THE EMERGENCE OF INTELLIGENT TREATY SYSTEMS AND THE FUTURE OF INTERNATIONAL LAW

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Abstract

Ensuring that multilateral regulatory treaties fulfill their stated purposes is important to solving many intractable global problems. Despite immense challenges, the prospects for achieving these aims have improved in recent years with the emergence of what I term Intelligent Treaty Systems (ITS). I define ITS to include five core capacities within treaty regimes: (1) sensing and generating data, (2) gathering and storing data, (3) processing and analyzing data, (4) creating models, maps, and visualizations of data, and (5) applying data to targets and indicators. I argue that, taken together, ITS has potential to improve the ability of state parties and relevant stakeholders to manage treaty operations, monitor implementation, and measure and improve treaty performance. These enhanced capabilities may constitute a new basis for treaty implementation and compliance, thus supplementing prevailing explanations of treaty compliance such as managerialism, reciprocity, rational choice, or reputation. Despite this potential, the technologies used in ITS raise significant legal and ethical challenges, which may impede their use in treaty practice. In the final part of the Article, I offer suggestions for future applications of ITS and ways of improving its utility and mitigating some of the potentially negative consequences from its use.

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I. INTRODUCTION

Demands to improve the results from treaties designed to regulate major global problems mount as evidence of global environmental destruction, human rights abuses, and the risk of armed conflict accumulates.[1] Despite significant concerns about the ability of multilateral agreements to help overcome these problems, the prospects for strict adherence to such instruments and strengthening their regulatory impact has potentially been enhanced in recent years through a variety of new technologies. Included are an array of remote sensing and Internet of Things (IOT) tools, high-speed and high-throughput communication infrastructure, enhanced data collection and storage systems, and machine learning tools for data classification and analysis.[2] Following usage in high-tech circles, I have coined the term Intelligent Treaty Systems (ITS) to refer to the combination of these capabilities.[3] Together these applications and instruments have dramatically improved the ability of treaty secretariats, international organizations, states, research communities, academics, non-governmental organizations (NGOs), and other stakeholders to: assess background conditions relevant to treaties' purposes and mandates, devise

1. *See, e.g.*, Roula Khalaf et al., *Emanuel Macron: 'For Me the Key is Multilateralism that Produces Results'*, FIN. TIMES (Feb. 18, 2021), https://www.ft.com/content/d8b9629a-92b1-4e02-92b7-41e9152d56ea [https://perma.cc/Q9RC-Q66K] (highlighting the views of French President, Emmanuel Macron, that the pandemic has exacerbated the need for multilateralism and increased cooperation between world powers).

2. GAUTAM SHROFF, THE INTELLIGENT WEB: SEARCH, SMART ALGORITHMS, AND BIG DATA 268–74 (2013); *see* Kari Sentz & François Hemez, LOS ALAMOS NAT'L LAB'Y, *The Future of Intelligent Systems for Safeguards, Nonproliferation, and Arms Control Verification*, *in* INFORMATION ANALYSIS TECHNOLOGIES, TECHNIQUES AND METHODS FOR SAFEGUARDS, NONPROLIFERATION AND ARMS CONTROL VERIFICATION WORKSHOP 76, 76–91 (Institute of Nuclear Materials Management ed. May. 12, 2014), https://cdn.ymaws.com/inmm.org/resource/resmgr/docs/events/informationanalysis/workshopproceedings2.pdf [https://perma.cc/4E64-QNP5] (highlighting the potential of intelligent systems to further the interest of national and global security); Cindy L. Mason, NASA AMES RSCH. CTR., *An Intelligent Assistant for Nuclear Test Ban Verification*, 10 IEEE EXPERT 42, 42–49 (1995), https://doi.org/10.1109/64.483116 [https://perma.cc/2QPZ-79Z7] (assisting nuclear test ban treaty verification via automatically processing seismic monitoring data); *see also* Xinyuan Dai, *Information Systems in Treaty Regimes*, 54 WORLD POL. 405, 405–436 (2002) (analyzing how and why treaty organizations do or do not perform information provision on their own).

3. *See infra* Part II (defining the elements of ITS).

strategic frameworks, manage treaty operations, monitor and review implementation, and measure treaty performance and compliance. These activities are part of what I have termed elsewhere as Strategic Treaty Management.[4] In tandem, these developments have increased the potential for multilateral regulatory treaties to help resolve or mitigate major global challenges. I consider these activities part of treaty practice, broadly understood as "all forms of conduct which may be relevant for the interpretation or the state of treaties."[5] This Article explores these new technologies and their application to key multilateral treaties, which are set forth in Table 1 below. It examines the implications of these developments for international law and policy and the steps needed to realize positive benefits from ITS in the future.

Table 1. List of Treaty Regimes Covered

- Anti-personnel Mine Ban Convention (APM Convention) (1997)
- Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unregulated and Unreported fishing (2016)
- Comprehensive Nuclear Test Ban Treaty (CTBT) (not yet in force)
- Convention on Biological Diversity (CBD) (1992)
- International Covenant on Civil and Political Rights (ICCPR) (1976)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRA) (2004)
- UN Fish Stocks Agreement (2001)
- UN Framework Convention on Climate Change (UNFCCC) (1992)
- WHO Framework Convention on Tobacco Control (WHO FCTC)(2005)

In recent years, high-tech innovations have transformed many aspects of our world. The influence of technology on business, government, education, healthcare, and our daily lives has been tremendous. It should not be surprising then that these developments are having major effects on all aspects of multilateral treaties. Considering only one aspect of this revolution, that is, the development of artificial intelligence (AI), Sam Altman, chief executive of Open AI, has said that "[t]he AI revolution will be more consequential than the agricultural, industrial and computer revolutions combined."[6] While the precise impact of AI is difficult to assess, it seems clear that international law, as well as society generally, will be substantially affected by these trends.

The application of technology to multilateral treaty implementation has been examined by other authors. However, there are notable limitations. Studies in international law have focused on the application of certain types of

4. *See generally* THOMAS F. MCINERNEY, STRATEGIC TREATY MANAGEMENT: PRACTICE AND IMPLICATIONS (2015) (describing and analyzing the ways in which treaty bodies can use strategic management tools to drive performance improvements in multilateral treaties).

5. GEORG NOLTE, TREATIES AND THEIR PRACTICE: SYMPTOMS OF THEIR RISE OR DECLINE 20 (2019).

6. John Thornhill, *Reimaging Business: An Interview with Microsoft Chief Satya Nadella*, FIN. TIMES, (Mar. 8, 2021), https://www.ft.com/content/d5a9f4da-e11f-49b9-a01d-9f9af4cc338c [https://perma.cc/9HV2-GZWP].

technology to environmental,[7] human rights,[8] and arms-control treaties, but they generally do not probe the legal and policy issues in any depth.[9] Other studies have considered the implications of big data[10] and remote sensing for international law.[11] Although providing valuable insights, what is missing in these accounts is a view of the full range and ever-increasing power of the technologies being used for treaty-related purposes, as well as the intricate ways in which they interconnect and interact. Through the concept of ITS we can gain a better view of the complete ecosystems of technology employed in different

7. *See, e.g.*, Alex de Sherbinin et al., *Remote Sensing Data: Valuable Support for Environmental Agreements*, 44 ENV'T: SCI. AND POL. FOR SUSTAINABLE DEV. 20, 20–31 (2002) (describing the need for accurate and timely environmental data to help scientists monitor treaties); Olav Schram Stokke & Oran R. Young, *Integrating Earth Observation Systems and International Environmental Regimes*, *in* SATELLITE EARTH OBSERVATIONS AND THEIR IMPACT ON SOCIETY AND POLICY 179, 179–203 (Masami Onoda & Oran R. Young eds. 2017) (discussing use of satellites to solve large-scale environmental problems); Victoria Bogdan Tejeda, *Science and Sleuthing: Improving CITES Enforcement Through Innovations in Wildlife Forensic Technology*, 47 ENV'T L. REP. 10580, 10580–90 (2017) (discussing utilization of wildlife forensic technology for CITES enforcement).

8. *See, e.g.*, James R. Walker, *Remote Sensing for International Human Rights Advocacy: Critiques and Responses*, 19 J. HUM. RTS. 183, 183–200 (2020) (discussing usage of remote sensing imagery in human rights advocacy); Frank D.W. Witmer, *Remote Sensing of Violent Conflict: Eyes from Above*, 36 INT'L J. REMOTE SENSING 2326, 2326–2352 (2015) (discussing use of remote sensing in violent conflict context); Susan R. Wolfinbarger, *Remote Sensing as a Tool for Human Rights Fact Finding*, *in* THE TRANSFORMATION OF HUMAN RIGHTS FACT-FINDING 463, 463–78 (Philip Alston & Sarah Knuckey eds. 2016) (discussing how human rights groups are attempting to integrate information communication technologies into existing workflows for compliance monitoring); Rebecca Hamilton, *Atrocity Prevention in the New Media Landscape*, 133 AJIL UNBOUND 262, 262–66 (2019) (analyzing impact of changes to journalism business models on atrocity prevention); Galit A. Sarfaty, *Can Big Data Revolutionize International Human Rights Law?*, 39 U. PA. J. INT'L L.73, 73–101 (2017) (noting concerns inherent in shifting human rights monitoring from reactive posture to a predictive model based upon big data solutions); Mark Latonero, *Big Data Analytics and Human Rights: Privacy Considerations in Context*, *in* NEW TECHNOLOGIES FOR HUMAN RIGHTS LAW AND PRACTICE 149, 149–61 (Molly K. Land & Jay D. Aronson eds. 2018) (analyzing privacy risks inherent in using big data analytics for human rights work); Marta Poblet & Jonathan Kolieb, *Responding to Human Rights Abuses in the Digital Era: New Tools, Old Challenges*, 54 STAN. J. INT'L L. 259, 259–83 (2018) (describing how near-real time documentation of human rights abuses poses challenges to the legitimacy of the international legal order); Jay D. Aronson, *Computer Vision and Machine Learning for Human Rights Video Analysis: Case Studies, Possibilities, Concerns, and Limitations*, 43 L. & SOC. INQUIRY 1188, 1188–1209 (2018) [hereinafter Aronson, *Computer Vision*], (discussing how machine learning and computer vision can be used by human rights groups to catalog and analyze citizen video and other footage); Jay D. Aronson, *Preserving Human Rights Media for Justice, Accountability, and Historical Clarification*, 11 GENOCIDE STUD. & PREVENTION: AN INT'L J. 82, 82–99 (2017) [hereinafter Aronson, *Preserving Human Rights Media*] (analyzing methods for archiving the vast data recording human rights events that is produced contemporaneously and tends to become lost).

9. *See, e.g.*, Sentz & Hemez, *supra* note 2, at 76–91; Ram Avtar et al., *Remote Sensing for International Peace and Security: Its Role and Implications*, REMOTE SENSING, Jan. 27, 2021, at 1–29, https://doaj.org/article/85a2d05b86d944d99af8bae3e5e1a7ee [https://perma.cc/DE37-6A8V]; David A. Koplow, *Symposium on New Challenges in Weapons Inspection: What Are You Lookin' At? Aerial and Space Observation for Arms Control*, 115 AM. J. INT'L L. UNBOUND 89, 89–94 (2021); Nicolas Sion & Annyssa Bellal, *Mobile Technology in the Interest of Law and the Protection of Civilians*, EUR. J. INT'L L.: TALK (May 29, 2015), https://www.ejiltalk.org/mobile-technology-in-the-interest-of-law-and-the-protection-of-civilians [https://perma.cc/NVC4-Y3KQ] (containing several sources only generally describing legal implications).

10. Fleur Johns, *The Turn to Data Analytics and International Law*, EUR. SOC'Y INT'L L.: REFLECTIONS, Apr. 17, 2014, at 1, 1–7; Caryn Devins et al., *The Law and Big Data*, 27 CORNELL J. L. & PUB. POL'Y 357, 357–413 (2017); Fleur Johns, *The Deluge*, 1 LONDON REV. INT'L L. 9, 9–34 (2013).

11. *See generally*, Raymond Ridderhof, *Satellite Data in International Law*, PEACE PALACE LIBR. (Aug. 10, 2017), https://peacepalacelibrary.nl/blog/2017/satellite-data-international-law [https://perma.cc/VC39-RCXK] (discussing the use of data acquired through earth observation satellites in an international law context).

treaty regimes and the complex workflows that have emerged; providing insights that may contribute to improvements in their design and management.

From another perspective, although the understanding of technology's role in international law has lagged adoption,[12] the technologies discussed in this Article are the subject of extensive research in the scientific communities. These studies entail a different limitation: they typically address technical and scientific issues involved in analyzing, monitoring, and implementing aspects of multilateral treaties, yet do not generally offer analysis relevant to international law as such. This Article seeks to engage with the scientific and technology communities to understand how they are contributing to international legal processes.

This Article is the first to examine the application of these various technologies to multilateral treaties in an integrated fashion that identifies and traces the intricate workflows, interconnections, and synergies between them. Understood in this way, the innovations occurring are even more impressive. Moreover, while research on applying distinct technologies to specific areas of international law has occurred, there has there been no effort to consider their application to multilateral treaties generally. As I will seek to show, the generic workflows and methods used across diverse treaty regimes are quite similar in the basic processes and tools they use. This finding raises the question of the desirability of maintaining distinctive approaches for specific treaty regimes, or whether some sort of consolidation or common approaches to ITS across diverse fields of international law may be appropriate.

The vibrant use of technology for treaty monitoring and implementation that this Article describes stands in contrast to the skepticism often expressed about the status and value of hard-law international agreements. Indicative of these views, the President of the Council on Foreign Relations, Richard Haass, has said, "[i]n this era of international relations, we may need to start thinking less about formal international treaties and agreements and much more about what you might describe as coordinated national policies."[13] Similarly, Anne Marie Slaughter has heralded the voluntary nature of the Paris Accord on climate change "as a model for effective global governance in the twenty-first century."[14] At the extreme are views championed during the Trump Administration that reflexively reject any sort of international agreements as

12. *See, e.g.*, INT'L SOC'Y FOR PHOTOGRAMMETRY & REMOTE SENSING (ISPRS), REMOTE SENSING AND THE KYOTO PROTOCOL: A REVIEW OF AVAILABLE AND FUTURE TECHNOLOGY FOR MONITORING TREATY COMPLIANCE § II (1999) (discussing unanswered legal considerations surrounding remote sensing technology); Jan Havránek & Daniel P. Bagge, *Technology Adoption: Are We Too Late to the Party?*, SMALL WARS J. (July 18, 2021, 6:08 PM), https://smallwarsjournal.com/jrnl/art/technology-adoption-are-we-too-late-party [https://perma.cc/VX2N-3FK6] (discussing how late nations have begun to use technology for international relations).

13. Richard Haass & Bernard Gwertzman, *The New 'Informal' Multilateral Era*, COUNCIL ON FOREIGN RELS. (Sep. 24, 2009 9:57 AM), https://www.cfr.org/interview/new-informal-multilateral-era [https://perma.cc/4P6V-4NLD].

14. Anne-Marie Slaughter, *The Paris Approach to Global Governance*, PROJECT SYNDICATE (Dec. 28, 2015), http://www.project-syndicate.org/commentary/paris-agreement-model-for-global-governance-by-anne-marie-slaughter-2015-12 [https://perma.cc/8V9Z-VFCD].

intrusions on US sovereignty.[15] Yet, such arguments overlook the ways in which treaties uniquely mobilize large numbers of actors and initiatives to act together for common goals in fields as diverse as arms control, biodiversity, cultural property, human rights, public health, and refugees.[16] Technological applications are important instances of such cooperation. Across these fields, technology is disrupting treaty practices in ways similar to what has happened in other areas of society—creating unparalleled levels of performance and knowledge while also kicking up novel, complex, and significant problems.[17] Overall, the combination of these technologies is having far-reaching effects on treaty practices across many areas.

Of importance to international law, ITS provide new means for promoting state-party implementation and compliance with multilateral treaties. International law and international relations scholars have long debated whether there is any inherent proclivity to comply with treaty obligations.[18] My argument complements and supplements theories finding that treaties generate some normative force.[19] Among the ITS components, visualization, mapping,

15. *See, e.g.*, John B. Bellinger III, *The Trump Administration's Approach to International Law and Courts: Are We Seeing a Turn for the Worse?*, 51 CASE W. RSRV. J. INT'L L. 7, 21–22 (2019) ("It seems clear that President Trump dislikes large multilateral agreements.").

16. *See, e.g.*, Arms Trade Treaty, Dec. 24, 2014, Apr. 2, 2013, 3013 U.N.T.S. 269 (adopting arms control treaty); Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 79 (adopting biodiversity treaty); Second Protocol to the Hague Convention of 1954 for the Protection of Cultural Property in the Event of Armed Conflict, Mar. 26, 1999, 2253 U.N.T.S. 172 (covering cultural property); Protocol Relating to the Status of Refugees, Jan. 31, 1967, 19 U.S.T. 6223; 606 U.N.T.S. 267 (adopting human rights treaty); Constitution of the World Health Organization, July 22, 1946, 4 U.S.T 119, 14 U.N.T.S. 185 (adopting public health treaty); Convention Relating to the Status of Refugees, July 28, 1951, 189 U.N.T.S. 137 (adopting refugee treaty).

17. *See* Jacob Parakilas & Hannah Bryce, *Introduction: Artificial Intelligence and International Politics*, *in* ARTIFICIAL INTELLIGENCE AND INTERNATIONAL AFFAIRS: DISRUPTION ANTICIPATED 1, 1–6 (M.L. Cummings et al. eds., 2018) (discussing the potential impact of artificial intelligence and related technologies on international relations); Harriet Harden-Davies & Paul Snelgrove, *Science Collaboration for Capacity Building: Advancing Technology Transfer Through a Treaty for Biodiversity Beyond National Jurisdiction*, FRONTIERS MARINE SCI., Feb. 28, 2020, at 1–14, https://www.frontiersin.org/articles/10.3389/fmars.2020.00040/full [https://perma.cc/FN84-FP9F] (advocating for utilizing UNCLOS for marine technology transfer to protect biodiversity).

18. *See, e.g.*, Beth A. Simmons, *Money and the Law: Why Comply with the Public International Law of Money?*, YALE J. INT'L L. 323, 327–32 (2000) (discussing literature regarding compliance with international law); Andrew T. Guzman, *A Compliance Based Theory of International Law*, 90 CALIF. L. REV. 1823, 1823–87 (2002) (examining compliance with international law from perspective of rational, self-interested states).

19. *See, e.g.*, ABRAM CHAYES & ANTONIA HANDLER CHAYES, THE NEW SOVEREIGNTY: COMPLIANCE WITH INTERNATIONAL REGULATORY AGREEMENTS (1998) (arguing normative force of treaties has more influence over compliance than coercive enforcement); XINYUAN DAI, INTERNATIONAL INSTITUTIONS AND NATIONAL POLICIES (2007) (analyzing treaty compliance via non-state actors like NGOs and social movements); ANDREW GUZMAN, HOW INTERNATIONAL LAW WORKS: A RATIONAL CHOICE THEORY (2010) (applying rational choice methodology to explain how international law can succeed in the absence of coercive enforcement); George W. Downs et al., *Is the Good News About Compliance Good News About Enforcement?*, 50 INT'L ORG. 379, 379–406 (1996) (criticizing selection bias inherent in then-existing studies of international compliance and suggesting more robust incentives would be required for more significant treaties); Jutta Brunnée, *Enforcement Mechanisms in International Law and International Environmental Law*, *in* ENSURING COMPLIANCE WITH MULTILATERAL ENVIRONMENTAL AGREEMENTS: A DIALOGUE BETWEEN PRACTITIONERS AND ACADEMIA 1, 12–22 (Ulrich Beyerlin et al. eds., 2006) (describing the limited utility of dichotomies like binding vs non-binding); KATHRYN SIKKINK, EVIDENCE FOR HOPE: MAKING HUMAN RIGHTS WORK IN THE 21ST CENTURY (2017) (taking a historical approach to argue human rights efforts have produced significant humanitarian gains); BETH A.

modeling, and indicator frameworks for monitoring results provide new incentives for such state behavior. The reasons stem from ITS' translation of treaty norms into readily understandable content for stakeholders including parties, civil society, and the public. These forces draw upon states' willingness to comply and reduce non-compliance caused by an incomplete or inadequate understanding of conditions, purposes, or results that a treaty may effectuate.[20] In addition, it enables judgments on the efficacy of treaties from a regulatory standpoint. Similarly, enhanced monitoring, data collection, and indicator frameworks all contribute to better judgments of treaties' regulatory impacts. Overall, the contribution of ITS to treaty compliance is not adequately accounted for in international law or international relations literature. ITS will increasingly shape the way international regulatory treaties function in the coming decades, which has implications for the utility of these legal instruments to solve pressing global regulatory challenges.

An underlying concern that runs throughout these uses is that in nearly all cases, the same technologies used in ITS that confer important benefits for treaty regimes can also enable very negative outcomes for society in different contexts. The use of facial imaging technology, for instance, can be used both to identify perpetrators of human rights violations and by governments seeking to target human rights campaigners.[21] Likewise, drones used to identify unexploded ordinances for humanitarian demining enable the deployment of weapons by the military.[22] Earth Observation Satellites (EOS) designed to monitor environmental conditions can be used to identify migrants, whom repressive governments seek to target.[23] Smartphone data enables citizen scientists to share information on conservation matters but may provide repressive governments geolocation data that facilitate targeting of those individuals.[24] In the context of human trafficking, technology has been seen as a primary enabler of the crime,

SIMMONS, MOBILIZING FOR HUMAN RIGHTS: INTERNATIONAL LAW IN DOMESTIC POLITICS (2009) (arguing that ratification of human rights treaties leads to better rights practices on average); BARBARA KOREMENOS, THE CONTINENT OF INTERNATIONAL LAW: EXPLAINING AGREEMENT DESIGN (2016) (arguing cooperation problems may be confronted through international law's detailed design provisions).

20. *See* Brunnée, *supra* note 19, at 14–15 (discussing how states' understanding of the policy issue at hand can reveal reasons for voluntary compliance); Ulrich Beyerlin, *Preface*, *in* ENSURING COMPLIANCE WITH MULTILATERAL ENVIRONMENTAL AGREEMENTS: A DIALOGUE BETWEEN PRACTITIONERS AND ACADEMIA at vii (Ulrich Beyerlin et al. eds. 2006) (arguing compliance with treaty obligations depends on soundness of the whole treaty regime, requiring clear-cut and definite obligations).

21. Aronson, *Computer Vision*, *supra* note 8, at 1201.

22. A. Walter Dorn, *Eliminating Hidden Killers: How Can Technology Help Humanitarian Demining?*, 8 STABILITY: INT'L J. SEC. & DEV. 4 (2019) https://www.stabilityjournal.org/articles/10.5334/sta.743 [https://perma.cc/ESR7-BJ3R] (describing how advances in humanitarian demining technology still face barriers like the prioritization of military operations).

23. *See Satellite Imagery for Human Rights Monitoring*, ENGINE ROOM LIBR., https://library.theengineroom.org/satellite-imagery-human-rights [https://perma.cc/NFV9-G2KJ] ("Just as satellite imagery can be used by human rights organisations, it can also be used by the perpetrators of human rights abuses."); G. M. Koretsky et al., *A Tutorial on Electro-Optical/ Infrared (EO/IR) Theory and Systems*, INST. FOR DEF. ANALYSIS (Jan. 2013), https://www.ida.org/-/media/feature/publications/a/at/a-tutorial-on-e-lectro--opticalinfrared-eoir-theory-and-systems/ida-document-d-4642.ashx [https://perma.cc/U3JX-AYHQ] (describing how non-imaging point target EO/IR systems can detect targets at long range).

24. Jay D. Aronson, *Mobile Phones, Social Media and Big Data in Human Rights Fact Finding*, *in*, THE TRANSFORMATION OF HUMAN RIGHTS FACT-FINDING 441, 448–50 (Philip Alston & Sarah Knuckey eds. 2016).

as well as a significant tool for law enforcement in combating the practice.[25] Technology is not the culprit here, but it is clear that in the absence of suitable legal, regulatory, and ethical controls, the benefits of technology for international law may be outweighed by its negative uses. These concerns are addressed in more detail in Section III.

Following this introduction, in Section II, I provide an overview of each of the five components of ITS. In Section III, I discuss the above referenced legal and ethical challenges involved in ITS and in Section IV I analyze the potential and implications of ITS for the future of international law.

II. THE ELEMENTS OF INTELLIGENT TREATY SYSTEMS

The notion of Intelligent Treaty Systems derives from studies in computer science and information technology. The notion of intelligent systems generally refers to the complex of multiple interrelating technologies that, taken together, constitute powerful new operating systems for diverse applications.[26] Management consultant Gautam Shroff models intelligence as the outcome of multiple processes, with intelligent systems referring to a series of technological capabilities that involve sensing, learning, connecting, predicting, and correcting.[27]

As framed in this Article, ITS includes an array of technologies, each powerful in its own right, yet delivering more powerful results when integrated. ITS combine multiple technologies to further the abilities of parties and other stakeholders to monitor, manage, and implement multilateral regulatory treaties. In this Article, I will examine treaty regimes in diverse fields to illustrate the specific elements of ITS they employ. The components of ITS include five core capacities for: (1) sensing and generating data, (2) gathering and storing data, (3) processing and analyzing data, (4) creating models, maps, or visualizations, and (5) applying data to targets and indicators to measure progress and improve results from treaty applications. In this Article, the application of each of these five practices will be analyzed and contextualized as parts of the workflows among stakeholders involved in the treaties studied. As others have written, the potential for these technologies individually has grown as the capabilities of other technologies have expanded in parallel.[28]

Authors examining the role of technology in treaties have tended to take one of two extreme positions. On the one hand are technological utopians, who view these developments as overwhelmingly positive and promising untold

25. Jennifer Lynne Musto & danah boyd, *The Trafficking-Technology Nexus*, 21 SOC. POL. 461, 461–483 (2014).

26. SHROFF, *supra* note 2; Sentz & Hemez, *supra* note 2 (using the term to refer to technological systems to monitor compliance and conduct verification in the context of arms control treaties).

27. SHROFF, *supra* note 2.

28. *Id.*

benefits.[29] On the other side are those who view technology in negative, if not dystopian terms.[30] My view is that neither view is correct.

To support this contention, it is important to understand how technology is transforming treaty practices from the inside. It is having dramatic effects on treaty practice, however, not so much exogenously as endogenously. Generally, technology is not introducing wholly new approaches to treaty implementation, monitoring, or compliance, but is supporting or altering existing practices.[31] Over time, institutions are co-evolving with the technologies. Gradually, it becomes difficult to dissociate the workings of treaty regimes from the application of relevant technologies. Powerful capabilities that technology has enabled are changing management practices in ways that neither technological utopians nor dystopians generally recognize.[32] Analogous to what Saskia Sassen has observed in relation to the effects of globalization on states, technology is changing what it means to be a treaty.[33] For this reason, prevailing views, which consider technology as exogenous or ancillary to treaties' operations, fail to assess technology's role accurately.[34]

In this Article, I have sought to provide an in-depth analysis of the chief ITS components from an operational point of view. Given the complexity of the technologies involved and intricacies of the interaction between the elements of ITS, in Table 2 I have provided an overview of the components of ITS, described their potential utility, and previewed some of the legal, ethical, and policy issues addressed in Section III.

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29. Walker, *supra* note 8, at 184 (noting "frontline practitioners have enthusiastically embraced RS").

30. *Id.* (collecting academic critiques of using RS for human rights work).

31. Parakilas & Bryce, *supra* note 17, at 5–6; *e.g.*, Patricia Birnie, *Comment on the Compliance Control Mechanism within the Framework of the International Whaling Convention*, *in* ENSURING COMPLIANCE WITH MULTILATERAL ENVIRONMENTAL AGREEMENTS: A DIALOGUE BETWEEN PRACTITIONERS AND ACADEMIA 175, 176 (Ulrich Beyerlin, et al. eds., 2006) (detailing how the use of modern concepts and technologies has only highlighted the already existing problem of whaling and ignoring international pressure to cease the harmful practice).

32. MCINERNEY, *supra* note 4.

33. SASKIA SASSEN, TERRITORY, AUTHORITY, AND RIGHTS: FROM MEDIEVAL TO GLOBAL ASSEMBLAGES 359 (1st ed. 2006).

34. *Id.*

Table 2. ITS components, potential benefits, risks and limitations

ITS element	Components	Potential Benefits	Potential Risks and Limitations
Sensing	Remote sensing; Earth Observational Satellites; smart phones; Internet of things devices, RFID, in situ monitoring devices (audio, video, accelerometers); Unmanned Aerial Vehicles (drones); field laboratories; biosensors	Automated data gathering; 24/7 operability; geographic range; scalability; precision; detail	Accuracy; incompatibility of components and systems; capacity constraints
Data collection and storage	Cellular connectivity; internet; RF signals; satellite ground stations; cloud computing; edge computing; enterprise servers	Variable cost; global reach; near-real time accessibility; 24/7 availability; scalability; facilitates collaboration	Private ownership and control; data protection; Global North dominance; cyberattack risks; environmental pollution; privacy
Data processing and analysis	AI/ML; data authentication; verification; data mining; data classification; supervised and unsupervised training; computer vision; convolutional neural networks; deep learning	Reliability; secure storage; high throughput of data analysis; scalable architecture; automation; analytic capacity; progressive improvements; versatility	Deep fakes; algorithm bias; mystification; non-transparency; assumptions of accuracy
Models, Maps, and Visualization	Maps (e.g. GIS); Models (ecosystems, climate, forests, human rights violations); Visualization (recreation of incidents; infographics); Assessment reports	Forecasts and predictions; inform citizenry and decision makers; simplify information; standardization of reporting; characterize data; scenario planning; interactivity; public/private collaboration; improve enforcement and compliance	Interoperability limits; blackbox on model design; Global North dominance; technocratic decision making; heterogeneity in approaches
Performance indicators	Quantitative indicators	Accountability; objectivity; uniformity; monitor regulatory performance	Technocratic; reductionistic; inaccuracy; data incompleteness; burdensome on states

A. Sensing

The first element of ITS, sensing, refers to enhanced capacities for identifying, documenting, and quantifying phenomena in the physical world relevant to treaty purposes. Aside from state reporting, historically, much of the work of monitoring treaty-related issues required direct observations by researchers in the field.[35] As with technology's impact on the wider social world, many of today's observational techniques were unavailable until recently.[36] Admittedly, remote sensing (RS) devices constitute a significant share of the modalities for treaty-related monitoring but are far from the only ones.

