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OGC Information Technology Standards for Sustainable Development

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Contents

i. Abstract

Sustainable development, "meeting the needs of the present without compromising the ability of future generations to meet their own needs,[1]" will be accomplished by balancing social, economic and environmental objectives. In this paper the authors explain that rigorous standards for communicating environmental data are absolutely essential to enable social and economic progress in the Age of the Environment[2] – the Anthropocene Epoch[3] – in which humanity's expanding footprint has become the main cause of change in the planet's geology, water bodies, atmosphere and biosphere. The authors argue for a concerted and ongoing global effort to 1) define data communication and system interoperability requirements for environmental science, business and policy, and then 2) develop and implement consensus-derived, free and open environmental Information Technology (IT) standards that meet those requirements and that co-evolve with the larger IT standards framework and advances in IT.

ii. Keywords

ogcdoc, OGC document, sustainable development, open standards, IT standards for the environment, green IT, Anthropocene, standards, WaterML 2.0, OGC standards

iii. Preface

One of Green IT's most important enablers – open standards – is seldom discussed. The authors propose an agenda for standards research, development and implementation to underpin communication of spatial data in support of sustainable development.

This document was written and reviewed by staff and members of the OGC to 1) describe the work of the OGC as it relates to sustainable development and 2) call for collaboration across a broad spectrum of sustainable development stakeholders to carry this work to the next level.

The paper includes overviews of existing standards, current work on new standards, technology trends affecting environmental standards, and descriptions of a few of the standards that are needed but do not yet exist. The authors argue for the development and use of domain-specific but technically interrelated IT standards for communication and data integration within and between domains that focus on the environment. These domains include the Earth sciences as well as the environmental response and management domains such as emissions monitoring, offsetting, trading, taxing and regulating; physical infrastructure monitoring; public health; embedded energy tracking/reduction, disaster response; etc.

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[1] World Commission on Environment and Development's (the Brundtland Commission) report, "Our Common Future," (Oxford: Oxford University Press, 1987)

[2] Edward O. Wilson, "On the Age of the Environment," Foreign Policy, no. 119 (Summer 2000), p. 34.

[3] See http://www.anthropocene.info/en/anthropocene. This website is a collaborative project between researchers and communicators from some of the leading scientific research institutions on global sustainability.

Environmental data is spatial data, that is, data describing features and phenomena and their locations relative to Earth coordinate reference systems. It is important to keep in mind, however, that "maps" and even GIS (geographic information systems) do not capture the full potential of digital environmental data. To secure humanity's future we need to put data describing natural and built environments – micro, meso and macro, indoor and outdoor – into the broader Web sphere, and we need consensus-derived, open, international encoding and interface standards and best practices so producers and users of that data can benefit from the extraordinary and rapidly advancing capabilities of IT. The Earth is a "flux coupler", simultaneously coupling complex dynamic Earth system processes of many kinds. The ability to introduce outputs from one Earth system model as inputs into another Earth system model improves our ability to model these complex interlinked and dynamic systems.[4] The nature of digital technology and the interrelatedness of Earth systems require that geoscience and environmental management domains use data encodings and geoprocessing software interfaces that are designed to be useful in holistic Earth system modeling, cross-disciplinary studies and longitudinal studies. Data provenance, quality, archival, semantics are important, as are the evolving trends in IT and these trends impacts on workflows.

The authors describe progress in the area of spatial IT standards and call for a concerted effort by academia, research funding agencies, NGOs, government and industry to build the required open standards framework. Analysis of data communication in current environmental workflows will yield specific technical requirements, and the authors call for funding of such analysis so that it may begin. The authors urge and anticipate future work and leadership in bringing together international partners who can build bridges connecting domain subgroups and connecting domains so that they may begin building common purpose, common understandings, and then standard interfaces, encodings and best practices.

iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

[4] Interfaces implementing the OGC Open Modelling Interface Version 2 (OpenMI) Interface Standard[4], introduced into the OGC by the OpenMI Association, enable the chaining of Earth system models.

Open Geospatial Consortium (OGC)

v. Submitters

All questions regarding this submission should be directed to the editor or the submitters:

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1. Introduction – Data communication for sustainable development

The Anthropocene is an informal term suggesting that human activities have now affected the planet to such a great extent that they mark the beginning of a new geological epoch. In this new epoch, world peace and prosperity, and perhaps our survival, will depend on how well we collaboratively manage our interactions, not just with each other, but also with the Earth's atmosphere, water, soil, geology, energy resources and non-human life forms.

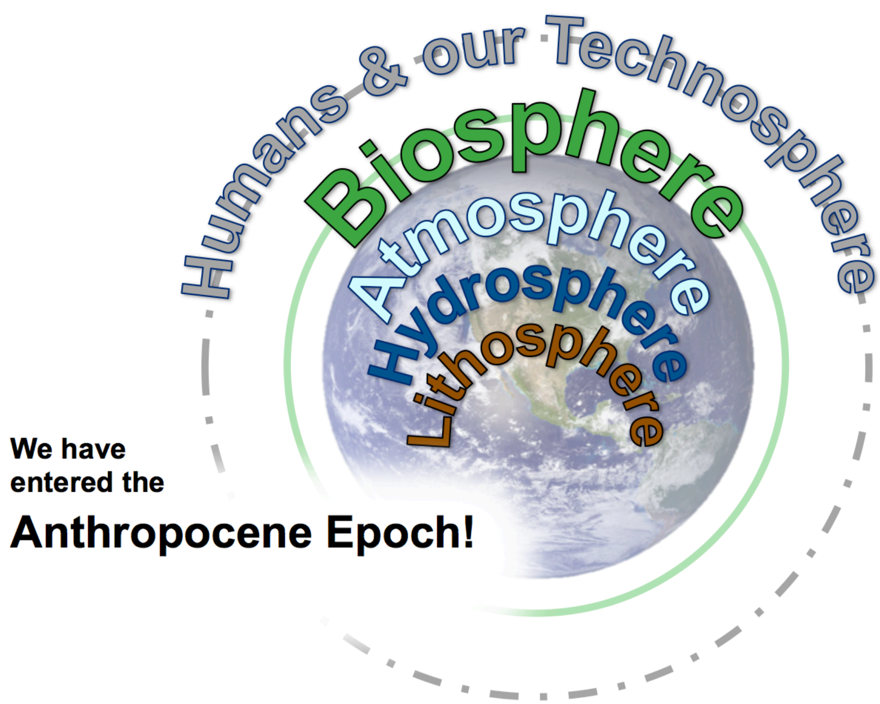

Figure 1: Now, in the Anthropocene, human activity is the dominant factor effecting change in the Earth's rocks and soils, water bodies, atmosphere and flora and fauna. We need to tune and sharpen our information technology for the purpose of managing change to benefit present and future generations.

We mustn't discount the fact that we have already begun managing our interactions with Earth systems: For example, fewer new dams are being built, energy efficiency is improving, controls have begun to be placed on pesticides and herbicides, and early programs are in place to limit CO2 emissions. We are also getting better at managing our responses to Earth systems' impacts on us. Our science, technology and collaboration have brought us steadily improving disaster response plans and increasingly accurate weather forecasts, algal bloom reports, climate change predictions, soil moisture monitoring etc. that help us to be resilient in the face of Earth system events.

Progress toward sustainability has significantly depended on electronic information technology (IT) that helps us develop and share knowledge about Earth changes and our role in those changes. To build on what has been accomplished, in this paper we argue for the development and use of domain-specific but technically interrelated IT standards for communication and data integration within and between domains that focus on the environment. These domains include each of the Earth sciences and many of the environmental response and management domains: emissions (trading, taxing and regulating), infrastructure monitoring, public health, embedded energy tracking/reduction, etc.

