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Spatially enabling the Global Framework for Climate Services: Reviewing geospatial solutions to efficiently share and integrate climate data & information

Gregory Giuliani[a,b,*], Stefano Nativi[d], Andre Obregon[e], Martin Beniston[a], Anthony Lehmann[a,c]

[a] *University of Geneva, Institute for Environmental Sciences, Bd Carl-Vogt 66, CH-1205 Geneva, Switzerland*
[b] *University of Geneva, Institute for Environmental Sciences, GRID-Geneva, Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland*
[c] *University of Geneva, Forel Institute, Bd Carl-Vogt 66, CH-1205 Geneva, Switzerland*
[d] *National Research Council of Italy – Institute of Atmospheric Pollution Research, Via Madonna del Piano 10, Sesto Fiorentino (FI), Italy*
[e] *GEO Secretariat, 7 bis avenue de la Paix, Case postale 2300, CH-1211 Geneva 2, Switzerland*

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A B S T R A C T

In November 2016, the Paris Agreement entered into force calling Parties to strengthen their cooperation for enhancing adaptation and narrowing the gap between climate science and policy. Moreover, climate change has been identified as a central challenge for sustainable development by the United Nations 2030 Agenda for Sustainable Development.

Data provide the basis for a reliable scientific understanding and knowledge as well as the foundation for services that are required to take informed decisions. In consequence, there is an increasing need for translating the massive amount of climate data and information that already exists into customized tools, products and services to monitor the range of climate change impacts and their evolution. It is crucial that these data and information should be made available not in the way that they are collected, but in the way that they are being used by the largest audience possible.

Considering that climate data is part of the broader Earth observation and geospatial data domain, the aim of this paper is to review the state-of-the-art geospatial technologies that can support the delivery of efficient and effective climate services, and enhancing the value chain of climate data in support of the objectives of the Global Framework for Climate Services. The major benefit of spatially-enabling climate services is that it brings interoperability along the entire climate data value chain. It facilitates storing, visualizing, accessing, processing/analyzing, and integrating climate data and information and enables users to create value-added products and services.

1. Introduction

According to the WMO Statement on the Status of the Global Climate in 2015 (World Meteorological Organization, 2016), the globally averaged temperature over land and ocean surfaces for 2015 was the highest among all years since record keeping began in 1880. This is also the largest margin by which the annual global temperature has been reached. During the 21st Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCC) in Paris in 2015, countries have renewed their commitments to continue their efforts against global warming with the aim to limit the increase if possible to a maximum of 1.5 °C above preindustrial levels (UNFCCC, 2015). This requires a profound transformation moving towards resilient low carbon economies and implies substantial reductions of fossil fuel emissions of 80–95% by 2050; a complete phase-out by 2100; and significant adaptation efforts (Christoph et al., 2016).

To support this objective and continue to narrow the gap between climate science and policy, the Paris Agreement that entered into force in November 2016 calls Parties to strengthen their cooperation on enhancing action on adaptation. In particular, Articles 7(a) and (c) emphasize the need of improved sharing of information and *"Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making"* (UNFCCC, 2015). As a consequence, there is an increasing need for translating the massive amount of climate data and information that already exists into customized tools, products and services to monitor the range of climate change impacts and their evolution (Dolman et al., 2016).

* Corresponding author at: University of Geneva, Institute for Environmental Sciences, EnviroSPACE Lab., Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland.
E-mail address: gregory.giuliani@unige.ch (G. Giuliani).

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The importance of climate change as a central challenge for sustainable development has been reinforced by the United Nations 2030 Agenda for Sustainable Development (United Nations, 2012, 2015). This agenda is a plan for action articulated around 17 Sustainable Development Goals (SDGs). Climate change has been identified as one of the greatest global challenges our society is facing today. It is considered as a cross-cutting challenge in various SDGs that can undermine the ability of countries to achieve sustainable development, putting billions of people at risk and in particular the most vulnerable communities in less developed countries. Specifically related to climate change, Goal 13 is calling for urgent action to combat climate change and its impacts, while enhancing resilience of our societies to natural hazards and climate change and developing a sustainable low-carbon economy.

To address the Paris Agreement and SDGs challenges, timely and reliable access to data and information on the environment, how it evolves is essential. Data provide the basis for a reliable scientific understanding and knowledge as well as the foundation for services that are required to take informed decisions (Trenberth et al., 2016).