Today much of the observational work involved in treaty performance monitoring, implementation review, or supporting scientific assessments employ some type of RS technologies. As these technological capabilities increase at a truly exponential pace, their power and utility are growing as well. The sensing devices available today are becoming vastly more powerful than their predecessors. Key features that make them more powerful include portability, reduced size and miniaturization, improved sensitivity, frequency of measurements, quality of measurements, reduced power use, long-term battery power, connectivity (particularly cellular and Internet), and greater autonomy and functionality.[37] These changes have made monitoring more powerful across many treaty regimes.

RS also allows access to sites that otherwise might not be reachable. Distant locations, hazardous areas, and inaccessible sites make RS particularly useful.[38] Not only do these capabilities enable monitoring on a larger scale but they also reduce the potential impact on the environment and matters under observation. Repeated visits by researchers to sites can cause damage to the environment or, depending upon the situation, can be dangerous.[39] RS techniques for many areas of treaty related monitoring can avoid both concerns.

35. R. Taylor et al., *The Rise of Big Data and Supporting Technologies in Keeping Watch on the World's Forests*, 22 INT'L FORESTRY REV. 129, 130 (2020) ("Historically, researchers documented the extent of and condition of forests – canopy cover, tree size, species, biodiversity, soil carbon content or seedling diversity – by boots-on-the-ground surveys."); Bilal Arshad et al., *Where is My Deer?-Wildlife Tracking and Counting via Edge Computing and Deep Learning*, 1–4 (2020) https://ieeexplore.ieee.org/document/9278802 [https://perma.cc/9YFU-8NS2]; Luis F. Gonzalez et al., *Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation*, SENSORS, Jan. 14, 2016, at 1, 16, https://www.ncbi.nlm.nih.gov/pubmed/26784196 [https://perma.cc/L2FR-CGVD]; Hua-Dong Guo et al., *Earth Observation Big Data for Climate Change Research*, 6 ADVANCES CLIMATE CHANGE RSCH. 108, 108–109 (2015), https://doi.org/10.1016/j.accre.2015.09.007 [https://perma.cc/6WTN-AXVQ] ("Prior to the development of Earth observation technology, scientists monitored the Earth predominantly through ground-based observations.").

36. *See, e.g.*, Guo et al., *supra* note 35, at 109 (noting three-dimensional Earth observation systems required "half a century of development").

37. *See, e.g.*, J.M. Read & M. Torrado, *Remote Sensing*, *in* INTERNATIONAL ENCYCLOPEDIA OF HUMAN GEOGRAPHY 335, 335–346 (Rob Kitchin & Nigel Thrift eds., 2009) (describing the evolution, workings, and utility of RS).

38. Gonzalez, *supra* note 35, at 2.

39. David J. Klein & Bernie Tershy, *Deep Learning for Large Scale Biodiversity Monitoring*, § 2 (Bloomberg Data for Good Exchange Conference, Sept. 28, 2015), https://www.researchgate.net/publication/282290618_Deep_Learning_for_Large_Scale_Biodiversity_Monitoring [https://perma.cc/4FK9-6MHW]; Witmer, *supra* note 8, at 2329.

RS devices encompass everything from EOS, drones or unmanned aerial vehicles, radio frequency identification devices (RFID), and IOT applications. RS devices enable a mind-boggling array of functions for multilateral treaties. At a most basic level, RS devices can be divided into those that are Earth-bound and others that are satellite-based, known as EOS. Among the types of terrestrial-sensing devices are a large class of RS that can be mobile or fixed *in situ*. The following discussion and analysis of sensing technology proceeds from the widest, most macro perspective to more detailed close-up views.

In situ RS includes air quality monitoring stations, water sampling instruments, seismic monitors for nuclear test verification, optical and video recorders, and other instruments. The International Monitoring System (IMS) operated by the Provisional Technical Secretariat of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is one illustration of *in situ* devices.

The CTBTO employs a range of devices within its IMS to identify evidence of nuclear tests.[40] Through a network of 337 fixed-base facilities and 16 laboratories in participating countries,[41] the IMS is designed to determine whether a suspected event that is discovered has, in fact, occurred, and whether it involved a nuclear explosion.[42]

The IMS uses two main types of monitoring instruments: waveform and radionuclide. Waveform instruments include seismic monitoring, hydroacoustic monitoring, and infrasound monitoring. Seismic monitoring measures seismic waves, recording their magnitude using the Richter scale.[43] Seismic waves travel rapidly and can be detected by seismic stations around the world in as little as ten seconds to ten minutes.[44] Hydroacoustic monitoring seeks to identify sounds traveling in the ocean and infrasound monitoring relates to high frequency sounds that cannot be heard with the human ear.[45] The second type involves radionuclide detection, which relies on radioactive signals that are markers of

40. Comprehensive Nuclear-Test-Ban Treaty, art. IV, ¶ 1, Sept. 10, 1996, 35 I.L.M. 1439 (specifying that the IMS must be operational as a requirement for the treaty's entry into force).

41. CTBT: Science and Technology 2017 Conference, *Scientific Advances in CTBT Monitoring and Verification: Review of Presentations and Outcomes of the Comprehensive Nuclear-Test-Ban Treaty*, 30–32 (June 2017), https://events.ctbto.org/sites/default/files/2019-07/SnT2017_Report_FINAL_LowRes.PDF [https://perma.cc/MEH2-5M8M].

42. *Overview of the Verification Regime*, CTBTO, https://www.ctbto.org/verification-regime/background/overview-of-the-verification-regime [https://perma.cc/GRA6-RMQC] (last visited Sept. 16, 2022).

43. *Seismic Monitoring*, CTBTO, https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/seismic-monitoring [https://perma.cc/RWG4-VVKK] (last visited Sept. 16, 2022).

44. *Id.*; *see also Infrasound Monitoring*, CTBTO, https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/infrasound-monitoring [https://perma.cc/ASK3-WTDM] (last visited Sept. 16, 2022).

45. *Hydroacoustic Monitoring*, CTBTO, https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/hydroacoustic-monitoring [https://perma.cc/GY68-RBL2] (last visited Sept. 16, 2022).

nuclear explosions.[46] The IMS uses these diverse sensing devices in combination to enable much more precise and comprehensive levels of verification.

In situ devices have also been installed in natural settings including aquatic areas and land to assess and monitor biodiversity. Instruments include microphones, cameras (including visual, thermal, infrared, hyperspectral, and accelerometers) that are deployed in natural environments to constantly monitor species populations and movements.[47] The combination of new technologies including improved batteries, GPS, and cellular networks have improved wildlife telemetry dramatically.[48] The use of remote cameras for species monitoring, for instance, has grown exponentially over the past 15 years and is doubling every 2.9 years.[49] These technologies can be combined with EOS, airplane, wave glider, and unmanned aerial vehicles to get a view of changes at the landscape level.[50]

Moveable RS encompasses EOS, unmanned aerial vehicles (UAV), radiographic sampling, robots, and autonomous ocean monitoring systems. Among these, EOS stand out for their utility across many different regimes. EOS are among the most powerful moveable RS devices. EOS were an important outcome of the space race. The first EOS, Landsat I, was launched in the 1970s.[51] They typically function as geostationary devices, which orbit the planet following a particular geographic location.[52] They are used extensively to monitor diverse phenomena on the Earth from oceans to climate to land cover as well as human rights and arms control.[53] For decades, governments limited access to EOS data, however, gradually governments are making more historical data available on an open-source basis.[54] As a result, researchers can now draw on nearly 50 years of satellite imagery, providing valuable temporal information and making scientific and treaty-related analysis much more robust.[55] Nevertheless, as described in Part III, this access is far from universal.

EOS are one aspect of the broader category of space-based applications, which due to the powerful range of functionality they support, are becoming a distinctive category promising major contributions across the entire treaty-related technology ecosystem. Space-based technology is poised to improve

46. *Radionuclide Monitoring*, CTBTO, https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/radionuclide-monitoring [https://perma.cc/H7K5-YHZJ] (last visited Sept. 16, 2022).

47. Klein et al., *supra* note 39, at § 3; Robin Steenweg et al., *Scaling-Up Camera Traps: Monitoring the Planet's Biodiversity with Networks of Remote Sensors*, 15 FRONTIERS ECOLOGY & ENV'T 26, 27 (2016).

48. Steenweg et al., *supra* note 47, at 27.

49. *Id.*

50. *Id.*; Klein et al., *supra* note 39, at § 3.

51. UNITED NATIONS SATELLITE IMAGERY & GEOSPATIAL DATA TASK TEAM, EARTH OBSERVATIONS FOR OFFICIAL STATS. 12 (2017), https://unstats.un.org/bigdata/task-teams/earth-observation/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf [https://perma.cc/SH7Q-S44U].

52. Masami Onoda & Oran R. Young, *Satellite Earth Observations in Environmental Problem-Solving*, *in* SATELLITE EARTH OBSERVATIONS AND THEIR IMPACT ON SOCIETY AND POLICY 1, 5–7 (Masami Onoda & Oran R. Young eds., 2017).

53. ANNETTE FROEHLICH & CLAUDIU MIHAI TĂIATU, SPACE IN SUPPORT OF HUMAN RIGHTS 63–117 (2020).

54. *See* UNITED NATIONS SATELLITE IMAGERY & GEOSPATIAL DATA TASK TEAM, *supra* note 51, at 21–23 (discussing available data sources).

55. *Id.*

EOS observations, Internet access, communications, and geolocation capabilities.[56]

Historically, governments launched and operated the bulk of EOS. Yet decreased size, coupled with more competition in the launch market, has lowered costs and enabled new configurations of satellites to be launched by the private sector.[57] In the past decade, the emergence of low earth orbiting (LEO) satellites deployed in constellations of sometimes hundreds have enabled coverage of wider portions of the planet, increased levels of data detail, and reduced latency.[58] As a result, greater numbers of satellites are in use and are expected to be launched in the coming years.

Satellites generate data, generically referred to as satellite imagery.[59] The main technologies for satellite imaging include optical, radar, and spectral imaging, which generate spatial, temporal, and spectral data.[60] The different types of observation technologies and imagery they provide confer advantages and disadvantages for research. Among the factors influencing the utility of satellites are their spatial resolution, revisit capabilities, spectral resolution, and radiometric resolution.[61] Over time, EOS have been enhanced with multi-band sensors that improve the quality and increase the volume and types of data each can provide.[62] The different types of EOS provide much different data which can be used for different purposes. Different sensors can deliver pixel sizes from tens of meters to as little as half a meter.[63] LANDSAT provides images of 30 meters and the Moderate Resolution Imaging Spectoradiometer (MODIS) provides 1 km resolution which enables monitoring of large geographic areas such as forestry and deforestation.[64] Images generated from those satellites have more bands and higher resolution.[65]

In addition to resolution, the revisit schedule of different satellites varies widely. In the past, the long latency of EOS data has impeded the speed with which observations could be acted upon.[66] But this issue is being overcome very

56. Saadia M. Pekkanen, *Introduction to the Symposium on the New Space Race: Governing the New Space Race*, AJIL UNBOUND 92, 92–93 (2020), https://www.cambridge.org/core/services/aop-cambridge-core/content/view/14BD9B37A7A15A8E225A5355BB29E51B/S2398772319000163a.pdf/governing_the_new_space_race.pdf [https://perma.cc/83QE-FF96].

57. Jeff Greason & James C. Bennett, *The Economies of Space: An Industry Ready to Launch*, REASON FOUND. (June 5, 2019), https://reason.org/policy-study/the-economics-of-space [https://perma.cc/NL8P-WUHF].

58. FROEHLICH & TĂIATU, *supra* note 53, at 49–53.

59. *Id.* at 90.

60. *Id.*

61. John A. Quinn et al., *Humanitarian Applications of Machine Learning with Remote-Sensing Data: Review and Case Study in Refugee Settlement Mapping*, 376 PHIL. TRANSACTIONS ROYAL SOC'Y A 2–3 (2018).

62. Freek D. van der Meer et al., *Multi- and Hyperspectral Geologic Remote Sensing: A Review*, 14 INT'L J. APPLIED EARTH OBSERVATION & GEOINFORMATION 112, 119 (2012).

63. FROEHLICH & TĂIATU, *supra* note 53, at 92.

64. UNITED NATIONS SATELLITE IMAGERY & GEOSPATIAL DATA TASK TEAM, *supra* note 51, at 12.

65. X. Z. Wang et al., *An Interactive Web-Based Analysis Framework for Remote Sensing Cloud Computing*, II-4/W2 ISPRS ANNALS PHOTOGRAMMETRY, REMOTE SENSING & SPATIAL INFO. SCIS. 43, 44 (2015); Wenxue Fu et al., *Remote Sensing Satellites for Digital Earth, in* MANUAL OF DIGITAL EARTH 55, 57–58 (Huadong Guo et al. eds., 2020).

66. *What is Data Latency*, NASA: EARTHDATA, https://earthdata.nasa.gov/learn/backgrounders/data-latency [https://perma.cc/2TMZ-M7BT] (last visited Sept. 16, 2022).

rapidly. Technology is already capable of providing real-time observations on demand.[67] According to one group of experts, "GEOS system can provide continuous and timely environmental and atmospheric observations over the Earth's surface, MODIS has a revisit cycle of 1–2-days, Landsat-7 has a revisit cycle of 16 days, and Sentinel-1 6 days."[68] Depending on the resolution of the imagery, the revisit schedule may pose greater challenges. For low resolution imagery, the calibration and consistency of data over time is not a huge problem, because the pixel size will not change between revisits.[69]

Optical satellites function in the visible and near-infrared part of the spectrum, but can also be extended to multispectral capabilities.[70] They can also gather data from the non-visible bands, which provide information about things such as vegetation and mineralogy.[71] Optical systems operate based on sunlight-generated reflected electromagnetic radiation, whereas radar systems function by sending pulses of microwave energy to the Earth's surface and capturing the return signal.[72] An important limitation of optical EOS is cloud cover interference. Radar sensors, such as TerraSAR-X, can provide resolution down to 0.25 m and support identification of surface characteristics, such as texture and geomorphology as well as DEM.[73] For these reasons as well as their ability to see through clouds, Synthetic Aperture Radar and Advanced Synthetic Aperture Radar are increasingly being used for agriculture, forestry, land cover classification, hydrology, and cartography.[74]

Although previously not a dominant source of data for human rights, EOS have enabled documentation of abuses in difficult to reach places, such as conflict zones or areas with restricted access to political barriers and violations that actors wish to hide.[75] Over the past 25 years, EOS have increasingly been used to monitor a wide range of human rights matters.[76] Landsat and Sentinel as well as open-source digital platforms such as Google Earth and Digital Globe (now Maxar) have been used to support treaty adherence.[77] For example, the Satellite Sentinel Project has used imagery and data provided by DigitalGlobe to identify attacks of the Janjaweed militias in Darfur.[78] Recently, satellite images were cited before the International Court of Justice as evidence in Gambia's case against Myanmar under the Convention on the Prevention and

67. *See, e.g.*, *Real-Time Satellite Monitoring with Planet*, PLANET, https://www.planet.com/products/monitoring [https://perma.cc/5XEA-Y68U] (last visited Sept. 16, 2022).

68. Quinn et al., *supra* note 61, at 3–4.

69. *Id.* at 3.

70. FROEHLICH & TĂIATU, *supra* note 53, at 92.

71. *Id.*

72. *Id.*

73. *Id.* at 63.

74. Fu et al., *supra* note 65, at 110.

75. Avtar et al., *supra* note 9, at 17.

76. FROEHLICH & TĂIATU, *supra* note 53, at 49–63; Qiuhua Liu et al., *Detection of Unexploded Ordnance Via Efficient Semisupervised and Active Learning*, 46 IEEE TRANSACTIONS ON GEOSCIENCE & REMOTE SENSING 2558, 2558 (2008); Wolfinbarger, *supra* note 8, at 463 (describing various initiatives using remote sensing for human rights).

77. Avtar et al., *supra* note 9, at 12–14.

78. Christian Knoth & Edzer Pebesma, *Detecting Dwelling Destruction in Darfur Through Object-Based Change Analysis of Very High-Resolution Imagery*, 38 INT'L J. REMOTE SENSING, 273, 276–77 (2017).

Punishment of Genocide (Genocide Convention) arising from atrocities committed against ethnic Rohingya in the Rakhine province of Myanmar.[79]

EOS have also been used in monitoring violations of land rights of indigenous communities in diverse countries, as well as forced resettlement practices in countries ranging from Ethiopia to Syria.[80] Satellites have also been used to track refugees and internally displaced people.[81] Among the information provided are details of numbers of people in settlements, damage assessments, and advocacy litigation.[82] The availability of such information is an improvement on prior practices, which, particularly during the early days of a conflict, historically depended upon anecdotal information of eyewitnesses.[83] In relation to socio-economic rights, EOS has been used to identify areas of social exclusion or deprivation, for instance.[84] Indications suggest that we are at an early stage and many uses will be found for EOS.[85]

The utility of RS in helping to monitor activity in distant locations is, if anything, more valid for ocean fisheries. One of the more powerful technologies to be applied in this area is satellite-enabled ship registry and tracking devices that have been mandated and promoted by the International Maritime Organization (IMO), the EU, and other national regulators.[86] For the purposes of monitoring fishing activity, RS data have evident advantages over existing methods including observers or logbooks.[87] EOS have also been used, but less prominently than in other regimes studied.[88] UAV have been used even less.[89] Other forms of *in situ* devices, such as onboard electronic monitoring systems

79. Application Instituting Proceedings and Request for Provisional Measures (Gam. v. Myan.), 2019 I.C.J. 178, at ¶ 54 (Nov. 11, 2019) (referring to High Commission of Human Rights' finding that "'testimonies as well as the satellite imagery analysis from three independent sources'" confirmed "that Myanmar security forces had 'deliberately targeted the entire Rohingya population in the area.'").

80. Witmer, *supra* note 8, at 2342; *Somalia: Satellite Imagery Reveals Devastation Amid Forced Evictions of Thousands Who Fled Conflict and Drought*, AMNESTY INT'L CAN. (Jan. 19, 2018, 5:00 AM), https://www.amnesty.ca/news/somalia-satellite-imagery-reveals-devastation-amid-forced-evictions-of-thousands-who-fled-conflict-and-drought [https://perma.cc/XW89-SRJL].

81. *See, e.g.*, Christopher Earney & Rebeca Moreno Jimenez, *Pioneering Predictive Analytics for Decision-Making in Forced Displacement Contexts*, *in* GUIDE TO MOBILE DATA ANALYTICS IN REFUGEE SCENARIOS: THE 'DATA FOR REFUGEES CHALLENGE' STUDY 101, 102–104 (Albert Ali Salah et al. eds., 2019) (describing the use of remote sensing to track internally displaced persons).

82. Quinn et al., *supra* note 61, at 2.

83. *Id.*

84. Daniel Arribas-Bel et al., *Remote Sensing-Based Measurement of Living Environment Deprivation: Improving Classical Approaches with Machine Learning*, PLOS ONE, May 2, 2017, at 1, 1; Monika Kuffer et al., *Slums from Space—15 Years of Slum Mapping Using Remote Sensing*, REMOTE SENSING, May 27, 2016, at 1.

85. UNITED NATIONS SATELLITE IMAGERY & GEOSPATIAL DATA TASK TEAM, *supra* note 51, at 86 (discussing pilot programs utilizing EOS); Witmer, *supra* note 8, at 2343 (discussing the increasing amount of free satellite data being made available including Landsat, the European Commission's Copernicus program, and French SPOT program).

86. Erico N. de Souza et al., *Improving Fishing Pattern Detection from Satellite AIS Using Data Mining and Machine Learning*, PLOS ONE, July 1, 2016, at 2.

87. David A. Kroodsma et al., *Tracking the Global Footprint of Fisheries*, 359 SCI. 904, 904–908 (2018); *see generally* IAN URBINA, THE OUTLAW OCEAN: JOURNEYS ACROSS THE LAST UNTAMED FRONTIER (2019) (documenting marine-based human rights and environmental abuses).

88. Onoda & Young, *supra* note 52, at 4.

89. Witmer, *supra* note 8, at 2345.

that employ cameras and video have been in development for decades and hold promise as well.[90]

The most comprehensive RS data derives from ship tracking devices. Most prevalent are the Automated Information System (AIS) and Vessel Monitoring Systems (VMS).[91] To promote adherence to the International Convention for Safety of Life at Sea (SOLAS), the IMO has mandated that all ships of 300 or more gross tons implement the AIS.[92] AIS data are "broadcast by on-board transmitters linked to the vessel's GPS and communicate the vessel's identity (IMO number, maritime mobile security information number (MMSI), vessel name, callsign), current position, speed and course."[93] Vessels operating within approximately 50 km can pick up the data which are transmitted every few seconds.[94] A satellite network was established to enable monitoring AIS signals through a satellite network operated by ORBCOMM.[95] AIS allows data on ship movements down to the individual vessel level.[96]

Despite the usefulness of AIS data, its limited coverage is a major shortcoming. The most basic issue is that the mandate to use AIS for ships above 300 gross tons excludes a very large share of fishing boats. Moreover, gaps occur due to saturation of the system in locations with high vessel density, poor quality transmissions due to equipment on either vessels or receivers, and intentional disabling of the transmitters.[97] Nevertheless, indications are that the coverage of AIS will increase over time, applying to many more vessels.[98] VMS is integrated in the GPS system on ships. It has greater utility closer to shore, but there is some question about its utility in comparison to the AIS. AIS systems exchange data with nearby vessels, ground-based AIS systems, and satellites.[99]

Movable RS has been used in biodiversity monitoring, such as aerial surveillance of species. One recent study used UAVs to monitor sea turtles off the coast of Costa Rica by capturing aerial photographs.[100] Illustrating the

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90. Aloysius T.M. van Helmond et al., *Electronic Monitoring in Fisheries: Lessons from Global Experiences and Future Opportunities*, 21 FISH & FISHERIES 162, 162 (2020).

91. Neil Nathan et al., *Public Data Sharing as a Means of Combating Illegal Fishing: Three Case Studies in Latin America*, *in* THE OUTLAW OCEAN: AN EXPLORATION OF POLICY SOLUTIONS TO ADDRESS ILLEGAL FISHING AND FORCED LABOR IN THE SEAFOOD INDUSTRY 10, 10 (STAN. CTR. FOR OCEAN SOLS. & STAN. L. SCH. eds., 2020).

92. Yoshioki Oozeki et al., *Reliable Estimation of IUU Fishing Catch Amounts in the Northwestern Pacific Adjacent to the Japanese EEZ: Potential for Usage of Satellite Remote Sensing Images*, 88 MARINE POL'Y 64, 65 (2018).

93. Daniel C. Dunn et al., *Empowering High Seas Governance with Satellite Vessel Tracking Data*, 19 FISH & FISHERIES 729, 732 (2018).

94. *Id*.

95. WHITE PAPER: UNDERSTANDING THE SATELLITE AIS ADVANTAGE AND THE SDPOB ADVANTAGE, ORBCOMM 1 https://www.sprep.org/attachments/VirLib/Global/understanding-AIS.pdf [https://perma.cc/M74S-UUAU] (last visited Sept. 16, 2022).

96. *Id.*

97. de Souza et al., *supra* note 86, at 17 ("The biggest weakness is the structure of the S-AIS system itself: not all vessels carry S-AIS transponders and those who do can still tamper with or disable the transponders, or falsify positional or identification data."); URBINA, *supra* note 87, at 61–62.

98. de Souza et al., *supra* note 86, at 17.

99. Jessica H. Ford et al., *Detecting Suspicious Activities at Sea Based on Anomalies in Automatic Identification Systems Transmissions*, PLOS ONE, Aug. 9, 2018, at 1, 1.

100. Patrick C. Gray et al., *A Convolutional Neural Network for Detecting Sea Turtles in Drone Imagery*, 10 METHODS ECOLOGY & EVOLUTION 345, 348 (2019).

creativity and do-it-yourself nature of many observational systems used in ITS, the UAV was an off-the-shelf model to which researchers attached a Canon PowerShot S110 near-infrared camera.[101] UAV flights were made across coastal areas where sea turtles migrate during breeding season.[102]

There are also a range of moveable RS that provide laboratory type analysis for treaty-related biodiversity monitoring in the field. Mobile kits with RS capabilities allow not only gathering of data through measurement and observation but also laboratory processing in the field.[103] Among these devices are the lab-on-a-disk or lab-on-a-chip, or lab-in-a-box (mobile instruments that allow testing *in situ*)[104] and other technologies that allow monitoring of microbial communities in oceans which have traditionally been excluded from much of these biodiversity monitoring efforts due to the difficulty of gathering samples and analyzing the results in a way that preserves the genetic material. Other examples include the various mobile molecular biology lab devices including autonomous underwater vehicles such as the Environmental Sample Processor,[105] the phytoplankton sampler, the remote access sampler, and water and micro plankton samplers which enable lab-based DNA measurements in the field.[106] These types of remote laboratory devices can be deployed from fixed ocean moorings, ship-based deployments, drifters which float in the ocean moving with the currents, and now remotely operated underwater vehicles. Among the benefits of these integrated sampling and analysis platforms is to permit rapid sampling and testing of genetic material even at great ocean depths.[107] These instruments function by collecting water and then filtering cells and suspended particles without having to preserve the material for lab-based analysis.[108] Likewise, new, eco-genomic sensors have been developed to perform *in situ* genetic analysis on collected samples.[109] For nuclear explosion monitoring by the CTBTO, its Onsite Inspection Program deploys field laboratories to measure radionuclide markers.[110]

EOS, UAV, and direct observation are very often combined.[111] For example, in initial stages of mine action programs, EOS are used to map the boundaries of mined territory.[112] EOS data provides an overall view of land

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101. *Id.* at 347.
102. *Id.*
103. *Bringing a Lab-on-a-Disc to a Place Near You*, ELSEVIER, https://www.elsevier.com/physical-sciences-and-engineering/chemistry/journals/new-chemistry-research/bringing-a-lab-on-a-disc-to-a-place-near-you [https://perma.cc/6AYL-JNPW] (last visited Sept. 16, 2022).
104. *Id.*
105. Christopher A. Scholin et al., *The Quest to Develop Ecogenomic Sensors,* 30 OCEANOGRAPHY 100, 101 (2017).
106. Jonathan S. McQuillan & Julie C. Robidart, *Molecular-Biological Sensing in Aquatic Environments: Recent Developments and Emerging Capabilities*, 45 CURRENT OP. BIOTECHNOLOGY 43, 43 (2017).
107. *Id.* at 46.
108. *Id.*
109. *Id.* at 45; *see also* Scholin et al., *supra* note 105, at 101.
110. CTBTO, *supra* note 42.
111. Witmer, *supra* note 8, at 2345.
112. John Fardoulis et al., *Drones in the Desert: Augmenting HMA and Socio-Economic Activities in Chad*, 23.1 J. CONVENTIONAL WEAPONS DESTRUCTION 62, 63–64 (2019).

surface data at low resolution covering relatively wide areas.[113] These observations are used to create geographic information system (GIS) maps. The actual remediation activities then rely on more detailed analyses that can be carried out through shorter range RS, such as drones.[114] Drone operators standing hundreds of meters outside of mined areas can distinguish visible features on the ground that provide clear evidence of mine contamination. Ground penetrating radar has been used on drones to enhance identification of buried landmines with 80 percent accuracy.[115] These data are supplemented by direct observation involving information from local communities and mine action professionals on the ground. Robotic devices and other mechanized equipment that have RS capabilities can also be used for landmine remediation.[116]

Aside from these observational RS devices, sensors can also take the form of microelectronics, which can be integrated in equipment to gain visual, environmental, or physical object data. Maritime sensors on ships can be used to monitor their resilience and safety.[117] Stationary sensors may be used to monitor environmental or atmospheric conditions on an ongoing basis.[118] Devices that monitor air pollution levels can monitor carbon levels in the atmosphere. Mobile sensors can also be used to monitor environmental or atmospheric conditions as well as provide information on humanitarian crises or human rights abuses.[119] Sensors built into different types of advanced materials can allow the material to change its nature as environmental conditions change.

RFID are a widely used means of RS. RFID are miniature devices with unique identification numbers (UID) that emit digital signals and are attached to physical objects. One way to understand them is as a means to "bridge the physical and digital worlds."[120] RFID are one of the key enablers of the IOT. The IOT and even the internet of everything (IOE) are beginning to be applied to matters prescribed by treaties in a variety of areas leading to an explosion of data for treaty purposes. At a basic level, the IOT means that data can be input by humans as well as machines.[121] RFID are used in many different applications and allow ongoing monitoring of equipment ranging from buildings and infrastructure to aircraft and cargo. To prevent deforestation, RFID labels have been used to monitor chain of custody in timber.[122] Because the IOT "grabs new and different data . . . combines data in different ways and allows humans and

113. *Id.* at 65–66.

114. *Id.*

115. Julián Colorado et al., *An Integrated Aerial System for Landmine Detection: SDR-based Ground Penetrating Radar Onboard an Autonomous Drone*, 31 ADVANCED ROBOTICS 791, 791 (2017).

116. John Fardoulis et al., *Robotics and Remote Sensing for Humanitarian Mine Action & ERW Survey (RRS-HMA)*, *in* 15TH INTERNATIONAL SYMPOSIUM "MINE ACTION 2018": BOOK OF PAPERS 33, 33 (Đurđa Adlešič et al. eds, 2018).