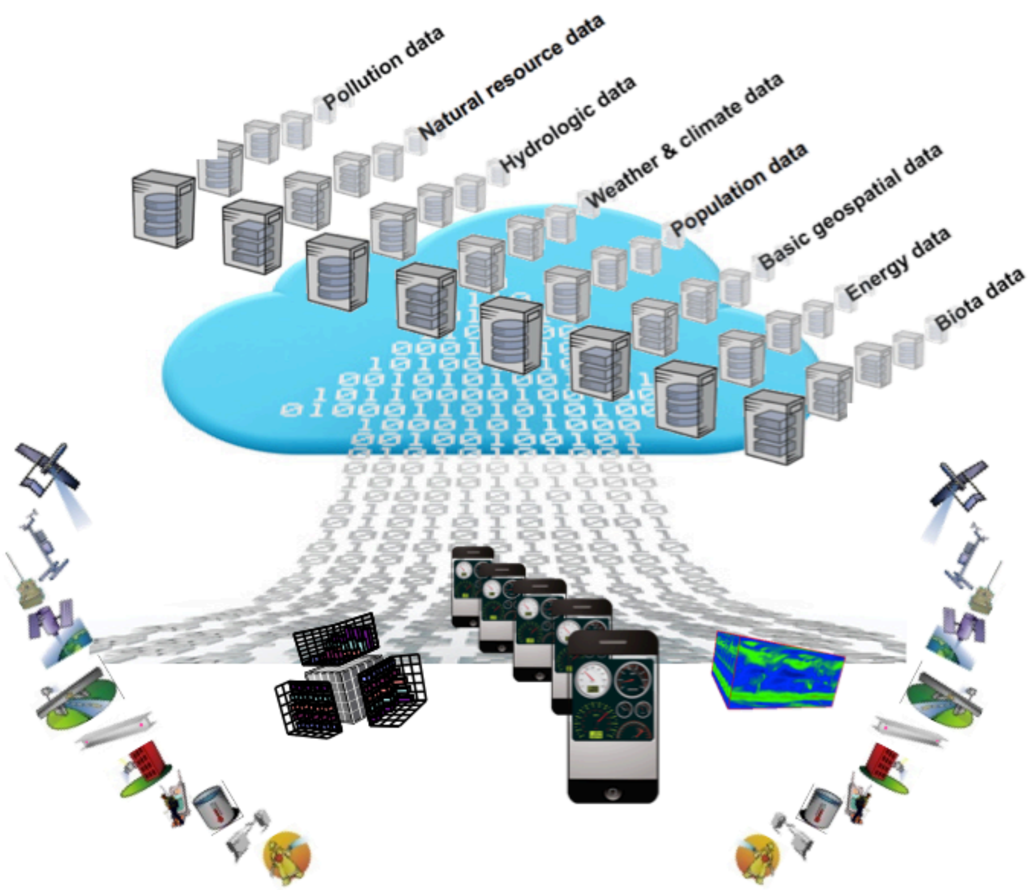

Figure 2: We get a rapidly increasing number of terabytes of data from an explosion of sensors, satellites, citizens, models etc. However, data has little value if it can't be easily discovered, assessed, accessed, aggregated, combined, passed from system to system, etc.

Environmental science, education, business and policy require Earth observations and measurements, but data is not enough. Equally important is the requirement to *communicate and process those measurements* to turn them into information, knowledge, wisdom, policy and business. Maps are also not enough. They put geographic information into a pre-digital paper space. We need to put environmental data – micro, meso and macro, indoor and outdoor – into IT space, and we need to be smarter about how we do this so we can benefit from the extraordinary and rapidly advancing capabilities of information technology.

The Earth is a "flux coupler", simultaneously coupling dynamic processes of many kinds. Our ability to model complex, dynamic and interlinked Earth systems[5] depends on our ability to transfer outputs (along with metadata – data about the data – including measures of error and uncertainty) from one model as inputs into another model. The interrelatedness of Earth systems requires that the disciplines focused on different systems – geology, hydrology, meteorology, etc. – use data encodings and geoprocessing software interfaces that are designed to be useful in cross-disciplinary and longitudinal studies.

Communication and large-scale data collection and processing depend on the ability of systems to interoperate through standards-based interfaces and encodings. Standardization means, "agreeing on a common system." In many cases these necessary standards don't currently exist. Despite the success of the Open Geospatial Consortium in raising the profile of these issues, more needs to be done to raise awareness of the required standards and the benefits they could bring. This paper provides examples of how this standardization work is currently being done and outlines a roadmap for developing a unified set of environmental communication standards. The authors call on stakeholders to help us add detail to the roadmap and enlist domain experts in building a unified standards platform for sustainable development.

2. What needs to be measured and communicated for sustainable development?

Researchers studying socio-technical aspects of sustainability could make important contributions by addressing this question. Insights from an analysis of what needs to be measured and communicated would act as a stimulus to businesses, organizations and government data policy experts to partner in data coordination committees. It would act as a stimulus for Standards Development Organizations to begin gathering interoperability requirements and developing standards. With this progress, the potential for businesses to explore innovative offerings and business models in anticipation of projected market opportunities arising from enhanced information flows would be enhanced.

[5] Interfaces implementing the OGC Open Modelling Interface Version 2 (OpenMI) Interface Standard[5], introduced into the OGC by the OpenMI Association, enable the chaining of Earth system models such as climate models.

The domains for which researchers might assess value chains to discern their environmental data communication needs and opportunities include:

- Greenhouse gases: sources, sinks, offsets[6] and effects
- Pollution: sources, sinks, mitigation efforts and effects
- Wastes: toxic wastes, industrial wastes available as feed stock for industrial processes or products, waste mitigation sites and processes
- Physical Infrastructure: buildings, capital projects, transportation, communication, energy facilities etc. – for efficiency, environmental safety and "emergy" (quantification of energy and resources embedded in structures)
- Resources: fossil fuels, biofuels, geophysical (water, wind, ores etc.); biological resources (fish, crops, forests, soil etc.), electromagnetic spectrum, temperature deltas and microclimates, ecosystem services (cooling, carbon capture, oxygen production, air filtering, groundwater recharge, silencing, wind breaks, etc.) provided by natural features such as waterways, forests, green space and urban trees
- Hazards: radiation; toxic wastes; crime; fire, flood, earthquake, drought, wind and ice storms; occupational hazards, hazards from unsafe physical infrastructure
- Health: environmental health; disease demographics; public safety statistics; health stressors; health facility siting, design and operation

<u>The IT standards community cannot undertake this effort without the leadership of the domain experts.</u> In each of these domains, stakeholders, including environmental researchers, government agencies and businesses, need to reach consensus on requirements for shared ontologies[7] and data integration.

This work would proceed by exploring workflows and use cases involved in a wide array of present day environmental activities, such as:

- Cap and trade schemes and valuation of, for example, carbon offset projects
- City rating systems (STAR[8], C40[9], ISO 37120[10], ICLEI U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions[11], etc.)
- Environmental regulation, taxes and impact statements
- Industrial waterways reclamation

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[6] CarbonML, an encoding standard that would, for example, enable international exchange, verification, assessment and commerce in carbon offsets, has been proposed to the OGC membership.

[7] "In computer science and information science, an **ontology** is a formal naming and definition of the types, properties, and interrelationships of the entities that … exist for a particular domain of discourse." Wikipedia:http://en.wikipedia.org/wiki/Ontology_(information_science)

[8] STAR: http://www.starcommunities.org/rating-system

[9] C40: http://www.c40.org/

[10] ISO 37120: http://www.iso.org/iso/catalogue_detail?csnumber=62436

[11] ICLEI: http://www.icleiusa.org/blog/iclei-releases-first-national-standard-for-measuring-a-community2019s-carbon-footprint

- Integrated community energy systems
- Oil spills
- Resource/waste circulation
- Sustainable agriculture
- Triple bottom line accounting

Analysis of such activities by IT standards developers would result in environmental data communication requirements – interoperability requirements – to be addressed in interoperability test-beds and standards working groups. Significant societal and economic returns could derive from relatively small strategic investments applied to such activity. As described below, with WaterML 2.0, GeoSciML, PipelineML and others, this work has begun.

The Russian economist Nikolai Kondratiev first postulated major cycles of innovation in 1925. Dr James Bradfield Moody, author of *The Sixth Wave*, argues that we have now entered a sixth major wave of innovation — that of resource efficiency.[12] Global warming and pollution-induced health problems are consequences of terrible inefficiencies. Much old physical infrastructure is inefficient and in disrepair and much new infrastructure, hopefully more efficient, needs to be built to serve expanding urban populations. The environment and the economy are degraded by an abundance of usable but unused industrial byproducts[13]. The simple facts of resource depletion and population growth underscore the widespread need for innovations in resource efficiency. Progress toward efficiency (including but not limited to economic efficiency) is a critical element in Sustainable Development and it depends on more efficient communication of environmental data.

Urgent discipline-specific and project-specific data integration efforts don't wait for international standards, and thus ad hoc encodings and interface specifications proliferate. A few of these come into wide use, but without a concerted international effort to identify and involve a critical mass of key stakeholders, important domain requirements are ignored in ad hoc standards development and thus most of the integration work is not reusable and must be repeated for the next project.

The next section explains why environmental accounting will motivate development of the environmental domain encoding standards that will be critical to sustainable development.

