Satellite Infrastructures and Law in the Making of Planetary Knowledge

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Abstract

Imaginations of Planet Earth as-a-whole—that is, Earth conceived in planetary terms by wide publics—have been shaped over several decades by the growing capabilities of artificial Earth satellites to image the whole Earth, to specify all locations, and to integrate the Earth's diverse orbital space with everyday human activities. Different Earth orbits are becoming more densely used, more securitized, more intensely managed from Earth, and more integral to activities on Earth.

This Article focuses on two categories of satellite systems that contribute directly to planetary knowledge, Global Navigation Satellite Systems (GNSS) and Earth Observation Satellite Systems (EOSS). GNSS and EOSS have earlier military and intelligence origins, but were readily associated with 1990s-type "globalization"—the encouragement of trade and communication, and the monitoring and discouragement of illicit activities and flows. More recently both have also been integral to a process of "planetization"—the construction and wide diffusion of understandings of Earth in planetary terms, as a shared and contingent habitat with many dependencies. This Article traces the policies and conditions under which data from these satellite systems has become (for the time being) open and widely available to general publics, and the basis for "planetary" infrastructural development and dependence.

We argue that the major GNSS have all become "infrastructural": broadcasting without charge freely available signals which enable timing, positioning, and navigation via receivers and downstream products for billions of users, as well as a fast-increasing range of important environmental uses. EOSS supply images and other data which flow into scientific models of Earth systems and many business and governmental use cases—with or without charge or restriction, depending on the provider and on government controls. EOSS have become, or are becoming, infrastructural for many forms of planetary knowledge. However, the provision of comprehensive, free-to-all, and highly reliable GNSS and EOSS data and services is not legally embedded or guaranteed, and it is far from assured. Both are "dual use" and vulnerable to kinetic or cyber disruption in conflict. GNSS are government-provided but readily spoofed or jammed, and governments are seeking to develop more resilient alternatives. EOSS are often privately owned or government-controlled, and the data or downstream products are increasingly liable to private enclosure or to government restriction on release. Questions about their assured availability

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and extension swirl together with renewed nationalism, military prioritization, and contestations of "planetary" politico-legal thinking and its imaginaries. It is now necessary to "think infrastructurally" about legal, policy, and economic means to ensure the reliable and universal availability, sustenance, and supplementation of these important foundations of planetary knowledge.

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I. INFRASTRUCTURAL INTEGRATION OF EARTH AND SPACE

Artificial satellites placed in Earth orbits (hereinafter "satellites") are in a symbiotic relation with Earth.[1] They rely on Earth's gravity to maintain stable orbits, and on Earth-based infrastructure for their construction, launch, and continuous control. In turn, satellites are essential infrastructure for military activities and intelligence gathering, and are now almost ubiquitous in navigation and telecommunications systems on Earth.[2] They also serve as key sources of data and action for collaborative human governance initiatives, ranging from early roles in arms control verification during the Cold War[3] to later applications such as satellite imagery for disaster response[4] and international criminal investigations.[5]

Establishing a legal framing for Earth orbits and orbiting objects almost instantly became a pre-occupation of lawyers and legal scholarship following the successful launch and orbit of Sputnik I in 1957.[6] It was widely, although by no means universally, thought that Earth-based state sovereignty, accompanied by mantras of effective control and practical ability to exercise jurisdiction, did not and ought not to extend into space beyond some limit of distance from Earth.[7]

1 Satellites in lunar and other orbits, and future satellites not constructed on Earth or controlled from Earth, will complicate this picture, but these possibilities are outside the focus of this Article. For a technical overview of satellite orbits, *see* OLIVER MONTENBRUCK & EBERHARD GILL, SATELLITE ORBITS: MODELS, METHODS, APPLICATIONS 1–8 (2000).

2 For a comprehensive introduction to satellite applications, *see* HANDBOOK OF SATELLITE APPLICATION (Joseph Pelton, Scott Madry & Sergio Camacho-Lara eds., 2017). For a survey of developments in satellite communication, *see* Hayder Al-Hraishawi et al., *A Survey on Nongeostationary Satellite Systems: The Communication Perspective*, 25(1) IEEE COMMC'N SURV. TUTORIALS (2023).

3 Aaron Bateman, *Trust but verify: Satellite reconnaissance, secrecy and arms control during the Cold War*, 46(5) J. STRATEGIC STUD. 1037, 1037 (2023).

4 Julie Rolla et al., *Satellite-Aided Disaster Response*, 6(1) AGU ADVANCES 1, 2–3 (2025).

5 Neil Savage, *Eyes in the Sky Help to Enforce Laws*, 635 NATURE S1-S3 (2024); *see also* Jonathan Hak & Sabrina Rewald, *The Satellite Era: How Earth Observation data is Being Mobilized as Potential Digital Evidence*, EJIL TALK (July 1, 2024), https://perma.cc/5MSN-2CR5. *See further* Micah Farfour, *The Role and Use of Satellite Imagery for Human Rights Investigations*, *in* DIGITAL WITNESS: USING OPEN SOURCE INFORMATION FOR HUMAN RIGHTS INVESTIGATION, DOCUMENTATION, AND ACCOUNTABILITY (Sam Dubberley et al. eds., 2019).

6 *See* Barton Beebe, *Law's Empire and the Final Frontier: Legalizing the Future in the Early Corpus Juris Spatialis*, 108 YALE L. J. 1737, 1744–45 (1999), for a survey of key themes.

7 *See* Wilfred Jenks, *International Law and Activities in Space*, 5(1) INT'L COMPAR. L. Q. (1956) 99, at 103 (observing that "missiles, space stations and space ships moving in space would be constantly changing their position in relation to the subjacent territorial sovereignties at such high speeds" that no real analogy existed with the jurisdiction of territorial sovereigns over the territorial sea or over superjacent airspace); *see also* Matt Craven, *'Other Spaces': Constructing the Legal Architecture of a Cold War Commons and the Scientific-Technical Imaginary of Outer Space*, 30(2) EUR. J. INT'L L. 547, 552–56 (2019).

Some advocated the Kármán line as a legal limit, separating airspace, in which sovereign rights had already been accepted, from outer space.[8]

More uncertain was whether "space" beyond the airspace outer limit was itself an operative legal idea, as was presumed both by those who characterized space in legal terms as a "thing" (res nullius, res communis, etc.) and by others who proposed to treat "space" as a legal locale or situs into which some human laws might be projected along with human activity but for which a large set of special laws and legal regimes would need to be devised.[9] Those who rejected "space" as a unified legal concept nonetheless agreed that inter-state rules and jurisdictional arrangements could potentially define legal rights and powers over, *inter alia*, satellites and celestial bodies, at least if other life forms capable of engaging in rule-making were not encountered.[10]

The advent of Earth satellites, orbiting well beyond the Kármán line but clearly in close and symbiotic relation to Earth, led to proposals for an intermediate zone between airspace and more remote space.[11] Before the placement of satellites in geostationary or geosynchronous orbit (GEO), the Mexican scholar Modesto Seara Vázquez proposed that a contiguous zone be declared in between airspace and free space, extending out to and including GEO.[12] In the contiguous zone, freedom of navigation would be the default principle, and "the stationing of satellites of relative immobility above a country other than the one by which they were launched" would be prohibited.[13] This was rapidly eclipsed by major spacefaring powers placing numerous heavy, expensive, and long-lasting broadcasting and Earth observation and other functional satellites in GEO; an enduring struggle ensued about fair principles for allocating

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8 The debate persists to this day. *See, e.g.*, *Working Group on the Definition and Delimitation of Outer Space of the Legal Subcommittee*, UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, https://perma.cc/2PZN-K9PF.

9 MODESTO SEARA VÁZQUEZ, COSMIC INTERNATIONAL LAW (ELAINE MALLEY TRANSL, 1965).

10 *See, e.g.*, Sergio Marchisio, *National Jurisdiction for Regulating Space Activities of Governmental and Non-Governmental Entities*, United Nations/Thailand Workshop on Space Law, 16–19 November 2010, Bangkok, Thailand, https://perma.cc/2MSZ-B89G. Frans von der Dunk, *Effective Exercise of 'In-Space Jurisdiction': The US Approach and the Problems It Is Facing*, 40 J. SPACE L. 147 (2015).