117. Richard T. Watson et al., Foundations of Maritime Informatics (World of Shipping Portugal, January 2021) at 4.

118. Steenweg et al., *supra* note 47, at 26.

119. Avtar et al., *supra* note 9, at 1.

120. SAMUEL GREENGARD, THE INTERNET OF THINGS 18–19 (2015).

121. *Id.*

122. Taylor et al., *supra* note 35, at 135.

machines to gain broader and deeper insights," it is transformative.[123] It is this linkage of remote sensors to the internet over the past 20 years that has dramatically changed the utility of these instruments for a wide array of purposes.[124]

A last emerging approach to RS is the use of biosensors, biological monitors, and genetic analysis. Biosensors include biological agents or material that can be used to identify and track diverse phenomenon relating to treaty matters.[125] Applications of this technology include detection of explosives, such as landmines,[126] biodiversity,[127] and chemical and wastes pollution.[128] Distinct from biosensors is the use of biological monitors, that is, live animals to facilitate or carry out sensing activities.[129] Examples include technology-enabled trained dogs, rats, pigs, and even honeybees for monitoring and compliance involving arms-control, illicit narcotics, and environmental treaties.[130] Genetic analysis has been used to monitor trafficking in endangered species such as elephant tusks.[131]

Communications devices are another important sensing technology that supplies data. Cellular phone data has become important in a variety of different contexts, such as humanitarian relief and refugee law. A well-known early example was the use of the Ushahidi app in Kenya during the period of post-election violence in 2007-2008.[132] A key turning point enabling such applications was the emergence of widespread mobile telephony, smartphones, and internet connectivity. Today these devices enable diverse actors to capture images, sounds, and movements. Smartphones today include "microphones, cameras, altimeters, accelerometers, barometers, gyroscopes, proximity sensors,

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123. GREENGARD, *supra* note 120, at 19.

124. *Id.*; Chunxue Wu et al., *Design and Analysis of an Data-Driven Intelligent Model for Persistent Organic Pollutants in the Internet of Things Environments*, 9 IEEE ACCESS 13451, 13451 (2021). IoT, by using local network or Internet and other communication technologies, sensors, controllers and machines, and people and objects can be connected together in new ways to form people-and-objects, and objects-and-objects links, so as to realize information-based remote management control and intelligent network.

125. Suman Singh, *Sensors—An Effective Approach for the Detection of Explosives*, 144 J. HAZARDOUS MATERIALS 15, 23 (2007) ("A biosensor is an analytical device that integrates a biological element on a solid-state surface, enabling a reversible biospecific interaction with the analyte and a signal transducer."); Maki K. Habib, *Controlled Biological and Biomimetic Systems for Landmine Detection*, 23 BIOSENSORS & BIOELECTRONICS 1, 9–10 (2007).

126. Benjamin Shemer et al., *Microbial Bioreporters of Trace Explosives*, 45 CURRENT OP. BIOTECHNOLOGY 113, 113 (2017); Singh, *supra* note 125, at 23.

127. McQuillan & Robidart, *supra* note 106, at 43.

128. Wu et al., *supra* note 124, at 13451.

129. Alan Poling et al., *Using Giant African Pouched Rats (Cricetomys Gambianus) to Detect Landmines*, 60 PSYCH. REC. 715, 715 (2010); Habib, *supra* note 125, at 2; Manjunatha D. Hadagali & Chua L. Suan, *Advancement of Sensitive Sniffer Bee Technology*, 97 TRENDS ANALYTICAL CHEMISTRY 153, 153 (2017).

130. Poling et al., *supra* note 129, at 715; Habib, *supra* note 125, at 2; Hadagali & Suan, *supra* note 129; Barbara Martinez et al., *Technology Innovation: Advancing Capabilities for the Early Detection of and Rapid Response to Invasive Species*, 22 BIOLOGICAL INVASIONS 75, 81 (2019) (discussing dogs used in conservation, including combatting illegally trafficked animal parts and invasive species).

131. Samuel K. Wasser et al., *Combating Transnational Organized Crime by Linking Multiple Large Ivory Seizures to the Same Dealer*, 4 SCI. ADVANCES 1, 1–10 (2018).

132. Phillip Alston & Colin Gillespie, *Global Human Rights Monitoring, New Technologies, and the Politics of Information*, 23 EUR. J. INT'L L. 1089, 1112 (2012).

compasses, Bluetooth network devices, and GPS sensors."[133] Camera phones collect images and track human rights violations and victims' movements.[134] Citizen scientists use digital cameras to document species and environmental conditions.[135] Rural communities use these devices to collect data on environmental conditions or landmine contamination.[136] UNHCR has used cell phone data to gain information on forced displacement including call details, phone recordings, real-time cash and financial transactions, commodity prices, and violent incident and other human rights violations.[137] Communications devices that are now ubiquitous have transformed scientific collaboration and treaty-related knowledge.

Smartphones include a range of capabilities that are useful to treaty monitoring including microphones, cameras, GPS chips, accelerometers, gyroscopes, and other sensors.[138] An important application of smart phone and other applications is to facilitate citizen scientific activities. Mobile applications are used to support environmental and biodiversity monitoring by citizen scientists and websites enable uploading of data they collect.[139] A recent European Commission report noted that "thousands of volunteers in around 20 countries collect data that are used to calculate the European butterfly indicator for grassland species, which covers 17 species of butterfly. The indicator is important for assessing progress under the EU's biodiversity strategy, reporting to the Convention on Biological Diversity and assessing progress on the SDGs."[140] Other citizen scientific research has focused on the presence and location of native and invasive species as well as dating and geo-referencing different biological events such as reproduction, and identifying land or seabed coverage.[141] Citizen science has been instrumental in the development of various scientific discoveries including unraveling protein structures and discovering new galaxies. Likewise, citizen scientists have played important roles in environmental monitoring such as reporting illegal logging, deforestation, and waste dumping.[142] An important form of citizen science is volunteered geographic information, which is a cross-cutting element of assessments and monitoring of treaties. The advent of volunteered geographic information "has

133. Martinez et al., *supra* note 130, at 80.

134. Earney & Jimenez, *supra* note 81, at 104.

135. *Id.*

136. Habib, *supra* note 125, at 9.

137. Earney & Jimenez, *supra* note 81, at 101–19.

138. GREENGARD, *supra* 120, at 47.

139. Aakash Lamba et al., *Deep Learning for Environmental Conservation*, 29 CURRENT BIOLOGY R977, R977 (2019); Michelle M. Thompson, *Upside-down GIS: The Future of Citizen Science and Community Participation*, 53 CARTOGRAPHIC J. 326, 326–334 (2016); Yann LeCun et al., *Deep Learning*, 521 NATURE 436, 436 (2015).

140. *Commission Staff Working Document on Best Practices in Citizen Science for Environmental Monitoring*, at 23–27, SWD (2020) 149 final (July 27, 2020), https://ec.europa.eu/environment/legal/reporting/pdf/best_practices_citizen_science_environmental_monitoring.pdf [https://perma.cc/SE4K-FLBQ].

141. Soledad Luna et al., *Developing Mobile Applications for Environmental and Biodiversity Citizen Science: Considerations and Recommendations*, *in* MULTIMEDIA TOOLS AND APPLICATIONS FOR ENVIRONMENTAL & BIODIVERSITY INFORMATICS 9, 9–30 (Alexis Joly et al. eds., 2018).

142. *See* Alexis Comber et al., *Crowdsourcing: It Matters Who the Crowd Are. The Impacts of Between Group Variations in Recording Land* Cover, 11 PLOS ONE, July 26, 2016, at 3 (discussing advances made through citizen science).

the potential to fundamentally change the nature of scientific investigation."[143] Overall, volunteered geographic information can increase data on diverse spatially referenced phenomena.[144]

We can expect that in time smartphones will acquire the ability to sense smells and tastes as well as become more contextually nuanced.[145] Refinements in smartphone technology will also improve the quality of the sensing activity that they already perform by reducing noise, improving the quality of visual and audio data. In the future, smartphones may even enable compliance monitoring for arms control.[146] The website Safecast provides access to information on radiation levels and was used following the Fukushima accident.[147] Gyroscopes and accelerometers built into personal electronic devices could even be used potentially to detect nuclear explosions.[148]

Video recording and cameras have been used for decades and with digitalization, their functionality has been enhanced. The availability of video and photography has increased with the proliferation of smartphones globally over the past decade. Sources of video and photographs come from activists, citizen law enforcement, and news media, notably in the human rights field.[149] The development of digital recording devices has dramatically expanded the number of unofficial investigators and citizen journalists who document human rights abuses.[150] ICTs are providing data that is at a finer scale and higher spatial resolution, providing hyper-local information on events in previously inaccessible locations.[151] These tools have helped create new communities of practitioners and led to partnerships between these individuals and national and international human rights NGOs.[152] While photography and video use for human rights has become commonplace, it has also been used in many other contexts, even tobacco control. To support monitoring of tobacco packaging for

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143. Linda See et al., *Comparing the Quality of Crowdsourced Data Contributed by Experts and Non-experts*, 8 PLOS ONE, July 31, 2013, at 1.

144. *See* Comber et al., *supra* note 142, at 1 (discussing advancements possible by crowdsourced data); Sophia B. Liu & Leysia Palen, *The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice*, 37 CARTOGRAPHY & GEOGRAPHIC INFO. SCI. 69, 70 (2010).

145. J. Angelo Racoma, *Your Smartphone Might Soon Be Able to Identify Scents and Flavors*, ANDROID AUTH. (Jan. 27, 2013), https://www.androidauthority.com/smartphone-smell-taste-151168 [perma.cc/Z8WJ-ZHFE].

146. Jill Hruby, *Challenges and Opportunities in Scientific and Technological Support for Monitoring in the Non-Proliferation Regime*, *in* INTERNATIONAL COOPERATION FOR ENHANCING NUCLEAR SAFETY, SECURITY, SAFEGUARDS AND NON-PROLIFERATION 83, 87 (Luciano Maiani et al. eds., 2020).

147. Anna Berti Suman, *Citizen Sensing from a Legal Standpoint: Legitimizing the Practice Under the Aarhus Framework*, 18 J. FOR EUR. ENV'T & PLANNING L. 8, 29-30 (2021).

148. Matthew Fargo, *Arms Control and Social Networking — Crowdsourcing Intelligence*, CTR. FOR STRATEGIC & INT'L STUD. (Jan. 3, 2013) https://web.archive.org/web/20140824070238/http://csis.org/blog/arms-control-and-social-networking-crowdsourcing-intelligence [perma.cc/BH28-P8YF].

149. Lindsay Freeman, *Digital Evidence and War Crimes Prosecutions: The Impact of Digital Technologies on International Criminal Investigations and Trials*, 41 FORDHAM INT'L L. J. 283, 333 (2018).

150. Jessica Heinzelman & Patrick Meier *Crowdsourcing for Human Rights Monitoring: Challenges and Opportunities for Information Collection and Verification*, *in* HUMAN RIGHTS AND INFORMATION COMMUNICATION TECHNOLOGIES: TRENDS AND CONSEQUENCES OF USE 123, 124 (John Lannon & Edward F. Halpin eds., 2012).

151. Wolfinbarger, *supra* note 8, at 463.

152. *See id.* at 463–64 (discussing the role of ICTs in work between individuals and NGOs).

the FCTC, researchers have deployed teams using digital cameras to gather data from retail stores.[153] Digital photographs of thousands of cigarette packs were gathered from fourteen middle-income countries as part of such monitoring efforts.[154] Video recording is also a key part of electronic monitoring systems in fisheries, which monitor fish catch for compliance with relevant treaties and regulations.[155]

For clarity, I have tried to describe the many technologies used for treaty purposes today, but these instruments and activities are most often used in combination. Direct observation and remote sensed data are often combined to validate and clarify one another.[156] Crowdsourced data from citizen scientists supplements expert data.[157] EOS data enable broad mapping that can then be used to conduct finer examinations often using *in situ* or other RS devices such as UAVs. Multiple technologies that measure the same phenomenon can be used together to triangulate data related to suspected nuclear events, for example.[158] Ultimately, the utility of these diverse technologies depends on the ingenuity of the user communities to address the practical needs for knowledge. For treaty law, the biggest impact of sensing technologies is to provide the basis for enhanced implementation and compliance monitoring. As a result of their dramatic improvement, they provide an important means of strengthening adherence to international law.

B. Data Collection, Communication, and Storage

Data collection, communication, and storage through information and communication technology is a second core element of ITS. In the treaty context, as in society generally, data flows are increasing exponentially.[159] Overall, global production of data is increasing at a level of fifty to sixty percent per year.[160] The amount of data that can be generated by different sensing technologies can be truly astounding. IOT applications, such as devices for *in*

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153. Katherine Smith et al., *The Tobacco Pack Surveillance System: A Protocol for Assessing Health Warning Compliance, Design Features, and Appeals of Tobacco Packs Sold in Low-and Middle-Income Countries*, 1 JMIR PUB. HEALTH SURVEILLANCE, Aug. 12, 2015, at 1, 2.

154. *Id.* at 5.

155. Jamie Gibbon, *Electronic Monitoring: A Key Tool for Global Fisheries*, PEW (Sept. 20, 2019), https://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2019/09/electronic-monitoring-a-key-tool-for-global-fisheries [perma.cc/YN3Z-YVVV].

156. Wolfinbarger, *supra* note 8, at 472 (noting that remote sensed data such as EOS is used to corroborate eye-witness testimony for instance).

157. François Waldner et al., *Conflation of Expert and Crowd Reference Data to Validate Global Binary Thematic Maps*, 221 REMOTE SENSING ENV'T 235, 236 (2019); Susanne Becken et al., *A Hybrid Is Born: Integrating Collective Sensing, Citizen Science and Professional Monitoring of the Environment*, 52 ECOLOGICAL INFORMATICS 35, 35 (2019).

158. *See* Fargo, *supra* note 148 (explaining use of technologies to monitor nuclear weapon use).

159. *See, e.g.*, JOHN GANTZ & DAVID RENSEL, IDC, THE DIGITAL UNIVERSE IN 2020: BIG DATA, BIGGER DIGITAL SHADOWS, AND BIGGEST GROWTH IN THE FAR EAST 1 (2012), https://www.cs.princeton.edu/courses/archive/spring13/cos598C/idc-the-digital-universe-in-2020.pdf [perma.cc/4V2S-9WWF] (finding that the total data produced globally will double every two years).

160. JAMES MANYIKA ET AL., MCKINSEY GLOB. INST., BIG DATA: THE NEXT FRONTIER FOR INNOVATION, COMPETITION, AND PRODUCTIVITY 11 (May 2011), https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/big%20data%20the%20next%20frontier%20for%20innovation/mgi_big_data_full_report.pdf [perma.cc/VW6F-ECZE].

situ monitoring of species, can generate fifty terabytes of data per year from just one site.[161] Likewise, one private satellite company produces eighty terabytes per day.[162] Biodiversity data housed in the Global Biodiversity Informatics Facility (GBIF) increased 1,150 percent between 2007 and 2020.[163] A major concern with these activities is the environmental risks, although much attention is being devoted to addressing the issue.[164] Moreover, these trends are accelerating. It is expected that the amount of data being gathered through all IOT applications globally will increase from petabytes to exabytes of data annually.[165] A significant share of the increase is due to the inclusion of data-heavy materials such as video, photographs, satellite imagery, and audio materials.[166] For this massive increase in data collected to be usable, storage and computing capabilities must improve correspondingly.

Gathering data involves communications systems used to transmit data and the storage systems where they reside. Communications systems include Internet, cellular systems, and RF. Across all elements of ITS, Internet connectivity plays a huge role in transmitting raw data as well as sharing data among research communities. The growth of mobile communications devices with Internet connectivity has been a critical enabler of data transmission.[167]

Data obtained through remote-sensing devices rely on a variety of technology and communications infrastructure to gather and store the material. Off-the-shelf sensor hardware increasingly may include bundled transmission radios and onboard processing capabilities.[168] The sensor devices located in remote areas are connected through communications networks which are in turn linked up to base stations, which transmit data through Internet, satellite, microwave, or cellular networks, or alternatively store the data until it can be recovered at the end of a monitoring period.[169] This data can then be uploaded to cloud servers or retained in stand-alone data centers.[170]

Likewise, for data from space applications, ground stations are an increasingly important component. Data transmitted by EOS is generally in the

161. GREENGARD, *supra* note 120, at 44.

162. Doug Mohney, *Terabytes from Space: Satellite Imaging is Filling Data Centers*, DATA CTR. FRONTIER (Apr. 28, 2020), https://datacenterfrontier.com/terabytes-from-space-satellite-imaging-is-filling-data-centers [perma.cc/NZ7X-J963].

163. J. Mason Heberling et al., *Data Integration Enables Global Biodiversity Synthesis*, PROC. NAT'L ACAD. SCI., Feb. 1, 2021, at 1, 2.

164. *See, e.g.*, Cláudio Rodrigues, *What Is Green Cloud Computing, and How Can Organizations Use It to Minimize Overall Carbon Footprint?*, PARALLELS (May 20, 2022), https://www.parallels.com/blogs/ras/what-is-green-cloud-computing [https://perma.cc/A6CV-7PFU] (explaining efforts to limit the environmental impact of cloud computing).

165. GREENGARD, *supra* note 120, at 13.

166. *Id.* at 11–12.

167. Luna et al., *supra* note 141, at 10; Martinez et al., *supra* note 130, at 80 (discussing smartphones enabling real-time linkages between field-based visual observations and internet-based identification, reporting, and mapping).

168. Klein et al., *supra* note 39, at § 3; Maged N. Kamel Boulos et al., *Crowdsourcing, Citizen Sensing and Sensor Web Technologies for Public and Environmental Health Surveillance and Crisis Management: Trends, OGC Standards and Application Examples*, INT'L J. HEALTH GEOGRAPHICS, Dec 21, 2011, at 67, 70.

169. Klein et al., *supra* note 39, at § 4.

170. *See id.* (describing the process of uploading data to cloud servers).

form of analog RF signals, which must be converted into digital signals by ground station antennas.[171] The market for these services is developing rapidly alongside the development of the commercial space industry.[172] Previously, ground stations were owned primarily by governments.[173] To address the needs of the rapidly expanding space industry, IT companies have begun offering complete integrated solutions for EOS data capture, server or cloud storage, global transmission through fiber optic networks, and data processing.[174] As in all other aspects of the economy, the business model for satellite services is moving away from fixed to variable costs, with ground station as a service (GSAS) emerging as a product. Already, major IT companies from Amazon Web Services, Microsoft Azure, and others are competing in this market.[175]

Across these applications, cloud computing is facilitating data gathering and storage on a variable cost basis and providing highly scalable access to computing and storage for researchers and applications operating in remote locations.[176] Use of enterprise owned servers is decreasing, yet many historical data are contained in such hardware.[177] These capabilities have been crucial in enabling the use of big data for a range of treaty purposes.

Cloud computing offers many benefits, but the simplest way to understand it is that it has made mainframe data storage available to individual users working at a distance. The growth in cloud computing has been a boon for scientific research, including in relation to treaty matters. Collaboration among researchers has been significantly enhanced.[178] Previously, researchers could collaborate through conventional Internet, telephone, or traditional mail applications, however, sharing data and working from the same materials was a much greater challenge. Inevitably, actors would forget something or fail to finish activities crammed into short occasional trips.[179] Today, researchers from

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171. ERIC ALLAIX, WORLD METEOROLOGICAL ORG. ORGANISATION MÉTÉOROLOGIQUE MONDIALE, ITU/WMO JOINT SEMINAR ON THE USE OF RADIO SPECTRUM IN METEOROLOGY, CLIMATE AND WATER: ESSENTIAL ROLE OF RADIO FREQUENCIES 9, https://www.itu.int/en/ITU-R/study-groups/workshops/RSG7-ITU-WMO-RSM-17/Documents/Essential%20role%20of%20radio%20frequencies%E2%80%8B%20for%20 meteorology.pdf [perma.cc/UTE9-ML85] (last visited Sept. 16, 2022).

172. *See* SPACE CAPITAL, *Space Investment Quarterly Q2 2022*, https://www.spacecapital.com/quarterly [https://perma.cc/CTU4-9PAU] (last visited Sept. 16, 2022) (noting a ten-year cumulative investment in spacecraft launches of $26B, compared to $23.3B in satellites, with a projection that "[s]atellite will soon surpass [l]aunch, fueled by the growth in satellite constellation numbers and capabilities.").

173. *Historical International Ground Stations*, U.S. GEOLOGICAL SURV., https://landsat.usgs.gov/historical-international-ground-stations [perma.cc/LFZ5-CACN] (last visited Sept. 16, 2022).

174. John Gilroy & Nora Zhan, *Microsoft Azure Orbital, Ground Station as a Service, and Dynamic Ground*, CONSTELLATIONS PODCAST (Sep. 23, 2020) https://www.kratosdefense.com/-/media/k/p/t/constellations-podcast-episode-84.pdf [perma.cc/T55N-3QLH] (transcript of audio recording).

175. *Id.*

176. *See, e.g.*, Élisabeth Ranisavljević et al., *A Dynamic and Generic Cloud Computing Model for Glaciological Image Processing*, 27 INT'L J. APPLIED EARTH OBSERVATION & GEOINFORMATION 109, 109 (2014) (discussing cloud computing in glaciological image processing); X. Z. Wang et al., *An Interactive Web-Based Analysis Framework for Remote Sensing Cloud Computing*, 2 ISPRS ANNALS PHOTOGRAMMETRY, REMOTE SENSING & SPATIAL INFO. SCIS. 43, 43 (2015).

177. Wang et al., *supra* note 176, at 44.

178. *Id.*

179. Ben Langmead & Abhinav Nellore, *Cloud Computing as a Platform for Genomic Data Analysis and Collaboration*, 19 NATURE REVS. GENETICS 208, 208 (2019).

all continents can collaborate with others around the world much more effectively. Among these benefits is to facilitate bringing researchers in the Global South into international research networks. Data can be collected through multiple channels simultaneously and analysis performed jointly.

Cloud computing can be done either using private infrastructure consisting of an entity's own hardware or public infrastructure, which involves the use of shared platforms.[180] For many organizations, the latter type of arrangement is preferable. Most of the large cloud computing vendors bundle data and statistical analysis services with their computing and storage products.[181] These include infrastructure as a service, platform as a service, software as a service, and data as a service.[182] An additional benefit of cloud computing is that users can receive information on their preferred devices, including mobile instruments. The information is also available to any user, anywhere, at any time.[183]

Cloud services have been important in the processing and gathering of geospatial data given the large volumes of data produced. The way cloud and distributed computing have enabled data analysis for treaty-relevant scientific research is described by Wang et al. in relation to global forest cover change from 2000–2012:

> Based upon analyses of massive quantities of Landsat data co-located in cloud storage, [the study] quantifies forest dynamics related to fires, tornadoes, disease and logging, worldwide. The analyses required over one million hours of CPU and would have taken more than fifteen years to complete on a single computer. But because the analyses were run on 10,000 CPUs in parallel in the Google cloud infrastructure, they were completed in less than four days. As cloud computing technology continues to evolve, placing remote sensing data into the cloud, and providing online interactive analysis services became more feasible.[184]

Illustrating similar workflows and collaboration to support research on cigarette packaging for FCTC monitoring, researchers from fourteen countries uploaded data to a cloud server, enabling lead researchers in Baltimore to monitor data quality and use among globally dispersed teams.[185]

Traditional on-premises servers that are owned by individual organizations and companies remain important repositories of much data, notably historical data in fields ranging from human rights, biodiversity, and genetics.[186] These

180. Ranisavljević et al., *supra* note 176, at 113.

181. AMAZON WEB SERVS. OVERVIEW OF AMAZON WEB SERVICES, https://docs.aws.amazon.com/whitepapers/latest/aws-overview/aws-overview.pdf [perma.cc/3TE8-XRG2] (last visited Sept. 16, 2022); Jorge T. Flores Callejas & Petru Dumitriu, Joint Inspection Unit, Managing Cloud Computing Services in the United Nations System, 14, U.N. Doc. JIU/REP/2019/5 (2019) [hereinafter U.N. Joint Inspection Unit].

182. UNITED NATIONS SATELLITE IMAGERY & GEOSPATIAL DATA TASK TEAM, *supra* note 51, at 14.

183. U.N. Joint Inspection Unit, *supra* note 181, at 14.

184. Wang et al., *supra* note 176, at 44.

185. Smith et al., *supra* note 153, at 5.

186. Joshua N. Cobb et al., *Next-Generation Phenotyping: Requirements and Strategies for Enhancing Our Understanding of Genotype–Phenotype Relationships and its Relevance to Crop Improvement*, 126

technologies play an important role for smaller projects as well as during the process of researchers gathering data on a smaller scale before processing. Edge computing, an approach to making computational capabilities more localized as a way of increasing speed and reducing bandwidth requirements, is one example of the continuing utility of traditional local servers.[187]

Most treaties today have some type of data collection and storage infrastructure that support operations and research.[188] In many cases the platforms are unique to the specific instrument, while in some cases data pertaining to multiple treaties are included. The CTBTO illustrates an approach to a dedicated system.

To gather the data from the dispersed network of sensing platforms in the IMS, the CTBTO Organization has created a centralized system for data capture and processing. The distributed IMS centers, which continuously monitor for signs of seismic, radionuclide, or hydroacoustic signals are linked together through the Global Communications Infrastructure (GCI), which gathers the IMS data at its base in Austria (the International Data Center or IDC).[189] Daily more than thirty-five gigabytes of data are being transmitted through the GCI from the monitoring stations or national data centers commensurate with the sensitive nature of the data.[190] The system is designed to ensure data integrity and availability and provide for encryption and authentication.[191] The GCI links all of the monitoring centers and the state signatories to the CTBTO. The communications network is designed to ensure that data transmitted to the IDC from the 337 facilities in the IMS occurs on a near real-time basis.[192] The IMS stations send different types of raw data to the IDC for storage and analysis through the dedicated global communications infrastructure.[193] After compiling and processing the IMS data, the IDC then distributes the data along with bulletins and reports to the member states.[194] There is a challenge in facilitating the distribution of this data and the reports to the dispersed IMS members. Various proposals have been made to improve these processes.[195]

A data center has also been created specifically for biodiversity conventions to manage massive data flows from biodiversity monitoring.

THEORETICAL & APPLIED GENETICS 867, 868 (2013); *see also* GLOB. BIODIVERSITY INFO. FACILITY, https://www.gbif.org [perma.cc/T5ED-XK6Y] (last visited Sept. 16, 2022) (demonstrating use of data in biodiversity studies).

187. Stephen J. Bigelow, *What Is Edge Computing? Everything You Need to Know*, TECHTARGET, https://www.techtarget.com/searchdatacenter/definition/edge-computing (last visited Sept. 16, 2022) [https:/perma.cc/E7VS-WDS3] (explaining edge computing and its uses).

188. *See* M. Z. Zolkaffly & F. I. A. Rashid, *The Comprehensive Nuclear-Test-Ban Treaty (CTBT): Seismic Monitoring*, 555 IOP CONF. SERIES: MATERIALS SCIENCE & ENG'G, no. 012010, 2019, at 1, 1 (explaining use of data collection and storage in monitoring the CTBT).

189. *Id.* at 2.

190. *The Global Communications Infrastructure*, CTBTO, https://www.ctbto.org/verification-regime/the-global-communications-infrastructure [perma.cc/K6CB-FH37] (last visited Sept. 16, 2022).

191. *Id.*

192. *Id.*

193. *Id.*

194. *Id.*

195. *See* Zolkaffly & Rashid, *supra* note 188, at 5 (describing a proposal to improve data collection for the CTBT).

Behind this data infrastructure is the Global Biodiversity Informatics Facility (GBIF). The GBIF is an open-data research infrastructure funded by governments and intended to provide persons everywhere with access to data about "all types of life on earth."[196] It is a multi-stakeholder initiative composed of IGOs, governments, and non-state actors. Its hybrid governance structure is composed of members which can be "a country, an economy, an intergovernmental or international organization, or an organization with an international scope."[197]

By creating common standards and open-source tools, GBIF enables sharing of information on recorded species.[198] It gathers historical information as well as contemporary data derived through crowdsourcing among professional scientists, citizen scientists carrying smartphones, remote-sensing devices, and earth observation technologies.[199] A key problem the GBIF seeks to address is that historical biodiversity data is often locked in museum drawers or printed publications, in isolated desktop computers, or incompatible digital formats, and in multiple languages.[200] Ongoing efforts seek to digitize those records, which are then combined with ongoing observation data coming from EOS, RS applications, and *in situ* sources.[201] The records in the GBIF are increasing at an exponential rate and now total nearly two billion.[202] Although the field of biodiversity monitoring is dominated by researchers and scientific organizations, the GBIF is making an effort to support gathering and inclusion of data sourced from citizen scientists and groups such as indigenous peoples, increasingly recognized as a crucial aspect of improving biodiversity monitoring practices.[203]

Similar dedicated data capture and storage systems have been created to support implementation of the APM Convention. The Geneva International Centre for Humanitarian Demining (GICHD) has developed the Information Management System for Mine Action (IMSMA), a comprehensive IT platform

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196. GLOB. BIODIVERSITY INFO. FACILITY, *supra* note 186.

197. GLOB. BIODIVERSITY INFO. FACILITY, https://www.gbif.org/become-member [perma.cc/GME8-EABT] (last visited Sept. 16, 2022).

198. Tim Robertson et al., *The GBIF Integrated Publishing Toolkit: Facilitating the Efficient Publishing of Biodiversity Data on the Internet*, PLOS ONE, Aug. 6, 2014, at 1, 1; Henrique Niza et al., *A Picture is Worth a Thousand Words: Using Digital Tools to Visualize Marine Invertebrate Diversity Data Along the Coasts of Mozambique and São Tomé & Príncipe*, ARPHA PREPRINTS, May 25, 2021, at 1, 2.

