to describe and justify their open-data advocacy in international forums. From 2002 onwards, INPE leadership argued that commercialization trends in publicly funded Earth observation systems would reduce the potential of geospatial technologies for the public good in the developing world, and called on emerging space powers – including India, China, and Russia – to adopt a public-oriented approach to geoinformation diffusion (Câmara, 2002). By 2010, this advocacy had a name. South Africa, during its Committee on Earth Observation Satellites (CEOS) Chairmanship, proposed the concept of "*data democracy*" – the proposition that open Earth observation data is foundational to the equitable participation of developing nations in global environmental knowledge production. Brazil adopted it as the organizing frame of its Group on Earth Observations (GEO) Second Ministerial Statement (GEO, 2010), giving institutional form to a normative argument that had been circulating in Brazilian advocacy since the early 2000s.

Applied as the third analytical lens, data democracy allows the Brazilian case to be situated within the normative claims the actors themselves articulated, rather than requiring the retrospective imposition of contemporary conceptual vocabulary. It is analytically distinct from the public-goods lens, which explains the economic logic of open data, because it foregrounds the distributional and geopolitical dimension: who gets to know, who gets to produce knowledge, and which institutions exercise the authority to represent territories from orbit. It is equally distinct from the institutional politics lens, which reconstructs the domestic mechanisms of the 2004 decision, because it examines how Brazil translated that domestic decision into an international normative argument about the obligations of publicly funded Earth observation programs. How that argument was received, and what its contemporary relevance is, is examined in Section 7.2.

3.2 The Boundary-Object Framework: Operationalizing Geoscience Communication

The three lenses above explain why open data became politically viable and economically defensible in 2004, but they do not explain how satellite imagery actually crossed social worlds – how it became usable evidence for a journalist, a prosecutor, or an Indigenous territorial monitor who shared no common technical training with the satellite engineers who produced it. To account for that communicative dimension, this study draws on the

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boundary-object framework (Star and Griesemer, 1989). Whereas the three lenses explain the political economy of the 2004 decision, the boundary-object framework explains its communicative effects: how open distribution transformed satellite data from a restricted technical product into a shared resource capable of sustaining governance action across heterogeneous communities.

In this study, satellite datasets and their derived maps are analyzed as artifacts robust enough to maintain a common identity across divergent social worlds (scientific, political, and activist) while remaining plastic enough to adapt to the specific informational needs of each. Within this framework, "shared geospatial language" – a standardized form enabling dispersed actors to work with the same data products without sharing technical training or interpretive frameworks (Star and Griesemer, 1989; Kuhn, 2005) – functions as a standardized informational package that enables cooperation among various actors without requiring consensus on underlying technical methodologies. In this study, its establishment is evidenced when actors from different institutional domains – enforcement agencies, NGOs, journalists, researchers, and Indigenous organizations – are documented using the same satellite-derived maps as the primary evidentiary basis for distinct and independently conducted activities.

"Communicative infrastructure" – the relational substrate through which boundary objects circulate and persist across social worlds, constituted by practice rather than by technical systems alone (Star and Ruhleder, 1996; Star, 1999) – encompasses the material systems (INPE's web-based portals and data cubes) that make boundary objects accessible, stable, and replicable across institutional contexts. This concept is operationalized in the Brazilian environmental context by Rajão and Jarke (2018) and Assis et al. (2019). Communicative infrastructure is treated here as empirically present when the documentary record shows: first, that access to the data was technically available to non-specialist actors through standardized interfaces; second, that those actors demonstrably adopted it; and third, that the adoption produced governance outcomes linked to the imagery rather than to other information sources.

A full boundary-object analysis would require systematic ethnographic evidence tracing how the same artifact was interpreted differently within each social world, however what lies outside the scope of a document-based historical study. Therefore, this study will focus on the structural precondition for boundary-object dynamics: open distribution,

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multi-community adoption, and documented governance outcomes across diverse actors. This is treated throughout as evidence that the data functioned as a boundary-object at the infrastructural level, while the community-level interpretive processes remain a productive direction for future empirical research.

It is important to highlight that the explanatory structure of this study is layered rather than additive. The *public-goods lens* clarifies why commercial cost-recovery was economically indefensible for medium-resolution data. The *institutional politics lens* explains why that economic logic alone was insufficient, and how INPE had to actively exploit legal ambiguity to make openness politically feasible. The *data democracy lens* supplies the normative vocabulary the actors themselves used in international forums. The boundary-object framework then explains what neither lens can: how the policy's effects actually reached a journalist, a prosecutor, or an Indigenous agent who do not share the same technical training that the satellite engineers who produced the data possess. Together, they allow the 2004 pivot to be read as a domestic governance strategy whose communicative impacts considerably exceeded the governance it was designed to serve.

4. Research Design and Methods

This study combines historical institutionalism with interpretive policy analysis to reconstruct how Brazil's 2004 free-data decision was formulated, justified, and implemented, and how it subsequently shaped environmental governance and geoscience communication. These two methodological traditions are complementary: historical institutionalism provides the analytical vocabulary for explaining why the decision was possible at all – tracing path dependencies, identifying the conditions of the critical juncture, and reconstructing the incremental layering strategy through which INPE built a de facto open-data regime inside a formally restrictive legal framework (Mahoney and Thelen, 2010; Thelen, 1999); interpretive policy analysis provides the tools for examining how that decision was made legible and legitimate – attending to the policy narratives, metaphors, and framing contests through which satellite data was recharacterized from a security asset into a public good and, eventually, a diplomatic instrument (Yanow, 2000; Hajer, 1995).

This paper adopts a focused single-case design. Brazil's CBERS open-data decision qualifies as a critical case in Flyvbjerg's (2006) sense: the institutional conditions were

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maximally unfavorable to an open-data outcome, which means that explaining the pivot requires reconstructing the specific moves INPE made rather than reading the result off from structural circumstances. The primary temporal scope is 2000-2012, capturing the pre-pivot legal tensions surrounding Decree 2278/97 and Project of Law 3587/00, the articulation and implementation of the 2004 policy, and the consolidation of Brazil's transparency infrastructure through the tenure of INPE Director Gilberto Câmara. Later episodes, such as the 2019-2022 contestation of INPE's deforestation data under political pressure, are discussed as stress tests of the infrastructure's resilience rather than as primary findings.