11 One example is the International Association for the Advancement of Space Safety's submission to the Legal Subcommittee under the U.N. Committee on the Peaceful Uses of Outer Space. *Definition and delimitation of outer space: views of State members and permanent observers of the Committee*, U.N. Doc. A/AC.105/1112/Add.13, at 7-14 (Feb. 28, 2025).

12 Modesto Seara Vázquez, *The Functional Regulation of the Extra-Atmospheric Space*, *in* SECOND COLLOQUIUM ON THE LAW OF OUTER SPACE, LONDON 1959, 139–46 (Andrew G. Haley & Welf Heinrich eds., 1960).

13 *Id.* at 144.

limited GEO slots and associated spectrum.[14] Infrastructural satellite systems expected to remain in service for many years also came to be placed in medium Earth orbit (MEO), including the principal GNSS, beginning with the U.S. Global Positioning System (GPS).[15]

By the 2010s, much cheaper satellites (small CubeSats, NanoSats, and reprogrammable FlexSats),[16] lower-cost commercial launch capabilities including re-usable rocket technologies[17] and vastly improved communications and computational power[18] enabled many new infrastructural applications. This facilitated a massive proliferation of satellites in low-Earth orbit (LEO), led initially by the deployment of the Starlink internet-data infrastructure from 2019 onward and several other commercial and military satellite constellations in LEO, MEO and/or hybrid orbits.[19] New thinking on the relations of Earth to satellites responds to the aggregate of changes taking place, including the diversity of use cases, the burgeoning numbers of satellites involved, the increasing heterogeneity of their capabilities, size, ownership, costs, orbits, communications, network structures, and vulnerabilities, and the dramatic increases in scale and intensity of military involvement and pre-occupations with satellites in several of the most

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[14] Declaration of the First Meeting of Equatorial Countries, signed in Bogotá, Colombia, Dec. 3, 1976 [hereinafter "Bogotá Declaration"]. For further discussion, *see* MARTHA MEJÍA-KAISER, THE GEOSTATIONARY RING: PRACTICE AND LAW (2020).

[15] Richard Langley, Peter Teunissen & Oliver Montenbruck, *Introduction to GNSS*, *in* SPRINGER HANDBOOK OF GLOBAL NAVIGATION SATELLITE SYSTEMS 3, 16 (Peter Teunissen & Oliver Montenbruck eds., 2017).

[16] Siegfried Janson, *The Concept and History of Small Satellites, in* NEXT GENERATION CUBESATS AND SMALLSATS (Francesco Branz et al. eds., 2023) (suggesting that satellite history began with small satellites in 1957, transitioned to the "Large Space Era" in the next decade—driven by the space race and the development of large launch vehicles—and evolved again with the "New Space Era" beginning around 1997, marked by the rise of active nanosatellite launches, new technologies, and CubeSats and other small satellites in cubic and near-cubic forms). For an overview of how the industry understands "new space", *see* Alessandro Golkar & Alejandro Salado, *Definition of New Space—Expert Survey Results and Key Technology Trends*, 2 IEEE J. MINIATURIZATION AIR SPACE SYS. 2 (2021). However, the concept of "new space" is controversial in the eyes of space historians, some of whom argue that its characteristics are not entirely new but rather a repetition of past patterns in the history of human space exploration. *Cf.* Matthew H. Hersch, *Pathfinder to Profit: Lessons from the Space Shuttle Era*, *in* THE RISE OF THE COMMERCIAL SPACE INDUSTRY: EARLY SPACE AGE TO THE PRESENT (Brain C. Odom ed., 2024).

[17] Harry W. Jones, *The Recent Large Reduction in Space Launch Cost* (48th Int'l Conf. on Environmental Systems, 2018), https://perma.cc/9RZN-NBB3.

[18] *See* Hammas Bin Tanveer et al., *Making Sense of Constellations: Methodologies for Understanding Starlink's Scheduling Algorithms*, *in* CONEXT 2023: COMPANION OF THE 19TH INT'L CONF. ON EMERGING NETWORKING EXPERIMENTS AND TECHNOLOGIES (2023).

[19] *See* Nils Pachler et al, *An Updated Comparison of Four Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband* (IEEE Int'l Conf. on Commc'ns Workshops, 14-23 June 2021) (compared Telesat, OneWeb, SpaceX Starlink, and Amazon Kuiper); Sandra Erwin, *Space Development Agency Shaking up How the Military Buys Satellites*, SPACENEWS (Aug. 11, 2023), https://perma.cc/K8P6-MVKN.

powerful states and groupings.[20] This new thinking is in progress in national legal and regulatory processes—and some international initiatives—on specific issues including increasing kinetic risks from debris in space and from (un)controlled reentry of debris and rockets,[21] atmospheric and oceanic pollution from launches and satellite de-orbiting,[22] light and radio interference affecting visual and radio astronomy, and spectrum protection and management to minimize interference.[23] Broad governance issues precipitated by technological and politico-military changes include military-corporate interactions over dual-use satellite systems, managing relations among key constituencies (military, commercial, science, civil) and among different space-capable powers, counter-space capabilities and their deployment, and specifics of matters such as orbit and spectrum allocations and crowding.

We understand the above process as contributing to partial *infrastructural* integration of Earth and Earth-orbit space. Understanding how infrastructures can themselves have regulatory effects, and the implications of their complex interactions with law and legal structures, is important for those concerned with legal concepts and governance design. Infrastructure has operationally-specific *technical* aspects, functionally-specific *organizational and governance* aspects, and (in many cases) *social* aspects which bring into consideration both the publics directly affected by each infrastructure and the inchoate publics whose lives and world-views are influenced by data and knowledge flowing from these infrastructures.[24]

We suggest that what has been learned in studies of other infrastructures offers some insights for the critical assessment and development of the policy, law, and governance of these Earth-satellite infrastructures. Our argument does not require adopting a precise definition of "infrastructure," but we endorse the

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20 *See* DANIEL DEUDNEY, DARK SKIES: SPACE EXPANSIONISM, PLANETARY GEOPOLITICS, AND THE ENDS OF HUMANITY (2020); MARY-JANE RUBENSTEIN, ASTROTOPIA: THE DANGEROUS RELIGION OF THE CORPORATE SPACE RACE (2022); David Koplow, *Large Constellations of Small Satellites: The Good, the Bad, the Ugly, and the Illegal*, 15 HARV. NAT'L SEC. J. 257 (2024).

21 Ewan Wright et al., *Airspace Closures due to Reentering Space Objects*, 15 SCI. REP. 2966 (2025); Phil Georgiadis et al., *Qantas Delays Flights to Avoid SpaceX Rocket Parts*, FIN. TIMES (2025), https://perma.cc/8WDF-FMYJ.

22 *See* Jamie Shutler et al., *Atmospheric Impacts of the Space Industry Require Oversight*, 15 NATURE GEOSCIENCE 598, 598–99 (2022); Alla Pozdnakova, *Pollution of the Marine Environment by Spaceflights*, *in* THE ENVIRONMENTAL RULE OF LAW FOR OCEANS: DESIGNING LEGAL SOLUTIONS (Froukje Maria Platjouw & Alla Pozdnakova eds., 2023). *See also* Compl., Center for Biological Diversity et al. v. Federal Aviation Administration and Billy Nolen (D.D.C., filed May 1, 2023) (No. 1:23-cv-01204).

23 Fabio Falchi et al., *A Call for Scientists to Halt the Spoiling of the Night Sky with Artificial Light and Satellites*, 7 NATURE ASTRONOMY 237 (2023); Jeff Foust, *U.N. Committee to Take Up Issue of Satellite Interference with Astronomy*, SPACE NEWS (Feb. 20, 2024), https://perma.cc/HU7A-Z8LZ; Int'l Dark-Sky Ass'n, Inc. v. Fed. Commc'ns Comm'n, 106 F.4th 1206 (D.C. Cir. 2024).

