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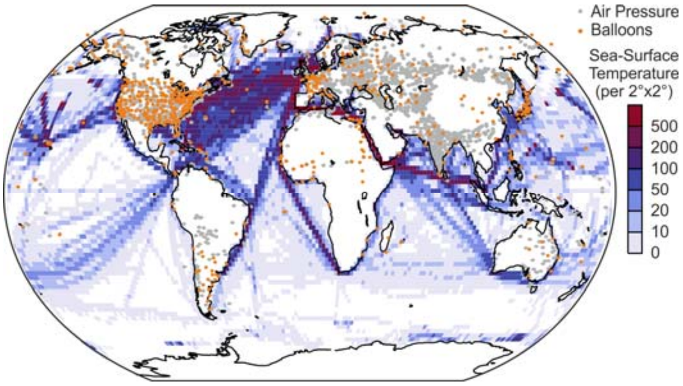
Abstract

In the era of climate services, which provide globally complete data products in a ready-to-use form, the context of climate data is in danger of being neglected or forgotten. However, the historical and present-day context imprinted on this climate data is important in its own right. The data depend on political, economic and technological factors, as we show with a range of data coverage maps. We term awareness of and sensitivity to this context-dependence "climate data empathy", and argue that context should be seen as a source of information to be communicated along with the data. Such context not only provides additional information about the data products, but may help in designing communication strategies and contribute more generally to raising awareness of the contingency of environmental data. Decision making should thus make use of both climate data and its context.

Graphical/Visual Abstract and Caption



Climate measurements also measure the needs of the powerful. Coverage from 1947 shows nation states, trade and a colonial world.

Introduction

Climate observations are increasingly important for decision making. It has proven extremely useful to produce and provide globally complete climate data sets for the past 50-150 years from infilling global land station data sets (e.g., Hansen et al., 2010; Becker et al., 2013), marine data sets (Rayner et al. 2003), combining station data with satellite data (Funk et al., 2015; see also www.eustaceproject.eu/), or combining historical measurements and weather forecast models (Compo et al., 2011; Poli et al., 2016; Laloyaux et al., 2018). For instance, reanalysis data sets allow for robust assessments of weather-related risks, which in turn may contribute to making societies more resilient (e.g., Allan et al., 2016; Bebber et al., 2016). This leads to more widespread distribution of climate data to non-experts. Global completeness and ease of application should not, however, obscure the fact that all atmospheric data sets describe not only a physical space, but also historical and present contexts. As Livingstone (1992) shows for geographical knowledge, atmospheric data also embed political, economic, technological and cultural histories. The context, however, is often forgotten, and not provided along with the data. We term awareness of and sensitivity to context-dependence "climate data empathy"[1], and argue that this should be an important consideration when generating data sets. Furthermore, the depiction of society provided by such context (and understanding why the data were measured) could inform climate services and make them more effective (Brönnimann and Wintzer, 2018). Note that "climate data empathy" is distinct from the more familiar term metadata. While metadata comprises structured (often machine-readable), descriptive information on the data, "data empathy" is reflexive (considering unconscious notions of the world), interpretative (addressing the conditionality upon a context and its history), and qualitative (considering qualities and underlying social values).

Data Coverage Reveals Context

Atmospheric measurements have always been dependent on available technology and institutions or individuals carrying out the measurements (see Fleming, 1990; Edwards, 2010). They have also depended on the means of preservation, availability, and access, and the prevailing ideas about climate (Heymann, 2010). All these factors have changed over time. In this way, climate data's present day context as well as its history is imprinted in long-term data sets and affects present science, for example, through data coverage. Conversely, data coverage reveals some of the history of climate-society interaction, as shown in the following four examples: a data coverage map of 1947, a map of stations of the International Geophysical Year 1957/58, a map of land stations and marine data from the current Global Climate Observing System (GCOS), and a map of mobile phone penetration.

In the first example, data coverage for the year 1947 (for sea-surface temperature data, air pressure and upper-air data) is shown in Fig. 1 (top left). The figure shows clear societal imprints. For instance, national boundaries appear, such as those of the United States. These boundaries reflect the organisation of the operation of meteorological networks. Sustained meteorological networks could only be established with the emergence of nation states in the 19th century (see Edwards, 2010), and

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[1] The term "data empathy" is sometimes used in data sciences. According to Faghmous and Kumar (2014) "every dataset has a story, and understanding it can guide the choice of suitable analyses; some have labelled this data understanding as data empathy". According to Tanweer et al. (2016), data empathy is the "ability for sharing and understanding different data valences, or the values, intentions, and expectations around data. "

nation states appear prominently in coverage maps since the mid-20th century. The map shows network boundaries, but the effect of nation states on climate data goes further and includes instrumentation, reporting, as well as other factors such as restrictive national data policies, leading to "white areas" on coverage maps. For an example of how climate services are affected by data policies, even for present-day data, see the coverage map of the European Climate Assessment & Dataset (https://insitu.copernicus.eu/news/the-european-climate-assessment-dataset-and-copernicus, last accessed 24 Sep 2018).