The empirical basis for the analytical approach is qualitative document analysis. Documents were selected if they directly addressed data access policy, institutional rationale for distribution decisions, or documented user and governance outcomes of the free-data regime; purely technical engineering manuals lacking these dimensions were excluded. Within this corpus, the analysis proceeds in two interpretive passes. The first reconstructs the chronological and institutional lineage of the 2004 pivot, establishing which actors held which positions at which moments and how the legal and political constraints evolved. The second attends to language: how satellite data was characterized across document types and over time, which actors deployed which framings, and how the vocabulary shifted from security to economic efficiency to democratic entitlement across the period 2000-2012. This attention to framing is not incidental; in the interpretive policy analysis tradition, the shift in how a problem is named and described is itself a political act that restructures what institutional responses appear reasonable (Hajer, 1995; Yanow, 2000).

The geoscience communication dimension was operationalized through a focused third pass over the corpus, attending specifically to documentary evidence of three phenomena: multi-actor adoption of the same satellite-derived evidence base for distinct institutional purposes; documented cases of non-specialist actors producing governance outcomes traceable to open imagery; and explicit framing contests in which the vocabulary used to describe satellite data shifted across actor communities or over time. These three markers were treated as empirically accessible representations for the communicative effects that boundary-object theory predicts but that a document-based study cannot directly observe at the community-interpretive level.

In this study, “primary” sources denote documents produced by the institutions directly involved in negotiating, implementing, or contesting the CBERS data policy – including bilateral agreements and legislation, INPE technical reports and legal analyses, and technical or policy presentations by INPE leadership and partner organizations. “Secondary” sources comprise private-sector testimonies, media reports, and academic or NGO literature that independently assess remote sensing practices and environmental governance outcomes, and are used to triangulate INPE’s self-descriptions and extend the analysis beyond the institution’s own narrative. The “corpus type” and “analytic purpose” columns in Table 1 therefore indicate, respectively, the institutional provenance and genre of each cluster of documents, and the specific questions they are mobilized to answer within the combined historical institutionalist and interpretive policy analysis.

Table 1 below summarizes the full analytical corpus, comprising 63 documents across five categories spanning 1986 to 2025.

Table 1: Summary of Analyzed Research Corpus (63 documents total)

Corpus Type	Corpus Type/Specific	No. Documents	Date Range	Analytic Purpose	Document List
Primary	Bilateral policy documents & legislation	6	1986-2010	Establish the legal mandate of the CBERS program and the 2004 data policy framework.	UNGA, 1986; Brasil, 1997; Câmara dos Deputados, 2000; MCTI, 2004; Câmara and Ning, 2004; CRESDA and INPE, 2010.
Primary	INPE technical reports, publications, and legal analyses	10	2000-2024	Analyze internal rationales for data openness and methodologies (PRODES/DETER) for forest monitoring, as well as other publications.	Câmara et al. 1996; Sausen, 2001; Câmara and Fonseca, 2007; Ferreira and Câmara, 2008; Assis et al., 2019; Ferreira et al., 2020; Gomes et al., 2021; Soler et al., 2021; Satolo et al., 2023; Boscolo et al., 2024.
Primary	Technical & policy presentations by INPE leadership	16	2002-2012	Document the international advocacy of INPE leadership in redefining satellite imagery as a public infrastructure and a global utility, contrasting open-access benefits with restrictive commercial models.	Câmara, 2002; Câmara, 2003; Câmara, 2004; Câmara, 2005; Câmara, 2006a; Câmara, 2006b; Câmara, 2007a; Câmara, 2007b; GEO, 2007a; GEO, 2007b; Câmara, 2010a; Câmara, 2010b; Ferreira, 2010; GEO, 2010; Câmara, 2011; Epiphanio and Silva, 2012.

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Secondary	Private-sector testimonies & media reports	6	2006-2018	Document the commercial response to free satellite imagery and the “internet paradox” of zero-cost distribution.	Space News, 2006; Groom, 2007; MundoGEO, 2009; Marques, 2009; eoPortal, 2012; AWS Public Sector Blog, 2018.
Secondary	Supporting literature on remote sensing & environmental governance	22	2009-2025	Comprehend and evaluate long-term normative influence, and to triangulate institutional history with independent assessments of civic monitoring and deforestation control.	Rajão and Hayes, 2009; Borner, 2010; Rajão, 2012; Rajão, 2013; Vitel et al., 2013; Chazdon, 2014; Nepstad et al., 2014; Rajão and Georgiadou, 2014; May et al. 2016; Fearnside, 2017; Rajão and Jarke, 2018; Maurano et al., 2019; Nascimento, 2019; Cerbaro et al., 2020; Souza et al., 2020; Parente et al., 2021; West and Fearnside, 2021; Higa et al., 2022; Sales et al., 2022; GEO, 2023; Nunes et al., 2024; UN-GGIM, 2025.

This design has acknowledged limitations. It relies on publicly available documents[4] rather than interviews with key decision-makers or access to classified material, and it does not provide comparative analysis of parallel cases in other countries. The data democracy framework, while drawn from the actors’ own international advocacy corpus rather than imposed retrospectively, is applied in the discussion to evaluate longer-term normative implications rather than as a characterization of the motivations operative in 2004. These constraints are consistent with the study’s purpose: to establish the institutional and communicative mechanics of a critical but underexamined case, and to generate theoretically grounded propositions that comparative analysis can subsequently test.