24 Benedict Kingsbury & Nahuel Maisley, *Infrastructures and Laws: Publics and Publicness*, 17 ANN. REV. L. SOC. SCI. 353 (2021).

stipulations that "infrastructures must have a significant material dimension and that they are built as opposed to simply natural." They are "extended material assemblages" that "mediate exchange over distance," typically linking dispersed specific practices, people, objects, and spaces."[25] Anthropologists seeking to discern when an infrastructure is operating or influential have been much influenced by the work of Susan Leigh Star and Karen Ruhleder. They suggested (here rephrased for clarity and brevity) that infrastructures often have characteristics of embeddedness (being located inside other social and technological structures), transparency (in the sense of being unnoticed), extensive spatial and temporal reach or scope (they are not one-off or momentary), and of their affordances or artifacts or organizational features being taken for granted.[26] Star and Ruhleder also suggested that infrastructures are learned as part of membership in a community of practice and shaped by conventions of practice, which they in turn also shape; plugged into other infrastructures and tools in a standardized fashion; and often are built on a (pre-)installed base which constrains them but may also be a source of strength. Finally, even if normally invisible, infrastructures become highly visible upon failure or breakdown.[27]

Drawing from insights already distilled by scholars working in infrastructure studies,[28] we inquire in the subsequent sections of this paper into the presence and significance in GNSS and EOSS of the following features.

(a) Historical Evolution: A pathway of historical evolution in which a specialized and often enclosed (non-public) technological system becomes linkable to other systems, a wider set of other users and uses become dependent on it, and demands are made to make it publicly, universally, and reliably available.

(b) Data Availability: Debates about the proper availability of data (open or restricted, processed or raw); the intermediation of (and concerns about competition with) private producers of proprietary data and data-analytics products.

(c) Public vs Private: Debates about whether the infrastructure should be provided by a public entity or by private enterprise; and about principles for regulatory oversight and requirements, such as for universal access, and commitments to provide continuous uninterrupted service. These are interwoven with choices about business and financing models, including whether the

25 *Id.* at 355.

26 Susan Leigh Star & Karen Ruhleder, *Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces*, 7 INFO. SYS. RSCH. 111, 113 (1996).

27 *Id.*

28 *See generally* PAUL EDWARDS ET AL., UNDERSTANDING INFRASTRUCTURE: DYNAMICS, TENSIONS, AND DESIGN—REPORT OF THE WORKSHOP HISTORY AND THEORY OF INFRASTRUCTURE: LESSONS FOR NEW SCIENTIFIC CYBERSTRUCTURES (Jan. 2007); INFRASTRUCTURES AND SOCIAL COMPLEXITY: A COMPANION (Penelope Harvey et al. eds., 2017); THE PROMISE OF INFRASTRUCTURE (Nikhil Anand et al. eds., 2018).

infrastructure is sustained by profit-making or subsidization, and also choices about cost recovery and charging (e.g. for data and data services); legal and funding issues concerning maintenance and upgrading of the infrastructural services; provision of physical and cyber-security for the infrastructure (especially "critical infrastructures"); emergency provision of free services; and military requisitions in times of tension.

(d) Publicness: Broader issues of publicness and equity in these infrastructures and in the constructions of planetary knowledge and governance they help enable.

(e) Securitization: The periodic recurrence of national security and geo-political considerations, and how to weigh these versus other considerations about the infrastructure.

While GNSS and EOSS are each known mainly for their specific functions and qualities, and we ourselves will focus on their infrastructural features which include dimensions of functionality, we believe it is insufficient to analyze infrastructures simply in functional terms. "Thinking infrastructurally typically entails understanding infrastructure not simply as a thing, but as a set of relations, processes and imaginations."[29]

We suggest that GNSS and EOSS have separately and together contributed, albeit in an abstract way not easy to trace or measure, to human imaginations and understandings of Earth *as a planet*.[30] This planetary sensibility encompasses ways of seeing and knowing Earth as a whole, and of relating the local and particular to the whole. It is shaped through imaging, mapping, and greater knowledge of Earth systems and of their prior and current processes of change. This sensibility is accompanied by an awareness of Earth and of life on it as highly contingent. Such planetary sensibility has helped open comparisons of Earth with other planets (including exoplanets) and moons, research into the ways in which carbon-based life develops, and wide reflection on the responsibilities as well as the puzzles of understanding ourselves and Earth in an apparently infinite space.[31]

This planetary sensibility should not be conflated with particular projects of governance and policymaking which refer to it. Some of these projects have become the objects of significant debates in politics, including the 2015 Paris Agreement on climate change. Others are contested in recondite scientific and academic debate, such as whether the specification of "planetary boundaries" as

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[29] Benedict Kingsbury, *Infrastructure and InfraReg: On Rousing the International Law "Wizards of Is"*, 8 CAMBRIDGE INT'L L. J. 171, 179 (2019). *See also* Fleur Johns, *Governance by Data*, 17 ANN. REV. L. SOC. SCI. 53 (2021); Florence Millerand & Karen S. Baker, *Data Infrastructures in Ecology: An Infrastructure Studies Perspective*, *in* OXFORD RESEARCH ENCYCLOPEDIA: ENVIRONMENTAL SCIENCE (2020).

[30] *See generally* DIPESH CHAKRABARTY, THE CLIMATE OF HISTORY IN A PLANETARY AGE (2021).

[31] *Cf.* Bronislaw Szerszynski, *Infrastructuring as a Planetary Phenomenon: Timescale Separation and Causal Closure in More-Than-Human Systems*, 47 HIST. SOC. RSCH. 193 (2022).

thresholds not to cross is well-grounded or scientifically arbitrary,[32] or insufficiently concerned with other matters such as poverty and justice.[33]

There are risks that sources of open data about Earth will become casualties of these political struggles or tinged by intra-science and inter-organizational jostling; and potentially serious implications for knowledge if data infrastructures become less open due to private for-profit enclosure or heightened government restrictions.[34] The openness of both GNSS and EOSS might in the future be affected by intensifying national rivalries and heightened focus on space in military doctrines and planning.[35] Their planetary dimensions—intrinsic to the relations between satellites and Earth, relations which they embody and help constitute—add a dimension both to their significance and their potential vulnerabilities.

II. HISTORIC EVOLUTION OF GNSS AND EOSS: THE ERA OF OPEN-DATA INFRASTRUCTURES FOR PLANETARY KNOWLEDGE

This Section is a historical review that shows how GNSS and EOSS evolved from their enclosed military origins into the underpinnings of "open" data infrastructures that serve much wider publics and add to widely-distributed planetary knowledge. This transformation was shaped by a series of design choices, responsive to social and organizational demands as well as the physical laws and practical constraints these technologies operated within. The ultimate infrastructural choices were influenced by, and contributed notably to, shifts in public policy. The role of binding formal "law," as traditionally conceived, has been deliberately limited, allowing knowledge infrastructure development in a dynamic and adaptable infrastructural public space. However, this has also meant that these infrastructures, now central to many aspects of daily public life, do not have strong legal protections against future securitization and enclosure. We return to this in the final section of this Article.

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32 José M. Montoya et al., *Planetary Boundaries for Biodiversity: Implausible Science, Pernicious Policies*, 33(2) TRENDS ECOLOGY EVOLUTION 71, 71 (2018).

33 Frank Biermann & Rakhyun Kim, *The Boundaries of the Planetary Boundary Framework: A Critical Appraisal of Approaches to Define a "Safe Operating Space" for Humanity*, 45 ANN. REV. ENV'T RES. 497, 502 (2020).

34 MARIEL BOROWITZ, OPEN SPACE: THE GLOBAL EFFORT FOR OPEN ACCESS TO ENVIRONMENTAL SATELLITE DATA 277–93 (2017).

35 *See, e.g.*, *General Assembly Debates Russia's Veto of Space Arms Race Resolution*, U.N. NEWS (May 6, 2024), https://perma.cc/MS9R-3JNB; Press Release, General Assembly, Outer Space Becoming Contested Domain for Supremacy with Space-Based Communications, Intelligence Assets, Anti-Satellite Weapons, First Committee Hears, U.N. Press Release GA/DIS/3722 (Oct. 19, 2023); *see also* Benjamin Staats, *Space Weaponization: Reexamining the Historical Air Analogy to Space*, 2 AETHER 31 (2023).