[12] Sixth wave of innovation: http://www.wired.com/2011/06/sixth-wave-of-innovation/

[13] *Cradle to Cradle: Remaking the Way We Make Things,* William McDonough and Michael Braungart, 2002, North Point Press.

3. Environmental accounting needs indices based on trusted data

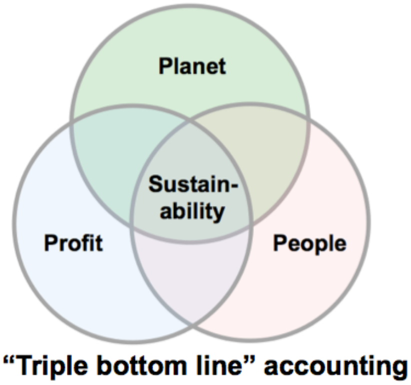

Figure 3: Sustainable development will impact commerce, government oversight, taxes and perhaps monetary systems. All of these require a unitary system of environmental data encoding standards that enable trustable, transparent and digitally useful communication of environmental measurements.

Science-based analysis of environmental factors has little effect on the environment until the analyses affect the way business is done. The US Environmental Protection Agency's "An Introduction to Environmental Accounting"[14] begins with this definition:

> "The term environmental accounting has many meanings and uses. Environmental accounting can support national income accounting, financial accounting, or internal business managerial accounting. This primer focuses on the application of environmental accounting as a managerial accounting tool for internal business decisions. Moreover, the term 'environmental cost' has at least two major dimensions: (1) it can refer solely to costs that directly impact a company's bottom line (here termed 'private costs'), or (2) it also can encompass the costs to individuals, society, and the environment for which a company is not accountable (here termed 'societal costs'). The discussion in this primer concentrates on private costs because that is where companies starting to implement environmental accounting typically begin. However, much of the material is applicable to societal costs as well."

Environmental accounting and environmental auditing will depend on standards for environmental evidence, and these will require widely accepted measurements and trustable, transparent and digitally useful description and communication of measurements. Trustable, transparent and useful measurement will be necessary in policy making and regulation; in commerce, such as emissions trading and "cradle-to-cradle" or "waste as a resource" transactions (see "circular economy")[15]; in documenting the value of a company's goodwill during an acquisition; and in auditing to verify value and compliance in all such activities.

[14] http://www.epa.gov/ppic/pubs/busmgt.pdf

[15] Circular Economy: http://ec.europa.eu/environment/circular-economy/

Environmental IT standards can be used as a basis for indices that simplify and standardize environmental accounting tasks. Indices exist for other accounting purposes such as quantifying liquidity[16] and summarizing changes in prices[17]. Environmental data encoding and software interface standards can reduce the complexity of environmental information in transparent ways so that accountants and auditors can use simply stated derived indices to produce, compare, aggregate and monetize results.

Eurostat[18], the statistical office of the European Union, is currently working to develop an environmental accounting framework[19] to:

- Track the links between the environment and the economy at EU, national, sector and industry level.
- Measure what impacts the economy has on the environment (e.g. pollution) and how the environment contributes to the economy (e.g. use of raw materials, resource efficiency, etc.) by using the accounting framework and concepts of the national accounts.
- List, in quantifiable terms, for example, the amount of pollution produced by different industries, which may in turn be compared with employment and the value of output produced by these industries.

Environmental accounting will require much more widespread and organized collection and communication of environmental data than current practices make possible. As described below, data will come from citizens' wireless devices and non-dedicated sensor webs as well as sensor webs, citizens, and businesses and environmental technologist teams dedicated to particular types of data collection. Environmental IT standards will play an essential role.

4. Citizen Science and data quality

Mass participation in environmental data collection helps raise awareness of environmental issues even as it helps to quantify environmental phenomena. Thus it is reasonable to assume that participation in environmental data collection by citizens will increase over time.

For citizen science and crowd-sourced data it will be particularly important to have collection apps that automatically record and transmit not only the sensor and human

[16] Liquidity Index: http://www.accountingtools.com/liquidity-index

[17] Price Index: http://www.businessdictionary.com/definition/price-index.html

[18] Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/about_eurostat/introduction

[19] Environmental accounts:
http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/introduction

observations but also metadata about those observations[20]. When data of known provenance is aggregated or conflated with data of unknown provenance, the quality of the resultant data is less certain than the quality of the data of known provenance, and thus "fitness for use" of the data product is less knowable. Steps in human and machine-executed workflows involving everything from sensor deployment, calibration and data reduction to passage of data through environmental models to environmental accounting indices will be logged, often automatically, to make data provenance and quality more knowable.

The COBWEB Citizen Observatory Web[21], a project of the European Union's 7th Research and Development Framework Programme, researches methods of validating and quality assuring crowd-sourced data so that it may be beneficially aggregated with reference data from authoritative sources. No single approach to this validation and QA process is likely to be adequate and so the research focus is towards developing a multi-stranded framework that could take input from several discrete sources.[22] For example, one technique useful in collection of volunteered geographic information (VGI) is "interactive direction of the observer". The observer is challenged with questions during the recording of observations, reducing the uncertainty associated with the data. GeoViQua[23] is a European Community Seventh Framework funded project that led to the development of the OGC Geospatial User Feedback Standards Working Group. User Feedback metadata can be valuable to quality estimates.

All data falls somewhere on a scale of precision and accuracy and no data are 100% precise and accurate. Users of spatial data and those adding metadata to data too often forget that a degree of uncertainty always exists. The GEOViQua studies have shown a huge quality deficiency in the recording of metadata even now where the emphasis is on the professional data collector.

It may be that we will need to move towards a much more probabilistic style of working using Big Data techniques for finding probabilistic associations between data items rather than tightly controlled matchings derived through formal ontologies. Nevertheless, those devising such Big Data techniques will benefit from also accessing quality estimates published as part of a data collection's metadata, and such estimates derive much of their value from compliance with international open standards such as ISO 19157 and ISO 19115 that define how quality has been calculated. Much work remains in development

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[20] Metadata is the first step of putting an observation into context. The context is not necessarily metadata, but can (hopefully and necessarily) be reproduced using it. Once context is known, data becomes meaningful.

[21] COBWEB Citizen Observatory Web - http://cobwebproject.eu/

[22] Meek, S., Jackson, M. J., Leibovici, D. (2014), "A Flexible Framework for Assessing the Quality of Crowd-sourced Data", in Huerta, Schade, Granell (Eds): Connecting a Digital Europe through Location and Place. Proc., AGILE'2014 Int. Conf. on Geographic Information Science, Castellón, June, 3-6. ISBN: 978-90-816960-4-3 http://repositori.uji.es/xmlui/handle/10234/98927

[23] QUAlity aware Visualization for the Global Earth Observation System of Systems - http://www.geoviqua.org/

of such environmental standards, including integration with still-emerging standards such as UNCertML.[24]

5. Open Data and sustainable development

Open interface and encoding standards are a critical requirement for Open Data.

In Spatial Data Infrastructure (SDI) efforts around the world, governments have wisely invested in gathering thematic data into databases and making those databases searchable and accessible by citizens for a wide variety of purposes. SDI efforts are motivated by the realization that in the Information Age, shared data is an integral part of infrastructure, a resource that contributes to national wealth. The more it is used, the more valuable it becomes.

The Internet can provide open access to data in SDIs and also, potentially, to a much larger array of spatially referenced data gathered from citizens and diverse distributed sensors and databases. Discovery, assessment, access and use all depend on standards implemented in the service of policies and business models.

"Radical reuse," "amplification of collective intelligence," "data-driven intelligence," and "virtual experiments" are some of the terms used to describe Open Data efforts such as the PolyMath Project[25], the Allen Brain Atlas[26], Galaxy Zoo[27], GenBank[28], the Sloan Digital Sky Survey[29], and Medline[30][31]. In the geosciences, we have OneGeology[32], the U.S. Geoscience Information Network[33] and the Ocean Observatories Initiative[34]. We need much more geoscience Open Data to accomplish what we must to achieve sustainable development in the Anthropocene. Some high quality journals are now

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[24] An OGC Discussion paper on UnCertML can be found at http://www.opengeospatial.org/standards/dp. The UnCertML specification available at the UnCertML web page remains the authoritative version. The specification is free and available to the public, but is not maintained through an open consensus process.

[25] PolyMath Project: http://michaelnielsen.org/polymath1/index.php?title=Main_Page

[26] Allen Brain Atlas: http://www.brain-map.org/

[27] Galaxy Zoo: http://www.galaxyzoo.org/

[28] GenBank: http://www.ncbi.nlm.nih.gov/genbank/

[29] Sloan Digital Sky Survey: http://www.sdss.org/

[30] MedLine: http://www.nlm.nih.gov/bsd/pmresources.html

[31] These are discussed in "Reinventing Discovery – The New Era of Networked Science," by Michael Nielsen, Princeton University Press, 2012.