199. Niza et al., *supra* note 198, at 4–5.

200. GLOB. BIODIVERSITY INFO. FACILITY, GBIF STRATEGIC PLAN 2017-2021 2 https://assets.ctfassets.net/uo17ejk9rkwj/3UnrwAF9tC8siA644COw8W/5c0a0068364b0b632c1bf20ad2954a4b/GBIF-strategic-plan-2017-2021.pdf [perma.cc/8HGY-4TFJ] (last visited Sept. 11, 2022).

201. Heberling et al., *supra* note 163, at 2; Ana Claudia Sima et al., *Semantic Integration and Enrichment of Heterogeneous Biological Databases*, *in* EVOLUTIONARY GENOMICS: STATISTICAL AND COMPUTATIONAL METHODS 655, 656 (Maria Anisimova ed., 2d ed. 2019).

202. *See* Heberling et al., *supra* note 163, at 2 fig.1A (explaining that data available through GBIF have surged in the past decade, growing by 1,150% since 2007 (2007: 125 million; 2020: 1.6 billion occurrence records)).

203. *Id.* at 2 (finding that volunteer members of the public accounted for sixty-five percent of data added to the GBIF in 2020).

that provides support for decision-making, monitoring, and reporting.[204] IMSMA was developed by the GICHD for the UN Mine Action Service and was launched in 1998.[205] The platform has been revised periodically since that time. IMSMA is a fundamental tool in demining activity today, enabling users to gather, store, and analyze data and geographic information on mined areas.[206] The GICHD has made creating and maintaining an up-to-date and fit-for-purpose information management system a core function of its work. Given the critical importance of ensuring accuracy in the information maintained about mine action as a consequence of the hazards of getting it wrong, the system has been designed to ensure a high degree of precision and quality control.[207] It has also made the process more efficient, therefore economizing resources. Information management from mine action has a crosscutting role in all of its strategic objectives and contributes to key outcomes of its strategies.[208] Over time, it has become "the *de-facto* standard [information management] tool in mine action."[209]

IMSMA supports data collection in the field, data processing, and the preparation of maps of areas contaminated by land mines or other UXO.[210] Other functions include the ability to define tasks, producing reports, drawing on data or statistics, printing maps, business intelligence capability, and even measuring the impact of planned demining activities to assist in determining priorities and make projections for the results from the de-mining activities.[211]

After maintaining IMSMA as a proprietary system for decades, the GICHD has recently joined forces with the Environmental Systems Research Institute (ESRI) to integrate IMSMA fully with the world's leading GIS platform, ArcGIS, to create what is now called IMSMA Core.[212] The new system is web and cloud-based, which overcomes limitations of the prior PC-based model, and now enables multiple diffuse mine action professionals to use the system simultaneously.[213] It is also modular, allowing diverse communities of users in the humanitarian community—including human rights, refugee support, food distribution, education, finance, agriculture, peacekeeping and disarmament agencies—to access components directly relevant to their work.[214]

204. GENEVA CTR. FOR INT'L HUMANITARIAN DE-MINING, *Welcome to IMSMA Wiki*, http://mwiki.gichd.org/IM/Main_Page [perma.cc/BYW6-JYNH] (last visited Sept. 16, 2022).

205. *Id.*

206. *Id.*

207. Interview with GICHD IMSMA Staff (Feb. 18, 2021).

208. Fourth Review Conference of the States Parties to the Anti-Personnel Mine Ban Convention, *Oslo Action Plan*, 5, U.N. Doc APLC/CONF/2019/5/Add.1 (Nov. 29, 2019).

209. GENEVA INT'L CTR. FOR HUMANITARIAN DEMINING, IMSMA DEVELOPMENT STRATEGY BRIEF 2 (May 2015), https://www.gichd.org/fileadmin/GICHD/topics/information-mgmt/IMSMA-Strategy-2015-2018.pdf [perma.cc/C5ZN-NKRK].

210. OPERATIONAL INTEL., *Taking the Next Technological Steps in Eradicating Landmines*, ARCNEWS (2018), https://www.esri.com/about/newsroom/arcnews/taking-the-next-technological-steps-in-eradicating-land-mines [perma.cc/8N5Q-ELCF].

211. *Id.*

212. *Id.*

213. *Id.*

214. *Id.*

To facilitate data collection, the system uses Survey123 and Collector for ArcGIS which are web and mobile enabled, and use the cloud for data storage.[215] Once input, data undergo basic quality control.[216] They are then uploaded to a national database.[217] From there, the managers of national mine action programs can determine priorities and assign teams to remediate mined areas.[218] As areas are cleared, the new data is fed back into the national database through web and mobile devices, providing decision makers with up to date information on progress.[219]

In contrast to the model of dedicated data collection and storage infrastructure for one or a select number of treaties, data for human rights is gathered through a variety of communications technologies and maintained in multiple databases. Much data is transmitted through cellular communications technologies and Internet connections.[220] Data may also be shared by social media and or messaging platforms, which pose new challenges to ensuring the reliability and retaining the data.

An example of the ways in which data on human rights has been gathered, stored, and verified can be seen in an innovative project developed by the Eyewitness to Atrocities NGO.[221] The project involves an app that allows human rights monitors to upload data to a secure cloud-based server.[222] The platform facilitates capture of time and location data in multiple locations and creates digital fingerprints of images that make them non-editable.[223] The purpose of the site is to assure that data collected can be used as evidence before courts and tribunals.[224]

As Eyewitness to Atrocities states, "reliability in relation to photos or videos requires the time/date/location of the recording, assurance that the video has not been altered, and assurance that the footage is the original version."[225] Oftentimes the applications used to gather data of human rights violations do not include that type of metadata and must be manually entered or processed using emerging machine learning applications.

Data storage for human rights purposes serves multiple functions and requires consideration of multiple technical and policy factors. At a basic level, preserving data pertaining to human rights violations requires serious efforts to ensure stability and safety of the location.[226] While data pertaining to all

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215. *Id.*
216. *Id.*
217. *Id.*
218. *Id.*
219. *Id.*
220. *Our Work*, EYEWITNESS TO ATROCITIES, https://www.eyewitness.global/our-work [https://perma.cc/4N9N-8H4E] (last visited Sept. 16, 2022).
221. *Welcome to eyeWitness*, EYEWITNESS TO ATROCITIES, https://www.eyewitness.global [https://perma.cc/XN9K-4J4F] (last visited Sept. 16, 2022).
222. *Id.*; EYEWITNESS TO ATROCITIES, *supra* note 220.
223. EYEWITNESS TO ATROCITIES, *supra* note 221.
224. *Id*.
225. *See* Poblet & Kolieb, *supra* note 8, at 270 (quoting the eyeWitness to Atrocities project on views about legal authentication of footage).
226. Aronson, *Preserving Human Rights Media*, *supra* note 8, at 83.

multilateral treaties have value and need to be preserved, data about the general conditions and specific regulatory performance of those agreements is different than proof of specific wrongdoing that might be introduced in legal proceedings. Loss of primary documentation of human rights matters has implications for legal proceedings and other types of human rights accountability mechanisms. A further purpose, albeit not directly related to legal processes, is the maintenance of historical records that show the events that occurred.

Storage of the information is also particularly important given the sensitivity of human rights data, however, there is a degree of fragmentation with the available options. The Responsible Data Forum has published a handbook which provides guidance on preserving human rights data.[227] Recently, the UN High Commissioner for Human Rights and the Berkeley Human Rights Center partnered to draft the Berkeley Protocol on Digital Open Source Investigations.[228] Academic institutions and NGOs including the Open Society Institute, Duke University, and Columbia University all maintain archives that have been used by different groups.[229] The Internet Archive is another location that can ensure for preservation of web-based material.

A particular challenge involving retention of video and images of human rights abuses and war crimes is the frequency with which such data may go missing.[230] There are a variety of explanations for this tendency. The creator or uploader of data may decide that maintaining it would be too risky: in some cases these persons can be threatened, hosting platforms can be removed because they violate standards or regulations, companies posting the data may shut down accounts of human rights perpetrators thus removing their own evidence, and hackers can remove material.[231] To address this issue a so-called "evidence locker" has been created to maintain human rights media that could be removed from content platforms to ensure long-term preservation.[232]

As the foregoing shows, data collection and retention have become central to work supporting multilateral treaties. Significant numbers of treaty regimes have dedicated platforms for data collection and storage, and it seems reasonable to expect that such services will be considered essential to the operations of multilateral agreements. While this type of data infrastructure supports work of parties, international organizations, and treaty bodies, it is noteworthy the extent to which the open-source nature of these platforms enables non-state

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227. *Human Rights Documentation Manila, March 25 2015*, RESPONSIBLE DATA https://responsibledata.io /event/human-rights-documentation [https://perma.cc/EQ6H-G3NW] (last visited Sept. 16, 2022).

228. *Berkeley Protocol on Digital Open Source Investigations*, U.C. BERKELEY HUM. RTS. CTR., https://humanrights.berkeley.edu/programs-projects/tech-human-rights-program/berkeley-protocol-digital-open-source-investigations [https://perma.cc/662B-J7KN] (last visited Sept. 16, 2022).

229. *See Human Rights Institute,* COLUM. L. SCH., https://web.law.columbia.edu/human-rights-institute/initiatives/about [https://perma.cc/RZ6H-CBK8] (last visited Sept. 16, 2022) (demonstrating other academic institutions archives); *Human Rights Archive*, DUKE UNIV., https://library.duke.edu/rubenstein/ human-rights [https://perma.cc/22UH-RRC3] (last visited Sept. 11, 2022) (same); *Human Rights Initiative*, OPEN SOC'Y FOUNDS., https://www.opensocietyfoundations.org/who-we-are/programs/human-rights-initiative [https://perma.cc/PF27-ZGWY] (last visited Sept. 11 2022) (same).

230. Aronson, *Preserving Human Rights Media*, *supra* note 8, at 83.

231. *Id.*

232. *Id.*

communities of researchers, academics, NGOs, and citizens to contribute data directly through these systems. The utility of these ubiquitous data storage systems for research and collaboration involving these diverse communities holds significant promise.

C. Data Processing and Analysis

While it might seem that ever larger quantities of data could be an unmitigated good, a common constraint all ITS face is the difficulty of analyzing the firehose of data that the sensing-transmission-storage complex generates.[233] Data gathered through IOT used in species monitoring, for instance, may include two orders of magnitude more data than would be gathered by observers in the field in the past.[234] Rapid and exponential improvements in data processing and analysis for learning and identifying connections between data—the third element of ITS—are thus a crucial means of managing these conditions. The use of RS and digital observation tools is tightly connected to data science tools such as machine learning, which is used to process and analyze this data. Notwithstanding the robust debate about the potential of artificial intelligence, the real workhorse in all of the treaty-related technology described here is machine learning.[235]

Data processing involves a fairly standard set of activities used by researchers who study aspects of treaty regimes across a range of different disciplines. These processes can be broken down into three main steps. The first is authentication, whereby data is checked to ensure its validity.[236] The second step involves verification in which data is examined to determine the identity of the object or persons believed to be captured in the data.[237] Third is a process of classification or coding of the data to assign categories that can be used for subsequent analysis.[238] Tremendous improvements in these processes have become possible in recent years through massive growth in computing power, which has now become widely and economically available through bundled cloud computing services and distributed computing.[239] To analyze gigabyte and even petabyte size datasets, parallel computing algorithms and scalable architecture are needed.[240] In addition, individual software packages, such as the

233. Gray et al., *supra* note 100, at 353; Klein et al., *supra* note 39, at § 6; Lamba et al., *supra* note 139, at R977 ("[L]imited capacity of conventional techniques to analyse these massive amounts of data is now a major bottleneck for practitioners.").

234. Klein et al., *supra* note 39, at § 4.

235. DANIEL SUSSKIND, A WORLD WITHOUT WORK: TECHNOLOGY, AUTOMATION, AND HOW WE SHOULD RESPOND 52 (2020).

236. *See* Poblet & Kolieb, *supra* note 8, at 271 (explaining in the human rights context, there are specific standards for authenticity based on evidence law).

237. *Id.* at 271–72.

238. JAMES D. MILLER, STATISTICS FOR DATA SCIENCE: LEVERAGE THE POWER OF STATISTICS FOR DATA ANALYSIS, CLASSIFICATION, REGRESSION, MACHINE LEARNING, AND NEURAL NETWORKS 39–40 (James C. Mott et al. eds., 2017).

239. SHROFF, *supra* note 2, at 268–74.

240. Yun Li et al., *Big Data and Cloud Computing*, *in* MANUAL OF DIGITAL EARTH 325, 337 (Huadong Guo et al. eds., 2020).

R statistical language and ArcGIS, consolidate multiple software packages in single environments and enable multidisciplinary contributions in integrated platforms.[241] The combination of improved computing power and Internet connectivity has facilitated dramatic improvements in machine learning, which is critical to data classification. Machine learning and its progeny, deep learning, are enabling automation of critical activities, improving efficiency, and increasing data throughput.[242]

Historically, classification was carried out manually by researchers or data scientists.[243] One of the biggest challenges facing data science is reducing the amount of human analysis of data. Increasingly, these processes are becoming wholly or partially automated, which is delivering orders of magnitude improvements in the volume of data that can be processed.[244] The automation of data processing and classification can facilitate significant increases in data throughput, quality, and speed.[245] By removing the need for human analysis of data, we can not only gain real-time imaging of occurrences like mass human rights abuses but also crucially real time analysis of patterns and practices. Essentially, machine learning and AI are shortening the time lag between data generation and analysis.

The process of gathering and analyzing data proceeds oftentimes in an iterative fashion. One of the benefits of machine learning is that:

> [C]omputer scientists do not hard code rules of action that a system uses to do the exact same thing every time; rather, they give the system the capacity to recognize patterns, trends, or categories in "training" data provided by the programmer and then to use those discoveries to analyze another set of data that has not yet been processed.[246]

Moreover, researchers are continuously engaged in processes of identifying better ways of gathering data and analyzing the results. Models that have been developed based on available data can be refined and updated as new data, which can be used to train subsequent algorithms, becomes available. These developments suggest that existing capabilities will only improve with time.

Similarly, deep learning works by employing computational models composed of stacks of processing layers that are iteratively applied to data to obtain increasingly refined representations of the data.[247] Deep learning enables scaling of machine learning algorithms by automating the process to apply much

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241. Debra P. C. Peters et al., *An Integrated View of Complex Landscapes: A Big Data-Model Integration Approach to Transdisciplinary Science*, 68 BIOSCIENCE 653, 654 (2018).

242. Eda Kavlakoglu, *AI vs. Machine Learning vs. Deep Learning vs. Neural Networks: What's the Difference?*, IBM CLOUD, (May 27, 2020), https://www.ibm.com/cloud/blog/ai-vs-machine-learning-vs-deep-learning-vs-neural-networks [https://perma.cc/UJB6-X4E9].

243. Brett A. Bryan, *High-Performance Computing Tools for the Integrated Assessment and Modelling of Social–Ecological Systems*, 39 ENV'T MODELLING & SOFTWARE 295, 295 (2013).

244. *Id.* at 296.

245. Lamba et al., *supra* note 139, at R977.

246. Aronson, *Computer Vision*, *supra* note 8, at 1193.

247. ANAND DESHPANDE & MANISH KUMAR, ARTIFICIAL INTELLIGENCE FOR BIG DATA: COMPLETE GUIDE TO AUTOMATING BIG DATA SOLUTIONS USING ARTIFICIAL INTELLIGENCE 124 (Sunith Shetty et al. eds., 2018).

greater numbers of training examples and computational cycles.[248] Computers thus can organize the data and then learn by training themselves on the data.[249] Deep learning applications are crucial to enable data processing, classification, and analysis of data collected through all of the IOT applications.

Deep learning involves iterative analysis of data designed to provide ever more precise differentiation of data.[250] Within the field of deep learning, the subfield of convolutional neural networks (CNN), has been particularly useful for visual object recognition (often referred to as computer vision), speech recognition, and genomics.[251] Across the regimes studied, CNN have proven an immensely powerful tool that appears likely to play a major role in identifying objects in visual data, particularly as the technology continues to improve.

One of the most significant developments in machine learning has occurred in relation to organizing unstructured data. Structured data is processed by a human and then can be analyzed using software.[252] Aspects of the process can be streamlined through automation but the need for human oversight slows the process.[253] More challenging and difficult to automate are unstructured data. As algorithms become more sophisticated through iteration and inclusion of greater amounts of training data, these capabilities are becoming more powerful. These approaches can be combined with techniques for processing and analyzing structured data, providing for very robust and high throughput capabilities for exploiting the massive quantities of data being generated through various sensor and other input sources. Despite the increasing functionality of automated systems, human analysts are still often needed to assign data to categories, however, this situation is changing rapidly.

Another branch of machine learning, computer vision, is being used to analyze video, audio, or photographs. Advantages of machine learning and computer vision are to enable search of large volumes of video for features or incidents of interest, support synchronization and geolocation of large collections of data on different events that lack metadata and draw connections between them.[254] This means that rather than rely on one perspective of a single moment, analysts can draw on large volumes of video shot from multiple perspectives.[255] Applications such as Microsoft Pix enable users to combine multiple images of the same event and create a single 3D image.[256]

There are a vast range of data processing and categorization approaches available. I will focus on RS data and visual data. For EOS and other RS data,

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248. Lamba et al., *supra* note 139, at R977.

249. *Id.*

250. Klein et al., *supra* note 39, at § 4.2.2.

251. *Id.*; Arshad et al., *supra* note 35, at 1.

252. *Structured vs. Unstructured Data: What's the Difference?*, IBM CLOUD EDUCATION (June 29, 2021) https://www.ibm.com/cloud/blog/structured-vs-unstructured-data [https://perma.cc/4QRH-A4BG].

253. DESHPANDE & KUMAR, *supra* note 247, at 18.

254. Aronson, *Computer Vision*, *supra* note 8, at 1190; Geoffrey French et al., *Convolutional Neural Networks for Counting Fish in Fisheries Surveillance Video*, *reprinted in* PROCEEDINGS OF THE MACHINE VISION OF ANIMALS AND THEIR BEHAVIOR (Telmo Amaral et al. eds 2015).

255. Aronson, *Computer Vision*, *supra* note 8, at 1190.

256. *See id.* at 1203. (discussing superimposing visual evidence onto 3D models).

visual interpretation involving the manual identification of features within photos or images is often undertaken first.[257] For all types of RS and visual data, machine learning is often applied using both supervised and unsupervised approaches. These applications are representative of the types of functionalities that are available for treaty purposes. The approach to analyzing EOS and other RS data differs from the analysis of video and film images. Each will be described separately.

A representative example of the processing of RS data can be seen with the CTBTO. The data gathered in the IMS for the CTBTO are subject to a variety of processing steps, many of which are automated. Computers process data pertaining to both wave form and radionuclides. Data captured by the IMS are analyzed using what the CTBTO secretariat calls "event screening."[258] Data of unknown seismic events, for instance, are compared to data from earthquakes to separate relevant data from irrelevant data.[259] Likewise, algorithms are used to process evidence of radionuclides to distinguish it from background meteorological conditions.[260] Because given events may be sensed by multiple stations in the IMS, the IDC must also combine the inputs and reconcile the data in assessing the nature of the seismic events.[261] Likewise, due to the tremendous sensitivity of the IMS sensors, great efforts must be made to distinguish between the tens of thousands of types of terrestrial movements occurring daily—be they geologic or other natural phenomena, industrial or other man-made causes, or nuclear tests.[262]

Similar use of machine learning can be seen in the completely different context of biodiversity. Across the different fields of biodiversity monitoring, machine learning is being used to process the diverse data flows. Machine learning assists in the classification of images and other data to clarify climate, ecosystems, and species coverage. Data can be classified manually, but increasingly structured and unstructured classification approaches are being used.[263] Data harvested through mechanical devices for species observation for the biodiversity conventions can then be analyzed through automated processes. Examples include data analysis involving habitat and species monitoring for such diverse subjects as sea turtles, plant phenotyping, forests, mangroves, and ocean microorganisms.

257. Witmer, *supra* note 8, at 2329; Knoth & Pebesma, *supra* note 78, at 274.

258. *Glossary*, CTBTO, https://www.ctbto.org/glossary/?letter=e&cHash=388a6c115d08e381a0ce8081826a6213 [https://perma.cc/Z6QN-HMFR] (last visited Sept. 16, 2022) ("In the CTBT context, an 'event' is any physical occurrence that is registered by the International Monitoring System, be it a natural or a manmade event, an earthquake or an explosion, a chemical or a nuclear explosion. With regards to determining the nature of an event, Members States make the final judgement.").

259. Zolkaffly & Rashid, *supra* note 188, at 3–4.

260. Wolfango Plastino et al., *Radioxenon Time Series and Meteorological Pattern Analysis for CTBT Event Categorisation*, 167 PURE & APPLIED GEOPHYSICS 559, 559–60 (2010).

261. Johnathan L. Burnett et al., *The 2014 Integrated Field Exercise of the Comprehensive Nuclear-Test-Ban Treaty Revisited: The Case for Data Fusion*, 189 J. ENV'T RADIOACTIVITY 175, 175 (2018); Christophe Millet, et al., *Bayesian Association of Multiple Infrasound Events Using Long-Range Propagation Models*, 144 J. ACOUSTICAL SOC'Y AM. 1728, 1728 (2018).

262. Burnett et al., *supra* note 261, at 177.

263. Taylor et al., *supra* note 35, at 134.

Digital images transmitted from EOS are manipulated and interpreted through specific digital image processing software techniques.[264] The steps include "(a) remote sensing data import; (b) radiometric correction; (c) geometric correction; (d) image enhancement; (e) image classification; (f) map generation (for output of maps)."[265] Different material being imaged will emit different electromagnetic radiation band frequencies.[266] Each image has corresponding numbers of pixels that indicate brightness levels. Processing begins with radiometric and geometric correction, and association with map coordinates to add other spatial data. Subsequent aspects of the processing involve image classification.

The calibration and consistency of EOS data will affect the demands and ability of machine learning functions. For lower resolution data with comparable pixel sizes, machine learning can be used more easily.[267] For higher resolution images, the precision of the images and lack of continuous data—some regions may not have been visited for years—may make comparisons more difficult.[268] High-resolution imagery can enable recognition and segmenting of images on the ground, but also raises challenges concerning issues such as dataset shift and model generalization.[269]

Experience in EOS data processing concerning human rights illustrates some of the technical challenges involved. While there have been important advances in automating the process of classifying and identifying events in EOS-sourced human rights data, capabilities are still at an early stage. A key issue is the resolution of the images. For EOS-generated high-resolution imagery of less than 1-meter, common objects such as buildings or vehicles can be identified but not people (other than shadows or crowds); in contrast, drone imagery may provide imagery down to 10 cm, thus enabling identification of individuals.[270] More precise images can provide greater insights and more reliable proof of violations, yet the resolution of images reduces the possibility of using the same algorithms across different data sources.[271] For low-resolution data, "machine learning modes can be transposed across space and time on this data relatively easily."[272] For high-resolution data provided by satellites such as World View and Pleiades, data is only transmitted on a "tasking basis" and thus the data from areas where requested is a "patchwork of images at different places and times."[273] Complicating matters further, the cameras used, even on the same satellite, are rotated to capture the requested images so "even images of the same place taken by the same satellite at different times may not be directly

264. FROEHLICH & TĂIATU, *supra* note 53, at 176.
265. *Id.*
266. *Id*.
267. Quinn et al., *supra* note 61, at 3.
268. *Id.*
269. *Id*.
270. *Id.* at 2–3.
271. Witmer, *supra* note 8, at 2329; Quinn et al., *supra* note 61, at 3.
272. Quinn et al., *supra* note 61, at 3.
273. *Id*.

comparable."[274] Despite the potential utility of high-resolution data, issues of dataset shift and model generalization are limiting conditions.[275] Although "increasing the degree of automation would…. [provide] results more quickly, and … take advantage of the increasing availability of high-resolution satellite data to provide more frequent updates," Quinn et al., caution that "routine deployment of machine learning-based systems for these purposes have so far been elusive."[276]

A further illustration of these tools can be seen with forestry data. Earlier approaches involved manual classification of geographic regions to train machine learning algorithms.[277] More recently data mining has emerged as a technique for classifying datasets and predicting causal relationships.[278] One novel approach to unsupervised classification involves spectral clustering, which groups satellite observations into clusters based on similarity metrics.[279] To underscore the novelty of this technique, it has only been feasible to use on RS data since 2018. Other approaches have emerged to address issues of bias or the representativeness of data used to train algorithms in particular geographies which may have distinctive seasonal, biometric, or cultural differences.[280] For monitoring wetlands in support of the Ramsar Convention on Wetlands of International Importance, heterogeneity of land makes classification difficult, and wetlands as a class have much wider variations than ordinary land.[281] In the context of land cover mapping, differences in classification schemes can cause disagreement in classification results and makes comparison and synergistic use of maps "challenging if not impossible."[282] An approach called conditional generative adversarial networks, a branch of neural networks, has been used to learn and distinguish transformations between different geographies.[283] These approaches are enabling improved accuracy and reducing the cost of generating data in specific geographies.

For fishery treaty compliance, data analysis involves vessel tracking and electronic monitoring systems. A variety of machine learning applications have been used to process and analyze data obtained through AIS and VMS systems. Among these applications are algorithms used to identify and reconcile gaps in AIS data transmission, calculate hours fished, and clean data of ship lights to remove noise, as well as using CNN to understand fishing behaviors.[284] These

274. *Id.*; Witmer, *supra* note 8, at 2329.

275. Quinn et al., *supra* note 61, at 3.

276. *Id.* at 2.

277. Taylor et al., *supra* note 35, at 134.

278. *Id.* at 132.

279. *Id.* at 134.

280. *Id.*

281. Kun Ma et al, *A Hybrid Wetland Map for China: A Synergistic Approach Using Census and Spatially Explicit Datasets*, PLOS ONE, Oct. 23, 2012, at 1, 6.

282. Peng Gong et al., *Finer Resolution Observation and Monitoring of Global Land Cover: First Mapping Results with Landsat TM and ETM+ Data*, 34 INT'L J. REMOTE SENSING 2607, 2616 (2013).

283. Guoshuai Dong et al., *A Shadow Constrained Conditional Generative Adversarial Net for SRTM Data Restoration*, REMOTE SENSING ENV'T, Dec. 18, 2019, at 1, 3.

284. de Souza et al., *supra* note 86, at 2–5; Ford et al., *supra* note 99, at 2; Oozeki et al., *supra* note 92, at 65–66; Andrey A. Kurekin et al., *Operational Monitoring of Illegal Fishing in Ghana Through Exploitation of*

models are built upon machine learning and deep learning algorithms.[285] Tracking of vessels through AIS and VMS combined with other data sources have enabled a variety of models to be developed to predict the likelihood that given vessels are engaged in fishing, thereby enabling determination of possible treaty violations.[286] As the number of vessels implementing AIS or VMS systems increases, as a result of regulatory requirements or industry practices such as installing the devices in ship hardware, the amount of data available will increase, which should help improve the reliability of these models.

To illustrate, the NGO Oceanmind uses a combination of collision-avoidance transponders, radar images, satellite imagery, and cell phone signals to track boats.[287] It has also developed algorithms to predict types of fishing behavior based on location in order to identify suspicious activity.[288] Oceanmind has transferred its data analytics to the Microsoft cloud service Azure.[289] This shift enables data analysis to occur on a near real time basis, thus improving its ability to support government enforcement of illegal fishing activity as it is happening.

One approach to determining possible illegal fishing activity is to analyze vessel behavior and determine the likelihood that AIS devices have been intentionally disabled. Ford developed a statistical model to identify gaps in AIS transmission, which allows judgment as to whether a gaps in transmissions are due to intentional action or other causes.[290] Similar studies have been carried out in the Northwest Pacific[291] and Ghana.[292] Another satellite-based system was developed by Kingfisher.[293] Its Image Sat International System applies deep learning algorithms to EOS images correlating this data to RS data such as AIS, radar satellite imagery, electro-optical satellite imagery, VMS, coastal radar, open-source intelligence, and weather patterns to determine vessels with AIS turned off.[294]

Automation of data processing has been done successfully for data generated by IOT applications. For species monitoring, "camera systems with the ability to capture and automatically classify images of wildlife in real-time using deep learning can be used to avert possible human-wildlife conflict

Satellite Earth Observation and AIS Data, REMOTE SENSING, Feb. 1, 2019 at 1, 17; Feng-Chi Hsu et al., *Cross-Matching VIIRS Boat Detections with Vessel Monitoring System Tracks in Indonesia*, REMOTE SENSING, Apr. 26, 2019, at 1, 3–23 (2019).

285. Kurekin et al., *supra* note 284, at 3.

286. *See* Feng-Chi Hsu et al., *supra* note 284, at 3.

287. *See Fisheries Compliance*, OCEANMIND, https://www.oceanmind.global/what-we-do/fisheries-compliance [https://perma.cc/4D2U-LXAJ] (last visited Sept. 16, 2022).

288. *Costa Rica Combats Illegal Fishing with Help from OceanMind and the Government of Canada*, OCEANMIND https://www.oceanmind.global/insights/costa-rica-combats-illegal-fishing-with-help-from-oceanmind-and-the-government-of-canada [https://perma.cc/KM3C-T63Q] (last visited Sept. 16, 2022).

289. *AI for Earth Partners*, MICROSOFT, https://www.microsoft.com/en-us/ai/ai-for-earth-oceanmind [https://perma.cc/9C86-KHJM] (last visited Sept. 16, 2022).

290. Ford et al., *supra* note 99, at 2.

291. Oozeki et al., *supra* note 92, at 65–66.

292. Kurekin et al., *supra* note 284, at 17.

293. *Persistent Maritime Surveillance*, KINGFISHER, https://www.imagesatintl.com/home/data-analytics/kingfisher [https://perma.cc/LX99-WLA2] (last visited Sept. 16, 2022).