Modern day GNSS grew to civilian importance with GPS, a military project developed by the U.S. Department of Defense (DoD) in the 1970s.[36] GPS, and GNSS in general, work by broadcasting precise timing signals from satellites in space. A user with a compatible receiver and a sufficient number of satellites in view can use these signals to calculate their position. The core structure of GNSS is passive: users do not need to send any signals to satellites or ground stations; instead, all positioning is calculated locally by the receiver.[37] Because GNSS receivers do not need to transmit data, the system can support virtually unlimited users without imposing significant added costs on satellite providers.[38] This architecture plays a key role in shaping whether and how GNSS can be open to broader publics, and foster the organic emergence of diverse GNSS-based applications and economic markets. Meanwhile, the system's reliance on globally broadcast signals requires stronger spectrum protection and coordination to prevent interference from other radio transmissions operating under ITU/national regulatory regimes.[39] When new GNSS providers enter the market, they face the challenge of whether and how to ensure compatibility with existing systems, a coordination problem with potential distributional elements.[40]

While GPS's design allowed for potential civilian use, a worldwide access to unencrypted GPS signals was initially regarded as too much of a national security risk by the DoD.[41] The U.S. decision to make GPS widely available was partly accelerated by the 1983 downing of the civilian Korean Air Lines Flight 007, which had flown into the airspace of the USSR. The navigation failure was widely argued to have related to the then-dominant civil aircraft navigation system.[42] In response, U.S. President Ronald Reagan directed in 1983 that GPS should be made available for international civil aviation once the system was ready.[43] To mitigate national security risks mentioned earlier, the DoD introduced Selective

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36 U.S. GOV'T ACCOUNTABILITY OFF., STATUS OF THE NAVSTAR GLOBAL POSITIONING SYSTEM, PSAD-77-23 (March 2, 1977). *But cf.* Norman Bonnor, *A Brief History of Global Navigation Satellite Systems*, 65 J. NAVIGATION 1, 3–4 (2012) (describing the U.S. Department of Defense's TRANSIT project, initiated in 1958, as the first GNSS, a precursor to modern satellite navigation technologies).

37 PAUL E. CERUZZI, GPS 79–80 (2018).

38 *Id.* at 137.

39 *See, e.g.*, Thomas W. Hazlett & Brent Skorup, *Tragedy of the Regulatory Commons: Lightsquared and the Missing Spectrum Rights*, 13 DUKE L. TECH. REV. 1 (2014).

40 *See, e.g.*., Ambassador Janice Obuchowski, *United States Delegation Report, World Radiocommunication Conference 2003, submitted to the Secretary of State*, Section 1.3.1; Dan Levin, *Chinese Square Off With Europe in Space*, N. Y. TIMES (Mar. 23, 2009), https://perma.cc/Z5CH-4HGN.

41 CERUZZI*, supra* note 37, at 85. *See also* Irving Lachow, *The GPS Dilemma: Balancing Military Risks and Economic Benefits*, 20 INT'L SEC. 126 (1995).

42 CERUZZI, *supra* note 37, at 95–103.

43 Letter from Federal Aviation Administration to the International Civil Aviation Organization, at 1 (Oct. 14, 1994), https://perma.cc/N5CT-FKUP.

Availability (SA) when the GPS became fully operational in 1990.[44] Under this system, the publicly accessible C/A code provided intentionally degraded GPS accuracy, limited to no better than 100 meters, while the encrypted P code ensured precise positioning for military use.[45] Over time, advocacy from commercial interests and multiple rounds of economic assessments conducted by national agencies led to the decision to discontinue SA in 2000.[46] The infrastructure supporting SA was completely phased out with the launch of a new generation of GPS satellites, known as GPS III.[47]

The U.S. phase-out of SA was influenced *(a)* by the anticipated emergence of alternative GNSS provided by other major countries, who were not content to rely on the U.S. provision of GPS, and *(b)* by advances in GNSS augmentation such as Differential GPS technology:[48]

(a) Multiple Providers. In addition to GPS, Glonass (Russia), Beidou (PRC), and Galileo (EU) now provide worldwide GNSS service. Regional systems such as that of India (which may soon become worldwide) and Japan, have largely similar infrastructural features with some variations in technical design and technology.[49] It is widely believed the PRC and India each decided in the 1990s to develop their own national systems after experiences of GPS non-availability in situations of tension or conflict in which the U.S. had active interests.[50] All of the major GNSS are government-supplied infrastructures offering generally-available civilian-grade signal and now in wide civilian use.

(b) Differential GPS is a technique that enhances location accuracy by using a network of well-surveyed reference stations (usually ground stations) to correct

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44 DAVID ALLAN ET AL., GPS TIME TRANSFER WITH IMPLEMENTATION OF SELECTIVE AVAILABILITY 145 (1990), https://perma.cc/7NNT-RE6D.

45 *Selective Availability*, GPS.GOV, https://perma.cc/J7TV-MRYX.

46 JOINT REPORT OF THE NATIONAL ACADEMY OF PUBLIC ADMINISTRATION AND THE NATIONAL RESEARCH COUNCIL, THE GLOBAL POSITIONING SYSTEM: CHARTING THE FUTURE 7–9 (1995).

47 GPS.GOV, *supra* note 45.

48 *See generally* SCOTT PACE ET AL., THE GLOBAL POSITIONING SYSTEM: ASSESSING NATIONAL POLICIES 86, 201 (1995).

49 Besides differences in the choices of orbits for the space segment, there have been differences in the incorporation of ground stations and of non-MEO satellites, as well as experiments with different time-clock technologies. Bernardo Jaduszliwer & James Camparo, *Past, present and future of atomic clocks for GNSS,* 25 GPS SOLUTIONS (2021); Peter Steigenberger, Jean-Marie Sleewaegen & Oliver Montenbruck, *Inside the Box: New NavIC Clock Outperforms Previous Generation*, GPSWORLD (Sept. 24, 2023), https://perma.cc/AGF8-L9YW. Some other aspects, such as messaging, have largely been standardized in practice by following the conventions set by early entrants. *See, e.g.*, *Indian Regional Navigation Satellite System: Signal in Space ICD for Standard Positioning Service*, ISRO-IRNSS-ICD-SPS-1.1 (Aug. 2017), https://perma.cc/JB39-R6VP.

50 Rumi Aoyama, *China's Dichotomous BeiDou Strategy: Led by the Party for National Deployment, Driven by the Market for Global Reach*, 11 J. CONTEMP. E. ASIA STUD. 282 (2022); BHARATH GOPALASWAMY, FINAL FRONTIER: INDIA AND SPACE SECURITY 111–12 (2019); *see also Frequently Asked Questions No. 5*, INDIAN SPACE RSCH. ORG., https://perma.cc/SK9R-FP36.

GPS signals and enable higher levels of precision, required for example for aircraft navigation in takeoff and landing. One domestic example is the U.S. Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS). It is designed to improve GPS accuracy for civil aviation. WAAS operates by using ground reference stations to generate correction signals, which are then transmitted to geostationary satellites equipped with navigation payloads. These geostationary satellites rebroadcast the corrected signals in a GPS-like format across the National Airspace System.[51] Similar regional augmentation agreements and infrastructural design specifications were later negotiated between the U.S. and other countries, such as Japan, the European Union, and later India.[52] Differential GPS demonstrates that degraded GPS signals alone can't effectively undermine navigation and positioning accuracy, as they can be improved through regional enhancement units. This capability remains relevant even after SA was disabled; in fact, there is no definitive threshold for accuracy being "accurate enough." The more signal sources or reference points available, the more precise and resilient the system can be.

Using chipsets and other components of receiving devices, GNSS-dependent services extend far beyond traditional navigation and positioning, as they are now integral components of diverse cyber-physical systems, including transportation, logistics, electrical grids, financial networks, and digital applications. The massive commercial growth and market expansion of GPS were neither fully foreseeable nor initially included in the U.S. government's cost-benefit calculations for developing the system.[53] Over time though, GPS's unexpected economic success has since provided a precedent that later entrants might use to justify government-backed development of similar services.

Despite its commercial success, the primary motivation for certain nations to develop autonomous GNSS systems has been the risk of potential service disruptions.[54] Though the U.S. government discontinued SA, it retains the technical capability to degrade or disable GPS access regionally in response to national security concerns.[55] As global economic and commercial activities become more dependent on GNSS, the possibility of access restrictions may further incentivize nations to pursue independent (satellite) positioning, navigation, and timing capabilities. In this context, the rising economic value of

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51 *Satellite Navigation – WAAS – How It Works*, FED. AVIATION ADMIN., https://perma.cc/5W5X-P7GQ.