[32] OneGeology: http://www.onegeology.org/

[33] U.S. Geoscience Network: http://usgin.org/

[34] Ocean Observatories Initiative:http://oceanobservatories.org/

requesting that authors provide data together with the manuscripts, and they are publishing the data, but these journals are still in the minority of journals.

Consider how much data development is wasted in the Earth sciences. Often with great effort and at great expense, scientists collect data that they use to write papers. The papers are preserved in journals, but the data, unless it has been collected and published en masse by government agencies, is seldom published and open for wider review and for reuse in longitudinal or cross-disciplinary studies. Most of it is lost.

The open data movement has begun, but effective open data policy and practice depends on open interface and encoding standards to provide efficient publishing, discovery, assessment, access (with protection and attribution) and use of data.[35] Consistent use of standard web service interfaces enables these operations to be "chained" in procedures that greatly enhance the value of the data and the scope of what can be done with it.

Data curation[36] will become more important as sustainable development becomes more dependent on science and open data. Data worth preserving is worth preserving with metadata that describes the data, including details about provenance and quality. Also, if it is worth preserving, it should be catalogued correctly so it can be found and used. As noted above, it should be served through open standard interfaces so it can be used efficiently.

6. Keeping up with rapidly evolving IT

TCP/IP[37], an IT standard, undergirds the Internet. Other IT standards such as HTTP[38] and XML[39] (and the associated HTML[40] standard) undergird the Web. Together, these fundamental IT standards and many others provide a foundation for the common system for communicating geospatial data and geoprocessing instructions, which is specified mainly in ISO/TC 211 and Open Geospatial Consortium (OGC)[41] standards. Most environmental datums have a location or area, so they are geospatial data[42].

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[35] See "18 Reasons for Open Publication of Geoscience Data" – http://www.earthzine.org/2010/08/04/18-reasons-for-open-publication-of-geoscience-data/, by Lance McKee.

[36] See "The Data Conservancy Instance: Infrastructure and Organizational Services for Research Data Curation" http://www.dlib.org/dlib/september12/mayernik/09mayernik.html

[37] TCP/IP: http://en.wikipedia.org/wiki/Internet_protocol_suite

[38] HTTP: http://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol

[39] XML: http://en.wikipedia.org/wiki/Xml

[40] HTML: http://en.wikipedia.org/wiki/Html

[41] OGC: http://www.opengeospatial.org

[42] Geospatial data: http://www.epa.gov/records/faqs/geospatial.htm

OGC Web Service standards[43] have brought geospatial technologies – GIS, remote sensing, navigation, facilities management etc. – out of their technology-type stovepipes and vendor stovepipes into a much larger world of users and possibilities. OGC Web Services standards include some of the first Anthropocene-epoch standards of the kind we are promoting: The OGC WaterML 2.0, GeoSciML and netCDF encoding standards. We describe these exemplars in sections that follow.

However, not all standards for sustainable development will be Web service[44] standards, because Web services are surely not the endpoint of IT evolution. During the 1980s and1990s, IT was database oriented, and the OGC's first standard, Simple Features for SQL, was database oriented. IT progress from 2000-2010 provided the Web services foundation that supports OGC Web Services, which depend on XML and the OGC Geography Markup Language (GML), an XML grammar for encoding geospatial information. OGC Web Services standards will probably be with us for a very long time, but the TCP/IP and HTTP standards also provide a platform for new technology approaches not bounded by the established Web services paradigm. Currently, these include JSON[45], REST[46], Linked Data[47] and the Semantic Web[48], all of which offer new possibilities and a path to the future. These complement the OGC's OGC Web Services standards with new approaches that can use and extend OGC Web Services. Linked data and the Semantic Web, in particular, will provide a quantum leap into a new level of IT-enhanced spatial awareness. Often these new approaches will involve simple point data. Schemes based on point data are unlikely to replace more complex spatial representations (polygons, grid arrays, 5D fluid models, triangulated irregular networks etc.), but simple point data will be useful in many situations, including much of Citizen Science[49] and the Internet of Things[50].

It's worth noting here that there are different temporal coordinate reference systems just as there are different spatial coordinate reference systems. Advances in combined spatio-temporal reference systems are a focus of work in the OGC.[51]

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43 OGC standards: http://www.opengeospatial.org/standards

44 Web services: http://www.w3.org/2002/ws/Activity

45 JSON: http://json.org/

46 REST: http://en.wikipedia.org/wiki/Representational_state_transfer

47 Linked data: http://www.w3.org/DesignIssues/LinkedData.html

48 Semantic web: http://www.w3.org/standards/semanticweb/

49 Citizen Science: http://www.nature.com/news/2010/100804/full/466685a.html

50 Internet of Things: http://www.mckinsey.com/insights/high_tech_telecoms_internet/the_internet_of_things

51 See the OGC Temporal Domain Working Group (http://www.opengeospatial.org/projects/groups/temporaldwg) and the OGC Name Type Specification for Coordinate Reference Systems (https://portal.opengeospatial.org/files/?artifact_id=46361).

We don't know what other geoprocessing and distributed computing requirements and innovations will emerge[52], but standards will surely play a role in making them useful and widely used resources for sustainable development.

It would be a mistake to assume that IT standards developed to serve near-term commercial mass market needs will meet all the digital communication requirements of science, commerce and government in an environmental age. While it is true that markets drive the evolution of technology, it is also true that fundamental standards shape technology and market outcomes. Wouldn't Internet and Web businesses be different if HTTP and XML had been specified differently? Standards are developed and evolve to meet market needs *as those needs are perceived by the standards' developers*, but in turn the standards probably only survive if those perceptions match the actual and evolving needs of the market. The mass market's scale drives investment for innovations and efficiencies that become available to science, but the mass market's requirements do not necessarily fully encompass the requirements of science or sustainable development. It is thus important for individuals and institutions concerned with science and sustainable development to participate in standards working groups.

In *Greening through IT – Information Technology for Environmental Sustainability*[53], Bill Tomlinson writes, "IT compresses complexity … by establishing agreed-on standards for the cooperation of devices and people." To be more precise, it is not IT itself that establishes agreed-on standards for the cooperation of devices and people; rather, the standards with the widest benefit derive from the tried and proven social processes facilitated by standards organizations to bring IT providers and users together. Dominant IT providers' sometimes open (but not consensus-derived) encodings and interfaces (or Application Programming Interfaces – APIs) often become important standards, but the consensus-derived open standards that provide a foundation for the Internet and the Web ultimately have wider value than the open APIs of any closed proprietary ecosystem. TCP/IP, HTTP and XML provide a foundation for a larger ecosystem of other consensus-derived open standards that extend the capabilities of the Internet and Web. **The authors of this paper argue for a concerted and ongoing global effort to first define interoperability requirements for environmental science, business and policy, and then develop and implement consensus-derived, free and open environmental IT standards that meet those requirements while co-evolving with the larger IT standards framework and advances in IT.**

A concerted effort – systematic collaboration – is absolutely essential. Collaboration is necessary to create good standards that are widely implemented. Collaboration in

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[52] There is increasing interest in geospatial filtering and processing through flexible query languages. See the OGC Filter Encoding 2.0 Encoding Standard (http://docs.opengeospatial.org/is/09-026r2/09-026r2.html), the OGC Web Coverage Processing Service (WCPS), (http://www.opengeospatial.org/standards/wcps) for filtering and processing on coverages, and GeoSPARQL (http://www.opengeospatial.org/standards/geosparql) for filtering and processing of metadata.

[53] *Greening through IT – Information Technology for Environmental Sustainability,* http://mitpress.mit.edu/books/greening-through-it

developing standards also reveals deeper collaboration opportunities and requirements that cannot be met by technical standards. This is why standards development is best undertaken by both technical experts and policy experts.

Because the need to address specific spatial information requirements cuts across the missions of so many Standards Development Organizations (SDOs), the Open Geospatial Consortium (OGC) collaborates with other SDOs to achieve spatial interoperability outcomes that would be impossible without inter-SDO cooperation. The OGC's established alliances[54] and history of success in forging alliances with other SDO's and professional organizations position the OGC as an SDO network hub for environmental standards development.

If geospatial data were simple, there would be no need for the OGC. However, it is not.