294. *Id.*

situations by alerting people to the presence of wild animals such as large carnivores."[295] New types of wireless sensor networks can be used in forest monitoring as well.[296] Some of these sensors have built in capabilities for integrated data mining such as clustering or anomaly detection, which can streamline machine learning data analysis and improve throughput.[297] To scale the ability of analysts to review data, deep learning can be used to progressively train computational models to detect and classify events of interest, resulting in a reduction in the amount of data reviewed by humans by orders of magnitude.[298] Deep learning algorithms use a ranked selection of visualized data to enable predictions of the probability that a given event is from a particular data class, in this case that an image corresponds to the species being monitored.[299] Previous techniques of manually analyzing data were time consuming and impractical with the size of data being generated by IOT devices. Manual processing of RS data of species is being supported by crowdsourcing platforms, with volunteers classifying images.[300]

For mobile RS, such as UAV, deep learning has been used to process imagery datasets for species monitoring. Based on the data collected using cameras mounted on UAVs to identify migrating sea turtles, the workflow was created to use a manually labeled set of data, which was then used to train and validate the CNN.[301] After training, the CNN was used to test the full dataset. Through successive testing of the dataset and cleaning of the data to eliminate noise, the model was developed, which was able to determine the probability that an image was of a turtle.[302] After reviewing the results against manual counting, the researchers found their model correctly identified eighty-nine percent more turtles than manual counting.[303] Similar results can be expected in other fields where "similarly noisy and imbalanced datasets" can deliver "increasing precision, improving detection of rarer image variants and saving considerable time relative to the brute-force manual inspection of all data."[304]

For visual data obtained through camera and video, computer vision has been used for such purposes as monitoring fish catch through electronic monitoring devices. These devices include cameras, video recorders, GPS, and other types of sensors to record or document catches.[305] Generally, EM has been used in fisheries in developed country jurisdictions such as the US, EU, Canada, Australia, and New Zealand.[306] Among the benefits of EM are cost efficiency, the ability to provide more representative coverage of fleets than observer or inspection systems, and improved registration of fishing activities and

295. Lamba et al., *supra* note 139, at R979.
296. Taylor et al., *supra* note 35, at 135.
297. *Id.*
298. Klein et al., *supra* note 39, at § 4; Lamba, *supra* note 139, at R977.
299. Lamba et al., *supra* note 139, at R977–79.
300. Steenweg et al., *supra* note 47, at 30.
301. Gray et al., *supra* note 100, at 347–48.
302. *Id.*
303. *Id.* at 352.
304. *Id.* at 353.
305. van Helmond et al., *supra* note 90, at 163.
306. *Id.* at 167–69.

locations.[307] EM systems allow automated review of images to determine fishery treaty compliance.[308]

For images of specific events in which human rights violations occur, footage can be analyzed by combining machine learning and computer vision. These techniques can be used to detect specific objects, segment multiple objects, monitor objects over time and space, provide three-dimensional reconstructions of objects and or scenes, and determine the location of the camera in time and space.[309] To perform these analyses, various approaches are used "including color analysis, shadow and illumination analysis, geometrical analysis of curves and edges, and photogrammetry," which involves "mathematical and geometric techniques to [t]ake measurements within an image."[310] To address distortion in the underlying images, computer scientists are attempting to develop tools that improve image clarity and resolution.[311]

Computer vision can be used for many purposes relevant to human rights investigation involving video or audio recordings. It can be used to detect specific objects such as "tanks, missiles, helicopters, airplanes, military vehicles, particular styles of building, soldiers in camouflage, large crowds, corpses, and visually distinct geographic locations like bridges over water, mountainous terrain, or a desert. . . ."[312]

It can also identify, "detect and tag [specific] sounds [such as] gunshots, explosions, cries, or screams."[313] Detection of events as opposed to specific objects is more computationally complex because it includes numerous semantic concepts (objects, sounds, scenes, and actions) in a dynamic setting. These types of video images, whether taken by professional camera operators or through social media, lack the kind of structure of video taken in other situations, which complicates the analysis. These elements require the development of "novel classifiers on the fly."[314]

In analyzing evidence of human rights abuses and potential war crimes, machine learning and computer vision, metadata analysis, and geolocation methods have been used to sort, identify, preserve, and analyze the data.[315] Benetech has worked with the United Nations International Impartial and Independent Mechanism On Syrian Accountability to create an index of the unique "fingerprints" representing each piece of potential evidence that is able to connect decentralized datasets without the need to share sensitive documentation.[316] Based on this index, researchers can duplicate, triage, and

307. *Id*. at 180–81.
308. *Id.*
309. Aronson, *Computer Vision*, *supra* note 8, at 1194.
310. *Id.*
311. *Id.* at 1195.
312. *Id.*
313. *Id.*
314. *Id.* at 1196.
315. *Id.* at 1203–1205.
316. BENETECH, BENETECH JUSTICEAI: TURNING CONFLICT DATA INTO ACTIONABLE EVIDENCE (2020), https://benetech.org/wp-content/uploads/2019/11/Benetech_JusticeAI_Overview_05_11_2020.pdf [perma.cc/ET6S-7MFN].

prioritize documentation for review by investigators and analysts, identifying videos and photos that have not yet been analyzed and facilitate coordination between civil society groups for effective, efficient review and analysis, and assist the mechanism to work more efficiently and digest structured data from human rights organizations.[317] The fingerprints developed for each video can identify relationships between videos, even if they have been edited and manipulated, using automated processing abilities. Benetech boasts a ninety-nine percent recall and precision rate for these techniques.[318]

As this discussion shows, data processing techniques across diverse treaty regimes have become much more powerful through data science innovations, notably machine learning. These capabilities can be seen in relation to diverse types of data. From EOS to acoustic and video monitoring of species and human rights abuses, machine learning is automating and speeding the processing of data, even as data flows are increasing.[319] The combination of these developments is creating improved levels of knowledge about conditions and regulatory performance of many types of multilateral treaties.

Data processing capabilities such as these are powerful contributors to enabling treaty bodies to oversee and take proactive approaches to compliance. Improved data processing and analysis can play positive roles in contributing to the types of cooperation predicted by managerialist theories of treaty compliance expounded by writers such as Chayes and Chayes.[320] Similarly, these technologies can contribute to reputational drivers of compliance.[321] As will be seen in the next section, these data can become even more powerful with additional technology-enabled tools.

D. Modeling, Mapping, and Visualization

The fourth element of ITS involves transforming processed data into tools that facilitate understanding by users and predictions about future trends and developments. While gathering data about conditions and performance of different treaties is important for the sake of expanding knowledge and informing decision making, without further action, data does not enable judgments to be made about the future. Models, maps, and other visualizations enhance the utility of data greatly and support more effective regulation. Modeling provides a means of translating data into frameworks that can make tangible possible future scenarios and outcomes based on patterns and interactions between the matters identified in the data.[322] As they become more sophisticated, the models enable users to experiment with changing variables to simulate possible outcomes. Models may not provide complete accuracy and are

317. *Id.*
318. *Id.*
319. *Id.*
320. CHAYES & CHAYES, *supra* note 19.
321. GUZMAN, *supra* note 19, at 33.
322. Complexity by the Santa Fe Institute, *Andrea Wulf on The Invention of Nature, Part 1: Humboldt's Naturegemälde*, SANTA FE INST., at 12:46 (May 20, 2021), https://complexity.simplecast.com/episodes/60 [https://perma.cc/SQ7J-TJ8D] (suggesting that Alexander von Humboldt had "basically invented data visualization").

not crystal balls, but they can provide a basis for making predictions about future scenarios. Modeling is thus crucial in helping translate enhanced knowledge into policy and legal action. Likewise, "[i]n a world of 'Big Data' and open government, the visual display of data has become central to how we understand social problems and their potential solutions."[323] Underscoring the importance of visualization to policy and decision making, Henrique Niza et al. noted that "[a]s biodiversity and habitat loss rates increase, it is crucial that we develop a simpler and more effective way of incorporating all biodiversity data into interactive digital platforms, such as web maps, and encourage the open sharing of data, so that the scientists, analysts and policymakers can apply it to research and policy decisions."[324] This judgment is equally valid across different fields of international law.

While models, mapping, and visualization facilitate comprehension of data, they involve different approaches. Modeling will typically encompass an entire system or portion thereof and seek to simulate or replicate its functioning. Visualization and mapping represent aspects of data in ways that illustrate specific instances to which data relates or characterizes its meaning in some way. These tools can also be used to separate models.

1. Modeling

Examples of the use of models abound in treaty-related work. Models are used in the environmental field as the basis of the Intergovernmental Panel on Climate Change (IPCC),[325] Global Environmental Outlook,[326] and Global Biodiversity Outlook reports,[327] which analyze and predict likely environmental outcomes from existing conditions. In arms control, data from seismic and radionuclide sensors support the development of models to determine the most likely source of seismic events or atmospheric radionuclide material.[328] In human rights, models are less developed, but are increasingly being used to understand events, causes, trends, or estimate numbers of victims.[329] As described earlier, models are used to calculate the likelihood that ships being monitored remotely are engaged in illegal fishing.[330]

323. Katharina Rall et al., *Data Visualization for Human Rights Advocacy*, 8 J. HUM. RTS. PRAC. 171, 172 (2016).

324. Niza et al., *supra* note 198, at 3.

325. *IPCC Data*, IPCC, https://www.ipcc.ch/data [https://perma.cc/23YM-PLN9] (last visited Sept. 30, 2022).

326. *The Future of the Global Environment Outlook*, UN ENV'T PROGRAMME, https://www.unep.org/global-environment-outlook [https://perma.cc/9TH4-GN3R] (last visited Sept. 30, 2022).

327. *Global Biodiversity Outlook (GBO)*, CONVENTION ON BIOLOGICAL DIVERSITY, https://www.cbd.int/gbo/ [https://perma.cc/LL8N-CC9F] (last visited Sept. 30, 2022).

328. Pieter De Meutter et al., *Assessment of the Announced North Korean Nuclear Test Using Long-Range Atmospheric Transport and Dispersion Modelling*, SCI. REPS., Aug. 18, 2017, at 1, 1; ALAN DOUGLAS, FORENSIC SEISMOLOGY AND NUCLEAR TEST BANS, 46–47 (2013).

329. Patrick Ball & Megan Price, *Using Statistics to Assess Lethal Violence in Civil and Inter-State War*, 6 ANN. REV. STATS. & ITS APPLICATION 63, 76–77 (2019).

330. van Helmond et al., *supra* note 90, at 162.

The most complex and rigorously tested modeling efforts for any treaty purposes have been undertaken for the IPCC. Following the development of the first weather models in the 1950s by Lewis Fry Richardson, in 1967 Syukuro Manabe and Richard Wetherald developed models that demonstrated that increasing carbon dioxide concentrations in the atmosphere would raise the altitude at which the planet would radiate heat back into space.[331] From there, Manabe collaborated with others to create the first simulation of the climate for the entire planet in 1969, which brought together ocean and atmospheric models, thereby establishing the oceanic role in global climate.[332] From the 1970s to 1980s, Manabe's research group generated extensive research focusing on the sensitivity of the climate to changes in greenhouse gas concentrations.[333] General Circulation Models or General Climate Models are among the most complex models.[334] To validate and refine models, scientists use multiple iterations.[335] First, they do a "control run" to verify if known climate features, such as ocean and atmospheric currents, captured in the model function consistent with empirical evidence.[336] Next, scientists run the model on changing variables, so-called climate "forcings" or drivers of climate change, such as "solar activity, volcanic eruptions, changing greenhouse gas concentrations," and human-induced changes including deforestation.[337] Then, the model is compared to actual results to see whether it accurately fits.[338] Rather than static constructions, "[c]limate models are living scientific tools that are constantly evolving rather than pieces of software built to achieve a certain goal."[339] Illustrating the distinct yet converging nature of ITS components of sensing and modeling, Bauer et al. write that "[t]he ongoing step change in the physical content of Earth system models is making them amenable to approaches that harmonize the physical laws they encode with ever more extensive observations to provide the best possible estimate of the state of our planet."[340]

The IPCC employs a great deal of effort in developing climate models and refining them and publishes extensive reports describing the process. A key participant in these efforts is the World Climate Research Program.[341] Over time, climate models have become ever more precise and comprehensive in their

331. G. THOMAS FARMER, MODERN CLIMATE CHANGE SCIENCE: AN OVERVIEW OF TODAY'S CLIMATE CHANGE SCIENCE 63 (2014).

332. *Id.*

333. *Id.*

334. Lauren Harper, *What Are Climate Models and How Accurate Are They?*, COLUM. CLIMATE SCH.: CLIMATE, EARTH, & SOC'Y (May 18, 2018), https://news.climate.columbia.edu/2018/05/18/climate-models-accuracy [https://perma.cc/KC3X-UG9D].

335. FARMER, *supra* note 331, at 63.

336. *Id.*

337. *Id.*

338. *Id.*

339. *Id.* at 64.

340. Peter Bauer et al., *A Digital Twin of Earth for the Green Transition*, 11 NATURE CLIMATE CHANGE 80, 80 (2021).

341. *World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project Phase 3 (CMIP3) Multi-Model Dataset*, U.S. GLOB. CHANGE RSCH. PROGRAM, https://www.globalchange.gov/browse/datasets/world-climate-research-programmes-wcrps-coupled-model-intercomparison-project-phase [https://perma.cc/8W6V-UKGA] (last visited Sept. 16, 2022).

ability to forecast changes.[342] Weather models provide important precedent for these developments. In the past 50 years, weather models have become incredibly accurate down to local scales covering relatively short time frames.[343] In contrast, climate models have enabled long-term predictions based on overall climate change over climate time scales.[344] As has become abundantly clear, the changes occurring in the climate globally are having short term effects today, requiring models that can capture "both very high-resolution" insights *and* "overall Earth system process complexity."[345]

One approach currently in development is the notion of a "digital twin" of Earth, which "combines simulations and near-real-time observations to monitor the evolution of the Earth system."[346] A critical enabler of such a system is improved computing power.[347] As illustrated in relation to data capture and processing, here too, advances in modeling have been made possible through step-by-step improvements in hardware coupled with programming.[348] Given the incredibly demanding requirements of realizing the next generation of climate models, current computing power will not suffice.[349] As we approach the end of Moore's law, there is a need for new approaches to provide the computing power needed.[350] Estimates are that performing calculations for the digital twin system would require 20,000 Graphic Processing Units, using 20 MW of electricity.[351] Significant collaboration and mobilization of resources will be needed to realize these aspirations.[352] Overall, the developments in climate models illustrate the tightly coupled relationship between ITS components including data capture, storage, computational ability, and modeling. The challenges seen in this context may be a harbinger of how modeling can improve in other fields of international law as technology and science advance.

Models are also used in other areas of international law, such as refugee and humanitarian law. A project by the UN High Commissioner for Refugees (UNHCR) provides a good illustration of the way modeling and prediction can be applied.[353] In seeking to anticipate forced displacement expected to occur in a border region of Somalia, UNCHR researchers gathered data on a variety of

342. Peter Bauer et al., *The Digital Revolution of Earth-System Science*, 1 NATURE COMPUTATIONAL SCI. 104, 107 (2021).

343. *Id.* at 104–05.

344. *Id.* at 104–05.

345. *Id.* at 105.

346. *Id.* at 107; Michael G. Kapteyn et al., *A Probabilistic Graphical Model Foundation for Enabling Predictive Digital Twins at Scale*, 1 NATURE COMPUTATIONAL SCI. 337, 337 (2021).

347. Bauer et al., *supra* note 342, at 107–08.

348. *Id.* at 108.

349. *Id.* at 104–05.

350. David Rotman, *We're Not Prepared for the End of Moore's Law*, MIT TECH. REV. (Feb. 24, 2020), https://www.technologyreview.com/2020/02/24/905789/were-not-prepared-for-the-end-of-moores-law [https://perma.cc/XYW8-YNS5].

351. Bauer et al., *supra* note 342 at 110. The environmental implications of these electricity demands are discussed in Section III below.

352. Bauer et al., *supra* note 342 at 110–11.

353. Earney & Jimenez, *supra* note 81, at 113.

factors that could influence the likelihood of people being forced to migrate.[354] Drawing on data sets on some of the most significant causes of displacement in the region in the past, the team used statistical calculations and machine learning to analyze the data. The factors assumed to explain potential movements included avoidance of conflict or epidemiological zones, forms of assistance and financial support available, surface water availability, and membership in particular ethnic groups.[355] This data was supplemented with data from sources not typically used by UNHCR. In addition, qualitative interviews of affected people caused UNHCR to add new data to the overall mix.[356] This data was combined with historical data on arrivals and departures of refugees and internally displaced people.[357]

The data was anonymized and aggregated by region using a time-series format.[358] Using the historical data, the machine learning and other applications identified the best fit for the data and best output that explained what had occurred in the past.[359] Based on this understanding, models could be developed to predict the number of arrivals per region and per month.[360] The UNHCR team tested the model repeatedly and used statistical techniques to select the best performing models. Ultimately, after multiple attempts, they were able to predict numbers of arrivals in 13 out of 19 regions studied.[361] These types of forecasts can enable preparation and planning for possible large scale humanitarian crises, thus helping achieve better outcomes.

Significant efforts are also underway to make models shareable across different domains. If models can be consolidated and used across different regimes or sectors, they can become even more powerful as data is added. Gradually, over several decades, systems for model sharing have been consolidating.[362] To facilitate sharing of models in the environmental context, the OpenMI Association was developed.[363] As the name suggests, it is based on an open-source approach to sharing models across a wide range of environmental management practices.[364] The latest version of the system is the OpenMI 2.0 standard.[365]

Other examples include the use of web technologies, the so-called "model web," which uses the "model as a service" approach "towards the

354. *Id.* at 113–14.
355. *Id.* at 113.
356. *Id.*
357. *Id.*
358. *Id.*
359. *Id.*
360. *Id.*
361. *Id.* at 116.
362. Zeqiang Chen et al., *A Framework for Sharing and Integrating Remote Sensing and GIS Models Based on Web Service*, SCI. WORLD J., May 11, 2014, at 1; Stefano Nativi et al., *Environmental Model Access and Interoperability: The GEO Model Web Initiative*, 39 ENV'T MODELLING & SOFTWARE 214, 214 (2012).
363. *See* Glenn Letham, *The OGC and OpenMI Association to Advance Computer Modelling Standards*, GISUSER (Aug. 25, 2011), https://gisuser.com/2011/08/the-ogc-and-openmi-association-to-advance-computer-modelling-standards [https://perma.cc/Y6B5-T8SC] (describing the association).
364. *Id*.
365. Quillon K. Harpham, et al., *Introductory Overview: The OpenMI 2.0 Standard for Integrating Numerical Models*, ENV'T MODELLING & SOFTWARE, Oct. 22, 2019, at 1.

implementation of integrated modeling systems layered on environmental information infrastructures."[366] In this approach, geospatial processing algorithms, models, and data are all made available as services which are integrated into workflows for integrated environmental modeling.[367] These approaches are still in development but portend greater sharing of models in the future.

2. Visualizations

Many of the technology-enabled applications used for treaties generate visualizations based on data obtained through other ITS processes. Visualization technologies ranging from video to mapping enable the translation of raw data into forms that are understandable among ever widening audiences. A prevalent and central technology is GIS, which converts data from EOS into highly functional visual tools that make data understandable and accessible to a range of users.[368] More recently, browser technologies such as Google Earth, NASA World Wind, Microsoft Virtual Earth, and ESRI's Arc GIS Explorer have provided millions of scientists and ordinary citizens with friendly graphic interfaced geospatial data.[369]

Examples of mapping include habitat mapping for biodiversity protection. Habitat mapping has been carried out by using a combination of remote sensed and *in situ* research.[370] Habitats can be understood as "physical expressions of biodiversity, covering a certain area with specific compositions and spatial features."[371] Habitat mapping, relying on EO data and new powerful data analysis tools, complements data obtained through *in situ* surveys of very localized phenomena.[372] The ability of RS to provide maps that differentiate between types of habitats is primarily a function of the resolution of the data and the complexity and heterogeneity of landscapes.[373] Moreover, different types of habitats will differ in the level of detail and accuracy of mapping.[374]

One of the more ambitious projects for mapping biodiversity is the Map of Life. It is a searchable website that enables users to see a vast number of maps

366. Nativi et al., *supra* note 362, at 214.

367. *Id.*

368. *See* B. Husseini & Zuhdi Bali, *Documentation, Using GIS Techniques in Conservation of a World Heritage Site, A Case Study of "The Old City of Jerusalem,"* XL-5/W7 INT'L ARCHIVES PHOTOGRAMMETRY, REMOTE SENSING & SPATIAL INFO. SCI. 229 (2015) (describing historic preservation in accordance with World Heritage Convention and other relevant conventions).

369. Guo et al., *supra* note 35, at 111–12; Taylor et al., *supra* note 35, at 131 ("Once accessible only through paper maps (or not at all), forest monitoring data has become widely available through online geoportals and databases that are simple for non-experts to use.").

370. Taylor, et al., *supra* note 35, at 130.

371. Stefan Lang et al., *Earth Observation for Habitat Mapping and Biodiversity Monitoring*, 37 INT'L. J. APPLIED EARTH OBSERVATION & GEOINFORMATION 1, 1 (2015).

372. *Id.* at 1–2.

373. Bin Jiang, *Geospatial Analysis Requires a Different Way of Thinking: The Problem of Spatial Heterogeneity*, 80 GEOJOURNAL 1, 1–13 (2014).

374. Thomas Strasser & Stefan Lang, *Object-Based Class Modelling for Multi-Scale Riparian Forest Mapping*, 37 INT'L. J. APPLIED EARTH OBSERVATION & GEOINFORMATION 1, 29–37 (2015).

pertaining to species and habitats of flora and fauna.[375] Information on the spatial extent of species, patterns such as the richness and rarity of species, and datasets are available on the site.[376] The Map of Life also has a mobile app, which citizen scientists can use to record information on species.[377] Since it was launched in 2013, the Map of Life has become a valuable resource for research on biodiversity.

Similar web-based tools are available in relation to forestry. The Global Forest Watch dashboard allows users to gain insights into land cover and forest change at the national and subnational levels.[378] Global Forest Watch Pro "combines remote sensing data and cloud computing" to enable companies to assess the risk of tree cover loss from locations where they source timber.[379] Through the application, users can identify the precise areas where they are purchasing timber to avoid contributing to deforestation.[380] In addition to these tools, new instruments such as NASA's spaceborne LIDAR instrument GEDI, have been developed and will enable mapping of biomass and forest structure and thereby quantify carbon in forests.[381] Through greater cloud computing capacity, more imagery data can be processed and with the application of machine learning such as advanced neural networks, more precise monitoring, and even predictions of forest change may soon be possible.[382]

In mine action, the ArcGIS program enables mapping of mine contaminated areas with great detail. Following the gathering of physical location data for landmines, mine action professionals develop contamination models, which become progressively more complex as more data is added from data collection in the field.[383] The GIS system allows mine action professionals to prioritize through scenario planning. As an example, if some type of public works construction is needed such as an irrigation system, authorities can overlay a map of the proposed project on top of the map of land mine contamination to determine priority areas for demining.[384] Capturing the importance of mapping to translating data into useful tools, Mohammed Qasim Hashimi, global information management advisor for Norwegian People's Aid stated "as soon as you put data onto the map, it's not data anymore . . . it becomes information. GIS gives the data its meaning."[385]

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375. MAP OF LIFE, https://mol.org [https://perma.cc/3XKW-UPPM] (last visited Sept. 16, 2022).

376. *Id*.

377. *Id.*

378. GLOB. FOREST WATCH, https://www.globalforestwatch.org [https://perma.cc/PD7U-HSGM] (last visited Sept. 16, 2022).

379. Taylor et al., *supra* note 35, at 136.

380. GLOB. FOREST WATCH, *supra* note 378. *But see*, Philip G. Curtis et al., *Clarifying Drivers of Global Forest Loss*, 361 SCI. 1108, 1108–11 (2018) (noting that Global Forest Watch mapping may erroneously attribute all forest loss (such as forestry) to deforestation, when in reality the loss may be temporary rather than permanent).

381. Taylor et al., *supra* note 35, at 131.

382. *Id*.

383. Ryan Lanclos, *Remnants of War: Smart Maps Help Teams Locate and Remove Land Mines*, ESRI BLOG (Mar. 4, 2020), https://www.esri.com/about/newsroom/blog/mapping-apps-guide-demining-efforts [https://perma.cc/5A5R-E25Z].

384. *Id.*

385. *Id.*

In the human rights context, a huge number of projects have been undertaken to map different issues. Many of these initiatives have drawn on spaceborne and UAV data sources.[386] Mapping and visualization in human rights can be used to illustrate matters such as violence in communities, human rights violations, trends and patterns, development and realization of economic, social, and cultural rights, and power structures relevant to human rights.[387] Amnesty International has outlined an approach to community-based mapping of human rights.[388] These types of maps may include cartographic or conceptual depictions.[389] Among the methods that have been used for conceptual mapping, are diagrammed or schematic maps, and tactical maps that show actors and relevant institutions. Maps of landscapes include social development and cultural maps.[390] All of these approaches can be undertaken in collaboration with communities. Other mapping approaches may be more technology-driven. In recent years, with improvements in technology, new approaches to mapping and visualization have been developed, which provide significantly enhanced insights into human rights situations.

To illustrate, the organization SITU Research has developed interactive platforms for mapping evidence of human rights abuses.[391] In a project pertaining to attacks on Rohingya villagers in Myanmar, SITU created a tool which brings together multiple evidence sources, such as testimony, video, and photos to provide spatial context.[392] The project built on EOS data to provide neutral basemaps that captured the broader landscape.[393] Against this background, more detailed images of terrain are added and combined with time series data.[394] Users can view chained animations that track movements of refugees. The net result is a virtual re-creation of the areas and changes that occurred over time. This project was undertaken for Amnesty International.[395] SITU did a similar project for the ICC Office of the Prosecutor in relation to Timbuktu, Mali.[396] The tool allows users to see the big picture and zoom in to specific details from photographs on the ground. Rather than requiring investigators to imagine scenes where crimes may have occurred, SITU's tool provides an overall view of the scenes.[397]

An additional approach to human rights mapping is crisis maps. Poblet and Kolieb provide a helpful breakdown of the features of crisis mapping for human

386. Wolfinbarger, *supra* note 8, at 466–67.

387. AMNESTY INT'L, MAPPING FOR HUMAN RIGHTS 1 (2017), https://www.amnesty.nl/content/uploads/2017/01/mapping_for_human_rights.pdf?x56589 [https://perma.cc/HPX2-7HZE].

388. *Id*. at 2.

389. *Id.*

390. *Id.* at 10.

391. *Mapping Myanmar's Atrocities Against Rohingya*, AMNESTY INT'L & SITU RSCH., https://mapping-crimes-against-rohingya.amnesty.org [https://perma.cc/GM8N-P9XJ] (last visited Sept. 16, 2022).

392. *Id*.

393. *Id*.

394. *Id*.

395. *Id*.

396. *Case Against M. Al Mahdi*, INT'L CRIM. CT. OFF. PROSECUTOR & SITU RSCH., http://icc-mali.situplatform.com [https://perma.cc/MQ9T-WKSB] (last visited Sept. 16, 2022).

397. *Id*.

rights. They describe (a) the use of social media to perform some of the monitoring, (b) gathering of diverse sources of digital cartography, (c) use of crowdsourcing or microtasking, and (d) automation typically through AI.[398] As seen in the forced displacement context, gradually, with the growth of big data, RS, and machine learning, algorithms are starting to enable predictions in relation to human rights crises.[399]

Illustrating the interplay of multiple technologies and the power of crowdsourcing, social media has been used to collect text, photos, and video reports in Syria to track local conflict.[400] These data have been used create live maps that visualize the scope of the conflict.[401] The approach used in that application is designed to obtain information on every incident and every victim, rather than large-scale population data obtained in aggregate.[402] This approach to crowdsourcing data will support big data type analysis rather than survey or other statistical sampling. These data are obtained through digital volunteers who have also supported the work of international organizations and NGOs.[403]

Mapping projects have also been undertaken to track transboundary movement in hazardous waste. In 2013, the Basel Convention Secretariat launched a new interactive tool that provides a visual depiction of annual transboundary movement of hazardous waste.[404] The information in the tool was drawn from state party reports under the Basel Convention from 2006 to 2010 and it enables users to view countries' production, import, and export of hazardous waste.[405] Users can clearly identify the flow of waste between each exporting country and those countries importing it. The platform also allows users to generate graphs comparing different states' activities.[406] Despite the apparent utility of the platform it has not been updated to track subsequent years. Other global mapping efforts on transboundary movement of hazardous waste have been undertaken by INTERPOL as part of a project to address illegal trade in hazardous waste[407] and UNEP in its report on global illegal waste trade.[408]

Modeling and visualization tools are critical to the potential impact of ITS because they provide a bridge between scientific knowledge, strategy, and

398. Poblet & Kolieb, *supra* note 8, at 262.

399. *Id.* at 268; Knoth & Pebesma, *supra* note 78, at 274.

400. Poblet & Kolieb, *supra* note 8, at 263.

401. *Id*.

402. *Id*. at 263–64.

403. *Id*. at 267.

404. *Data Visualization Tool for the Basel Convention on the Generation, Export and Import of Hazardous Wastes and Other Wastes*, BASEL CONVENTION http://www.basel.int/Countries/NationalReporting/DataVisualizationTool/tabid/3216 [https://perma.cc/28FB-NAPU] (last visited Sept. 11, 2022).

405. *Id*.

406. *Id*.

407. *Operation 30 Days at Sea 3.0 Reveals 1,600 Marine Pollution Offences Worldwide*, INTERPOL (Apr. 29, 2021), https://www.interpol.int/en/News-and-Events/News/2021/Operation-30-Days-at-Sea-3.0-reveals-1-600-marine-pollution-offences-worldwide [https://perma.cc/MWA9-WUEG].