52 *International Cooperation*, GPS.GOV, https://perma.cc/9RWJ-5M4X.

53 *Compare* U.S. GOV'T ACCOUNTABILITY OFF., PSAD-79-16, THE NAVSTAR GLOBAL POSITIONING SYSTEM – A PROGRAM WITH MANY UNCERTAINTIES (1979), *with* ALAN O'CONNOR ET AL., ECONOMIC BENEFITS OF THE GLOBAL POSITIONING SYSTEM (GPS) (2019).

54 PACE ET AL., *supra* note 48, at 147.

55 William J. Clinton, *Statement on the Decision to Stop Degrading Global Positioning System Signals* (May 1, 2000), https://perma.cc/WAE4-5GBE.

GNSS has paradoxically amplified strategic anxieties about the potential costs of exclusion/disruption from these critical services.[56]

In many aspects, EOSS, like GNSS, have deep military origins that continue to shape their public-infrastructural qualities today.[57] From the 1960s, the development and deployment of U.S. remote sensing satellite technology was superintended by the National Reconnaissance Office (NRO), for which the priority was (and remains) defense, intelligence, and reconnaissance objectives. The high capabilities of the U.S. in that initial period were thought to be unknown to most other nations, and maintaining the secrecy of these was a significant competitive advantage, which also reduced risks of frictions with states that would strongly object to overhead satellite surveillance if they became aware of its frequency and precision. Hence U.S. civilian-facing EOSS such as NASA's Landsat missions met with years of initial delays due to internal clearance and security reviews.[58] Over time, as other states and commercial providers abroad developed comparable satellite imaging technologies, U.S. export controls on imagery were reset so that U.S. commercial providers could generally offer to most foreign clients any levels of resolution and coverage already available to them from others.[59] Much more Earth observation data has since become available, and many science systems and commercial services have been built on it.[60] Some limitations continue on the public or external availability of highest-resolution imagery (optical and non-optical) from different national providers; this may remain largely under the control of military and commercial entities (many of which count the military as a primary client).[61]

Unlike GNSS, which is built on a centralized architecture provided by a handful of governmental actors with a clear core segment and layered applications, Earth observation missions are more heterogeneous. Each mission is typically designed to observe specific geographic regions and collect particular types of data, depending on the sensors onboard, with different mission lifespans. There is no

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56 RASMUS FLYTKJÆR ET AL., THE ECONOMIC IMPACT ON THE UK OF A DISRUPTION TO GNSS: FINAL REPORT (2023).

57 *See, e.g.*, CONG. RSCH. SERV., U.S.-CHINA COMPETITION IN EMERGING TECHNOLOGIES: LIDAR (Dec. 6, 2024); U.S. GOV'T ACCOUNTABILITY OFF., GAO-23-106042, NATIONAL SECURITY SPACE: OVERVIEW OF CONTRACTS FOR COMMERCIAL SATELLITE IMAGERY (Dec. 8, 2022).

58 JAMES E. DAVID, SPIES AND SHUTTLES: NASA'S SECRETE RELATIONSHIPS WITH THE DOD AND CIA 103–49 (2015); DEP'T OF THE AIR FORCE, MEMO FOR THE MANNED SPACEFLIGHT POLICY COMMITTEE, DOD CONCERN WITH NASA REMOTE SENSING ACTIVITIES (Apr. 11, 1966).

59 Scott Pace, *The Regulation of Commercial Remote Sensing Systems*, RAND CORP. (1994), https://perma.cc/U9AY-3UTZ; *see also* JAMES A. VEDDA, UPDATING NATIONAL POLICY ON COMMERCIAL REMOTE SENSING (Mar. 2017). Similar regulations were adopted in Canada per Canada-U.S. Agreement Concerning Commercial Remote Sensing Satellite Systems, Can.-US, June 16, 2000, T.I.A.S. 00-616.

60 *See, e.g.*, CONG. RSCH. SERV., LANDSAT: OVERVIEW AND ISSUES FOR CONGRESS (Oct. 27, 2014).

61 Brad Townsend, *The Remote Sensing Revolution Threat*, 15 STRATEGIC STUD. Q. 69 (Fall 2021).

single shared space segment that functions as a universal backbone for all Earth observation activities. Shared data relay satellites and ground stations do provide some linkages, especially as part of telecommunications infrastructure for EOSS, but they are not as yet a unifying infrastructural backbone enabling the many separate systems to function as a unified one.

That said, EOSS is in some respects becoming , infrastructuralized through the combining of specific Earth observation data arrangements. This is driven by initiatives, markets, policies and institutions seeking for specific purposes to assemble a fuller account of the planet and of major Earth systems. One example is the incorporation of Earth observation data into international climate and weather governance structures. In 1990, the Second World Climate Conference recognized the urgent need to acquire comprehensive information on the properties and evolution of the Earth's climate system, stating that "a major international observational and research effort will be essential to strengthen the knowledge-base on climate processes and human interactions, and to provide the basis for operational climate monitoring and prediction."[62] Building on this momentum, the Global Climate Observing System (GCOS) was formally established in 1992, co-sponsored by the World Meteorological Organization (WMO), ICO-UNESCO, UNEP, and the International Council for Science (now ISC). GCOS was designed to integrate and coordinate major existing systems and networks.[63] The same year, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted to prevent dangerous human interference with the climate system. To operationalize the global climate observational network, the WMO maintains fifty-five Essential Climate Variables (ECVs), specifies their respective reporting requirements, and has developed a communication *network* for observing data—the WMO Information System (WIS).[64]

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62 U.N. Secretary-General, *Progress Achieved in the Implementation of Resolution 44/207 on the Protection of Global Climate for Present and Future Generations of Mankind,* U.N. Docs. A/45/696/Add.1 (Nov. 8, 1990).

63 Including subsets of the WMO World Weather Watch, the WMO Global Atmosphere Watch, the WCRP/Global Energy and Water Exchanges Baseline Surface Radiation Network, the Global Ocean Observing System, the Global Terrestrial Observing System, and the World Hydrological Cycle Observing System. WORLD METEOROLOGICAL ORG. [WMO], GUIDE TO CLIMATOLOGICAL PRACTICES 137 (2018 ed. 1960).

64 In 2019, the WMO Congress endorsed a new *Earth System approach* as a significant policy shift. Guided by this approach, the WMO initiated reforms such as WIS 2.0, the Unified Data Policy, and the overarching vision of the WMO Integrated Global Observing System (WIGOS). In this context, Earth is considered as an integrated system comprising the atmosphere, ocean, cryosphere, hydrosphere, biosphere, and geosphere. The stated objective is to better inform policies and decisions through a deeper understanding of the physical, chemical, biological, and human interactions that define the past, present, and future states of Earth. WMO, *WMO Strategic Plan 2020–2023*, WMO-No. 1225 (2019).

Despite the globally widespread user base of GNSS and (to a lesser extent) EOSS as critical infrastructures, there is only a limited and patchy set of explicit international legal arrangements requiring infrastructure providers to ensure service continuity or guarantee data availability and non-discriminatory access.

For GNSS, utility-like obligations are found in the International Civil Aviation Organization Charter on Rights and Obligations of States Relating to GNSS Services, which states that "[e]very State and aircraft of all States shall have access, on a non-discriminatory basis under uniform conditions, to the use of GNSS services" and that "[e]very State providing GNSS services . . . shall ensure the continuity, availability, integrity, accuracy and reliability of such services." The Charter also contains principles of cooperation and mutual assistance in global GNSS planning and implementation, as well as the obligation of States to exercise due regard for the interests of other States when conducting GNSS activities.[65] A more comprehensive set of obligations of openness, continuity of service, non-discrimination, and prohibition of user charges, is set out in the 2004 EU-U.S. Agreement on the Promotion, Provision and Use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications, which entered into force in 2011 and was renewed in 2021.[66]

For EOSS at data level, the WMO Unified Data Policy mandates that core meteorological data be shared freely and without restriction, while "recommended" data should be made available free of charge but may be subject to certain conditions.[67] These two categories together encompass only a small subset of data relevant to weather, climate, and broader Earth systems monitoring.[68] Beyond WMO and other U.N. institutions, different data sharing and repository ideas have emerged with geographically and thematically specific treaties[69] or regional institutions.[70] Yet such report obligations are sometimes hindered by low

65 Int'l Civil Aviation Org. [ICAO], Resolutions Adopted at the 32nd Session of the Assembly Provisional Edition, at A32-19 (Sept.–Oct. 1998), https://perma.cc/3KLM-NWXD.