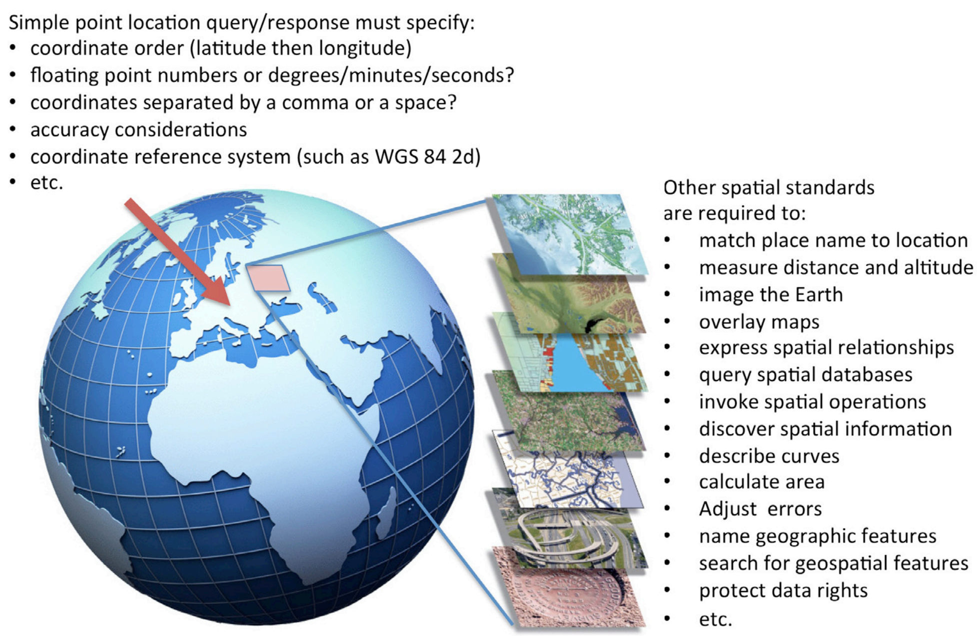

Figure 4: Developing standards for geospatial data and services requires special expertise.

Ed Lazowska, founding director of the University of Washington's data-centric eScience Institute, says that his goal in hiring eScience Institute faculty has been to hire a breed of "pi (π) people."[55] The π symbol has two legs connected at the top. Pi people have a leg in each of two disciplines. They are researchers who are equally conversant in two or more seemingly disparate fields, such as neuroscience and sociology, and these researchers serve as interdisciplinary connectors.

[54] http://www.opengeospatial.org/ogc/alliancepartners

[55] http://crosscut.com/2014/05/22/science/120199/washington-research-fdation-grant-uw-atkins/?page=2

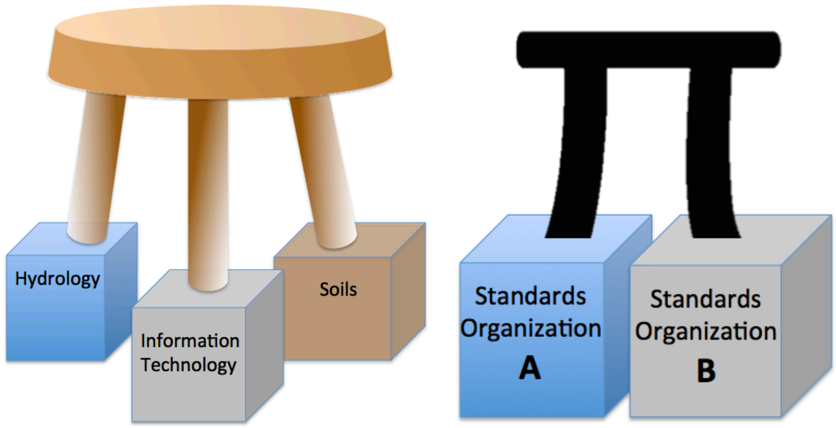

Figure 5: Environmental domain experts with expertise in multiple worlds have great value in the development of environmental IT interface and encoding standards.

Developing environmental standards requires "pi people" who are expert in one or more environmental domains and also in IT. The OGC encourages its members and the members of other SDOs to cross-participate in different SDO's working groups to address the requirements of environmental workflows. Because of the need in sustainable development for interdisciplinary and cross-community communication and coordination, there is a great need in standards activities for "milking stool people" with a foundation in each of three disciplines, one of which is IT, and two of which are different domains or different IT standards organizations.

Most of the environmental standards we anticipate in this paper will be standards designed for particular domains of activity and particular "information communities." We explore this in the following sections.

7. Semantic standards and technical standards

The domain-specific environmental IT standards development we call for in this paper will come as two worlds converge: the world of semantic standards (metadata, ontologies, data models, etc.) and the world of technical standards (such as the OGC's software interfaces and encodings). Several key OGC standards were designed to be tailored to suit the needs of particular applications. In this section and the following section, we explain why and how environmental information communities (including, so far, hydrology, geology, weather/climate, pipelines and 3D urban models) have begun to do this tailoring by bringing their semantic standards experts together with technical standards experts in OGC working groups.

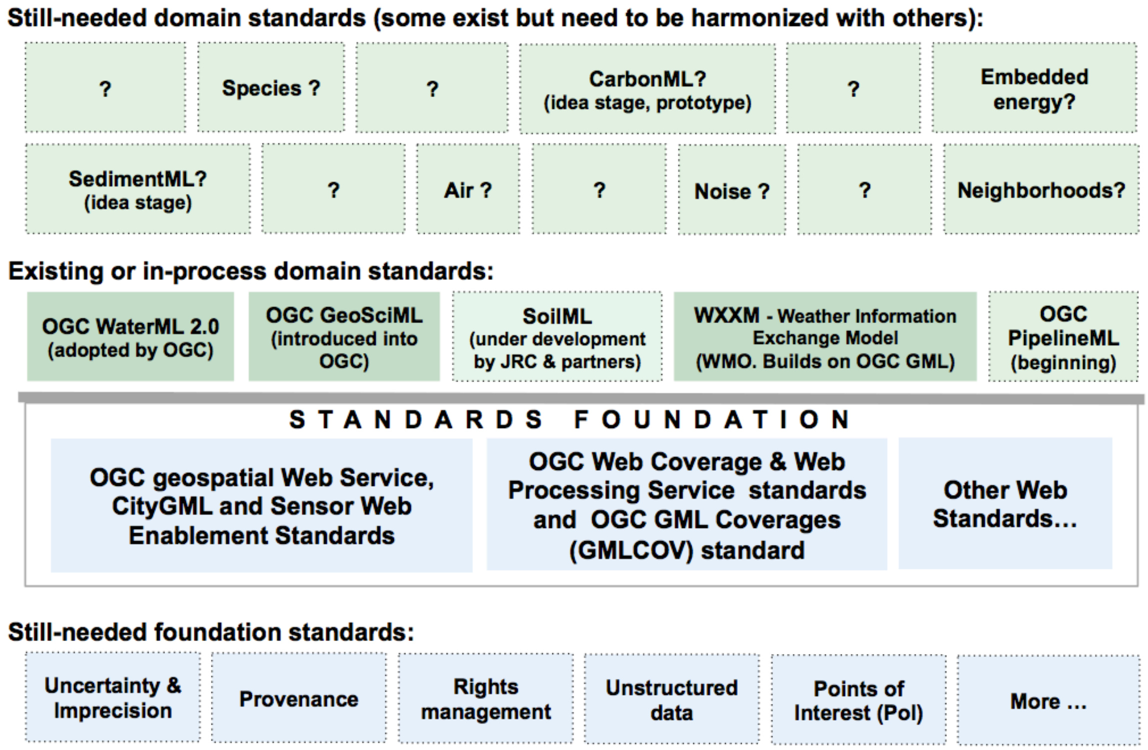

Figure 6: Important foundational standards are in place, as are domain standards for hydrology, geology, weather and soils. Much work remains, however, to create a coherent "system of systems" for environmental communication. Progress depends on the commitment and participation of communities of interest who have a critical role to play in sustainable development.

7.1 Domain semantics necessitate semantic standards

Over the last two decades, many information communities have learned the importance of data coordination and have learned how to do it. Information communities who depend on sharing information often put in place data coordination committees and processes for creating and maintaining standard data models[56] and metadata content standards. The data model used by an information community is their standard way of describing spatial information. It provides a data dictionary and related details necessary for the sharing, aggregation and comparison of data within the community. Metadata associated with a data set includes the data model along with other data about the data – date of collection, person or organization responsible for the collection, etc. Data model development proceeds as a part of an information community's metadata standards development effort.