408. I. RUCEVSKA, ET AL., WASTE CRIME — WASTE RISKS: GAPS IN MEETING THE GLOBAL WASTE CHALLENGE, U.N. ENV'T. PROGRAMME, 53–61 (2015), https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/27/original/RRA_WasteCrime_screen.pdf [https://perma.cc/F4U6-VER8].

decision making.[409] The complexity of the topics addressed by multilateral treaties are substantial. Notwithstanding our ability to understand data at a conceptual level, modeling helps us make sense of the data and use it to understand future scenarios. In addition, humans can relate to visual material more immediately than with abstractions.[410] At the very least, modeling and visualization provide alternative ways of understanding data generated by ITS.[411] The value of these types of tools for decision making and engagement of broader segments of the policy community and general public suggests that they deserve prioritization and resources from treaty bodies and stakeholders. Although the development of these types of comprehensive modeling and visualization tools are incomplete and heterogeneous across regimes, it appears likely that they will continue to be improved and that they will play increasingly important roles in applying and devising multilateral treaties in the future.

As with improved data processing and analysis capabilities, modeling, mapping, and visualization tools provide treaty bodies with new ways of assessing compliance, monitoring implementation, and improving regime effectiveness. The tools may be useful at both the international and domestic levels to promote compliance. At the domestic level, visualization and mapping can catalyze domestic constituencies more directly and powerfully than in the past.[412] These tools may affect voters' preferences with respect to government efforts to comply with treaty obligations.[413]

At the international level, these tools help drive cooperation among states parties as envisaged by Chayes and Chayes.[414] By making the stakes clearer, visualization, modeling, and mapping support "states' general propensity to comply."[415] In particular, it helps states identify and understand how their national interests are positively or negatively advanced by compliance. As conditions change, these tools enable states to recognize them and update their views of why compliance may support their interests.

E. Performance Indicators

Data creation and curation serves many functions in ITS, however, a significant and growing purpose is to populate indicator frameworks developed for multilateral treaties. The fifth element of ITS, performance indicators, have become increasingly common as part of broader treaty management practices. Across diverse treaty regimes, data feeds into frameworks of indicators that correspond to targets or act as criteria to judge the performance of treaty

409. *See, e.g.*, JONATHAN SCHWABISH, BETTER DATA VISUALIZATIONS: A GUIDE FOR SCHOLARS, RESEARCHERS, AND WONKS 397 (2021); SARAH WILLIAMS, DATA ACTION: USING DATA FOR PUBLIC GOOD (2020).

410. *The Psychology Behind Data Visualization*, TREEHOUSE TECH. GRP., https://treehousetechgroup.com/the-psychology-behind-data-visualization [https://perma.cc/U2MP-H68W] (last visited Sept. 16, 2022).

411. Rall et al., *supra* note 323, at 171.

412. Dai, *supra* note 2, at 369–70.

413. *Id*.

414. CHAYES & CHAYES, *supra* note 19.

415. *Id.* at 3.

regimes.[416] These frameworks have been developed by treaty bodies to measure the results of the activities involved in implementation and other aspects of treaty operations. Often these indicators have been derived from strategic frameworks developed for those same treaties.[417] Treaty bodies have increasingly employed indicator frameworks to measure progress. In addition, the UN Sustainable Development Goals (SDG) provide a set of goals, targets, and indicators, many of which are drawn from multilateral treaties or correspond to indicators for the treaties.[418] With the continued approach to results-based management in public sector organizations and the routine use of evaluation to analyze government performance, it is likely that indicators will remain an important part of the treaty landscape.[419]

The CBD offers one of the more compelling examples of how indicators are used in conjunction with technology enabled data gathering. Data obtained through technological instruments feed into the monitoring of the Aichi Biodiversity Targets adopted for the 2011-2020 Strategic Plan for Biodiversity.[420] Under the Aichi Targets, a set of 97 indicators has been developed to measure results.[421] To make providing the data for the indicators more manageable, GEO has developed a smaller set of 22 "essential biodiversity variables" (EBV) to measure biodiversity conditions and trends.[422] The EBV are defined at levels of specificity that are intermediate between the aggregated indicators for the Aichi Targets overall and low-level or primary observations.[423] The EBV were conceived and developed following the initiative to create Essential Climate Variables for the FCCC.[424] GEO BON led the development of the EBV as a way of facilitating monitoring to understand the changes in Earth's biodiversity.[425] Together, implementation of the EBVs requires cooperation from scientists and the operators of the research infrastructure.

The UNCCD illustrates the ways data collection for treaty strategies and indicator frameworks interrelate with the SDGs. In the UNCCD 2018-2030 Strategic Framework, the parties define a vision to achieve a land degradation-

416. MCINERNEY, *supra* note 4, at 234–68.

417. *Id.*

418. Steffen Fritz et al., *Citizen Science and the United Nations Sustainable Development Goals*, 2 NATURE SUSTAINABILITY 922, 922 (2019).

419. *See generally*, EDUARDO MISSONI & DANIELE ALESANI, MANAGEMENT OF INTERNATIONAL INSTITUTIONS AND NGOS: FRAMEWORKS, PRACTICES, AND CHALLENGES (2014) (describing how international organizations are managed and coordinate with each other).

420. SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, STRATEGIC PLAN FOR BIODIVERSITY 2011–2020 AND THE AICHI TARGETS, https://www.cbd.int/doc/strategic-plan/2011-2020/Aichi-Targets-EN.pdf [perma.cc/92ZP-8TAF] (last visited Sept. 16, 2022).

421. CONVENTION ON BIODIVERSITY, GENERIC AND SPECIFIC INDICATORS FOR ASSESSING PROGRESS IN THE ATTAINMENT OF THE AICHI BIODIVERSITY TARGETS, INCLUDING AN ASSESSMENT OF THEIR MAIN CHARACTERISTICS, https://www.cbd.int/doc/strategic-plan/strategic-plan-indicators-en.pdf [perma.cc/V7PH-E9LY] (last visited Sept. 16, 2022).

422. GEO BON, *Essential Biodiversity Variables*, https://geobon.org/ebvs/what-are-ebvs [perma.cc/Q99U-WHNL] (last visited Sept. 16, 2022)

423. *Id*.

424. Frank E. Muller-Karger et al., *Advancing Marine Biological Observations and Data Requirements of the Complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) Frameworks*, FRONTIERS MARINE SCI., June 27, 2018, at 1, 2–3.

425. *Id.*

neutral world.[426] The concept of a net zero-land degradation has been a continuing priority for the convention for many years and preceded the SDGs, so that when the SDGs were adopted, target 15.3 committed to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world."[427] To measure progress against this target, indicator 15.3.1 was adopted which seeks to measure the "[p]roportion of land that is degraded over total land area."[428]

Indicator 15.3.1 is a binary indicator and is quantified based on an analysis of data available for three sub-indicators that national authorities must validate and report on.[429] The sub-indicators correspond to the three "progress indicators" for Strategic Objective 1 in the UNCCD Strategic Framework ("[t]o improve the condition of affected ecosystems") and includes (1) trends in land cover, (2) land productivity, and (3) carbon stocks.[430] These indicators were also adopted by the UNCCD governing body in 2013 as part of its monitoring and evaluation system.[431] Its monitoring and evaluation approach consists of indicators, a conceptual framework that facilitates the integration of indicators, and indicator sourcing mechanisms at the national and local level.[432] Under the principle of "the one out, all out", if any of the sub-indicators is negative compared to the baseline or previous monitoring year for any specific land unit, then that unit is considered degraded, subject to validation by national authorities.[433]

A variety of organizations are responsible for monitoring and reporting on this data including the Secretariat for the UNCCD and partners, FAO, the UN Statistics Division, UN Environment, the UNFCCC and the CBD.[434] The data sources for the various sub-indicators include the European Space Agency, Catholic University of Leuven, NASA, and the EU Copernicus program, among others.[435] The relationship between the international data gathering and national authorities is typical and a function of principles of diplomacy.[436] National validation and interpretation can involve mixed methods research including

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426. U.N. Conference on Convention to Combat Desertification, *Report of the Conference of the Parties on its Thirteenth Session*, 9, U.N. Doc. ICCD/COP(13)/21/Add.1 (Oct. 23, 2017) [hereinafter Desertification Thirteenth Session], https://www.unccd.int/sites/default/files/sessions/documents/2017-11/cop21add1_eng.pdf [https://perma.cc/P7BY-SCPR].

427. G.A. Res. 70/1, at 24, Transforming Our World: The 2030 Agenda for Sustainable Development (Oct. 21, 2015).

428. SDG Indicator Metadata: Target 15.3, U.N. STAT. DIV. (Mar. 31, 2022), https://unstats.un.org/sdgs/metadata/files/Metadata-15-03-01.pdf [https://perma.cc/DC8E-8C49].

429. *Id.*

430. Desertification Thirteenth Session, *supra* note 426, at 24.

431. Convention to Combat Desertification Res. 22/COP.11, U.N. Doc. ICCD/COP(11)/23/Add.1, ¶ 3 (Sept. 20, 2013).

432. *Id.*

433. U.N. STAT. DIV., *supra* note 428.

434. *Id.*

435. *Id.*

436. *Id.* ("In the absence of, to enhance, or as a complement to national data sources, good practice suggests that the data and information derived from global and regional data sets should be interpreted and validated by national authorities.").

multiple sources of information both quantitative and qualitative consisting of Google Earth images, field surveys or combinations of those sources.[437] Once the data is received, the UNCCD will validate the data in collaboration with national and international counterparts.[438]

Similar to these environmental indicators, the parties to the APM Convention have developed a series of indicators to support implementation of the Oslo Action Plan, which is a strategic framework for priority activities from 2020 to 2025.[439] The information used to assess progress against the indicators is primarily derived from the parties' reports under Article 7 of the Convention.[440] Baseline values for the indicators were determined based on data reported in the first year of implementation pursuant to Article 7.[441] Progress will be tracked based on those baselines.

In relation to the survey and clearance of mines, under the Oslo Action Plan, parties have agreed to 10 specific actions, all of which are subject to one or more indicators.[442] Overall, the approach to remediation of mined areas emphasizes the need for evidence-based and accurate work plans, mapping of mined areas, and continuing improvements to those practices as well as the application of technology generally. To illustrate, for Action 18 concerning gathering accurate data on the precise geographical areas with mines and contamination levels, two indicators were chosen.[443] One relates to the percentage of parties with accurate and evidence-based contamination baselines.[444] The second relates to the percentage of parties which established their baselines through inclusive consultations with women, girls, boys, and men.[445] Other indicators relate to the numbers of parties adjusting their national strategies and remediation activities in light of improved evidence on contamination.[446] Data on levels of contamination are generally derived from national de-mining programs, which typically rely on IMSMA to gather and retain such data.[447]

To review progress against the Oslo action plan, the Mine Action Review initiative was launched with support of the Norwegian and Swiss governments.[448] The Mine Action Review report is published regularly in

437. *Id.*

438. *Id.*

439. Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on Their Destruction, *Fourth Review Conference of the States Parties to the Convention on the Prohibition of the Use, Stockpiling, Prod. and Transfer of Anti-Personnel Mines and on Their Destruction*, APLC/CONF/2019/5/Add.1 at 12 (2020) [hereinafter Anti-Pers. Mines Fourth Rev. Conf.], https://www.osloreviewconference.org/fileadmin/APMBC-RC4/Fourth-Review-Conference/Oslo-Review-Conference-final-report-en.pdf [https://perma.cc/9FWM-ZLQ7].

440. *Id*. at 28–29.

441. *Id.* at 35.

442. *Id*. at 38–40.

443. *Id*. at 38.

444. *Id*.

445. *Id*.

446. *Id*.

447. MINE ACTION REVIEW, A GUIDE TO THE OSLO ACTION PLAN AND RESULTS OF 2020 MONITORING: SURVEY AND CLEARANCE 8 (Feb. 1, 2021), https://www.mineactionreview.org/assets/downloads/A_Guide_to_the_Oslo_Action_Plan_and_Results_of_2020_Monitoring.pdf [https://perma.cc/KVH4-649D].

448. *Id*. at 2.

connection with the meeting of states parties to the APM convention. The report monitors 24 indicators from the Oslo action plan relevant to survey and clearance, and diverse sources for monitoring progress against the indicators are used.[449] These include official state reports under the convention, statements in United Nations mine action director group meetings and other relevant forums, and other information directly provided to the report writers from mine action actors including United Nations, the GICHD, the Organization for Security and Cooperation in Europe, among other actors.[450]

As an example of the items reviewed, action item 9 calls for parties to "[e]stablish and maintain . . . national information management system[s] containing accurate and up-to-date data at the national level on the status of implementation."[451] As an indicator for this action item, the plan seeks to measure the percentage of mine affected states parties that report having a sustainable national information system in place.[452] Hence for the report, a baseline was whether or not states parties had a functioning mine action database in place.[453] According to the report, 20 of 29 affected states parties assessed met the baseline value, with some states showing unclear results, and other states in the process of upgrading or migrating their systems.[454]

Likewise for action number 18 which calls states to "identify the precise perimeter of mined areas, to the extent possible, and establish evidence-based, accurate baselines of contamination based on information collected from all relevant sources no later than by the Nineteenth Meeting of the States Parties in 2021."[455] As an indicator for this action item, the plan stipulates that the percentage of affected parties that have established accurate evidence-based contamination baselines would be used. Only three of twenty-nine affected states assessed satisfied this criteria.[456] The report noted that "in many instances the baseline is assessed not to be accurate or evidence-based" thus explaining the low number of states meeting the baseline.[457] The basis for determining the accuracy and evidence base for this action item hinges on the extent and reliability of surveys performed at the national level, which, necessarily implicates the use of many of the technologies described earlier in this Article.

A significant amount of data for human rights has been about documenting numbers of violations, particularly around atrocities. A variety of efforts have been undertaken to develop the methodologies for measuring trends in progress on a broader range of human rights norms such as economic and social rights by developing indicators and quantitative methods. Indicators for human rights can be useful in both conducting assessments and in furthering implementation and

449. *Id.* at 1.
450. *Id.*
451. Anti-Pers. Mines Fourth Rev. Conf., *supra* note 439, at 36.
452. *Id.*
453. MINE ACTION REVIEW, *supra* note 447, at 8.
454. *Id.*
455. Anti-Pers. Mines Fourth Rev. Conf., *supra* note 439, at 38.
456. MINE ACTION REVIEW, *supra* note 447, at 9.
457. *Id.*

realization of rights.[458] The rationale for developing indicators for human rights purposes, according to the High Commissioner for Human Rights, is that "[h]uman rights standards and principles as a value-based, prescriptive narration, essentially anchored in the legalistic language of the treaties, are not always directly amenable to policymaking and implementation.[459] They have to be transformed into a message that is more tangible and operational."[460]

To support this activity, the Office of the United Nations High Commission for Human Rights (OHCHR) has developed an indicator framework for measuring progress on human rights treaties.[461] The indicators were developed based on review of good practices and quantitative information on monitoring human rights.[462] OHCHR has defined human rights indicators as "specific information on the state or condition of an object, event, activity or outcome that can be related to human rights norms and standards; that addresses and reflects human rights principles and concerns; and that can be used to assess and monitor the promotion and implementation of human rights."[463]

The OHCHR framework distinguishes between indicators in terms of their content and approach.[464] Broadly speaking there are indicators that either measure phenomena or performance. Sometimes these categories merge and blend, but roughly speaking, the former category is broader and more general and seeks to identify from a scientific basis the matters they seek to measure. On the other hand, performance indicators focus on the performance and achievements of different institutions.[465] In addition to OHCHR, a variety of other indicators for human rights have been developed by nonstate groups. One example is the Human Rights Measurement Initiative, which was recently developed to address the need for impartial and independent data on human rights practices.[466]

The use of indicators is thus a key factor in the gathering and use of data for the many treaties studied. Like visualization and modeling, indicators enable research and judgments about treaty performance, parties' compliance, and background conditions. They also contribute to decisions concerning strategy and operations. As data becomes richer and more comprehensive, the quality of indicators can and must be refined, which can support future improvements in treaty practice.

The use of data for indicators and performance management plays a role in furthering treaty compliance and implementation, most notably through managerial types of processes described by Chayes and Chayes. By making clear

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458. United Nations High Commissioner for Human Rights, *Human Rights Indicators: A Guide to Measurement and Implementation*, at 5, U.N. Doc. HR/PUB/12/5 (2012), https://www.ohchr.org/Documents/Publications/Human_rights_indicators_en.pdf [https://perma.cc/5XJZ-86T2].

459. *Id.* at 2.

460. *Id.*

461. *Id*. at 1.

462. *Id*. at 5.

463. *Id.* at 16.

464. *Id.* at 34–38.

465. *Id.* at 110–11.

466. Anne-Marie Brook et al., *Human Rights Data for Everyone: Introducing the Human Rights Measurement Initiative (HRMI)*, 19 J. HUM. RTS. 67, 68 (2020).

the results that treaties generate, indicators serve as tools for "regime management."[467] Among other things, indicators help concretize objectives of treaties in ways that reflect current developments. Importantly, for the managerial perspective, indicators can facilitate deliberations of the parties towards achieving the underlying purposes of treaties.

III. Legal, Ethical, and Policy Concerns and Risks

The description of ITS offered in Part II was intended to show the diversity of tools being used in treaty regimes and offer an account of their systemic nature. Having set out the scope and elements of ITS, in Part III, I turn to some of the potential risks and limitations of ITS, particularly relating to law and ethics. This analysis does not purport to be exhaustive but rather an introduction that seeks to identify concerns that must be addressed to prevent negative consequences from the use of ITS. A caveat is that much of what has been described about ITS involves technologies and processes that are new or emerging, which may limit the possibility of reaching definitive conclusions about its potential effects.

I will address five main sets of questions. A first issue is the question of knowledge and its production. ITS reflects a general approach to gathering data for treaty purposes. On one level the question is what counts as knowledge in these systems? Two related questions are: who gets to participate and whose knowledge counts? An additional question concerns public policy considerations involving data collection and retention, particularly privacy and security related. Next, I consider the issue of statistical and data science techniques and the implications flowing from flaws in those systems. A further consideration concerns risks and implications of government restrictions on the use of ITS components. The final issue relates to imbalances in the role of actors in the Global North versus Global South in ITS and the challenges posed by the so-called digital divide. A major conclusion is that for ITS to contribute positively to international law, these significant legal and policy issues will need to be addressed.

A. Epistemic Concerns

The use of ITS can be understood as predicated on the belief in the importance of scientific ways of knowing. In this way it reflects beliefs of society in general about the value of scientific knowledge. While science has generated many profound and useful insights, the risk is that it becomes seen as an exclusive method for gaining knowledge or deserves a position elevated beyond other forms of understanding. Yet in recent years, new insights have emerged which clarify the nature and limitations of formal scientific method and resulting knowledge. Among these insights are the emergence of scientific

467. Chayes & Chayes, *supra* note 19, at 10.

pluralism, the notion of epistemic injustice, and the role of science in influencing policy.

The use of ITS reflects a belief in the role of science and approaches to scientific inquiry. These implicit beliefs may be subject to question, particularly given developments in the philosophy of science. Following Thomas Kuhn's pathbreaking work on the history of science, which showed science to be provisional and contextual rather than timeless and universal, scholars have come to rethink notions of scientific truth.[468] Going back as far as 1978, the former president of the Philosophy of Science Association, Patrick Suppes, argued forcefully against the so-called "unity of science" movement contending that the need to defend science against metaphysics (e.g. the Kantian transcendental project) had long since passed.[469] In the ensuing decades, some version of pluralism has gained acceptance among larger shares of the scientific community.

The pluralist account denies that there is a possible universal form of science that can wholly explain the complexity of the world. At a basic level, "[b]ecause the scientific enterprise is itself a complicated phenomenon, no single disciplinary approach can provide a fully adequate account of its conceptual, technical, cognitive-psychological, social, historical, and normative aspects."[470] According to one leading volume on the topic, those who disagree on the basic ideas of pluralism commit three errors "(1) to minimize or overlook important differences among scientific approaches, (2) to dismiss from consideration legitimate scientific approaches that seem to lie outside the mainstream, and (3) to exaggerate the explanatory importance of scientific approaches that are in the mainstream."[471]

Not only is there not a single discipline but scientific pluralism denies that there is one account of the natural world that exists and can be explained using scientific methods. Instead, pluralists accept that there may be multiple models or theories suitable for representing aspects of the world but that there is not one model or theory that can encompass the entire world.[472] This understanding does not mean that every phenomenon will require multiple models or explanations, but rather that "[a] more complete representation of some phenomena requires multiple accounts, which cannot be integrated with one another without loss of content."[473]

A practical implication of scientific pluralism is that research to which ITS are applied may not claim to be the exclusive basis for knowledge. Accordingly, multiple approaches to research may be appropriate for different circumstances and no singular basis for knowledge can be claimed. This observation has

468. *See* John Naughton, *Thomas Kuhn: The Man Who Changed the Way the World Looked at Science*, THE GUARDIAN (Aug. 18, 2012, 7:05 P.M.), https://www.theguardian.com/science/2012/aug/19/thomas-kuhn-structure-scientific-revolutions [https://perma.cc/H2A2-F937].

469. STEPHEN H. KELLERT, ET AL., SCIENTIFIC PLURALISM vii-xxix (C. Kenneth Waters et al. eds., 1st ed. 2006).

470. *Id.* at ix.

471. *Id.* at xii.

472. *Id.* at xiv.

473. *Id.*

important implications for indigenous and local communities, historically marginalized people, non-technically adept citizens, and research communities outside the scientific mainstream. Rather than an either/or proposition, other research has found complementarities between indigenous ways of knowing and mainstream science.[474] At the same time, there are limits to local knowledge that mainstream science can better address.[475]

While formal structures can be created to facilitate the engagement of non-mainstream communities, a practical question is how to integrate their inputs into end products. Examples include the inclusion of traditional knowledge and indigenous knowledge as well as input from citizen scientists in assessment reports, the use of data from outside the mainstream to measure progress against indicator frameworks and ensuring that governing bodies or treaties weigh knowledge in reaching decisions.[476] The science-policy gap may be wider and more problematic with respect to such knowledge than other sources.

Consistent with the idea of a multiplicity of disciplines and methods for gaining knowledge about the world, the exclusion of different actors from knowledge production processes cannot be justified. Exclusionary approaches to science may lead to selection bias due to the unrepresentative nature of the persons inputting or analyzing data.[477] A simple example of such bias may occur when researchers do not know a local language when documenting human rights abuses, for instance.[478] If the data sets used to train ML algorithms reflect such bias, then the outputs will merely reinforce such error. A similar concern has been raised with respect to expert dominated international processes.[479]

A key implication of the epistemic concerns described here is that they undermine claims that scientific knowledge and its production are somehow value neutral endeavors. When knowledge is deemed scientific, it gains value in deliberations on social and political issues including multilateral treaty matters. Conversely, views considered unscientific may be excluded. An illustration of this tendency can be seen in the ways in which treaty activities today call for "evidence-based" decision making.[480]

Another aspect of the scientific-technical bias is to assume the superiority of knowledge generated through such processes. Just because phenomena can

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474. Fikret Berkes, *Indigenous Ways of Knowing and the Study of Environmental Change*, 39 J. ROYAL SOC'Y N.Z. 151, 152 (2009).

475. Sandra Grant & Fikret Berkes, *Fisher Knowledge as Expert System: A Case From the Longline Fishery of Grenada, the Eastern Caribbean*, 84 FISHERIES RSCH. 162, 162–170 (2006).

476. *See e.g.*, *ILK Publications & Resources*, IPBES, https://ipbes.net/ilk-publication-resources [https://perma.cc/2N4Z-RBAT] (last visited Sept. 15, 2022) (discussing examples of integrating indigenous data); *The GEO Indigenous Summit Report*, GRP. ON EARTH OBSERVATIONS (July 19, 2021), https://earthobservations.org/geo_blog_obs.php?id=515 [https://perma.cc/JUU6-FYDK].

477. Nema Milaninia, *Biases in Machine Learning Models and Big Data Analytics: The International Criminal and Humanitarian Law Implications*, 102 INT'L REV. RED CROSS 199, 208 (2020).

478. *Id.*

479. DAVID KENNEDY, A WORLD OF STRUGGLE: HOW POWER, LAW AND EXPERTISE SHAPE GLOBAL POLITICAL ECONOMY 121 (2016).

480. Margherita Melillo, *Evidentiary Issues in* Phillip Morris v Uruguay*: The Role of the Framework Convention for Tobacco Control and Lessons for NCD Prevention*, 21 J. WORLD INV. & TRADE 724, 726–27 (2020).

be documented and analyzed through technological means does not mean those approaches are superior to prior approaches. Data captured through manual means in the past may retain value and could shed light on important research questions.[481] As an example, biodiversity data gathered in the eighteenth and nineteenth centuries may provide deeper and more comprehensive insights that recent data harvested through technologically sophisticated means cannot.

The tendency to assume greater value to technologically derived data is recognized as a form of cognitive bias called "automation bias."[482] Research on jurors, for instance, has shown that they tend to view data collected through technological means as more authoritative or reliable.[483] Surveys of the general public regarding traffic accidents find that they are more likely to attribute error to human drivers over autonomous driving vehicles.[484] Technology may offer new insights but we cannot assume that it will.

A separate concern is datafication, which raises numerous problems. Illustrative of the issue is whether reducing certain phenomenon to data constitutes a form of epistemic injustice to the subjects of such research. In the context of human rights, while quantitative data has enabled identifying group based and indirect forms of discrimination, gathering multiple violations to sign individual responsibility, and enabling global assessments of aspects of human rights, some advocates find such approaches to undermine the respect for individual victims as well and was glossing over the individual responsibility of perpetrators.[485] In the environmental context, translating complex ecosystems into data may obscure important insights about the interactions between species and the natural world. While ITS have developed piecemeal through pragmatically driven iteration, attention must be given to implicit knowledge commitments it entails.

The final epistemic concern involves the so-called science-policy disconnect in international law and governance. The notion refers to the condition in which scientific knowledge does not feed into decision making in governance institutions. The science-policy issue represents an important cautionary lesson for aspirations about the gains technology may provide. The salience of this concern is palpable given that despite tremendous scientific advances and developments to support treaties described in Part II, we are not seeing corresponding improvements in treaty results. Human rights are routinely trampled, arms control measures violated, and the environment decaying rapidly. The disconnect between ever-better scientific knowledge and

481. *See* Debra P. C. Peters et al., *Harnessing the Power of Big Data: Infusing the Scientific Method with Machine Learning to Transform Ecology*, ECOSPHERE, June 5, 2014, at 1, 13 (2014).

482. Milaninia, *supra* note 477, at 215.

483. *Id*. at 216.

484. UNIV. EXETER, *Public Blame Accidents on Drivers More than Their Automated Cars When Both Make Mistakes*, SCIENCEDAILY (Oct. 28, 2019), https://www.sciencedaily.com/releases/2019/10/191028164405.htm [https://perma.cc/S24L-KWHX].

485. *See e.g.*, Robert Justin Goldstein, *The Limitations of Using Quantitative Data in Studying Human Rights Abuses*, 8 HUM. RTS. Q. 607, 608–09 (1986) (describing the limits of quantitative data in the human rights context).

technological sophistication is an important reality check on what ITS can deliver.

This phenomenon is well recognized, particularly in the field of international environmental law, as the science-policy divide.[486] Given the amount of scientific information being generated for treaties in other areas, this issue arises in relation to treaties in other fields as well. The debates regarding the application of science to decision making involving multilateral agreements expose the complex relationship between these factors, which raises important questions about underlying assumptions regarding activities underway.

Science in environmental law has been typically understood as an uncomplicated, straightforward proposition.[487] Unlike policy, which is recognized to involve normative questions and value judgments, in this context too, science has been conceived as providing objective truths that can deliver knowledge that policymakers can use to make decisions.

The knowledge generated by science is seen as applying in a linear input-output fashion. According to Pielke, an assumption is that the knowledge generated by science starts with basic research, is then extended to applied research, development, and then to societal benefits.[488] In addition, science is understood to lead to political consensus and coordinated action that will compel certain policy responses.[489] This view rests on the understanding of science as politically neutral rather than resting on antecedent decisions that are normative.[490]

Yet, in the context of international environmental politics and law, much of the scientific input is generated through institutional arrangements that are established by states and international organizations.[491] The way these arrangements are structured has an important bearing on the scientific knowledge that is generated and the way in which it is received by policymakers. It has become increasingly recognized in recent years that these arrangements, while ostensibly based on apolitical objective scientific considerations, do entail

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486. *See e.g.*, Rachel Kyte et al., *Bridging the Science-Policy Divide*, 2 ONE EARTH 300, 300-01 (2020) (discussing international cooperation and collaboration to bridge the science-policy divide); Thomas Koetz et al., *Building Better Science-Policy Interfaces for International Environmental Governance: Assessing Potential Within the Intergovernmental Panel on Biodiversity and Ecosystem Services*, 12 INT'L ENV'T AGREEMENTS 1, 6 (2012).

487. Mary Jane Angelo, *Harnessing the Power of Science in Environmental Law: Why We Should, Why We Don't, and How We Can*, 86 TEX. L. REV. 1527, 1530 (2008) (stating that "[t]he purpose of science is to seek the truth," and discussing how every scientific hypothesis ultimately must be tested and reproduced to be accepted).

488. Roger Pielke, THE HONEST BROKER: MAKING SENSE OF SCIENCE IN POLICY (2007).

489. *Id.*; Koetz et al., *supra* note 486, at 5.

490. Koetz et al., *supra* note 486, at 6.

491. *See e.g.*, *Examples of Existing Institutional Arrangements and Measures in Addressing Loss and Damage Associated with Climate Change Impacts*, U.N. CLIMATE CHANGE https://unfccc.int/topics/resilience/resources/loss--damage-inputs-on-institutional-arrangements [https://perma.cc/UKM8-Z5X6] (last visited Sept. 15, 2022).

important normative consequences.[492] The question of the inclusiveness of the process has important bearing on these questions.