66 *See* SCOTT W. BEIDLEMAN, GPS VS. GALILEO: BALANCING FOR POSITION IN SPACE (2006), for a deeper dive into the early years of GPS and Galileo competition, motivation, and negotiation that eventually led to the agreement.

67 WMO, WMO UNIFIED DATA POLICY (2022).

68 The Group on Earth Observation, an inter-governmental institution with numerous other organizations and associates also involved, promotes sharing of Earth observation data, but based on voluntary compliance with its data sharing principles and aspirational goals. *See* BOROWITZ, *supra* note 34, at 79–94.

69 *See, e.g.*, Andrea Gerlak, Jonathan Lautze & Mark Giordano, *Water Resources Data and Information Exchange in Transboundary Water Treaties*, 11 INT'L ENV'T AGREEMENTS: POL., L. ECON. 179, 179–99 (2011).

70 For example, the International Centre for Integrated Mountain Development (ICIMOD), headquartered in Kathmandu, Nepal, is an intergovernmental organization comprising eight regional member states: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. "It was conceived in a movement that recognized mountains present a unique set of

compliance rates, poor dataset maintenance, restricted access to relevant databases due to the nature of information exchange, or outdated user interface.[71] In addition to sustenance of long-term open databases, an assortment of international collaboration mechanisms have been designed for short-term on-demand sharing of Earth observation data. One prototype is the International Charter on Space and Major Disasters ("Disaster Charter"), which has evolved from a club good (in which data was shared only by and agencies in network) to a largely universal-access model.[72]

III. PUBLIC VS. PRIVATE PROVISION, AND PUBLICNESS

As discussed at the beginning of this paper, GNSS and EOSS are central and transformative in the knowledge governance of "Earth" in digitalized planetary terms,[73] alongside their many other applications. EOSS capture sensing data bearing on planetary-scale issues such as climate change governance,[74] natural resource management,[75] forest monitoring,[76] ocean and ice management,[77]

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governance challenges." Aditya Valiathan Pillai, *Abiding by Nature, Not National Borders: Institution Building in the Himalayas*, WORLD BANK GRP. GOOD NEIGHBORS SERIES, https://perma.cc/NC3U-BR7Y. It had what was until 2025 a USAID-supported SERVIR program as a downstream application for NASA's air quality monitoring instruments. Meryl Kruskopf et al, *Insights on Building Capacity to Support the Integration of Earth Observations into Air Quality Operations in South Asia*, 106(4) BULL. AM. METEOROL. SOC'Y E 639–51 (2025).

71 *See, e.g.*, Qaraman Hasan et al, *When the Law is Unclear: Challenges and Opportunities for Data and Information Exchange in the Tigris-Euphrates and Indus River Basins*, 25(8) WATER POL'Y 780, 780–96 (2023) (the Indus Waters Treaty 1960); N. C Davidson et al, *A Review of the Adequacy of Reporting to the Ramsar Convention on Change in the Ecological Character of Wetlands*, 71(1) MARINE FRESHWATER RSCH. 117, 117–26 (2019) (the Ramsar Convention 1975).

72 *Universal Access*, INT'L CHARTER: SPACE & MAJOR DISASTERS, https://perma.cc/UM2V-WKH2.

73 *See, e.g.*, Richard Conniff, *Eyes on Nature: How Satellite Imagery is Transforming Conservation Science*, YALEENVIRONMENT360 (June 22, 2017), https://perma.cc/2WS7-TXWH; JENNIFER GABRYS, PROGRAM EARTH: ENVIRONMENTAL SENSING TECHNOLOGY AND THE MAKING OF A COMPUTATIONAL PLANET 81–108 (2017).

74 Michaela I. Hegglin et al., *Space-Based Earth Observation in Support of the UNFCCC Paris Agreement*, 10 FRONTIERS ENV'T SCI. 1, 3–17 (2022).

75 NATHALIE PETTORELLI, SATELLITE REMOTE SENSING AND THE MANAGEMENT OF NATURAL RESOURCES (2019).

76 Some dedicated missions for forestry include *ESA's Mission Biomass*, EURO. SPACE AGENCY, https://perma.cc/Q6JF-LG8U; *NASA-ISRO Radar Mission to Provide Dynamic View of Forests, Wetlands*, NASA JPL. (Oct. 27, 2023), https://perma.cc/8M2J-F5HV; Xueli Peng et al, *GF-1 WFH Satellite Images-Based Forest Cover Mapping in China Supported by Open Land Use/Cover Datasets*, 11 SCI. DATA 1355 (2024).

77 For example, the Surface Water and Ocean Topography (SWOT) mission was jointly developed by NASA and the Centre National D'Etudes Spatiales, with contributions from the Canadian Space Agency and United Kingdom Space Agency. *Overview*, NASA JPL: SWOT, https://perma.cc/TJ9C-MZ5A.

atmospheric and stratospheric composition,[78] and large-scale scientific investigations, including changes in Earth's morphology, magnetic field, and radiation exposure (with the specific types of data collected depending on the infrastructural system and payload).[79] GNSS enables the precise geo-referencing of this EOSS-linked sensing data, and aids in determining precise positions of other satellites measuring phenomena such as sea-surface level. Beyond geo-referencing, GNSS has long had applications in geodesy[80] and meteorology,[81] and emerging uses in applications such as ionosphere composition measurement accomplished by interacting satellite position and timing data with location data reported by millions of cellphones.[82]

These data are actively used in regulatory processes of planetary issues,[83] including *ex-ante* environmental impact assessments for licensing (e.g., land approvals for large infrastructure projects), continuous compliance monitoring (e.g., tracking wildlife, forests, and wetlands), and *ex-post* evidentiary functions (e.g., reconstructing sequences of events in environmental violations). International data exchange mechanisms have been structured in arrangements such as the Disaster Charter, an international mechanism for sharing satellite data among national agencies during disasters, and UNEP's Methane Alert and Response System (MARS), which uses satellite data to detect methane concentrations and prompt responsive actions without assigning accountability.[84] Earth observation and geolocation data contribute to some prominent global knowledge infrastructures.[85] The IPCC, for instance, has relied heavily on the GCOS, with

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78 One of the famous missions is NASA's Mission *Aura*, NASA, https://perma.cc/4UWS-NK7T. *See also* Ross Salawitch et al, *The Imminent Data Desert: The Future of Stratospheric Monitoring in a Rapidly Changing World*, 106 BULL. AM. METEOROL. SOC'Y E 540 (2025).

79 *Gravity Recovery and Climate Experiment (GRACE)*, NASA, https://perma.cc/4V34-C74Y.

80 For example, Civilian GNSS has helped geoscientists to validate tectonic movement theory with concrete data, an achievement that would have been nearly impossible or impractical relying solely on ground-based measurements. *Tectonic Plates Movements Studied Using Satellites*, NASA JPL (Feb. 29, 1988), https://perma.cc/3JVY-EC7L.

81 For example, GPS enabled the documentation of the wind and thermodynamic structure of the hurricane eyewall with unprecedented accuracy and resolution. *See generally* James Franklin et al., *GPS Dropwinsonde Wind Profiles in Hurricanes and Their Operational Implications*, 18 WEATHER FORECASTING 32 (2003).

82 Anton Kast & Jamie Smith, *Mapping the ionosphere with the power of Android*, GOOGLE RESEARCH (Nov. 13, 2024), https://perma.cc/FU2H-8522.

83 *See generally* SATELLITE EARTH OBSERVATIONS AND THEIR IMPACT ON SOCIETY AND POLICY (Masami Onoda & Oran R. Young eds., 2017).