5. Findings: The 2004 Pivot – Institutional Context, Strategic Rationales, and Implementation

5.1 Institutional Context: From Commercial Vision to Free Distribution

The China-Brazil Earth Resources Satellite program, established by a 1988 cooperation agreement and operationally initiated with the CBERS-1 launch in 1999, represented a

[4] The corpus of technical and policy presentations by INPE leadership was mostly compiled through targeted searches of publicly available digital repositories. Gilberto Câmara’s personal academic archive (http://www.dpi.inpe.br/gilberto/new_page.php?lm=present.csv&lr=present_right.csv) was reviewed to isolate presentations delivered to international institutions, such as the GEO and CODATA, which articulated the rationale for the free-data policy.

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historic South-South technological collaboration (Sausen, 2001; eoPortal, 2012). Two developing nations pooled resources and expertise to build an independent medium-resolution Earth observation system designed to break the "pattern of single-country ownership" by wealthy nations (Sausen, 2001; GEO, 2007a). CBERS-1 and CBERS-2 (launched 2003) featured a multi-sensor payload, notably a High-Resolution CCD Camera providing 20-meter spatial resolution imagery, a strategic niche between expensive commercial systems and coarser public alternatives (Sausen, 2001; eoPortal, 2012).

Critically, both Brazil and China initially envisioned CBERS as a commercial venture. Early operational frameworks relied on selling imagery, reflecting conventional space-agency wisdom that data sales should help recover high capital costs (Groom, 2007; Borowitz, 2020). The total investment for the first two satellites eventually reached US$350 million (Marques, 2009), and partners anticipated that commercial data sales would be necessary to fund operations and future satellites. This model underperformed significantly: INPE sold fewer than 1,000 CBERS images annually prior to the 2004 shift, a stark contrast to the approximately 2,000 Landsat scenes it distributed each year as a USGS distributor under the same fee-based regime (Ferreira and Câmara, 2008; Ferreira, 2010).

It was precisely this commercial underperformance that created the institutional opening for a fundamentally different approach. The CBERS Data Policy Version 1.8, signed in June 2004 by Gilberto Câmara (INPE) and Guo Jian Ning (CRESDA), established a dual-regime framework crucial to understand accurately (Câmara and Ning, 2004). The formal policy was not a blanket open-data mandate; it codified commercial norms for international distribution, including revenue sharing and mandatory "international price lists" for third-party distributors (MCTI, 2004). However, a strategic clause explicitly stated that "distribution policy for data collected by [each nation's] ground stations will be defined by each operator" (Câmara and Ning, 2004, p. 2). This legal artifice effectively dissociated domestic distribution from international commercial obligations, granting INPE autonomy to unilaterally abolish user fees for Brazilian territory without violating the bilateral treaty.

On June 28, 2004, INPE announced that all CBERS-2 imagery received at Brazilian ground stations would be freely distributed via the internet through the INPE Catalog and

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Dissemination System for Remote Sensing Images (CDSR).[5] Contrary to past tiered pricing, this new regime required only user registration and eliminated fees for all sectors (Câmara, 2006a, 2006b; Nascimento, 2019). This was a strategic "de facto data policy," adopted within a formally commercial bilateral framework and explicitly designed to bypass the security-constrained legal environment of Decree 2278/97 (Ferreira and Câmara, 2008). Distribution scaled progressively as adoption grew: INPE delivered 53,000 scenes in the first eight months alone (averaging approximately 6,600 images per month), reaching 210,000 cumulative scenes by May 2006 and surpassing 350,000 images distributed between April 2004 and January 2008 – at which point monthly distribution rates had climbed to over 10,000 images per month, effectively rendering the military-era information control paradigm obsolete (Câmara, 2006a, 2006b; Epiphanio and Silva, 2012). This development, from less than 1,000 CBERS transactions annually under a fee regime to a cumulative 350,000 free distributions over 45 months, prefigures the pattern Wulder et al. (2012) later documented for Landsat after 2008, when annual distributions rose from 25,000 to 2.5 million within two years.

The domestic distribution logic of 2004 was formally extended at the international level in 2010, when Brazil and China signed an updated CBERS data policy establishing free and open access for all developing nations (GEO, 2010; CRESDA and INPE, 2010). Brazil simultaneously announced agreements with ground stations in the Canary Islands (Spain/Maspalomas), Egypt (Aswan), and South Africa (Hartebeesthoek) to expand the CBERS for Africa initiative launched at Cape Town in 2007, with ongoing discussions covering the Congo Basin, Gabon, and Kenya (GEO, 2010). This distribution trajectory – from a unilateral domestic clause in 2004 to a multilateral open-access commitment in 2010 – illustrates how the institutional strategy reconstructed in this study scaled from national governance innovation to explicit South-South infrastructure diplomacy.

5.2 Strategic Rationales

Document analysis reveals that INPE justified the 2004 pivot through several interlocking arguments. The primary economic rationale was productivity: INPE leadership explicitly framed high data cost as a "barrier to entry" stifling innovation, arguing that removing

[5] The CDSR interface allowed users to employ "quick-looks" (preview thumbnails) to verify cloud cover and scene relevance before downloading full-resolution files, significantly reducing bandwidth waste and user frustration (Ferreira, 2010).

financial and transactional hurdles would unleash repressed demand for geospatial information and catalyze an expansion in Earth observation capacity within Brazil and the Global South (Câmara, 2006a, 2006b; Groom, 2007).

The empirical record supports this hypothesis. As the distribution trajectory documented in Section 5.1 shows, demand was not absent but suppressed: once financial barriers were removed, uptake expanded at a scale that INPE's own productivity framing had anticipated. User surveys reinforced this, revealing that over 50% of registered users had never engaged with satellite imagery before the policy change, and that over half were private companies using free imagery to develop value-added services rather than for scientific purposes (MundoGEO, 2009; Câmara, 2006a, 2006b).

Beyond productivity, INPE justified the pivot as an assertion of strategic geopolitical autonomy. By offering satellite data as infrastructure for global science, Brazil and China demonstrated that developing nations could not only build independent Earth observation systems but provide essential infrastructure for global environmental monitoring (Câmara, 2006a, 2006b; Câmara, 2007a, 2007b; Epiphanio and Silva, 2012). This repositioned CBERS from a unsuccessful commercial Landsat competitor into a complementary resource filling critical data gaps for the Global South (Space News, 2006; Groom, 2007). INPE framed this as reinforcing Brazil's institutional leadership in tropical Earth observation and South-South technological cooperation, converting a commercial liability into a diplomatic asset (GEO, 2007a).