Despite expectations that scientific research should be value neutral and apolitical, politics permeates international affairs. The political aspects of the science policy relationship have achieved scrutiny in recent years in relation to climate science in particular.[493] Notable political leaders and multiple countries outright deny or refuse to accept scientific findings about climate change, for instance.[494]

The so-called Climategate scandal in the early 2000s only added to the contentious debates. In this case, scientists conducting research on climate change were found to have engaged in online discussions about manipulating data pertaining to climate change research and also disparaging climate skeptics.[495] Nevertheless, efforts have been made to develop constructive approaches to overcoming the science-policy division, notably through science-policy arrangements or interfaces.[496]

To understand the effectiveness of such approaches, researchers have developed a set of criteria. These include assessments of the credibility, relevance, and legitimacy of the arrangements.[497] Credibility concerns the perceived validity of the information, methods, and procedures followed, relevance the extent to which the work is response to conditions and the needs of policy processes, and legitimacy concerns matters such as fairness, balance, and political acceptability.[498] Subsequent scholarship has argued for the need to add "iterativeness" to this list of criteria, to capture the extent to which the science-policy interface responds to new information.[499]

Another approach to addressing the science-policy division has been the creation of specific scientific research bodies to cultivate research that support policy making.[500] The IPCC, the International Council for the Exploration of the Sea (ICES), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) are noteworthy examples.[501] IPBES underwent

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492. *See* Angelo, *supra* note 487, at 1527 (noting how legal scholars, practitioners, and regulators failed to consider a valuation technique due to normative considerations).

493. Koetz et al., *supra* note 486, at 10. *See* Silke Beck & Martin Mahony, *The IPCC and the New Map of Science and Politics*, WIREs CLIMATE CHANGE, Aug. 21, 2018 at 1, 1 (discussing the impact of the Paris agreement on the science and politics relationship).

494. *See* Nicholas St. Fleur et al., *The Road to a Paris Climate Deal*, N.Y. TIMES: ENV'T (Dec. 14, 2015), https://www.nytimes.com/interactive/projects/cp/climate/2015-paris-climate-talks/where-in-the-world-is-climate-denial-most-prevalent [https://perma.cc/Q938-QDQF] (discussing world leaders who deny climate change).

495. Andrew C. Revkin, *Hacked E-Mail is New Fodder for Climate Dispute*, N.Y. TIMES (Nov. 20, 2009), https://www.nytimes.com/2009/11/21/science/earth/21climate.html [https://perma.cc/2CPK-84DG].

496. Pia Kohler, *Science-Policy Interfaces: From Warnings to Solutions*, INT'L INST. FOR SUSTAINABLE DEV. (Jan. 24, 2022), https://www.iisd.org/articles/science-policy-interfaces [https://perma.cc/TF92-KYJL].

497. David W. Cash et al., *Knowledge Systems for Sustainable Development*, 100 PROC. NAT'L ACAD. SCIS. 8086, 8086 (2003); Koetz et al., *supra* note 486, at 1.

498. Koetz et al., *supra* note 486, at 3.

499. Simo Sarkki et al., *Adding 'Iterativity' to the Credibility, Relevance, Legitimacy: A Novel Scheme to Highlight Dynamic Aspects of Science–Policy Interfaces*, 54 ENV'T SCI. & POL'Y, 505, 505 (2015).

500. Kohler, *supra* note 496.

501. *Id.*

an external evaluation in 2019, which reviewed its effectiveness.[502] The evaluation was for the most part favorable, however, the evaluators had interesting observations relevant to the discussion here. It found that while the IPBES had led to improvements in global understanding of the status and trends in biodiversity and ecosystem services, there were several matters requiring urgent attention. Among those was the finding that "the policy relevance and actionability of the assessments, especially at the national level, can be improved."[503] Indeed, of its four functions, policy support was the least successful. The external evaluation recommended that "IPBES has to significantly strengthen the policy dimensions of its work" while noting that "building the evidence base is necessary but not sufficient."[504] The review said that policy relevance should be used to frame all aspects of IBPES's work rather than a limited mechanism to keep scientific advice in check.[505]

Addressing the political dimension of scientific research for policy requires consideration of governance arrangements. Two main challenges have been identified. The first pertains to the arrangements through which scientific research can be collected and aggregated. The second challenge pertains to creation of mechanisms for discursive exchange between policymakers and scientists.[506] This latter challenge reflects the non-linear relationship between science and policy.

A key consideration in the debate on science policy interface is the fact that while science can and certainly must inform policy, decisions at the intergovernmental or national level by political actors involve judgment calls. Risk assessments and evaluation of policy alternatives are important to this equation. Understanding these limitations and challenges is essential to evaluating the impact of technology on multilateral treaties.

B. Data Law and Governance

The lifeblood of ITS is data. In this context as in society generally, the growing importance of data raises many important legal and policy issues. Among these issues are human rights concerns, particularly involving privacy and government surveillance. Another major consideration is data security in relation to risks of cybercrime and cyberattacks. While these concerns are about mitigating risk to ensure the utility of data, approaches to data availability are of critical importance. Overall, the normative requirements for addressing these concerns highlight the need for new policies and procedures for all organizations involved.

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502. Intergovernmental Sci.-Pol'y Platform on Biodiversity & Ecosystem Servs, *Report on the Review of the Platform at the End of its First Work Programme*, IPBES/7/INF/18, at 5 (Mar. 14, 2019).

503. *Id.* at 7.

504. *Id.* at 8.

505. *Id.*

506. *See id.* at 66 ("The longitudinal and large-scale approach would address one of the greatest challenges of science policy interface: the stabilization of the relationship between science and policy communities for enhanced interactions to foster knowledge-sharing and mutual understanding over time around major continuing themes or problems.").

As data collection has grown in scope and volume, governments around the world have begun to regulate the matter in several ways.[507] Much of this work has been shaped by an individual rights perspective.[508] An important basis for this orientation is set forth in international human rights law. Under Article 17 of the International Covenant on Civil And Political Rights (ICCPR), data collection must be done in accordance with the right to privacy.[509] This understanding was elaborated in the UN Human Rights Council's (UNHRC) General Comment No. 16 (1988), which provided that "[t]he gathering and holding of personal information on computers, data banks, and other devices, whether by public authorities or private individuals or bodies, must be regulated by law."[510]

Key elements of the UNHRC's approach are the right of individuals to know what information governments maintain on them and their right to rectify erroneous information.[511] Further restrictions have been defined for the use of ethnic or racial classifications in data collection processes.[512] In addition, the Committee on the Elimination of Racial Discrimination adopted General Recommendation No. 8 (1990), which provides that any classification based on such characteristics must be done through the self-identification of the individuals concerned.[513]

Consistent with these normative baselines, the EU has developed the most influential regulatory framework for privacy protection under the General Data Protection Regulation (GDPR) adopted in 2016.[514] The GDPR applies to firms or organizations doing business in the EU or processing data of EU citizens.[515] Because it covers data of EU citizens wherever the data is located, the regulation effectively has extraterritorial effect. Firms or organizations must ensure compliance with the norms even in their operations outside of the EU if they will share data pertaining to EU citizens. Given the difficulty of organizations

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507. *Beyond GDPR: Data Protection Around the World*, THALES (May 10, 2021), https://www.thalesgroup.com/en/markets/digital-identity-and-security/government/magazine/beyond-gdpr-data-protection-around-world [https://perma.cc/JZ5Z-5LAK].

508. *See* HUMAN-RIGHTS BASED APPROACH TO DATA: LEAVING NO ONE BEHIND IN THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT, U.N. HUM. RTS. OFF. OF THE HIGH COMM'R 2 (2018) https://www.ohchr.org/sites/default/files/Documents/Issues/HRIndicators/GuidanceNoteonApproachtoData.pdf [perma.cc/G4G2-RVAG] (describing how numerous countries have signed on to the 2030 Agenda for Sustainable Development, which includes significant protections for human rights in data collection consistent with international law).

509. G.A. Res. 2200 (XXI) A, International Covenant on Civil and Political Rights, at 17 (Dec. 16, 1966).

510. UN Human Rights Committee (HRC), CCPR General Comment No. 16: Article 17 (Right to Privacy), The Right to Respect of Privacy, Family, Home and Correspondence, and Protection of Honour and Reputation, ¶ 10, Apr. 8, 1988.

511. *Id.*

512. *See* U.N. Hum. Rts. Off. of the High Comm'r, International Human Rights Standards and Recommendations Relevant to the Disaggregation of SDG Indicators, 1 (2018) ("Disaggregated data can inform on the extent of possible inequality and discrimination. Data collection and disaggregation that allow for comparison of population groups or characteristics are central to a Human Rights Based Approach to Data (HRBAD) and forms part of States' human rights obligations.").

513. CERD, Comm. on the Elimination of Racial Discrimination, U.N. Doc. A/45/18 (Aug. 22, 1990).

514. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the Protection of Natural Persons with Regard to the Processing of Personal Data and on the Free Movement of such data, and Repealing Directive 95/46/EC (General Data Protection Regulation) 2016 O.J. (L 119).

515. *Id.* at 32, 33.

maintaining different privacy standards for data of non-EU citizens, many organizations with international reach have simply adopted the EU standards across their operations globally.[516]

In recent years, countries around the world have developed their own approaches to data regulation, including with respect to privacy. This situation has complicated the global landscape and made it more difficult for organizations working internationally. While the GDPR has required private companies and organizations to adopt its standards, the same is not true for international organizations. Treaty bodies are generally constituted as international organizations. As such, for the UN, other international organizations, and treaty bodies, domestic privacy regulation will not be directly applicable. Nevertheless, influence of international human rights standards, the GDPR, other national law and regulation, and private ethics codes and standards have led international organizations to implement rules and policies that also protect individual privacy.[517]

An important approach to privacy regulation is to require that data be obtained through informed consent. International experience has shown problems in relation to this model. In the humanitarian relief context, for instance, aid agencies have engaged in significant breaches of the privacy rights of persons receiving assistance. One such example illustrates the potential risks involved. As part of its assistance to Rohingya refugees fleeing mass violence inflicted by Myanmar military with nonstate actor support, the UN High Commission for Refugees gathered personal data on hundreds of thousands of Rohingya. According to Human Rights Watch (HRW), UNHCR did not conduct a full data risk assessment as required by its internal rules nor did it seek the informed consent of many refugees.[518] UNHCR gathered information on the refugees to provide identity cards, which were used to disseminate aid.[519] It then shared such information including "analog photographs, thumbprint images, and other biographic data" with the Bangladesh government, which in turn shared the information with the Myanmar government.[520] According to the HRW report, the informed consent procedure UNHCR followed consisted of an English language form and provided a check box whereby the refugees could consent to release of their data to the Myanmar government in relation to

516. *See* Anupam Chander et al., *Catalyzing Privacy Law*, 105 MINN. L. REV. 1733, 1735 (2021) (noting "Europe is setting the global standard for information privacy. . . . some 142 countries and counting now have a broad data privacy law, typically modeled on the GDPR.").

517. *See* Christopher Kuner, Symposium on the GDPR and International Law, *The GDPR and International Organizations*, 114 AM. J. INT'L L., 15, 15, 18 (2020) (noting that ethical concerns over the consequences of inadequate data security, influence of data-related laws, and "soft enforcement" of the GDPR against international organizations have led them to adopt "internal data protection rules.").

518. *UN Shared Rohingya Data Without Informed Consent: Bangladesh Provided Myanmar Information that Refugee Agency Collected*, HUM. RTS. WATCH (June 15, 2021, 12:00 AM), https://www.hrw.org/news/2021/06/15/un-shared-rohingya-data-without-informed-consent [https://perma.cc/JZ5Z-5LAK].

519. *Id.*

520. *Id.*

possible repatriation.[521] According to a sample of twenty-four refugees by HRW, only three spoke or read English.[522]

Although there was some dispute about whether UNHCR made its identification cards contingent on waiver of personal data, research has found a general tendency of aid organizations to require beneficiaries to waive their rights to restrict the use of their personal data.[523] The inequality of bargaining power between persons in need of humanitarian assistance and aid providers is substantial and raises significant ethical concerns. Currently, these uses of data by humanitarian organizations are essentially unregulated or subject only to loose forms of self-regulation.

One approach to addressing this situation is the Harvard Humanitarian Initiative's Signal Code, which provides guidance on how to uphold international human rights and humanitarian law and standards in the context of crises.[524] Likewise, the UN Global Pulse has developed privacy and data protection principles.[525] Organizations involved in collecting data on EU citizens would of course be required to comply with the EU's GDPR initiative.[526] According to these standards, exceptions to data privacy and protection must be undertaken consistent with international human rights and humanitarian law standards, individuals should have the right to be informed about information collected and its use, as well as the opportunity to correct erroneous information about themselves.[527]

Issues of data privacy are not uniformly applicable across the different treaty regimes considered in this Article. While treaty-related monitoring and documentation directly pertaining to individuals may require privacy and other protections to safeguard the interests of people or communities, on first glance such considerations appear less salient in relation to environmental matters for instance. Nevertheless, privacy concerns may arise as ancillary to seemingly benign uses, such as environmental monitoring. Smart phone data, for instance, may be used not only for the intended purpose but also to facilitate triangulation of persons' identities and other personal information.[528]

Aside from situations where data is collected through intentional processes, the use of "big data" collected for purposes other than information gathering raises different types of privacy concerns. It has been observed that "big data

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521. *Id.*

522. *Id.*

523. *See* Patrick Vinck et al., *"Do No Harm" in the Age of Big Data: Data, Ethics, and the Refugees*, *in* GUIDE TO MOBILE DATA ANALYTICS IN REFUGEE SCENARIOS: THE 'DATA FOR REFUGEES' CHALLENGE STUDY 87, 91 (Albert A. Salah et al. eds., 2019) ("However, as noted above, among refugee population, the notion of informed consent is hindered by the link that exists between the sharing of information and access to assistance.").

524. FAINE GREENWOOD ET AL., HARV. HUMANITARIAN INITIATIVE, THE SIGNAL CODE: A HUMAN RIGHTS APPROACH TO INFORMATION DURING CRISIS 10 (2017).

525. *UN Global Pulse Principles on Data Protection and Privacy*, U.N. GLOB. PULSE, https://www.unglobalpulse.org/policy/ungp-principles-on-data-privacy-and-protection [https://perma.cc/NK3E-YTH6] (last visited Aug. 29, 2022).

526. Latonero, *supra* note 8, at 160–61.

527. *Id.* at 160.

528. Victor Galaz et al., *Artificial Intelligence, Systemic Risks, and Sustainability*, TECH. SOC'Y, Sept. 17, 2021, at 1, 4.

analytics often relies on 'found' data, which is collected without a user's consent or even knowledge."[529] It also necessarily involves using this information in ways not intended by the individual(s) to whom it relates. Government surveillance is one risk of such data harvesting. Here, as in other aspects of the technologies described in this Article, both governments and human rights organizations may employ the same techniques for the collection and use of big data from social media platforms like Facebook, albeit for different purposes.[530] An exposé from Reuters journalists in 2018 showed that despite having adopted codes of conduct and self-regulatory measures, Facebook was unaware of large-scale dissemination of hate speech and images of atrocities against the Rohingya in Myanmar on its site.[531] Among the reasons for the ineffectiveness of its self-regulatory measures was the fact that it lacked sufficient local language capabilities among its staff.[532]

Social media can facilitate human rights abuses of another sort, namely by enabling repressive governments to use GPS data and personal information to track millions of people.[533] Safeguards that have been developed, such as anonymization techniques, are insufficient since "the currently accepted fact in computer science is that no data set can be fully anonymized….[T]he best intentions of human rights organizations using big data are not enough to protect privacy rights or automatically justify privacy violations."[534] Thus, with respect to big data, "privacy harms are likely unavoidable."[535] To remedy some of these issues, Mark Latonero suggests that human rights monitoring organizations "may need to update their standards for data collection and analysis to take new technologies like big data into account."[536]

Notwithstanding the legitimate scientific and regulatory purposes that ITS can serve, simultaneous with these developments are extensive efforts of governments to surveil citizens through the same types of technologies. Governments monitor mobile and stationary IT devices for social media or Internet usage. IOT connections open a new front for surveillance. In many countries, cameras have been installed widely in public places.[537] The same types of computer vision technologies that enable human rights researchers to

529. Latonero, *supra* note 8, at 157.

530. *Id.* at 158.

531. Steve Stecklow, *Why Facebook Is Losing the War on Hate Speech in Myanmar*, REUTERS: HATEBOOK (Aug. 15, 2018, 3:00 PM), https://www.reuters.com/investigates/special-report/myanmar-facebook-hate [https://perma.cc/UF82-NSAB].

532. *Id.*

533. *See* Vinck et al., *supra* note 523, at 92 ("Photographs shared on social media sites with timestamps and GPS locations can easily provide bodies with access to sufficient computing power an accurate way of identifying and tracking millions of people.").

534. Latonero, *supra* note 8, at 159.

535. *Id.* at 157.

536. *Id.* at 159.

537. William Webster, *AI-Driven CCTV Upgrades Are Coming to the 'World's Most Watched' Streets – Will They Make Britain Safer?*, CONVERSATION (Mar. 29, 2021, 10:16 AM), https://theconversation.com/ai-driven-cctv-upgrades-are-coming-to-the-worlds-most-watched-streets-will-they-make-britain-safer-157789 [perma.cc/ZT2T-495S] (noting how the UK is "often referred to as the most surveilled nation on Earth" with at least 5.9 million camera units on UK streets).

identify perpetrators can be used by governments to identify citizens in footage taken from security cameras.[538]

Another major concern in respect of data protection relates to security. Two significant sources of risk are cybercrime and cyberattacks.[539] Notwithstanding the protections of data privacy law and governance, the possibility of data security breaches can compromise those rights fundamentally.

All computer systems are vulnerable to cybercrime and cyberattacks. In recent years, governments, non-governmental, and private sector organizations have experienced data releases following intrusions into their IT systems.[540] The nature of these risks has shifted as a result of the adoption of cloud computing. Unlike the IDC of the CTBTO, most treaty bodies and organizations in the research communities cannot maintain proprietary standalone systems for data storage. Non-governmental human rights organizations are one exception, as several have adopted private secure facilities for data warehousing, although their coverage is unclear.[541]

A significant concern of both cybercrime and cyberattacks is the potential chilling effect resulting from the fear that actors may seek to impede or eliminate stored data. Actors may choose not to hold data for fear of being attacked by state or nonstate actors. An additional concern, particularly relevant to ITS given its systemic nature, is the risk of interruption through such attacks.[542] Such considerations become more acute with the use of distributed and cloud-based systems.

An additional consideration in data governance and law are policies for data sharing. Free data sharing is critical to reaping the benefits of ITS. There has been a movement among some governments to make data obtained through public resources generally available.[543] As described in Part II.1, in the context of EO data, for instance, many governments have made data freely available. To

538. Aronson, *Computer Vision*, *supra* note 8, at 1206–07.

539. Steve Morgan, *Cybercrime to Cost the World $10.5 Trillion Annually by 2025*, CYBERCRIME MAG. (Nov. 13, 2020), https://cybersecurityventures.com/hackerpocalypse-cybercrime-report-2016 [https://perma.cc/LY8A-2YKK]; Chuck Brooks, *Alarming Cyber Statistics for Mid-Year 2022 That You Need to Know*, FORBES (June 3, 2022, 3:57 PM), https://www.forbes.com/sites/chuckbrooks/2022/06/03/alarming-cyber-statistics-for-mid-year-2022-that-you-need-to-know [https://perma.cc/6WMF-S3NQ?view-mode=client-side].

540. David E. Sanger, *Russian Hackers Broke Into Federal Agencies, U.S. Officials Suspect*, N.Y. TIMES, https://www.nytimes.com/2020/12/13/us/politics/russian-hackers-us-government-treasury-commerce.html [https://perma.cc/SD7F-CW7Q?view-mode=server-side] (May 10, 2021); Ben Parker, *Dozens of NGOs Hit by Hack on US Fundraising Database*, THE NEW HUMANITARIAN (Aug. 4, 2020), https://www.thenewhumanitarian.org/news/2020/08/04/NGO-fundraising-database-hack [https://perma.cc/3P3X-VZYZ]; Nicole Perlroth & Stacy Cowley, *Security Gap Leaves 885 Million Mortgage Documents Exposed*, N.Y. TIMES (May 24, 2019), https://www.nytimes.com/2019/05/24/technology/data-leak-first-american.html [https://perma.cc/6Z53-GMW6?view-mode=server-side].

541. *See, e.g.*, *Data Protection*, INT'L ORG. FOR MIGRATION, https://www.iom.int/data-protection [perma.cc/M2KT-FXAF] (last visited Sept. 15, 2022) (describing its adoption of Data Protection Principles in 2009 and the promulgation of a Data Protection Manual).

542. Galaz et al., *supra* note 528, at 5.

543. *See, e.g*., Foundations for Evidence-Based Policymaking Act of 2018, Pub. L. No. 115-435, §§ 201-202, 5530, 5533. *See also* Open, Public, Electronic, and Necessary Government Data Act, Pub. L. 115–435, 132 Stat. 5534–44 (2019).

illustrate, the US made all Landsat data freely available in 2008.[544] Other governments have taken similar approaches. Organizations such as the Group on Earth Observations have championed the application of open data policies among its member organizations.[545] Yet, significant numbers of governments continue to restrict the availability of EO data.[546] National security is often used as justification for such measures, if only as a pretext. Further complicating the situation is the fact that significant shares of EO data are being collected by private firms, which may only make it available for a fee.[547]

A related technical issue associated with ITS concerns interoperability between systems and data. Even within the research communities associated with specific treaty regimes, there are diverse data sources and classification protocols used. The lack of common standards for data being collected means that the ability of researchers to draw on data from different sources may be limited. Likewise, instrumentation used for collection of data may require completely different tools to analyze data collected. New initiatives have emerged to address some of these issues such as the FAIR data standard and efforts within the statistical community associated with the SDGs, however, these processes are still in an early stage and much more work will need to be done before these different systems can be reconciled to enable data sharing.[548]

One implication of the introduction of safeguards for data usage, for instance, is that organizations must introduce new systems and standards for their internal compliance. This understanding is equally true among international organizations, NGOs, and academic organizations involved in treaty-related research. In the humanitarian context, some have observed that the use of technology and datafication "fundamentally changes what it means to be a humanitarian organization."[549] This observation may be equally true of the treaty bodies and associated organizations driving ITS. Standards are still emerging even though organizations are using data extensively in their operations and accumulating "massive volumes of digital information."[550] Complicating the compliance challenge is the fact that much data is gathered and stored through private sector firms.[551]

544. EARTH RES. OBSERVATION & SCIENCE (EROS) CTR., *Free, Open Landsat Data Unleashed the Power of Remote Sensing a Decade Ago*, U.S. GEOLOGICAL SURV. (Apr. 17, 2018), https://www.usgs.gov/news/free-open-landsat-data-unleashed-power-remote-sensing-decade-ago [https://perma.cc/7SV6-6MAD].

545. *GEO and Open EO Data*, GRP. ON EARTH OBSERVATIONS, https://www.earthobservations.org/open_eo_data.php [https://perma.cc/EH6J-KXZF] (last visited on September 30, 2022).

546. MARIEL BOROWITZ, OPEN SPACE: THE GLOBAL EFFORT FOR OPEN DATA FOR EARTH OBSERVATION 3 (2017).

547. Valery Komissarov, *Earth Observation Data: Multibillion-Dollar Opportunity — or Dud?*, VENTUREBEAT (Aug. 14, 2016, 10:25 AM), https://venturebeat.com/business/earth-observation-data-multibillion-dollar-opportunity-or-dud [https://perma.cc/E43F-RQHX].

548. *See* Heberling et al., *supra* note 163, at 1 ("The necessary infrastructure for the integration of disparate data poses significant informatic and social challenges.").

549. Vinck et al., *supra* note 523, at 91–92.

550. *Id.* at 92.

551. *Id.* at 88; *See, e.g.*, Joe Berens, *Private Sector Data for Humanitarian Response: Closing the Gaps*, BLOOMBERG NEWS ECON., https://www.bloombergneweconomy.com/news/private-sector-data-for-

C. Algorithms and Statistical Data

Quantification of phenomena relevant to multilateral treaties and the processing of data both pertaining to its collection and analysis raise a variety of major concerns. Although I have described the potential utility of data for treaty processes, I have also sought to convey the risk of giving too much credence to technologically-generated data. Across most of the technology applications constituting ITS, the use of algorithms for both data collection and data analysis raises many important legal and policy concerns. Algorithms are the basis for many of the ITS applications discussed in this Article. A common assumption on the use of algorithms in diverse areas is scientific and objective in nature. Against this view, as the prevalence of algorithms has grown, so has awareness of the potential limitations and harms that may be caused.[552] "Algorithms search, collate, sort, categorize, group, match, analyze, profile, model, simulate, visualize, and regulate people, processes, and places."[553] A broader question pertains to the general appropriateness of quantitative approaches to analyzing treaty-related matters.

A threshold consideration in studying the legal and policy implications arising from the use of algorithms is the difficulty of understanding precisely what is going on. Several challenges make research and analysis of algorithms difficult. First, they can be "black boxed," meaning that "they are not open to scrutiny and their source code is hidden inside impenetrable executable files."[554] While open-source repositories such as Github may allow access, others are written by private sector and government programmers who may not share their code.[555] Second, rather than individual algorithms, many applications use combinations of algorithms, both open-sourced and proprietary. They are thus embedded in "complex socio-technical assemblages" which are "messy, full of 'flux, revocability, and negotiation.'"[556] Even having access to a specific algorithmic system may not suffice to enable understanding of its operations. Third, as the discussion of ITS shows, developments are iterative as teams of researchers tinker with and adjust systems over time. AI and ML applications, in particular, may evolve in response to new inputs.[557] They are often emergent in a complex adaptive system sense. Their consequences may be unpredictable at the outset.

A central question in the use of algorithms is biases and inaccuracies in their construction. Contrary to assumptions that data collection is neutral in

humanitarian-response [https://perma.cc/6NKN-EJ9J] (last visited Sept. 11, 2022) ("One source of humanitarian data is the private sector . . .[but] [c]ompanies and their customers are often wary of data being used in ways not related to the original purpose of data collection.").

552. *See, e.g.*, CATHY O'NEIL, WEAPONS OF MATH DESTRUCTION: HOW BIG DATA INCREASES INEQUALITY AND THREATENS DEMOCRACY 2 (2016) ("By 2010 or so, mathematics was asserting itself as never before in human affairs, and the public largely welcomed it. Yet I saw trouble. . ..[M]any of these models encoded human prejudice, misunderstanding, and bias into the software systems that increasingly managed our lives.").

553. Rob Kitchin, *Thinking Critically About Researching Algorithms*, 20 INFO. COMMC'N & SOC'Y 14, 18 (2017).

554. *Id.* at 20.

555. *Id.*

556. *Id*. at 20–21.

557. *Id. See also id.* at 21 ("Many algorithms are designed to be reactive and mutable to inputs.").

terms of the substance of the subjects to which data relates, the methods and technologies used in these processes shape the ways in which it is accessed, how it can be processed, and its ultimate uses for monitoring, assessments, and decision-making.[558] Research has identified ways in which seemingly value-free use of algorithms has led to unfair or unjust outcomes.[559] These concerns threaten to undermine the contribution that technology can play in advancing global treaty regimes. The utility of algorithms that enable facial recognition of human rights perpetrators, for instance, must be weighed against the risks of public surveillance systems that can be used in a discriminatory fashion by governments to target political opponents or minority groups.

A major source of algorithm bias is the over- or under-representation of specific groups or events.[560] This risk is especially acute with big data, which is generated as the by-product of other activities and purposes.[561] Nema Milaninia describe biases that may affect international criminal law and international humanitarian law concerns. These include implicit bias, selection bias, reporting bias, group attribution bias, and automation bias.

Implicit bias occurs when one's personal assumptions are generalized. Examples include confirmation bias, whereby data is processed or analyzed in ways that reinforce previous beliefs.[562] Selective information processing, belief perseverance, and the avoidance of cognitive dissonance are examples of how actors may discount relevant information in favor of information that confirms prior beliefs.[563] Regardless of the quality of the ML algorithms, if the data sets used to train the models are affected by implicit bias, they may provide erroneous "correlation, relationships or patterns."[564]

Selection bias occurs where the chosen data does not reflect real world distributions.[565] Examples include participation or non-response bias in surveys in which marginalized or underrepresented groups may not participate.[566] Selection bias may also creep into the use of ITS because the costs of gathering information through non-technological means may make such activity less attractive. Another example is sampling bias, which may occur when samples are chosen for a subgroup of a target population rather than the whole.[567] Reporting bias occurs when data is generated through reports that erroneously attribute certain characteristics to specific groups.[568]

558. Vinck et al., *supra* note 523, at 89.
559. *See, e.g.*, O'NEIL, *supra* note 552, at 3–10 (Describing how Washington D.C.'s system for evaluating the performance of students in the area's underperforming high schools led to the termination of a teacher, who, by all other accounts, was excellent at her job).
560. Milaninia, *supra* note 477, at 202.
561. *Id.*
562. *Id.* at 204.
563. *Id.*
564. *Id.* at 206.
565. *Id.*
566. *Id.* at 207.
567. *Id.*
568. *Id.* at 209.

The notions of convenience sampling and selection bias are concerns for many of the techniques used in ITS. As the coverage of ITS extends to encompass a greater share of the globe, research may simply dispense with local sources of data collection, which may be seen as marginal in importance. Although many aspects of ITS reflect comprehensive global data, as shown above in relation to climate change and global fishing, other fields such as biodiversity and human rights involve more local data collection.[569] Techniques for triangulating data by combining multiple sensing technologies may mitigate these issues. Likewise, the expansion of sensing technologies globally may reduce these risks over time. This issue reflects the potential benefits of sharing experience across different fields of international law that employ ITS.