Such standards are often referred to as "semantic standards". Because of these standards, different information systems used within the community can "speak the same language". Different data sets that use the same data model can be aggregated or compared.

[56] A deeper discussion of data models, ontologies, conceptual schemas etc. is beyond the scope of this paper. See "Ontologies and Data Models – are they the same?" http://topquadrantblog.blogspot.com/2011/09/ontologies-and-data-models-are-they.html.

Semantic standards also facilitate communication *between* information communities: When each community's data model is published and relatively stable, translation between different data models is easier and more precise, despite some inevitable loss of information. Data models necessarily evolve as information communities evolve, and so this data coordination process within and between domains is an ongoing activity. Data modelers working with other data modelers are key standards developers for the Anthropocene.

Geospatial standards are important for environmental work because virtually everything in our environment has a spatial component and because interactions between environmental features and phenomena depend on proximity. In the geospatial world, an "information community" is an industry, profession, academic discipline or other domain that shares a set of spatial information communication requirements. Because the geospatial element is so important, many data coordination efforts have begun in efforts to create "spatial data infrastructures." See for example the US Federal Geographic Data Committee[57] and the European Commission's INSPIRE Directive[58].

7.2 Technical standards hitch environmental standards to IT innovations

Also over the last two decades, the members of the OGC have developed policies and procedures for working together to develop consensus-based open interface and encoding standards that provide a way for any two computer systems to request and return any kind of spatial data. These "technical standards" are broadly useful within all spatial data information communities. They support inter-community communication and they are also essential for convergence and integration of different kinds of spatial technologies, such as 2D/3D/4D imaging, vector GIS, surveying, CAD, tracking, etc. The members of the OGC maximize new standards' viability by working together to promote widespread product implementation and market uptake of the standards.

Like semantic standards, technical standards evolve. The fundamental domain-neutral spatial technology standards framework is now in place, but rapid advances in technology make OGC members keenly aware that this foundation needs continual attention, as described above in the discussion of JSON, RESTful programming approaches and linked data. Such industry-wide advances force revision and rethinking of established technical standards. Discussions about revision invariably run into the issue of backwards compatibility, a standard's lifetime of usefulness, and the importance of stability to both technology providers and technology users who have made investments based on the standard. These are difficult but important issues. Mature standards development organizations and their long-term members have experience in negotiating these issues. They also have a keen awareness of the costs and risks associated with letting market leaders establish proprietary standards outside of an open consensus process. Industry market leaders work in standards organizations because they, like their competitors and

[57] FGDC (Federal Geographic Data Committee): https://www.fgdc.gov/

[58] INSPIRE (Infrastructure for Spatial Information in the European Community): http://inspire.ec.europa.eu/

despite their natural desire to "lock in" customers, have business reasons to implement and help develop open standards.

Technical standards are in place that can provide access control, security and certain privacy protections, but development also needs to address other issues such as geospatial data rights management and, as discussed above, data quality.

Much work remains in the broad area of technical standards for geospatial interoperability, despite the fact that a mature domain-neutral open spatial technology standards framework is already largely in place. One reason work remains is that technology is advancing so rapidly. Another reason is that new information communities keep appearing, as shown in Figure 6 below.

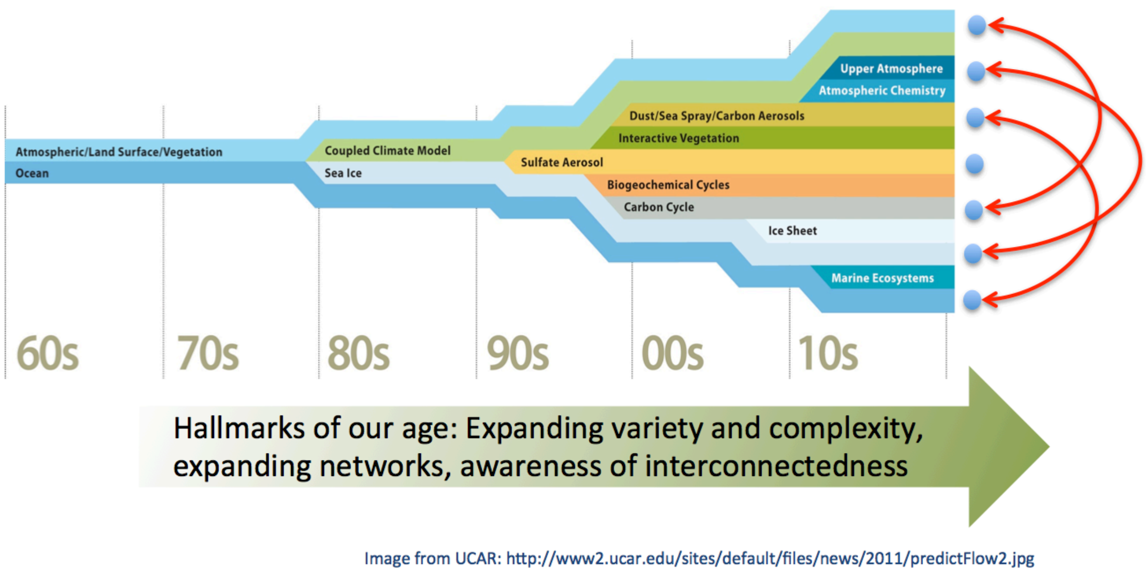

Figure 7: In climate science, as in many domains, new disciplines arise, and they are new information communities. Their data models differ, but they need to share data and communicate. Communities in relationship need interoperability.

In the next section we describe how the OGC Geography Markup Language (GML) Encoding Standard and other OGC standards can be used to develop international domain-specific encoding standards that bring semantic standards and technical standards together. This is a key cyberinfrastructure innovation for environmental science, business and policymaking. A domain that develops a domain-specific data encoding standard based on OGC standards and on the domain's semantic standards gives domain participants much fuller access to developments in the mainstream digital technology world: Web searches, chained computer models, full use of cloud infrastructures, Big Data, data analytics, data fusion, management tools for open data, heterogeneous sensor webs and much more.

8. GML and SWE profiles and application schemas – Basis for domain-specific environmental encoding standards

Just as calculations like F=MA and $e=mc^2$ require a unitary system[59] of standard measurements of energy, matter, time and space, digital communications" involving environmental data require a unitary system of communicating not only measurements but also descriptions of where, how and when the measurements were made.

The OGC Geography Markup Language (GML) Encoding Standard[60] (also an ISO standard since 2007) provides the essential "where" and "when" components. An international open standard that is now widely implemented, GML is an XML[61] grammar for expressing geographical features. Fundamental OGC Web Service Interface Standards such as the OGC Web Feature Service (WFS) Interface Standard[62] are specifically designed to write and read GML-encoded data. The WFS standard is implemented in virtually all commercial GIS products, and therefore GML is the "lingua franca" of those products. The use of GML reduces the need to use data transfer standards for batch conversion of data from one encoding to another as a first step in integrating differently encoded data sets. Information systems that contain and process geospatial data in any encoding can be provided with interfaces that enable direct two-way inter-system communication via GML. Also, pared-down profiles and application schemas of GML are embedded in many non-OGC standards to assure consistent communication of geospatial data in the wider global information infrastructure.

The OGC Observations and Measurements (O&M) Encoding Standard[63] specifies an XML implementation of the OGC and ISO Observations and Measurements (O&M) conceptual model. O&M provides a unitary system for encoding any type of observation or measurement, including volunteered geographic information (VGI), which may be anecdotal or photographic rather than the result of an instrument measurement.

Both GML and O&M can be adapted to the particular needs of domains. They provide the means for domains to build their domain-consensus data models into an XML encoding that is recognized by any system that implements GML or O&M. The OGC WaterML 2.0 Encoding Standard, described below, provides a good example.

Any GML or O&M data can be used directly with other GML or O&M data. For example, an agronomist could do analysis using a hydrology layer and a crop type layer. Or an emergency response coordinator could use WaterML-encoded river flow data to

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[59] For most such calculations, British imperial, US customary or metric system units can be used, but consistent use of one or another is necessary! The alternative is frequent use of error-introducing unit conversions.

[60] http://www.opengeospatial.org/standards/gml

[61] eXtensible Markup Language: http://www.w3.org/XML/

[62] http://www.opengeospatial.org/standards/wfs

[63] OGC Observations and Measurements Standard. http://www.opengeospatial.org/standards/om. (OGC Observations and Measurements v2.0 IS also published as ISO/DIS 19156).

trigger a Common Alert Protocol (CAP)[64] alert, because GML is embedded in CAP. Similarly, in the US the National Information Exchange Model (NIEM), an XML encoding for exchanging information across state and local government bodies, uses GML and is interoperable with GML-based standards such as WaterML 2.0.