Regarding transparency and accountability, INPE emphasized that free CBERS data strengthened Brazil's environmental governance infrastructure. In a context where deforestation rates were accelerating dramatically in the early 2000s, satellite data became a critical tool for producing verifiable, reproducible evidence of environmental change and for "protecting our home planet" through improved rainforest monitoring (Câmara, 2005, 2007b; Epiphanio and Silva, 2012). DETER deployment in 2004 marked a turning point: by making both monitoring products (PRODES, DETER) and underlying satellite imagery freely available, Brazil made it significantly harder for state or private actors to deny or obscure forest loss (Câmara, 2006a; Câmara, 2007b). External actors – such as NGOs, scientists, environmental and Indigenous organizations – could independently verify and reanalyze official outputs, converting data into infrastructure for accountability rather than merely national environmental governance (Rajão and Georgiadou, 2014).

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Finally, INPE justified the pivot through an industrial-policy logic, reimagining the state's role in the geospatial value chain. Communications from INPE leadership and private-sector testimonies reveal a deliberate choice to shift commercial value from "upstream" satellite operation to "downstream" value-added services (Câmara, 2006a; Epiphanio and Silva, 2012). Revenue from selling medium-resolution scenes was modest and insufficient to finance meaningful Research and Development (R&D), while pricing barriers stifled the broader economy (Groom, 2007). By removing these barriers, INPE subsidized raw data to catalyze a competitive market for analysis, Geographic Information System (GIS) integration, and specialized consulting targeted at environmental management, deforestation control, and land-use regulation (Câmara, 2006a, 2006b; Epiphanio and Silva, 2012; Nascimento, 2019). Private firms testified that free CBERS data enabled new business development and job creation by reducing data acquisition costs, allowing them to redirect capital from purchasing imagery to developing proprietary algorithms (Câmara, 2006a, 2006b; Epiphanio and Silva, 2012; AWS Public Sector Blog, 2018; Cerbaro et al., 2020).

5.3 Implementation: Web Portals and Direct Data Access

The 2004 policy was operationalized through the deployment of INPE's Catalog and Dissemination System for Remote Sensing Images (CDSR), mentioned in section 5.1. This web-based portal fundamentally altered the user experience by allowing individuals to search, preview, and download imagery without institutional intermediaries or specialized expertise (MundoGEO, 2009). Prior to web portals, data distribution was defined by high transactional costs: researchers were required to submit formal requests, wait for manual processing, and pay per-scene fees, a cycle restricting access to a small elite (Ferreira and Câmara, 2008). The web-based system democratized this infrastructure by making imagery browsable and immediately downloadable through standardized interfaces.

The logic of the "internet paradox"[6] meant that while digital platforms reduced distribution costs to near zero (the idea that "a pixel saved is a penny wasted"), a free-data policy was necessary to satisfy the enormous demand for imagery in developing

[6] INPE's use of "internet paradox" here is idiosyncratic and should not be confused with the productivity paradox identified by Solow (1987), which refers to the absence of computer-driven productivity gains in aggregate economic statistics. INPE's usage refers specifically to the disjuncture between near-zero marginal distribution costs and artificially maintained access barriers.

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nations (Câmara, 2006a, 2006b). This synergy transformed the CBERS archive from a static repository into a dynamic global resource, validating INPE's argument that removing barriers to entry was a prerequisite for capacity building (Câmara, 2006b).

However, while web portals successfully dismantled financial and institutional barriers, they simultaneously exposed a secondary limitation: the severe shortage of individuals possessing the technical skills needed to interpret and leverage newly available datasets (Câmara, 2006b). Although data access was democratized, taking full advantage of Earth observation archives still required considerable expertise in data management, specialized file formats, and spatial analysis (Gorelick et al., 2017). In the Brazilian context, the lack of skilled personnel capable of processing raw satellite imagery into actionable information emerged as the primary bottleneck for environmental management (Cerbaro et al., 2020). This knowledge gap highlighted that simply providing direct access to raw imagery was not always sufficient, and that overcoming the 'lack of expertise' remained a critical challenge in fully realizing the capacity-building potential of open-data policies (Câmara, 2002; Câmara, 2006b). The structural dimensions of this gap suggest that open-data policy is a necessary but not sufficient condition for the capacity-building outcomes INPE envisioned, presenting a limit that the distribution figures document but cannot fully explain.

6. Analysis: Transformative Effects

6.1 Capacity Building Across Sectors

The most immediate and measurable consequence of the 2004 pivot was the creation of a distributed monitoring ecosystem. By removing financial barriers to entry, INPE catalyzed a dramatic expansion in satellite data utilization, critically altering the operational capacity of environmental, academic, and governance sectors in Brazil.

Environmental organizations previously relying on expensive commissioned analysis gained autonomy to conduct independent monitoring and evaluation. Organizations such as the Amazon Institute of Environmental Research (Imazon) and the Socio-environmental Institute (ISA) utilized the open-data regime to undertake multi-year forest change analyses, publishing peer-reviewed reports holding the government accountable (Rajão and Georgiadou, 2014). The validation by external actors also reinforced official

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alerts' political resonance, creating what Rajão and Hayes (2009) call "common ground" for policy debate.

The policy also addressed the acute knowledge gap in the Global South. Universities, often underfunded for research infrastructure, could finally access satellite imagery without dedicated grant funding solely for data acquisition (Groom, 2007). Access democratization promoted research frontier expansion beyond the Amazon: local universities began using CBERS and Landsat data to monitor the Cerrado biome, paving the way for later PRODES and DETER expansion to non-forest ecosystems (Parente et al., 2021). Through the "CBERS for Africa" initiative, Brazil exported this model, providing free imagery to ground stations in South Africa, Kenya, and Gabon (GEO, 2007b, 2010).