84 *About Methane Alert and Response System (MARS)*, UN ENVIRONMENT PROGRAMME, https://perma.cc/37W6-Q54Z; Jonathan O'Callaghan, *Tracking methane super-emitters from space*, NATURE SPOTLIGHT (Nov. 6, 2024), https://perma.cc/EC7U-RQBM.

85 *See generally* Paul N. Edwards, *Meteorology as Infrastructural Globalism*, 21 OSIRIS 229, 229–50 (2006).

over two-thirds of essential climate variables derived from satellite data.[86] Data from these sources have at times been used as inputs for a wide range of global governance indicators, including the U.N. sustainable development goals (SDG), corporate social responsibility (CSR) metrics, and some environmental, social, and governance (ESG) metrics.

Open-access data about Earth have enabled not only inter-governmental organizations but also a range of environment-oriented non-governmental organizations to monitor activities in particular locations or on near-planetary scale, and in some cases to seek to influence behavior. Examples include Global Forest Watch,[87] LandMark (for indigenous forest protection),[88] Amazon Mining Watch (monitoring illegal mining and construction),[89] Global Fishing Watch (in collaboration with Planet Labs for illegal fishing),[90] Planet's Project Centinela (for biodiversity conservation),[91] FireSat (through Earth Fire Alliance),[92] and MethaneSAT (for methane mitigation),[93] as well as active use of sensing data to come up with localized proposals of preserving heritage sites,[94] planning renewable energy,[95] measuring carbon emissions,[96] and mapping industrial activities impact.[97]

An infrastructural approach to GNSS and EOSS emphasizes the formation and maintenance of publics whose direct or indirect interests are affected by these

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86 *Overview of the Climate Change Initiative*, EURO. SPACE AGENCY, https://perma.cc/EJ8X-NWFC.

87 GLOBAL FOREST WATCH, https://perma.cc/9ZZT-WKMU.

88 Katie Reytar et al., *Indigenous Peoples and Local Communities Are Using Satellite Data to Fight Deforestation*, WORLD RES. INST. (Nov. 20, 2023), https://perma.cc/FT3V-HLE4.

89 *About*, AMAZON MINING WATCH, https://perma.cc/77L6-DGQ4. *See also* Planet Labs PBC, *How Colombia and Brazil Tackle Crime in Vast Protected Areas*, PLANET PULSE (Apr. 8, 2025), https://perma.cc/4BHH-DGS5; *Tracking Gold Mining With New Radar-Based Satellite Monitoring Tool*, AMAZON CONSERVATION (June 30, 2021), https://perma.cc/T6Q2-NCBT.

90 *Our Technology*, GLOBAL FISHING WATCH, https://perma.cc/ZT58-39B4. *See also Oceans of data: tracking illegal fishing over 140 million square miles*, GOOGLE SUSTAINABILITY (Sept. 2018), https://perma.cc/5XJG-AKA7.

91 Amy Rosenthal, *Planet's Project Centinela: Monitoring Vulnerable Biodiversity Hotspots for Conservation Action*, PLANET PULSE (Oct. 1, 2024), https://perma.cc/38Q8-QCYH.

92 EARTH FIRE ALLIANCE, https://perma.cc/MLK2-RVHV.

93 METHANESAT, https://perma.cc/ZLH5-ATHF.

94 UNESCO, *Monitoring World Heritage from Space*, 98 WORLD HERITAGE (Apr. 2021), https://perma.cc/MM7Z-CLU5.

95 *See, e.g.*, Cecilia N. Clark & Fabio Pacifici, *A solar panel dataset of very high resolution satellite imagery to support the Sustainable Development Goals*, 10 SCI. DATA 636 (2023).

96 *See, e.g.*, Kate Ramsayer, *Carbon Dioxide Emissions Estimates Available at Neighborhood Scale*, U.S. GHG CTR. (Sept. 19, 2024), https://perma.cc/7KB9-8WR2.

97 *See, e.g.*, Fernando Paolo et al., *Satellite mapping reveals extensive industrial activity at sea*, 625 NATURE 85 (2024); Liang Tang & Tim Werner, *Global mining footprint mapped from high-resolution satellite imagery*, 4 COMMC'NS EARTH ENV'T 134 (2023).

planetary infrastructures. The experiences of different publics with these infrastructures are far from uniform or universal.[98] Data-gathering is experienced by some as surveillance or as hostile. Data availability to different governments and other users varies hugely. GNSS and EOSS's precision, detail, and accuracy vary significantly across different regions, regardless of whether the system is designed to have global coverage. Satellite systems heavily rely on ground surveys and ground stations to calibrate satellite-collected data, which brings Earth disparities to planetary data production, distribution and use.[99]

The core architecture of GNSS has remained a uniquely public-provided (government or EU) infrastructure. Major providers have at different times explored the possibility of user-charges or generating other specific revenue streams which might offset some of the costs of public provision.[100] Governments have the advantage that they are able to tax income and profits from economic activity, so major economic centers receive substantial offsetting revenues. The layered civilian applications, along with the development, engineering, and manufacturing of downstream software and hardware technologies, are largely driven by private sector actors. These value-added services can recover their costs by charging customers reasonable and affordable prices, thereby offsetting the investments made in enhancing GNSS capabilities.

EOSS, however, involve a much more complex mix of data collectors, processors, and providers of value-added products, starting from outer space all the way to the end-user market, due to the limited sharing space segment mentioned in the last section. Leading government satellite operators and civilian-use data providers include the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and equivalents in some other countries such as the Japan Aerospace Exploration Agency (JAXA),[101] the China

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98 Luis F. Alvarez Leon, *An Emerging Satellite Ecosystem and the Changing Political Economy of Remote Sensing*, *in* THE NATURE OF DATA (Jenny Goldstein & Eric Nost eds., 2022) (offering a political economy analysis of the geographic expansion of satellite access, functional diversification, and the production, distribution, and use of remotely sensed data).

99 One example is the global elevation model, which is widely used and essential for processing synthetic aperture radar (SAR) data. However, elevation data is not uniformly accurate—some regions have gaps or lower precision. *See, e.g.*, Rebekke Muench et al, *Assessment of Open Access Global Elevation Model Errors Impact on Flood Extents in Southern Niger*, 10 FRONTERS ENV'T SCI. (2022). Another example is GNSS's regional augmentation which often requires a dedicated slot in geostationary orbit, as well as the capacity to install, maintain, and operate ground stations. Beyond that, launching and maintaining augmentation satellites in orbit demands significant technical and financial resources. *What is SBAS?*, EU SPACE PROGRAMME, https://perma.cc/87TM-DZ4B.

100 *See, e.g.*, JOINT DOD/DOT TASK FORCE, THE GLOBAL POSITIONING SYSTEM: MANAGEMENT AND OPERATION OF A DUAL USE SYSTEM, A REPORT TO THE SECRETARIES OF DEFENSE AND TRANSPORTATION 18–27 (December 1993), https://perma.cc/M27K-2QB2.

101 *Access JAXA Satellite Data*, JAXA, https://perma.cc/GK2A-QTBH.

National Space Administration (CNSA),[102] and the India Space Research Organization (ISRO).[103] A fast-expanding array of private companies with significant satellite and data-processing capabilities are also in this market.[104] In contrast, many countries and regions have little or no such capacity, weakening their positions and leaving much of the governance in the hands of others. Ameliorative national and regional initiatives aimed in part to offset such imbalances include the inauguration of the African Space Agency in 2025, as well as numerous (in some cases externally-supported) national agencies. Some countries oppose the use of data by international agencies without approval from their authorities.[105] Others are apprehensive that weaponization in space and the growth of dual-use capabilities may lead to a coercion-based regime, undermining what has largely been an open scientific commons.[106]

IV. ENCLOSURE, SECURITIZATION, AND PLANETARY INFRASTRUCTURING

The commercialization of space-based imagery (and of the space industry in general) has been primarily (but far from exclusively) concentrated in the U.S. market and has been nurtured through national policies, R&D funding, and technical support from national agencies.[107] The major commercial imagery satellite companies/startups include Maxar (U.S.), Planet (U.S.), BlackSky (U.S.),

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102 *China Platform of Earth Observation System*, CNSA, https://perma.cc/E5N8-ZTAY.

103 *Space Based Earth Observation Applications*, ISRO, https://perma.cc/C6DS-MD48.

104 *See* discussion *infra* Section IV.