OGC coverages associate positions within a bounded space to feature attribute values. Examples include Earth images, referenced and non-referenced rasters, curvilinear grids, and point clouds. The OGC GML Coverages (GMLCOV) standard provides a unified method for encoding OGC coverages in GML, the OGC Sensor Web Enablement (SWE) Common Standard, and the OGC Web Coverage Service (WCS) Interface Standard. As GMLCOV is independent of a particular service definition, it allows coverage data to be exchanged through different types of services that implement these OGC standards. The OGC's modular, scalable coverage model provides a foundation for a wide variety of environmental "Big Data" applications.

9. GEO and the GEOSS AIP

The Group on Earth Observations (GEO)[65] has helped establish a platform of cooperation among government data providers interested in sustainable development. GEO includes 80 Governments, the European Commission and 58 intergovernmental, international, and regional Participating Organizations with a mandate in Earth observation or related issues. The ten years of GEO have yielded pledges of thousands of core datasets and web services. Progress has been made in encouraging interoperability across GEO through the adoption of standards by Members and Participating Organizations and the testing of infrastructure through a series of annual prototyping projects undertaken through the Global Earth Observation System of Systems (GEOSS) Architecture Implementation Pilot (AIP)[66] activity. The OGC leads the multi-year AIP activity using the OGC Interoperability Program policy and procedures. The AIP is now in its 7th year.

The AIP task involves developing and deploying new process and infrastructure components for the GEOSS Common Infrastructure (GCI) as well as for the broader GEOSS architecture. The GCI provides operational components that enable 1) the registration of EO assets to GEOSS, 2) the identification of adopted standards and best practices, and 3) the discovery and access of data via download, web services, and through custom portals and websites.

The current AIP activity, AIP-7, aims to create and deploy several modern, lightweight web or mobile apps that are fed by multiple registered standards-based data and

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[64] CAP 1.2 is an OASIS standard that grew out of an effort begun in 2001 by an international, independent group of over 120 emergency managers who began specifying and prototyping the Common Alerting Protocol data structure based on the recommendations of a US National Science and Technology Council (NSTC) report.

[65] Group on Earth Observations

[66] GEOSS Architecture Implementation Pilot (AIP)

processing services - each app designed to address a specific user-driven problem. As with previous AIP activities, this year's (2015) AIP work is adding to the framework of standards described in previous sections of this paper.

10. Examples of domain standards for the Age of the Environment

10.1 WaterML 2.0 – hydrology

Nations are moving towards more holistic structuring of hydrologic monitoring systems in order to provide integrated local, national and international views on the state of water resources. This is necessary to address issues such as water quality monitoring, flood warnings, water management guidelines (applying restrictions, setting allocations etc.), and drought management. In addition, terrestrial water movement plays a role in climate processes; cross-domain climatological enquiry and modelling requires access to diverse types of observational data, including hydrological observations.

In response, key players in the international hydrology community came together in the OGC to develop an international hydrologic data encoding standard. The Australian Bureau of Meteorology and CSIRO's Water for a Healthy Country Flagship project in Australia; the Consortium for the Advancement of Hydrological Sciences Inc. (CUAHSI), the San Diego Supercomputer Center, NOAA in the US; The Federal Waterways Engineering and Research Institute (disy Informationssysteme GmbH), the German Federal Institute of Hydrology and Kisters AG in Germany; the International Office for Water – Sandre in France; Deltares in the Netherlands and various other national authorities and companies contributed to initial working group discussions and also development and testing in OGC testbeds and pilots. The work proceeds under the joint World Meteorological Organisation (WMO) and Open Geospatial Consortium (OGC) Hydrology Domain Working Group[67].

The OGC WaterML 2.0 Encoding Standard, now an adopted OGC standard, is the main product of this joint effort. WaterML2.0 is implemented as an application schema of the Geography Markup Language version 3.2.1 and it makes use of the OGC Observations & Measurements standard. The core aspect of the model is the correct, precise description of time series hydrologic observations.

Hydrology data models are notoriously diverse, and yet most can be mapped to WaterML 2.0. WaterML 2.0 thus provides a “data model Rosetta Stone” for data sharing between heterogeneous observation points and observation networks. A WaterML 2.0 compliant interface can be configured for a hydrological database that uses a unique data model. Access to similar data stored using two unique and dissimilar data models can proceed without manual intervention once the mapping between the two unique data models and the WaterML 2.0 data model has been completed. The internationally vetted data model

[67] OGC Hydrology Domain Working Group (http://www.opengeospatial.org/projects/groups/hydrologydwg)

built into WaterML 2.0 also provides a model for optional improvement or harmonization of local, regional or national hydrological data models.

WaterML 2.0 and the collaborative way it was developed provide a model for the development of other domain standards.

10.2 WXXM – weather

The aeronautical community depends heavily on WMO weather data, but this community has special requirements for the sharing and use of the data. A new standard, WXXM – Weather Information Exchange Model, has been developed by the International Civil Aviation Organisation ICAO, the US Federal Aviation Administration (FAA) and EUROCONTROL in collaboration with the WMO and the OGC for the exchange of aeronautical weather information in the context of a net-centric and global interoperable Air Transport System (ATS).

WXXM uses GML tailored to the specific requirements of aeronautical meteorology. It is based also on the OGC Observation and Measurement Model (O&M). Because WXXM is a well-designed GML-based weather data encoding model, other domains, such as the electric utility information system domain[68], are exploring options for using WXXM or harmonizing it with their standards, or else developing GML and O&M based weather models designed for their domains, in which most aviation use cases are irrelevant.

10.3 netCDF – climate and oceans

The network Common Data Form (netCDF) is a data model and a collection of access libraries for array-oriented scientific data. Originally developed by the University Corporation for Atmospheric Research (UCAR), netCDF has been formally recognized by U.S. government standards bodies and has become a de facto standard used around the world, particularly in climate and ocean observation, analysis and modelling. For example, output datasets from climate models being used for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change must be submitted in netCDF format, using the associated Climate and Forecast (CF) metadata conventions (CF-netCDF).

The multi-dimensional gridded and multi-point data used in Fluid Earth Systems (FES) work (primarily involving oceans and the atmosphere) is complex and different from the 2D images in Earth imaging and the 2D/3D data layers in GIS. NetCDF and its extensions provide an unprecedented degree of interoperability between complex FES data and coverage-based data and systems (e.g. satellite observations); feature-based data and systems (e.g. GIS layers); and specimen measurements (e.g. sensor observations).

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68 International Electrotechnical Commission (IEC), US National Rural Electric Cooperative Association (NRECA), Smart Grid Interoperability Panel (SGIP). Another SDO whose remit requires weather information exchange is the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). ASHRAE SCP201P is a building/facility information model standard focused on loads; it includes a weather model based on WXXM. Weather forecast information may be needed, for example, at wind/solar generators located on buildings other facilities subject to ASHRAE standards.

This cross-technology interoperability is becoming increasingly important as FES observations and forecasts achieve higher spatial resolutions — just a few kilometers. The challenge is to enable practitioners in each technology realm to continue using the powerful tools available through their traditional applications while allowing for integration of data and applications between the two realms by means of standard, web-based interfaces.

10.4 GeoSciML – geology

GeoSciML – Geoscience Markup Language – is a GML Application Schema used to support interoperability of geologic information provided by national Geologic Survey organizations and other geological data custodians. GeoSciML is useful for encoding the relatively simple "interpreted geology" information that is conventionally portrayed on geologic maps, but it can also be used to model more complex information types such as physical and chemical characteristics. Its feature-type catalogue includes geologic units, mapped features, geologic structures, as well as Earth materials (rocks and unconsolidated materials) and specializations of sampling features from the Observations and Measurements standard such as boreholes and geologic specimens. Supporting resources such as vocabularies for geoscience terminology and geologic timescales are developed in concert with the GML and O&M application schemas.

The GeoSciML project was initiated in 2003 under the auspices of the International Union of Geoscientists (UGS) Commission for the Management and Application of Geoscience Information (CGI)[69] working group on Data Model Collaboration - now the CGI Interoperability Working Group. The development of GeoSciML was strongly influenced by predecessor projects in North America, Europe, Australia and Japan.