At the state level, the open-data policy provided an operational backbone for environmental enforcement. Satellite data integration into enforcement operations via DETER allowed agencies including the Brazilian Institute of Environment and Renewable Natural Resources (Ibama) to shift from reactive to proactive policing (Sales et al., 2022). Real-time imagery enabled rapid identification of illegal logging and land-grabbing, facilitating enforcement deployment to precise coordinates (Nunes et al., 2024). Nunes et al. (2024) explicitly credit satellite-derived deforestation monitoring (combining PRODES, DETER, and CBERS data) with the acceleration of Brazil's historic deforestation reduction between 2004 and 2012. During this period, the correlation between deforestation hotspots and fines issued rose sharply, suggesting that transparency successfully converted data into operational state capacity.

The democratization of satellite imagery also catalyzed supply-chain interventions by bridging civil society activism and legal enforcement. Intermediary entities – including the public prosecutor's office (*Ministério Público*) acting alongside NGOs like Greenpeace – utilized newly accessible visual evidence to forge novel forms of corporate accountability. By translating raw Earth observation data into actionable market and legal metrics, these actors successfully pressured industries to adopt zero-deforestation supply

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chain commitments, most notably the 2006 Soy Moratorium[7] and the 2009 Cattle Agreement[8] (Nepstad et al., 2014).

6.2 Transparency, Verification, and Multi-Scalar Accountability

Before freely accessible satellite data, quantifying forest loss depended almost solely on official government estimates, which could be contested or concealed by competing interests (Rajão and Georgiadou, 2014). Release of raw satellite imagery alongside processed monitoring data rendered denial politically costly: forest loss became visible, mapped, and quantifiable by any analyst with internet access (Rajão and Hayes, 2009).

The success of this transparency regime depended on a communicative infrastructure whose origins Rajão & Jarke (2018) document partially. They show that PRODES and DETER shaped the configuration of different forms of environmental activism through the material properties of the data. The documentary corpus examined here recontextualizes that finding: what they attribute to data materiality was also, and crucially, the communicative effect of the 2004 institutional decision to open the underlying satellite archive. Without CBERS free distribution, the disaggregated DETER alerts would have lacked the independent imagery layer that civil society monitors needed to cross-check official data. INPE leadership championed this logic under the motto "transparency builds governance," and open satellite imagery fed directly into public monitoring platforms such as "amazônia.vc," hosted by the media outlet Globo with INPE's data (Câmara, 2010a; Sá and Grieco, 2016). The resulting visibility catalyzed widespread civic mobilization: campaigns urging citizens to "keep a watch on the Amazon and protest against its destruction" reportedly generated 500,000 registrations and 46 million protest actions (Câmara, 2010a). This distributed monitoring capacity also facilitated coordinated law enforcement on the ground, including illegal timber seizures by the Federal Police, and contributed to a historic decline in forest loss – Amazonian deforestation fell by roughly 78%, from over 27,000 km² in 2004 to just 6,200 km² by 2011 (Câmara, 2010a).

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[7] Initiated in 2006 following a Greenpeace-led campaign targeting the Brazilian Amazon soy industry, the Soy Moratorium was a landmark agreement joined by major soybean buyers to exclude from their supply chains any farmers who grew soy on lands deforested after July 26, 2006.

[8] The 2009 Cattle Agreement emerged from targeted NGO campaigns combined with legal proceedings by the public prosecutor's office against irregular slaughterhouses. It compelled the region's largest beef processing companies to boycott livestock producers who deforested after October 2009.

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This mechanism transformed both media practice and public accountability. Journalists could no longer be limited to official government sources; they collaborated with NGOs and independent researchers to translate technical satellite data into civic monitoring campaigns (Rajão and Jarke, 2018). The cumulative effect was to establish a public evidential resource that made political denialism of deforestation scientifically untenable (Rajão and Jarke, 2018).

The transparency infrastructure faced its most significant test between 2019 and 2022. Deforestation figures released by INPE were more trusted at a politically delicate moment precisely because independent researchers could replicate them with freely available data (Rajão and Georgiadou, 2014). Despite high-level political attempts to dispute INPE findings that culminated in the 2019 dismissal of INPE Director Ricardo Galvão[9] for publicly defending data accuracy, the open system nature of the infrastructure made it resilient. Because raw satellite imagery and interpretation methodologies remained public, independent organizations such as Imazon and MapBiomas could provide counter-verification of deforestation trends and support Galvão's claims.[10] This episode demonstrated that the 2004 pivot created epistemic resilience: even when the state's political narrative shifted away from conservation, the distributed geospatial infrastructure remained a public asset. However, this pattern of contestation and institutional resilience was not new to 2019.

An earlier episode, reconstructed by Sá and Grieco (2016) from interview data, occurred in early 2008 when the state government of Mato Grosso challenged the accuracy of DETER alerts, arguing they overstated deforestation within its borders. INPE's subsequent quality assessment demonstrated that 96% of its alerts were correct, and the controversy led to a formal monthly evaluation protocol that ultimately strengthened DETER's credibility rather than undermining it (Sá and Grieco, 2016). The episode is analytically consistent with the argument developed here: transparency, by making

[9] In August 2019, INPE Director Ricardo Galvão was removed from his post after publicly defending the integrity of DETER and PRODES data against accusations of being "at the service of some NGO." This event is widely cited as a benchmark for the tension between scientific autonomy and political interference in environmental monitoring.

[10] Independent monitoring systems, such as Imazon's SAD (Deforestation Alert System) and the multi-institutional MapBiomas Alerta, utilize the same open-data philosophy initiated in 2004, providing a civil-society safeguard that ensures data continuity even during periods of official government pressure or budget constraints.

methodology publicly auditable, converts political challenges into occasions for institutional reinforcement rather than collapse.