To answer this need, the Global Framework for Climate Services (GFCS) has been established by the United Nations and spearheaded by the World Meteorological Organization (WMO) to support the development and application of science-based climate information and services for effective decision-making (see Table 1 for a glossary of terms used in this paper). For the GFCS, climate services involve the production, translation, transfer, and use of climate data and information to support climate-informed decision-making, policy development and planning (World Meteorlogical Organization, 2011). The ultimate objective is to ensure that the best available climate science is effectively used and communicated to various sectors (e.g., agriculture, water, health) that may benefit from climate knowledge (Lucio et al., 2016). This requires accessing reliable national and international repositories of data such as temperature, precipitation, wind, soil moisture, or ocean conditions as well as assessments, projections, scenarios or vulnerability and risk analyses. Moreover, following users' needs, these data may be combined with other types of data like socioeconomic variables, health trends, and agricultural production or energy production (Swart et al., 2017).

Currently, the demand for climate services is lower than what is required to deliver the expected benefits so that the potential market is largely unrealized (Lourenço et al., 2016; Street, 2015). One of the main challenges that climate services have to face is to reduce the gap between climate science and decision-makers (Vaughan et al., 2016). Indeed, on the one hand, climate scientists are generally interested in an improved understanding of the processes that regulate the climate, while on the other hand, decision-makers need simple and easy to obtain knowledge for informed decision making. This has led to a disconnection between real and perceived needs of climate knowledge. Consequently, to close this gap, it is essential to have proper engagement and interactions between providers and users of climate information together with an effective data access mechanism to answer various user needs (Buontempo et al., 2014).

Achieving the objective of a sustainable development requires the integration of different data sets on physical, chemical, biological, and socio-economic systems coming from various sources (Lehmann et al., 2017). Collectively, these diverse data constitute a set of environmental attributes describing a specific location; they can therefore be considered to be part of geospatial data. Environmental data are valuable when combined with other data sets, e.g., social and economic, allowing one to monitor and assess the status of global, regional or local environments, to discover relationships between them, or to model future changes. To make sense of the huge amount of environmental data that exists and that is currently generated on a daily basis, it is essential to agree upon common standards to facilitate their sharing and integration. It is in this context that the concept of Spatial Data Infrastructure (SDI) has emerged. This term, first introduced by the U.S.

Table 1
A glossary of terms used in this paper.

Term	Context
Climate data (series)	A time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change (Committee on Climate Data Records from NOAA Operational Satellites, 2004). These data series can be generated by in situ measurements (e.g. ground-based sensor measurements), remote sensing (e.g., satellite observations) and models (e.g., predictions and projections)
Climate services	Climate information that assists decision making by individuals and organizations[a]
Essential Climate Variables (ECV)	An ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth' s climate[b] and support policy action
Data value chain	Information flow that describes a series of steps needed to generate value and useful insights from data (European Commission DG Connect, 2014). These steps includes: enhanced data discovery (e.g., capture, storage, organization), integration (e.g., visualization, access), and exploitation (e.g., transformation, analysis, tailored products and services)
Interoperability	The extent to which systems and devices can exchange data, and interpret that shared data. For two systems to be interoperable, they must be able to exchange data and subsequently present that data such that it can be understood by a user[c]
Standard	A document that provides rules or guidelines to achieve order in a given context[d]. In the domain of Information and Communication Technologies (ICT), standards address especially the needs for interconnection and interoperability. Standards are frequently referenced by regulators and legislators for protecting user and business interests, and in support of government policies.
Web service	A collection of operations offered by a provider to users, using the World Wide Web for communicating
Sustainable Development Goals (SDG)	A set of 17 goals to end poverty, protect the planet, and ensure prosperity for all as part of the United Nations Sustainable Development Agenda[e]
Group on Earth Observation (GEO)	The Group on Earth Observations (GEO) was established in 2005 as an intergovernmental mechanism for coordinating all existing and future Earth observations systems and implementing a "Global Earth Observation System of Systems" (GEOSS). It was launched in response to calls from the WSSD, the G8 and three ministerial Earth Observation Summits to improve existing Earth observation systems
Global Earth Observation System of Systems (GEOSS)	GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS links these systems to strengthen the monitoring of the state of the Earth. It facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organizations within GEO

[a] http://www.wmo.int/gfcs/what_are_climate_weather_services.
[b] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables.
[c] http://www.himss.org/library/interoperability-standards/what-is-interoperability.
[d] http://www.etsi.org/standards/what-are-standards.
[e] http://www.un.org/sustainabledevelopment/sustainable-development-goals/.