GeoSciML is intended to support data portals publishing data for customers, for interchanging data between organisations that use different data definitions, data models and even different languages and software/systems environments, and in particular, for use in geoscience web services. GeoSciML is currently used by national and international data sharing projects, including the OneGeology[70] project, an effort to create a live geological map[71] of the entire Earth by delivering data from many national geological surveys. It is also used as the geologic data transfer standard by the European Union INSPIRE Project[72], the US Geoscience Information Network[73], and the Canadian Groundwater Information Network[74].

GeoSciML Version 3.1 was released in December 2012. In January 2013, a GeoSciML Standards Working Group was initiated in OGC, in collaboration with CGI, to develop a

69 http://www.cgi-iugs.org/O

70 http://www.onegeology.org/

71 http://en.wikipedia.org/wiki/Geologic_map

72 http://inspire.ec.europa.eu/

73 http://usgin.org/

74 http://gin.gw-info.net/service/api_ngwds:gin2/en/gin.html

version 4 release as an OGC modular specification. This release will include simple feature 'portrayal' schemes to support interoperable view services. Links to documentation, XML schema and other resources are available at the GeoSciML resource repository[75].

In a notable recent development, two geologists who have been instrumental in the development of GeoSciML, Simon Cox and Stephen Richard, have published "A geologic timescale ontology and service"[76]. This is an OWL (Web Ontology Language) ontology for the geologic timescale, derived from a Unified Modeling Language (UML) model. The W3C Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things and their relationships. Based on GeoSciML and other relevant standards, the geologic timescale ontology is an important exemplar for making data encoded using OGC domain standards discoverable and accessible to OWL queries. OWL is part of the W3C's Semantic Web technology stack. As the Web matures, the technologies of the Semantic Web will bring unprecedented reasoning power to computer programs. These technologies will help to verify the consistency of knowledge and help make implicit knowledge explicit.

10.5 PipelineML SWG – pipeline management

Pipelines are not natural resources, but OGC standards developed for energy, transportation, Smart Cities, emissions trading, urban modeling, indoor location, etc. belong to an important category of sustainable development standards for the Anthropocene, those that facilitate efficient management of natural resources and environmental impacts.

An OGC PipelineML Standards Working Group (SWG) was chartered in June 2014 to develop an open extensible standard intended to enable the interchange of pipeline data between parties, disparate systems and software applications without loss of accuracy, density or data resolution and without need for conversion between intermediate or proprietary formats. The PODS Association[77], a not-for-profit pipeline industry standards organization, initiated the discussions that led to the formation of the PipelineML SWG. They are using the OGC to develop a web services-based encoding standard that incorporates the experience and expertise represented in the current PODS standard and that is consistent with other geospatial data through its implementation of GML and O&M.

Currently, pipeline operators must take in information in a wide variety of media and formats. Considerable effort and expense is incurred converting, transforming, and often massaging this data into a state in which the data is consumable by data management tools. Additionally, this conversion process tends to introduce errors and loss of density and resolution of data. A robust system for data exchange and service-oriented data discovery, assessment, access and use would enable pipeline operators and service

[75] http://www.geosciml.org/

[76] http://link.springer.com/article/10.1007%2Fs12145-014-0170-6

[77] http://www.pods.org/

providers to dramatically reduce costs and shorten the time it takes to get critical information into the hands of decision-makers. Maintaining a higher degree of integrity, reliability, and accuracy of the data in an important anticipated benefit of the proposed PipelineML. The PODS data exchange format was an important step in that direction. Now PipelineML will bring PODS into the world of dynamic web service based data discovery, access, integration and use.

Not directly related to the PipelineML activity, another OGC activity serving resource management in the oil and gas industry is the collaborative effort to develop an Oil Spill Response (OSR) Common Operating Picture (COP)[78]. It is anticipated that this will be advanced to the state of an OGC Best Practice. The OGC is working on this with the International Association of Oil & Gas Producers (OGP)[79] through the Geomatics Committee, IPIECA (the global oil and gas industry association for environmental and social issues)[80] and Resource Data, Inc.[81]

10.6 Other environmental domains in the OGC

The OGC City Geography Markup Language (CityGML)[82], a GML application schema, provides an open encoding for multiple levels of 3D detail about the built environment. CityGML "Application Domain Extensions" (ADEs) have been developed for modeling noise, tunnels, bridges, Building Information Models (buildingSMART International's Industry Foundation Classes (IFCs)[83]), water flow, utility networks, and immovable property taxation. It fills an important gap in urban spatial data infrastructures and is destined to play an important role in Smart Cities and sustainable development.

The OGC IndoorGML standard[84] is being developed to establish a common schema framework for indoor navigation applications. IndoorGML, which will also be an application schema of GML, will use data encoded using CityGML and buildingSMART International's Industry Foundation Class (IFC) Building Information Model (BIM) standards.

As of June 2014, new OGC working groups have been chartered or are being chartered to address interoperability issues in urban planning[85], health[86], agriculture[87], and civil

[78] http://www.opengeospatial.org/projects/initiatives/ogpoilspill

[79] http://www.ogp.org.uk/

[80] http://www.ogp.org.uk/committees/geomatics/

[81] http://www.resdat.com/

[82] http://www.opengeospatial.org/standards/citygml

[83] buildingSMART International's Industry Foundation Classes (IFCs): http://www.buildingsmart.org/standards/ifc

[84] OGC IndoorGML: http://www.opengeospatial.org/projects/groups/indoorgmlswg

[85] http://www.opengeospatial.org/pressroom/pressreleases/2067

[86] http://external.opengeospatial.org/twiki_public/HealthDWG/WebHome

[87] http://www.opengeospatial.org/pressroom/pressreleases/2060

engineering[88]. In addition, a recent memorandum of understanding between the OGC and the Electronic Commerce Code Management Association (ECCMA)[89] has been announced that aims to establish a joint working group to develop and promote implementation of a new standard under the name ePROP - electronic Property standardization. That proposed standard is intended to be a valuable support for workflows involving real estate and related financial dealings. This standard for communicating characterizations real estate will play a role in environmental workflows.

All of these new OGC working groups offer opportunities for universities, research organizations, professional organizations, businesses and government agencies to bring requirements and expertise to the task of developing standards that will be important in environmental activities related to each of these domains. All of these new domain standards will have implications for environmental research, business and policy.

11. A call for a sustainable development IT standards research agenda

In each of the domains described above, domain experts brought domain data modeling expertise into the OGC to create an international standard to benefit a particular information community. By doing this work in the OGC and by basing the new standards on the OGC GML, O&M and coverage standards, they have made it much easier for developers and users in their domains to integrate their data with other geospatial data and processing resources.

Many other domains have yet to realize data encoding standards based on international data model coordination and international geospatial technical standards. The authors suggest a coordinated high-level analysis of what needs to be measured and communicated to enable collaborative and effective management of our interactions with Earth systems. The authors therefore call for a research agenda that focuses on identifying information types needed for sustainable development. Such an analysis will raise awareness, across all the environmental domains, of the need for and the path toward better communication of environmental data and better use of information technology in the service of sustainable development.

12. A call for leadership

The OGC and its many partner organizations encourage qualified and interested individuals, organizations, government agencies and businesses to join in global domain-focused efforts to develop coordinated agendas for environmental standards research, development, implementation and use.

[88] http://www.opengeospatial.org/projects/groups/landinfradwg

[89] http://www.opengeospatial.org/pressroom/pressreleases/2042

Key to success is visionary leadership. Experience with OGC working groups has shown the importance of visionary and committed individuals who decide to lead a standards effort. If one person in one OGC member organization can persuade member representatives from two other OGC members to join as co-initiators, a Domain Working Group or Standards Working Group can be formed. If their idea is sound, then papers, presentations, and outreach by OGC staff attract other organizations to the effort. The group's progress is reported out to the world, the group's issues are brought into testbeds, candidate standards are drafted, tested, vetted and approved, and soon the standard takes on a life of its own. The need for leadership remains, but after a time new business opportunities and policy imperatives drive participation, implementations and deployments forward.

Every domain – weather, aviation, geology, etc. is different, with different associations, history, culture, market realities and so on. For domains that are not well organized and not accustomed to collaboration, progress is slower, but sometimes a major government agency or charitable foundation can fund participation by companies, universities and others to "prime the pump." Those who seize on the opportunity provided by institutional support quickly become recognized in their domains as leaders and visionaries. We live in an age that recognizes the value of networking and the value of those who build networks.

We also live in an age when people are waking up to the importance of sustainable development. The authors hope that this paper will encourage environmentally minded researchers, policy makers and business people to help develop the standards-based interoperability framework that enables the kind of communication they need to accomplish their missions in the Anthropocene era.

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See the OGC Standards web page (http://www.opengeospatial.org/standards) for other OGC documents and links to those documents.