At the international level, the open-data policy functioned as a geopolitical asset, moving Brazil from a defensive target of environmental criticism to a proactive advocate for open-data norms for environmental monitoring. By providing verifiable evidence of forest monitoring capabilities, Brazil positioned itself as a responsible planetary resources manager at the time, a prerequisite for attracting international climate finance such as the Amazon Fund (Rajão and Georgiadou, 2014; May et al., 2016). This transformed satellite data into what effectively became a currency of trust required for REDD+ mechanisms, positioning Brazil as an active contributor to, rather than a passive recipient of, the technical standards emerging in international climate finance architecture (Borner et al., 2010). The 2010 GEO Ministerial Statement provides direct documentary evidence of this dynamic: Brazil described a 2009 COP-15 agreement with FAO committing it to transfer its forest monitoring technology to other developing nations under the UN-REDD program, with the Congo Basin as the primary focus and capacity-building operations planned for the first half of 2011 (GEO, 2010). This agreement materially demonstrates that Brazil's transparency infrastructure had become an exportable diplomatic asset, confirming the transformation of INPE's monitoring capacity from a domestic governance tool into a constitutive element of international climate finance architecture.

Perhaps the most symbolically significant consequence was the democratization of territorial monitoring for Indigenous communities. By removing cost and authorization barriers, the policy enabled a shift from state-led surveillance to the emergence of Indigenous counter-mapping initiatives (Peluso, 1995; Rajão, 2013). Subaltern actors began appropriating high-tech infrastructure to render their own territories visible and legally defensible, turning state-developed tools against illegal intrusion and occupation.

A landmark example, though one requiring careful qualification, is the Paiter Suruí Carbon Project (2009-2018). In its first years, the Suruí people strategically used open access satellite imagery to document forest carbon stocks, entering international carbon markets and exercising territorial sovereignty independently of federal intermediaries (Vitel et al., 2013). The project was indefinitely suspended in 2018, however, due to illegal mining incursion, internal governance breakdown, and a fundamental gap between monitoring capacity and state enforcement. Its suspension cannot be read as evidence of

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open data's limits, neither cause was addressable by the 2004 data policy. What the case demonstrates is more precise: open data was a necessary but insufficient condition for epistemic sovereignty, and its effectiveness was contingent on enforcement and institutional support structures that lay entirely outside INPE's open-data infrastructure.

The transparency regime's benefits were not without operational complications. Sá and Grieco (2016) document that by 2014, INPE and IBAMA had introduced a staggered release schedule for DETER alerts, publishing aggregate statistics at the end of each quarter while delaying spatially specific alert data by one additional quarter. The reason was a direct and somewhat paradoxical consequence of the open-data logic itself: those responsible for illegal deforestation had begun using real-time alerts to anticipate enforcement visits and prepare accordingly. This reveals a structural tension in transparency-as-governance, since the same openness that enables civic monitoring and accountability can, under certain conditions, also forearm the actors it was designed to surveil (Sá and Grieco, 2016). The authors affirm that the 2014 adjustment was a pragmatic recalibration rather than an abandonment of open-data principles, but this makes it clear that the transparency infrastructure was not self-sustaining once established; it required ongoing institutional management to remain effective without being turned against its own purpose.

6.3 Cross-Disciplinary Collaboration and Shared Geospatial Language

The transition toward open-access satellite data promoted a convergence of analytical languages across disciplines (Câmara, 2002; Câmara, 2004). By removing data access friction, this shift created the structural conditions for satellite imagery to operate as a boundary-object at the infrastructural level: the open archive provided historians, ecologists, and policymakers with a common baseline of evidence while leaving each community free to develop its own interpretive practices, a pattern documented in the secondary literature on Brazilian environmental governance (Star and Griesemer, 1989; Rajão, 2013; Wulder et al., 2022).

However, this cross-disciplinary collaboration was not automatic; it relied heavily on the active cultivation of geoscience communication. As data became abundant, a critical need emerged for "boundary-spanners" – credible mediators capable of translating between remote sensing experts and non-specialists (Ramachandran et al., 2021). These intermediaries were essential to ensure that shared geospatial language successfully

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crossed disciplinary and social boundaries, turning raw boundary-objects into mutual understanding.

The availability of multi-decadal temporal series fundamentally shifted environmental history and political ecology. Environmental historians and anthropologists studying Amazonian occupation utilized these series to reconstruct land-use transitions with spatial precision (Brondizio and Moran, 2012). Ecological research transitioned from snapshot measurements to dynamic monitoring of forest fragmentation and wildlife corridor connectivity, quantifying "re-greening" signatures of secondary forests and forest regeneration (Chazdon, 2014; Fearnside, 2017).

The convergence on a common evidential baseline is most concretely documented in the MapBiomas initiative, where NGOs, universities, and technology companies used the same open satellite archive to produce land-cover maps that both civil society, media, and state agencies subsequently cited, an instance where shared access to the same imagery demonstrably sustained collaboration across institutional boundaries without methodological consensus (Souza et al., 2020).[11] By utilizing the open-data legacy alongside cloud computing platforms like Google Earth Engine, MapBiomas established a multi-institutional network effectively crowdsourcing land-use change interpretation across all Brazilian biomes (Souza et al., 2020). This decentralized satellite data, allowing civil society to speak the same geospatial language as the government, effectively transferred epistemic authority from the state to a distributed network of monitors (Rajão and Jarke, 2018; Souza et al., 2020). Policymakers and scientists' dialogue was also transformed by PRODES and DETER outputs. Deforestation maps (visual, spatially explicit, and regularly updated) proved more persuasive than statistical tables alone, a representational clarity institutionalized through platforms like TerraBrasilis[12] (Assis et al., 2019).

The free availability of CBERS and Landsat data, paired with open-source software innovations – initially through INPE's TerraLib/TerraAmazon, later through global platforms like QGIS and Google Earth Engine – democratized the capacity for high-level

[11] MapBiomas, a collaborative network of NGOs, universities, and technology companies, builds upon the open-data foundation to produce annual land-cover and land-use maps, providing a high-resolution counter-narrative and validation for official state figures. Accessible at: https://brasil.mapbiomas.org/.
[12] TerraBrasilis is the official web-based platform created by INPE to provide access to the results of its monitoring programs (PRODES and DETER). Accessible at: https://terrabrasilis.dpi.inpe.br/.