105 *See, e.g.*, U.S. DEP'T OF STATE, *Mounting Demand for International Control of Earth Resource Satellite Data*, Central Intelligence Agency Directorate of Intelligence (Mar. 1974). https://perma.cc/MYH7-2BCL.

106 *See generally* DANIEL DEUDNEY, DARK SKIES: SPACE EXPANSIONISM, PLANETARY GEOPOLITICS, AND THE ENDS OF HUMANITY (2020).

107 *See generally Space Commercialization*, NASA, https://perma.cc/FX5N-EFRW. Beyond commercial launch services, NASA has also been a primary driver of innovation in small satellite technologies. *See* Larry Kepko, *Advancing Technology for NASA Science with Small Spacecraft*, 32nd Annual AIAA/USU Conference on Small Satellites (2018), https://perma.cc/3T4D-YUAB; *see also Harnessing the Small Satellite Revolution to Promote Innovation and Entrepreneurship in Space*, THE WHITE HOUSE (Oct. 21, 2016), https://perma.cc/5DSB-FLC6. The combination of commercial launch capabilities and the development of low-cost small satellites has been a major force behind the rise of commercial optical satellite imagery companies.

and ICEYE (Finland).[108] The first three initially provided optical imagery,[109] and ICEYE specialized in synthetic-aperture radar (SAR) imagery early on.[110]

The prospects of continued openness of EOSS data and data products, along with the broader perception of their openness, could be put in doubt by commercial instability and enclosure. As noted earlier, national (and EU) governmental agencies have historically been the primary suppliers of open or long-run 'infrastructural' EOSS data. Although these agencies face risks such as budget constraints, capability limitations, or political upheaval that could re-orient or jeopardize their missions,[111] private companies are vulnerable to a different set of risks, including bankruptcy,[112] which could result in the permanent termination of their missions and cessation of the maintenance or availability of datasets/data services they produced. Private companies operating EOSS, and indeed almost all civilian-market satellite services other than in the lucrative telecommunications and Internet sector, tend (with exceptions) to prefer low-cost small satellites and instruments where practicable, and the flexibility of being able to adjust constellation composition, leading them to accept shorter expected lifespans compared to longstanding public imagery missions like Landsat or the EU Copernicus program.[113]

The biggest private EOSS providers still rely heavily on government contracts for revenue,[114] and typically engage with multiple governments (and different national agencies), international organizations, and commercial actors, each with differing demands and regulatory frameworks. In addition, many

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108 ICEYE has a U.S. subsidiary that specifically promotes itself as being "built, launched and operated on U.S. soil" and listed its customers as "the United States Government, its allies and commercial partners using SAR technology." ICEYE US, https://perma.cc/3WPK-LP2C.

109 Sandra Erwin, *Remote sensing companies try to capture bigger piece of satellite imaging market*, SPACENEWS (Mar. 26, 2023), https://perma.cc/L2LY-5Z43.

110 Airbus is an example of a different kind of major players in the satellite imagery industry, distinctive because unlike the specialized "new" space imagery companies, it is also a large long-established aerospace corporation with a different historical background, corporate structure, and strategy.

111 *See, e.g.*, Austyn Gaffney, *White House Plan Calls for NOAA Research Programs to Be Dismantled*, N.Y. TIMES (Apr. 11, 2025), https://perma.cc/ZV9F-8CAB.

112 *See, e.g.*, Sandra Erwin, *Geospatial intelligence startup Kleos Space files for bankruptcy*, SPACENEWS (July 26, 2023), https://perma.cc/3P6U-DSD6.

113 ICEYE's individual satellites have a designed lifespan of 5 years. *Satellite Program: ICEYE*, WMO OSCAR, https://perma.cc/9XVG-Z22P. Planet Labs' satellites similarly have a designed lifespan of 5 years. *Satellite Program: RapidEye*, WMO OSCAR, https://perma.cc/A99X-S5FX. Maxar is an exception; its Worldview satellites have significantly longer designed lifespans, ranging from 10 to 13 years. Zuzana Hajkova, *Maxar Worldview Legion Satellites: The Successful Launch & Its Impact on EO Applications in Europe*, EUSI (Nov. 29, 2024), https://perma.cc/5UMR-ED6A. Meanwhile, BlackSky's satellites have a shorter designed lifespan of 3 years. *BlackSky Constellation*, EOPORTAL, https://perma.cc/T939-SGEY.

114 *See, e.g.*, *Planet Reports Financial Results for Fourth Quarter and Full Fiscal Year 2025*, PLANET (Mar. 20, 2025), https://perma.cc/Z5YK-T654.

satellite imagery companies not only supply raw data but also offer data services, which might incentivize them to limit competition across both horizontal and vertical markets.[115] As a result, while many of them participate in certain open data initiatives,[116] these companies also have reasons to exercise private ordering power through data encasement and contractual practices that restrict broader access to their data.

Another source of pressure on the open nature of most GNSS and EOSS data infrastructures comes from the inevitability of abusive uses, and the risks of severely dangerous uses by malevolent actors. Soon after Google Earth's free, high-resolution mapping tools became widely available, it was feared that someone might use them to facilitate a terrorist attack.[117] Satellite imagery also raises tensions regarding the exposure of secret sites and national security information,[118] and many other demands not to infrastructurally install an open data policy.[119] Similarly, when GNSS supplies timing and positioning data to support systems like AIS shipping identifiers, this enables surveillance for any purpose.[120]

Both GNSS and EOSS have dual-use significance. The advanced expertise, massive scalability, and nimbleness demonstrated by commercial satellite operators, makes it increasingly likely military agencies will solicit or require exclusivity and secrecy from private commercial operators, so that EOSS data or even service provision gradually become less open to public and science uses.[121] The attributes of GNSS and EOSS also make them likely targets in situations of security tensions or military action. Awareness of that vulnerability is in turn likely to stimulate more and more investment in alternatives to GNSS[122] and to some

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115 *See, e.g.*, U.S. DEP'T OF COM., NAT. OCEANIC & ATMOSPHERIC ADMIN., NOAA OBSERVING SYSTEMS COUNCIL, GUIDANCE FOR NOAA COMMERCIAL DATA BUYS: A FRAMEWORK FOR NOAA PROGRAMS AND OFFICES CONDUCTING COMMERCIAL DATA BUYS, 13, 18 (2024).

116 *See, e.g.*, *Planet Labs – Open Data*, PLANET, https://perma.cc/DN5C-NTYM; *ICEYE Now Contributing to the International Disasters Charter*, ICEYE (June 25, 2020), https://perma.cc/X4JM-BV82.

117 PAT NORRIS, WATCHING EARTH FROM SPACE: HOW SURVEILLANCE HELPS US – AND HARMS US 12–14 (2010).

118 Chris Perkins & Martin Dodge, *Satellite Imagery and the Spectacle of Secret Spaces*, 40(4) GEOFORUM 546–60 (2009).

119 BOROWITZ, *supra* note 34, 277–93.

120 *See, e.g.*, Lorenzo Pezzani & Charles Heller, *AIS Politics: The Contested Use of Vessel Tracking at the EU's Maritime Frontier*, 44(5) SCI TECH. HUM. VALUES 881–99 (2019).

121 *See, e.g.*, Sangeet Kumar, *Google Earth and the Nation State: Sovereignty in the Age of New Media*, 6(2) GLOB. MEDIA COMMC'N 154 (2009) (discussing several security-military related contestations made against Google Earth).

122 *See, e.g.*, Danilo Avola et al, *UAV Geo-localization for Navigation: A Survey*, 12 IEEE ACCESS 125332 (2024).

kinds of observational satellite services.[123] This may stimulate more planetary knowledge production in a new cycle. But in times of increased nationalism and military preparedness, and fractious politics in relation to planetary issues, reversals from the heyday of open planetary data may also be likely. In extreme circumstances, this could abet an unraveling of the planetary-knowledge structures which law-abetted satellite infrastructures have helped to build. Initiatives to ensure sustained provision of planetary data through open infrastructures are increasingly necessary.

123 *See, e.g.*, Sandra Erwin, *U.S. halts satellite imagery support to Ukraine in major policy shift*, SPACENEWS (Mar. 7, 2025), https://perma.cc/X3BZ-VW7U.