Other types of algorithmic biases relevant to the treaties examined in this Article include transfer context bias, which may occur when data developed for use in one context are applied to completely different contexts.[570] Another risk is concept drift, whereby systems trained on data taken from historical ecological conditions fail when applied in a different time or environmental conditions, as may occur as a result of climate change.[571] A further example is interpretation bias, which may arise when an algorithm's designer does not understand its utility or makes inferences unsupported by the system.[572]

Aside from concerns about the processes by which data is harvested and analyzed, there are important questions about the basic approach to quantifying many phenomena of relevance to treaty analysis. Patrick Ball has written a wide-ranging criticism of the concept of big data in human rights work and the approach and utility of many analyses undertaken for such data. He argues that "statistics without the rigorous foundation are more confusing than helpful: weak statistics can be worse than having no statistics."[573] While Ball notes that data regarding homicides are among the clearest statistics of human rights abuses that can be found, there is an element of interpretation and gaps in the information available that makes using statistics on such matters an uncertain activity. He notes that it is crucial to understand what has been included in and what has been excluded from the data and not assume that they "[represent] the world in a direct way."[574]

Ball distinguishes between the ways in which big data can function in industry compared to human rights context. He uses the example of a manufacturing business in which every widget produced would be tracked and the manufacturer could note all the details of each widget, any deep defects, and be able to make comprehensive assessment of everything produced.[575] In

569. *See, e.g.*, GLOB. BIODIVERSITY INFO. FACILITY, *Managing Biodiversity Data from Local Government*, PHYS.ORG (May 25, 2012), https://phys.org/news/2012-05-biodiversity-local.html [https://perma.cc/B5J4-WKU5] (acknowledging that local governments now possess large amounts of biodiversity data).

570. Galaz et al., *supra* note 528, at 4.

571. *Id*.

572. *Id.*

573. Patrick Ball, *The Bigness of Big Data: Samples, Models, and the Facts We Might Find When Looking at Data*, *in* THE TRANSFORMATION OF HUMAN RIGHTS FACT-FINDING, 425, 425 (Philip Alston & Sarah Knuckey eds., 2016).

574. *Id.* at 426.

575. *Id.* at 426–27.

contrast, in human rights situations, much of the information that is needed is intentionally or unintentionally hidden. He notes that in statistics, killings that are observed are considered the sample, while the set of all killings is called the universe or population, i.e. the subject we wish to measure.[576] Rather than the traditional definition of big data as the unintentional outcome of other processes such as social media screens, telephony metadata, or geolocation information generated through automated transit payment systems, Ball proposes a definition for human rights purposes as "the proportion of the population that is actually captured in the sample."[577] The distinction he has in mind is illustrated by the hypothetical conflict:

> If all (or very nearly all) of the killings were documented in YouTube videos and are in the automated coding, then the data qualify for the label "big". However, if some unknown number of killings is not captured in the YouTube videos, or if the automated coding system misses some killings that are in videos, or if both are true, the database resulting from this process is only partial.[578]

He notes that rarely is human rights data big in the sense of including all or nearly all instances of relevant phenomena.[579] Individual incidents may allow for complete data to be obtained, but if discussing a wider conflict that proposition becomes much less likely.[580] He notes that for statistical analysis there must be a clear link between the sample and the population, to justify the inference that the sample actually describes the population.[581] Indeed, many of the samples that are taken of human rights incidents are what statisticians call "convenience samples," which are nonrandom thus raising many questions about why given samples were chosen.[582]

Aside from these specific questions about appropriate statistical techniques, the increasing use of quantitative data for human rights monitoring raises larger questions about the appropriateness of translating human rights into quantifiable information. A key issue is whether it undermines the respect for individual victims as well as glossing over the individual responsibility of perpetrators. A related concern is the question of the role of "datafication" and the reductionistic nature of governance by indicators. Considered a "technology of governance," some observers charge that indicators are inaccurate simplifications of reality that provide only superficial understandings of underlying issues, ignore whole constituencies including marginalized peoples, and perpetuate misconceptions.[583]

576. *Id.* at 427.
577. *Id.*
578. *Id.* at 427–28.
579. *Id*. at 428.
580. *Id.*
581. *Id.*
582. *Id.*
583. René Urueña, *Internally Displaced Population in Colombia: A Case Study on the Domestic Aspects of Indicators as Technologies of Global Governance*, *in* GOVERNANCE BY INDICATORS: GLOBAL POWER THROUGH CLASSIFICATION AND RANKINGS 249, 249–80 (Kevin Davis et al. eds., 2012).

D. Governmental Restrictions and Repression

A key problem that has arisen in relation ITS is that governments have used many of the underlying technologies for repressive purposes. Research in the humanitarian context has found that "governments and perpetrators of human rights violations that forcibly displace millions of people around the world are learning quickly how to leverage public data, networks, and technologies to identify sources of information, spread rumors and fake data, and attempt to use, evade, or adapt to surveillance capabilities."[584]

A key element of such repression involves Internet freedom. The ability of ITS to provide the types of benefits described in the foregoing chapters is the extent to which governments seek to curtail Internet freedom. As described in Part II, the Internet is the oil that keeps the entire ecosystem supporting ITS running. Without access to Internet connectivity, remote sensors, EOS, and crowdsourcing activities would be extremely difficult to undertake. Lack of Internet availability would impede the use of cloud computing servers and the enhanced data processing and computational capabilities that they provide. It would also impede the abilities of researchers to share data and models easily. Without the Internet, much of the ITS system will grind to a halt.

Yet global trends in terms of Internet freedom are quite worrisome. The Covid-19 pandemic has empowered governments to employ new forms of repression. Major countries—including scientifically advanced and important countries such as China and Russia—are taking major steps to restrict access to the Internet.[585] Freedom House in its Freedom on the Net 2021 report reviewed these trends in seventy countries.[586] Among the findings was that Internet freedom had declined for the eleventh consecutive year.[587] Moreover, many governments are seeking to create closed national systems for the Internet while also employing increased surveillance methods on citizens.[588]

Aside from the Internet, governments are restricting many of the specific applications in ITS. For example, with the predominance of citizens using cameras or other recording equipment to video or photograph violations of human rights by military and police, governments have taken steps to quash these efforts in many countries.[589] In some countries law or judicial decisions have found that a right to record exists and therefore that human rights defenders or ordinary people may use their personal devices to document human rights violations.[590] The rationale for protecting the right to record stems from both the

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584. Vinck et al., *supra* note 523, at 95.

585. Adrian Shahbaz & Allie Funk, *Freedom on the Net 2021: The Global Drive to Control Big Tech*, FREEDOM HOUSE, 3 (2021) https://freedomhouse.org/sites/default/files/2021-09/FOTN_2021_Complete_Booklet_09162021_FINAL_UPDATED.pdf [https://perma.cc/JK8Y-6JRK].

586. *Id.* at 4.

587. *Id.*

588. *Id.* at 2–3.

589. *E.g.*, David L. Hudson Jr., *Filming the Police*, FIRST AMEND. ENCYCLOPEDIA, https://mtsu.edu/first-amendment/article/1550/filming-the-police [https://perma.cc/8SZW-BFTY] (last visited Sept. 15, 2022).

590. *Id.*

right to freedom of expression and right to peaceful assembly, as protected in the International Covenant on Civil and Political Rights.[591]

The UNHRC has recognized this right to record in resolution passed in 2018.[592] In the resolution the UNHRC found that "all persons enjoy the right to observe, and by extension monitor, assemblies."[593] The concept of monitoring encapsulates not only the act of observing a public assembly, but also the act of collection, verification, and immediate use of information to address human rights problems. The UNHRC recognized that monitors could include a range of different actors including national human rights institutions, ombudsman, inter-governmental entities and civil society organizations, journalists, as well as citizen journalists.[594] Further it recognizes that monitors are entitled to all other human rights and that the state has an obligation to investigate any human rights violation or abuse of monitors, prosecute those violations, provide adequate remedies will.[595]

Finally, the resolution states unequivocally that "everyone—whether a participant, monitor or observer—shall enjoy the right to record an assembly, which includes the right to record the law enforcement operation… This also includes the right to record an interaction in which he or she is being recorded by a state agent—sometimes referred to as the right to "record back."[596] By extension, it recommended that states "should prohibit by law any interference with the recording of an assembly, including the seizure or damage of any equipment, except that pursuant to a warrant from a judge, where the judge considers that it has probative value."[597]

Whether these human rights standards will be applied by governments is unclear. It is also unclear whether research involving other aspects of ITS will be entitled to similar protection under human rights law.

E. North-South Imbalances

Many of the technological capabilities described in this Article emanate from institutions in the Global North. Research communities including universities, NGOs, independent scientists, technology companies, and international organizations are disproportionately based in developed countries.[598] The technology to enable actors to engage and apply ITS is more limited in the global South than in the global North.[599] Mitigating these concerns

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591. *Id.*

592. G.A. Res. 38/7 (July 17, 2018).

593. Human Rights Council, Joint Report of the Special Rapporteur on the Rights to Freedom of Peaceful Assembly and of Association and the Special Rapporteur on Extrajudicial, Summary or Arbitrary Executions on the Proper Management of Assemblies, U.N. Doc. A/HRC/31/66, ¶ 68 (Feb. 4, 2016).

594. *Id.* ¶ 69.

595. *Id.* ¶ 70.

596. *Id.* ¶ 71.

597. *Id.* ¶ 72.

598. *See* Heberling et al., *supra* note 163, at 2–3, 5 (finding in research using the GBIF that "nearly 8% of regional studies were completed without regional authors").

599. *See id.* at 2–3.

is the continual reduction in costs of many instruments used in ITS from data storage to computer hardware to satellite data.[600] Yet as noted in the human rights context, although likely generally relevant to ITS, the use of technologies like ML and computer vision require expertise that is limited in many countries.[601]

A similar concern is a question of whether the movement towards ITS is driven by concerns within the global North rather than in the developing world. A further question is whether the activities involved in using ITS are sufficiently inclusive of different social groups. Various commentators have criticized or condemned the reliance on technology on the grounds that it muscles out and marginalizes people, particularly indigenous, minority groups, or otherwise vulnerable communities from participation and status in international law.[602] Others critique the dominance of experts—typically in the global North—in international processes.[603] Although as described earlier there have been efforts made to address the concerns of indigenous people around issues such as EOS remote-sensing, for instance, more attention needs to be given to the ways in which technology for treaty purposes affects indigenous and other local communities.[604]

One challenge involved in the effort to preserve documentation produced by communities and local actors is the risk that more elite organizations or dominant institutions may take charge of the agenda in ways that are contrary to the wishes or interests of those communities.[605] These topics correspond to many of the treaties described in this Article. Examples include ecosystem modeling, marine conservation efforts, tracking of illegal wildlife trade, and so-called smart urban planning.[606] Among these concerns are inequality in terms of access, benefits, and impacts.[607] To illustrate, technologies used for treaty monitoring may be applied to certain areas more than others. Technology-based monitoring may also affect livelihoods as persons historically engaged in such activities locally and be made redundant.[608] The benefits of the use of technology may accrue to wealthier states or population groups based on geography.[609]

As described elsewhere, for ITS to have positive impacts on treaty compliance and performance, knowledge and information must be shared with the public. Engagement of broader segments of the public requires dissemination of information on international agreements' operations and performance. Yet as widely discussed, the so-called digital divide represents a key impediment to realizing this potential. Although improving in many countries, there are still

600. Aronson, *Preserving Human Rights Media*, *supra* note 8, at 90.

601. Aronson, *Computer Vision*, *supra* note 8, at 1206.

602. Heberling et al., *supra* note 163, at 2–3.

603. KENNEDY, *supra* 479, at 104.

604. *Indigenous Summit*, GEO INDIGENOUS ALLIANCE, https://earthobservations.org/geo_indigenous_alliance.php [https://perma.cc/K9PT-NB5X] (last visited Sept. 15, 2022).

605. Aronson, *Preserving Human Rights Media*, *supra* note 8, at 86.

606. Galaz et al., *supra* note 528, at 2.

607. *Id.* at 4.

608. *Id.* at 4.

609. *Id.* at 4–5.

great discrepancies in levels of connectivity between developed and developing countries.[610]

A related concern is the dominance of the private sector in the Global North as providers of many of the services used in ITS. These services include EOS, cloud computing, and AI/ML products. This role complicates many of the concerns described. Among these risks are dependency on the private sector for essential services, which can, among other things, enable rent extraction.[611]

IV. SUMMARY

A key theme that emerges from the foregoing discussion is the way in which all of the processes described are viewed ostensibly as value-neutral and objective in nature yet in reality entail value judgements that can influence the outcomes of treaty processes.

From the analysis of the role of ITS in the different treaty regimes studied here, it does not appear that there are easy answers to many of the questions raised. While many of the issues are common to all ITS components, the concerns often differ in nature and degree between different treaty regimes. An important question is whether different treaty regimes require *sui generis* approaches or whether value can be obtained by adopting common standards across different fields. Given the novelty of ITS and its continued development, we can expect that here, as with society generally, norms and rules governing our increasingly digital societies will continue to evolve in response to new challenges, experience, and better understanding.

Ultimately, the value of ITS is to expand the knowledge basis for multilateral treaties, not provide the final answers or definitive truths. At each stage in the processes, judgments must be made about what to measure, how to measure it, how to process the resulting data, how to interpret them, and how to present them. As the discussion of epistemic considerations above illustrates, our conception of science must accept its limitations judged even on the standards of conventional scientific communities. This understanding does not lead inevitably to a form of relativism, as philosophers such as Jurgen Habermas have shown. In responding to critiques of knowledge by postmodern thinkers, Habermas acknowledged that efforts to define some universal basis for knowledge as epitomized by Immanuel Kant could not be sustained.[612] Knowledge, he argued, is inherently intersubjective and discursive.[613] Only by engaging in deliberation among a wide range of actors can we determine the truth.

Hence, the use of ITS must be viewed as not only supporting deliberation and decision making within multilateral treaty regimes, but also the development

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610. *Id.* at 5.
611. *Id.*
612. JURGEN HABERMAS, THE PHILOSOPHICAL DISCOURSE OF MODERNITY 23–24 (Fedrick Lawrence trans., 1987).
613. *Id.*

and application of ITS and the outcomes of research it enables must be subject to deliberation and choice.

V. ASSESSMENTS AND IMPLICATIONS

As Part II reflects, ITS affect many aspects of multilateral treaty practice including compliance, implementation, verification, and the knowledge base for assessing and adjusting performance. There may also be ancillary benefits from the use of technology, which, while not the basis for the initial decision to adopt treaties, confer important societal benefits.[614] I would like to focus on specific contributions of ITS including efficiency, better information, and data, continuing technological advancement, stimulation of communities who support and carry out work in furtherance of treaty purposes, and contribution to compliance and regulatory performance.

Across the regimes examined, ITS is having important effects on the overall efficiency of the relevant instruments. These enhancements cut across all elements of ITS. Sensing technologies are enabling observations and insights on a scale and scope previously unattainable.[615] Data storage capabilities enable the speedy retention of data and make them available throughout the world almost immediately. For many applications, the range of data science techniques available to analyze and process these data is providing orders of magnitude improvements on what was possible in the past. Improved data processing facilitates more sophisticated models and user-friendly visualizations for decision making. Collectively, they contribute to improved monitoring of treaty performance against relevant indicators. Overall, as technologies are becoming more powerful, many applications are becoming more user-friendly and accessible to non-technical persons.[616] Together these improvements in efficiency can reduce the amount of effort devoted to taxing mechanical processes, thus conserving researchers' and officials' time for higher value-added analysis.[617] Likewise despite the increase in the power and information available, all of these tasks are being done more cost-effectively, which can conserve resources.

Not only are ITS enabling efficiency improvements, but the scope and quality of information being generated by these systems are improving significantly. Increasingly the knowledge base associated with multilateral treaties is truly global. Initiatives like Global Fishing Watch already provide global scale, near-real-time information. Landmine monitoring, while based on national mine action programs, offers broad understanding of mine contamination in nearly all affected countries. Climate change research offers planetary scale information on a wide range of variables, with the digital twin of

614. *Cf.* Tim Doherty et al., *Expanding the Role of Targets in Conservation Policy*, 33 TRENDS ECOLOGY & EVOLUTION 809, 810 (2018).

615. Alston & Gillespie, *supra* note 132, at 1112.

616. Husseini & Bali, *supra* note 368, at 299; Taylor et al., *supra* note 35, at 131.

617. Lamba et al., *supra* note 139, at R978 ("[D]eep learning [can] efficiently automate the analysis of very large conservation datasets, thereby allowing conservation researchers to focus on important ecological questions rather than spending time on repetitive tasks.").

Earth representing maximum levels of comprehensiveness. The IMS of the CTBTO provides near real time data on potential nuclear events anywhere in the world. The fact that many ITS applications cover geographic areas that are global or at least not limited to one country, supports responses to global problems at a planetary level. One of the hallmarks of scientific research in recent decades is the increasing understanding that global problems are often tightly interrelated and overlapping in nature.[618]

Not only is planetary-scale information becoming common among treaty regimes, but information is also becoming available on a real-time basis even from difficult to reach locations.[619] The quality of data and the tools available to analyze the data are enabling insights into the relationships between different systems and different phenomena that may have been previously impossible to conceive. This enhanced information and knowledge can improve the process of creating and managing multilateral agreements.

A crucial element to all ITS surveyed in this Article is an open-source approach.[620] Governments are routinely making satellite data available to the public gratis.[621] Scientific replicability requirements necessitate sharing of datasets with other researchers. Government standards for transparency and requirements that publicly funded research be made available freely have become common.[622] Standards for data sharing have been established in many areas and are developing further.[623] Maintaining this common open-source philosophy will be important to realizing the potential of ITS.

Although the growth in efficiency and knowledge are already impressive, changes across the areas studied are underway, many of which promise exponential improvements over even current capabilities. Some of these improvements have to do with continued innovation surrounding existing technologies from sensing devices to computing and storage capabilities. But many other improvements are occurring through the combination of these technologies and growing know-how about the purposes to which they can be put.[624] To some degree, innovations in the practices of treaty bodies, whether in the form of strategic plans and indicator frameworks or the SDGs, are helping to stimulate innovations to provide data required for those purposes.

These activities are occurring through the efforts of diverse communities of practice around many international instruments. Collaboration among research communities is becoming significantly easier with more widely available cloud computing and bundled services, information and communication technology, and platforms for collaboration such as virtual

618. Peters et al., *supra* note 241, at 654.

619. Lamba et al., *supra* note 139, at R979.

620. *See, e.g.*, Poblet & Kolieb, *supra* note 8, at 266 ("The use of open data—as publicly available datasets are popularly known—is now becoming a standard practice in humanitarian and human rights work.").

621. Witmer, *supra* note 8, at 2243.

622. Langmead & Nellore, *supra* note 179, at 208–19.

623. Heberling et al., *supra* note 163.

624. *See, e.g.*, Taylor et al., *supra* note 35, at 134 ("Mobile data collection systems, such as Open Data Kit and CyberTracker, will help to unite ground-based perspectives with remote sensing data.").

research environments and scientific gateways.[625] These epistemic communities are developing new forms of know-how relevant to the treaty purposes.[626] The depth and vitality of these communities provides an important argument for the utility of multilateral instruments. These new forms of community need to be weighed against the epistemological concerns noted in Part III and the representativeness of these developments from the standpoint of the Global South. At the same time, there is evidence that improved ICT availability notably through cloud computing and greater consciousness in scientific communities of the value of indigenous and local communities' knowledge, are mitigating these concerns. The self-organizing efforts of these communities to innovate are key drivers to the continued improvements of these systems. Despite the importance of this type of collaboration, as described more fully below, there are significant discrepancies between the engagement of actors from the global South compared to the global North.

A. New Horsepower for International Agreements

It is clear from these developments that something new has emerged within international law, which is potentially changing the playing field for how it is assessed, analyzed, monitored, and enforced. Despite the importance of these many innovations, it is important to recognize exactly how they contribute to work within the different regimes. Their contribution may be significant, but it is important to not overstate its role. Rather than driving or controlling treaty processes, ITS is enabling treaty processes. Technology is very much in the service of the normative frameworks that have been created. Contrary to the notion of a single "killer app," individual technologies are often used not in isolation but in combination with other technologies. Moreover, technology is used often to confirm insights gained from other actors and sources, rather than provide proof that overrides all other sources of information.[627] In addition, technologies do not change so much what work is being performed in support of treaties, but rather the ways in which tasks are carried out. This does not mean that practice will continue unchanged. Instead, I argue that new approaches are warranted.

Nevertheless, viewed as a whole, ITS may ratchet up the regulatory power of multilateral treaties. Greatly improved and expanded observational

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625. Michelle Barker et al., *The Global Impact of Science Gateways, Virtual Research Environments and Virtual Laboratories*, 95 FUTURE GENERATION COMPUT. SYS. 240, 244 (2019); Massimiliano Assante et al., *The gCube System: Delivering Virtual Research Environments as-a-Service,* 95 FUTURE GENERATION COMPUT. SYS. 445, 446 (2019); Roger Barga et al., *A Virtual Research Environment (VRE) for Bioscience Researchers*, 2007 INT'L CONF. ON ADVANCED ENG'G COMPUTING AND APPLICATIONS IN SCIS 31, 31–38.

626. Peter Haas, *Introduction: Epistemic Communities and International Policy Coordination*, 46 INT'L. ORG. 1 (1992).

627. Aronson, *Preserving Human Rights Media*, *supra* note 8, at 84 ("Video and images often compliments official narratives and press accounts of an event or situation, adding detail and nuance."); Birgitta Putzenlechner, et al., *Validation of Sentinel-2 fAPAR Products Using Ground Observations Across Three Forest Ecosystems,* 232 REMOTE SENSING ENV'T 111310 (2019); Wouter Dorigo et al., *Evaluation of the ESA CCI Soil Moisture Product Using Ground-based Observations*, 162 REMOTE SENSING ENV'T 380, 395 (2015); Ilaria Santin, et al., *Recent Evolution of Marmolada Glacier (Dolomites, Italy) by Means of Ground and Airborne GPR surveys*, REMOTE SENSING ENV'T, Dec. 15, 2019, at 5; Ranisavljević et al., *supra* note 176, at 113.

capabilities, data collection, and data processing are foundational and important, but through the application of modeling, mapping, visualization, and performance monitoring, the stakes have been raised for states. Together these tools translate the improved knowledge base for treaties into understandable insights for decision making. Modeling, visualization, and indicator-based performance management combine to create new regulatory drivers for treaty adherence. These elements add to existing understandings of regulatory treaty compliance such as cooperation and managerialism, reputation, reciprocity, and rational choice. It also adds new sources of pressure because, based on the improved knowledge and the ease of demonstrating the cost of inaction, citizens and civil society can be spurred to action to hold states accountable.

As suggested in Section I, these developments are being integrated in treaty governance and management. They are thus changing the capabilities of treaty regimes.[628] Assessment reports developed before meetings of treaty governing bodies, draw on research ITS enables. Likewise, science and technology committees of treaty governing bodies rely on and steer ITS uses.[629] Compliance committees rely on the information ITS provides to evaluate state compliance. Indicator frameworks are developed with a view to what data can be gathered through ITS. Together these activities are endogenously shaping treaty regimes and altering the capabilities which all actors involved can draw upon to advance treaty regimes.

B. Future Trends and Opportunities

There are a number of implications for the development of ITS. In addition to addressing some of the potential shortcomings, there are number of steps that can be taken to build on the capabilities that ITS creates. Among these approaches are factoring in ITS in designing multilateral treaties, building infrastructure to enable ITS to support multilateral agreements, intentionally cultivating ITS through strategies and decisions of treaty bodies, taking steps to promote cross-regime interoperability through ITS, and capitalizing on the capabilities ITS enables to achieve more dynamic and responsive governance and regulation. Understanding the capabilities created by ITS is a first step to unlocking its potential.

The regimes studied reflect tremendous progress in building the infrastructure to support ITS. Much of this activity has been carried out through decentralized processes or has emerged through gradual developments within treaty regimes with support from stakeholders. The data infrastructures created for some of the treaty regimes described in this Article provide a view to what may be done in the future. It is unclear what form these initiatives need to take

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628. *See* RICHARD NELSON & SIDNEY WINTER, AN EVOLUTIONARY THEORY OF ECONOMIC CHANGE (1982) (describing the notion of organizational capabilities). *See also* Christopher Balding & Daniel Wehrenfennig, *Theorizing International Organizations: An Organizational Theory of International Institutions*, 2 J. INT'L STUD. 7, 7–27 (2011) (describing institutional tools and mechanisms as giving capabilities to international organizations to meet their objectives).

629. MCINERNEY, *supra* note 4.

but it is evident, given the value of ITS to the regimes studied, that its contribution could be enhanced by thinking in advance about the possibilities for the infrastructure needed. Oran Young, for example, has written about the possibility of creating infrastructure to support EOS.[630] Others have proposed shared infrastructure for human rights data[631] and shared satellite architecture for arms control.[632] Another possible institution would be to create a worldwide monitoring network for essential variables including climate, biodiversity, and ocean.[633] One consideration is whether infrastructure can be shared by multiple regimes. Likewise, the standards for issues of privacy and data integrity must be addressed in advance and much work remains to be done in this regard.[634]

One potential model for these types of enabling initiatives is GEO.[635] Given the tremendous value of EOS to scientific research across many fields, national space programs and international organizations created GEO in 2003.[636] GEO has strategies to support its efforts to address treaty-related issues including the UN's 2030 Agenda, biodiversity (CBD), the FCCC, forests (CBD and FCCC), land degradation (UNCCD), wetlands (Ramsar Convention), persistent organic pollutants (Basel, Rotterdam, and Stockholm Conventions).[637] A key value of GEO is to bring together actors from multiple fields, who share an interest in Earth observation.[638] Similar types of organizations could help bring diverse communities together around broader applications of technology for international law.

Among treaty bodies, efforts can be made to cultivate ITS as a strategic opportunity. While the type of self-organization seen among many of the ITS examples discussed is something that should not be discouraged, having a clear understanding of what technology can contribute to ongoing priorities within treaty regimes could drive intentional decisions to build ITS into the regimes. An important vehicle for ramifying ITS into treaty regimes is the use of strategic management techniques.[639] Major multilateral treaty bodies have used science and technology to develop multiyear strategic frameworks, while using those strategies to prioritize and mobilize scientific and technology-enabled capabilities for treaty regimes.[640] In addition, as described above in Section II.E, treaty strategic plans provide the basis for devising indicators that use data to measure treaty performance, while setting in motion efforts to develop

630. Stokke & Young, *supra* note 7, at 179–80.

631. Alston & Gillespie, *supra* note 132, at 1116–19.

632. *See* Koplow, *supra* note 9, at 93 (suggesting the possibility of a treaty-based institution funded by the international community to "develop, deploy, and operate space-based observation platforms in support of arms control treaty verification and other functions").

633. W. Daniel Kissling, et al., *Towards Global Interoperability for Supporting Biodiversity Research on Essential Biodiversity Variables (EBVs)*, 16 BIODIVERSITY 99, 100 (2015).

634. Wolfinbarger, *supra* note 8, at 464.

635. GROUP ON EARTH OBSERVATIONS, *2020-22 GEO Work Programme Summary Document*, https://www.earthobservations.org/documents/gwp20_22/gwp2020_summary_document.pdf [https://perma.cc/X5R3-M8QD] (last visited Sept. 15, 2022).

636. *Id.*

637. *Id.* at 30.

638. *Id.* at 32.

639. MCINERNEY, *supra* note 4.

640. *Id*. at 199.

technology to provide such data. As technology enables new forms of data to be collected, the metrics we use to gauge progress can be aligned to those standards.

The choice of methodologies such as algorithms for the gathering, processing, and analysis of data pertaining to treaty matters is inherently a matter of policy significance. There is an assumption that science and research is based purely on non-normative considerations. Even if the actors involved in gathering and executing technology-enabled research are well-intentioned, the decisions about what to study, the level of accuracy required, and the way to make sense of data obtained requires policymakers' input.[641] We cannot approach the question of the utility of research for international agreements with the assumption that policymakers are passive recipients of that data but instead must recognize their important role in setting the terms and methods for producing that knowledge in the first place.

VI. CONCLUSION

The use of ITS shows potential for improving compliance and the performance of multilateral regulatory treaties through the heightened levels of knowledge available to many treaty regimes. Unfortunately, studies suggest the performance of treaty regimes on many key issues has fallen short of what is needed to address issues such as environmental degradation, human rights, humanitarian law violations, de-mining among other things.[642] Of course, it is hard to assess the counterfactual, but there are at least grounds to believe that better results are needed from multilateral treaties given the critical state of many aspects of today's world. Among the opportunities ITS creates is for treaty bodies to take more active approaches to responding to emerging or imminent problems within treaty regimes. In many areas of international law, notably climate change, the need for science and technology to deliver *now* is imperative.[643]

Ultimately the growing prevalence of real time data on global scales are transforming the opportunity horizon for existing treaty regimes and enabling potentially more dynamic and responsive approaches to international treaty law and regulation.[644] Might more frequent meetings be needed, new approaches to streamlined decision making, or provisional decisions made with a view to reassessing decisions in a relatively short time? Could different types of meetings or events be devised to improve the impact of visualization and modeling? These are the types of considerations that the real-time and more comprehensive data available to treaty regimes raise. With the increased knowledge available, if the responsiveness of treaty bodies can be improved,

641. O'NEIL, *supra* note 552.

642. Khalaf et al., *supra* note 1.

643. Bauer et al., *supra* note 340, at 80.

644. Rebecca Lewison, et al., *Dynamic Ocean Management: Identifying the Critical Ingredients of Dynamic Approaches to Ocean Resource Management*, 65 BIOSCIENCE 486, 494 (2015); JOHN BRAITHWAITE & IAN AYRES, RESPONSIVE REGULATION: TRANSCENDING THE DEREGULATION PARADIGM (1992).

better results around multilateral treaties may be realized which may in turn contribute positively to resolving some of our greatest global problems.