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analysis (Gorelick et al., 2017; Assis et al., 2019). This contributed to Global South researchers' ability to act as knowledge producers and confident communicators of their own environmental realities, rather than merely data subjects and consumers, which became central to what Brazilian actors would later articulate as the data democracy agenda (GEO, 2010; Câmara, 2011).

7. Discussion: Implications for Geoscience Communication and Open Earth Observation Governance

The three implications developed in this section extend the historical findings into geoscience communication practice and open Earth observation governance. They are grounded in the documentary record but go beyond what it alone can demonstrate, and are offered as analytically informed propositions intended to orient comparative research rather than as independently established conclusions.

7.1 Open Earth Observation Data as Infrastructure for Climate Finance Transparency

In the 2020s, satellite Earth observation data has become central to climate finance architecture. Monitoring, Reporting and Verification (MRV) systems for climate mitigation and adaptation depend fundamentally on transparent, non-proprietary data streams that allow donors and recipients to agree on consistent baselines (Wulder et al., 2022), and mechanisms under UNFCCC REDD+ programs and the Paris Agreement rely on this open infrastructure to verify emission reductions independent of state self-reporting (West and Fearnside, 2021). The genealogy of this infrastructure reaches further back than is commonly acknowledged: Zhu et al. (2019) note that the UNFCCC REDD+ mechanism was specified partly based on what could be monitored using Landsat – a specification developed in the same international forums where Brazilian representatives were actively arguing for open Earth observation data as a precondition for equitable climate governance. Whether that advocacy directly shaped the final REDD+ specifications cannot be established from the documentary record; what is demonstrable is that it circulated in precisely the institutional spaces where those decisions were made (Câmara, 2007b; Câmara, 2010b; Nascimento, 2019).

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The broader pattern of Brazilian advocacy in these forums is well documented. In his 2007 Royal Society lecture and subsequent Beijing briefing, Câmara framed CBERS as a contribution to a future constellation of satellites that would provide free global land imaging for all countries, explicitly calling for a CEOS land imaging constellation built on open-access norms (Câmara, 2007b; Câmara, 2010a). Brazil's 2010 GEO Ministerial Statement exemplifies this advocacy at the intergovernmental level: the Brazilian delegation linked open Earth observation data to sustainable development transitions for the Global South, outlined the expansion of CBERS data-sharing agreements across Africa, and announced the operationalization of the COP-15 FAO agreement for MRV technology transfer – all within the same forum where global Earth observation data norms were being actively debated (GEO, 2010).

Beyond carbon accounting mechanics, the open-data legacy has become a prerequisite for epistemic equity in Loss-and-Damage (L&D) assessments. As UNFCCC negotiations intensify following the L&D Fund establishment, non-proprietary satellite imagery enables developing countries and civil-society organizations to independently document climate-related disasters, challenging the geospatial dominance historically held by Global North agencies (Boscolo et al., 2024; Rufin et al., 2025; UN-GGIM, 2025). Recent work on CBERS-04A active fire mapping in the Brazilian Pantanal biome illustrates how nationally operated satellites and open data can generate high-resolution evidence of climate-related disasters in vulnerable biomes (Higa et al., 2022).

7.2 Data Democracy as a Global South Framework for Open Earth Observation

As Section 3.1 established, the data democracy framework is grounded in the actors' (INPE's leadership) own vocabulary rather than imposed retrospectively. What that grounding enables, analytically, is a connection between the Brazilian case and a broader scholarly conversation about the distributive consequences of open data policies for the Global South. Academic usage of the concept has converged on a core tension: that mere availability of open data does not constitute data democracy if the capacity to interpret and derive policy-relevant knowledge from it remains concentrated in Northern institutions (Pearlman et al., 2016; Johnson et al., 2021). INPE's simultaneous investment in open software platforms (SPRING, TerraLib, TerraAmazon) alongside open imagery anticipates precisely this distinction: the 2004 decision was calibrated to enable

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interpretation capacity, not just data access, across the Global South (Câmara and Fonseca, 2007; Ferreira and Câmara, 2008).

This tension was not theoretical for INPE. The same documents that record the triumph of free distribution also acknowledge its limit: within years of the 2004 pivot, INPE identified a severe shortage of personnel capable of processing raw satellite imagery into actionable information as the primary bottleneck to realizing the capacity-building potential of open access (Câmara, 2006b; Cerbaro et al., 2020). The 2004 opening was adjusted to address this by releasing open software alongside the data, but the gap between data availability and interpretive capacity persisted well beyond the initial distribution phase, pointing to a structural limit that free access alone could not resolve: the shortage of trained personnel capable of converting raw satellite imagery into actionable environmental knowledge.

Its contemporary relevance has only intensified. While medium-resolution data has been substantially democratized since 2004, new access pressures are emerging around high-resolution commercial imagery: operators increasingly gather granular data over Global South territories at resolutions unmatched by public systems, often selling this intelligence back to the very nations over which it was collected (Rufin et al., 2025). Grounded in the logic of publicly funded infrastructure obligations rather than efficiency arguments alone, the data democracy proposition offers a more durable normative foundation for resisting this enclosure than technical or economic reasoning alone. The 2004 precedent established that a Global South nation could assert the terms of access to its own territorial data and build the institutional infrastructure necessary to sustain that assertion independently. Both the CBERS-04A active fire mapping work in the Pantanal (Higa et al., 2022) and the MapBiomas initiative (Souza et al., 2020) exemplify this trajectory: sovereign analytical capacity, grounded in publicly funded data and open-source tools, that has so far proven resilient against both commercial enclosure pressures and direct political interference – as the 2019-2022 episode demonstrated.

7.3 Interdisciplinary Collaboration and Geoscience in Sustainable Development

The preceding analysis has shown how the 2004 decision transformed satellite imagery into shared infrastructure for cross-disciplinary knowledge production. What the historical record cannot resolve, however, is whether that transformation is sufficient for

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the knowledge production demands of the present moment – and the evidence suggests that alone it is not.

Contemporary challenges (climate adaptation, biodiversity conservation, Indigenous territorial rights recognition, among others) require not only that data be accessible but that the capacity to interpret, analyze, and act upon it be genuinely distributed (Kapur et al., 2018). Other studies also identify a structural gap here: open data policies address the first condition but not the second, often failing to provide the institutional resources or shared infrastructures needed to translate raw data into actionable knowledge on the ground (Cerbaro et al., 2020; Craglia and Nativi, 2018). Modern Earth system science demands a shift toward open science more broadly conceived, entailing algorithmic and workflow transparency alongside raw imagery sharing, so that Global South researchers can function as active knowledge producers rather than data consumers who remain dependent on Northern analytical infrastructure (Ramachandran et al., 2021; Craglia and Nativi, 2018). Platforms co-locating data and computing (such as Data Cubes) are emerging as essential infrastructure to lower technical barriers for interdisciplinary teams (Baumann et al., 2018; Ferreira et al., 2020; Gomes et al., 2021; Satolo et al., 2023).

The 2004 decision anticipated this challenge more than is commonly recognized. By opening access to data and tools simultaneously, INPE implicitly acknowledged that data availability without interpretive capacity is insufficient. This simultaneity facilitated the emergence of a new generation of environmental data scientists and geoscience communicators across the developing world (Câmara and Fonseca, 2007; Kapur et al., 2018). The implication for contemporary open-data policy here is direct: the 2004 model's most replicable feature is the institutional commitment to building sovereign analytical capacity alongside free distribution, a bundling that distinguishes it from policies that treated access as sufficient in itself. Where that commitment was present, the authority to define, monitor, and communicate environmental reality could be shared with the communities most affected by planetary change rather than concentrated in well-resourced institutions elsewhere (Câmara, 2002; Câmara, 2011).

8. Conclusion

This study aimed to answer two interconnected questions: how and why INPE was able to implement a strategic open-data policy within a formally commercial and security-constrained institutional environment, and what the 2004 decision reveals about the communicative mechanisms through which open Earth observation data becomes actionable evidence for heterogeneous governance actors. By combining historical institutionalism with interpretive policy analysis of a 63-document corpus, the study reconstructed the institutional mechanics of Brazil's CBERS open-data pivot and traced its communicative effects across state agencies, civil society organizations, and Indigenous actors. In doing so, it established the CBERS case as an underexamined Global South contribution to open geoscience governance and demonstrated that what INPE achieved was not simply a data release but a governance intervention that restructured the rules of who could engage with orbital evidence of environmental change and on what terms, particularly in Brazil.

The three findings reconstructed in this study converge on a single institutional logic: that the communicative effects of Brazil's 2004 CBERS open-data policy were inseparable from the institutional conditions that made it possible. First, INPE navigated a legally restrictive, military-controlled environment by exploiting a specific bilateral treaty clause to dissociate domestic distribution from international commercial obligations, adopting a calculated "de facto data policy" rather than awaiting legislative reform. This institutional strategy, reconstructed from primary policy documents and internal INPE communications, establishes the 2004 pivot as a deliberate governance innovation rather than an incidental outcome.

Second, the decision restructured the geoscience communication landscape in ways the documentary record allows reconstruction at the infrastructural level. By removing financial and institutional barriers to satellite imagery, INPE created the structural conditions under which heterogeneous actors could engage with the same orbital evidence for distinct institutional purposes. The documentary record supports that this restructuring operated across heterogeneous institutional communities, each adopting the same open imagery for distinct and independently conducted purposes, a pattern consistent with boundary-object dynamics at the infrastructural level, though the community-level interpretive processes remain beyond what documentary evidence alone can establish. As previously presented by Rajão and Jarke (2018), the accountability infrastructure that resulted, evidenced most clearly in the combined operation of PRODES, DETER, and freely available CBERS imagery, shifted political contestation from whether

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deforestation was occurring to actionable debates about enforcement and policy response. Its resilience was tested more than one time, particularly between 2019 and 2022, when independent organizations were able to counter official attempts to dispute INPE findings precisely because the underlying data and methodologies remained publicly available, demonstrating that open-data infrastructure can sustain epistemic continuity beyond any single government's administrative control.

Third, the Brazilian precedent established an underacknowledged Global South model for open Earth observation governance. Documentary evidence confirms that Brazilian representatives systematically advocated for open-data principles in international forums including GEO and the Committee on the Peaceful Uses of Outer Space (COPUOS), and that this advocacy was present in the same institutional forums where those subsequent policy decisions were debated, though whether it directly influenced them cannot be established from the available documentary record. What can be affirmed is that the 2004 CBERS policy constituted the first operational example of free medium-resolution satellite data from a Global South national system, a precedent that preceded, and was cited in relation to, the broader global open-data shift.

These findings carry several limitations. The study relies on publicly available documents rather than interviews with key decision-makers, and the corpus of INPE leadership presentations carries inherent self-legitimation risk that triangulation with independent evidence only partially mitigates. The analysis does not provide systematic comparative examination of parallel cases in other countries, which would be necessary to assess the generalizability of the institutional mechanisms identified here. Comparative institutional analysis of Earth observation data policies in China, India, and the European Union would allow more precise isolation of the conditions under which public-goods framing succeeds in overcoming security-control logics. Ethnographic studies of how different communities (enforcement agencies, Indigenous organizations, independent scientists) actually interpret and dispute the same satellite imagery would provide a fuller boundary-object analysis than is possible from documentary sources.

Data Availability

All the materials consulted for this research are present in the References with proper access links.

Author Contributions

AGRO was responsible for conceptualization, methodology, formal analysis, data curation, and prepared the first draft of the manuscript. GM contributed to the investigation through literature review and assisted in the writing, review and editing of the manuscript.

Competing Interests

I declare that neither I nor my co-author have any competing interests.

Ethical Statement

This research article complies with the ethical standards of the authors' home institutions. The study relies exclusively on the analysis of publicly available policy documents, bilateral treaties, institutional communication materials, technical reports, and peer-reviewed academic literature. No human subjects were involved, nor was any classified or non-public material accessed during the investigation.

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