Furthermore, the figure shows a clear imprint of a colonial world. In fact, the colonial period is particularly data rich in some colonies (for example, India, which became independent in 1947, or, for upper-air data, Egypt), but data poor in others (particularly in Africa south of 5° N). Corresponding differences in meteorological networks can last long after the end of colonialisation. Apart from the fact that coverage maps mirror population density, maps from recent decades also mirror development maps where even population-rich areas of developing countries typically have fewer stations than developed countries. (https://www.esrl.noaa.gov/psd/data/ISPD/v4.0/img/Map_ispd-2013.png, last accessed 24 Sep 2018)

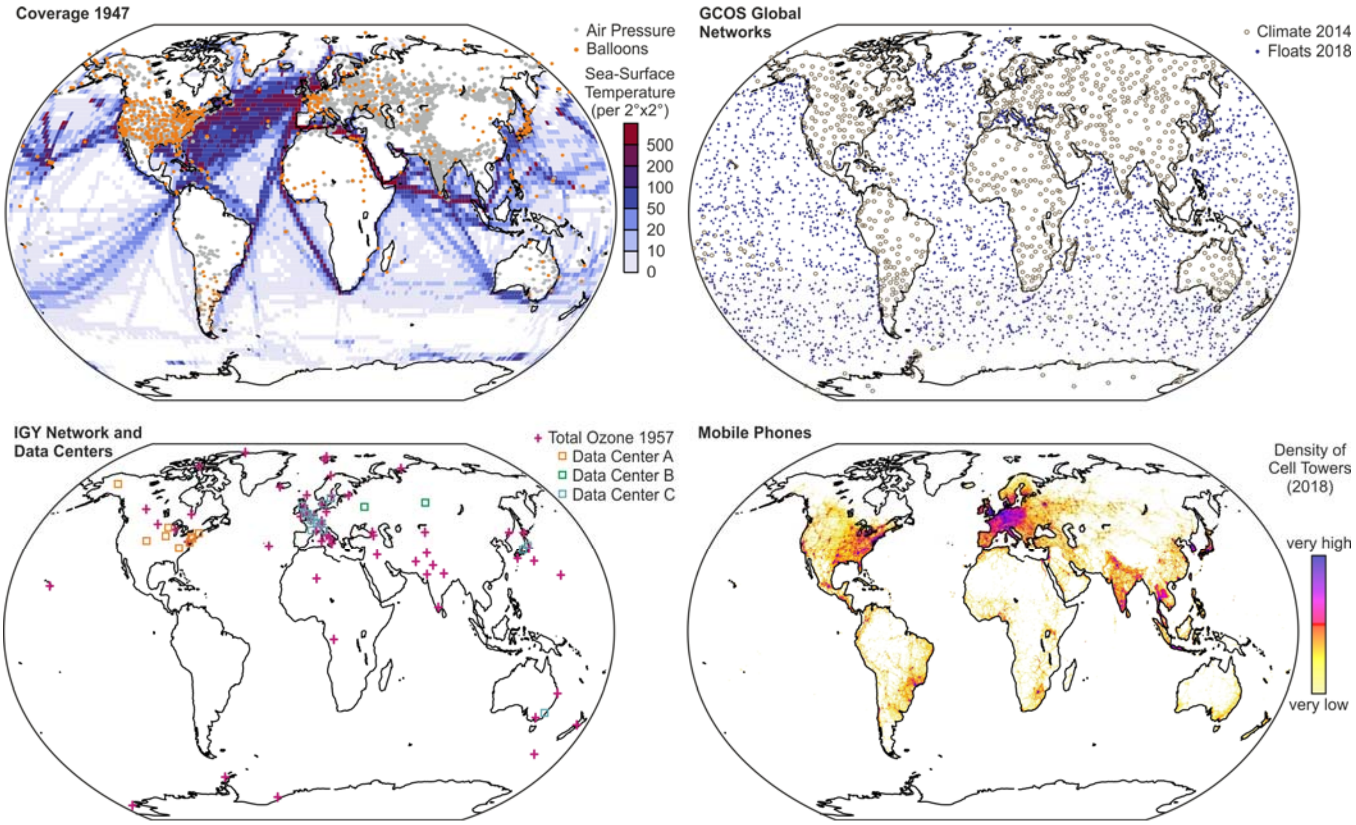

FIGURE 1 Climate measurements also measure the needs of society. (top left) Data coverage in 1947 for surface pressure (ISPDv3.2.9, Cram et al., 2015), upper-air (CHUANv.2.1, Stickler et al., 2014) and marine data (ICOADS3, Freeman et al., 2017), (bottom left) Stations from the total column ozone network of the IGY in 1957/58 (London et al., 1976) as well as IGY World Data Centers, (top right) climate stations of the GCOS surface network (GSN, Peterson et al., 1997) in 2014 and position of Argo floats (Roemmich et al., 2001) in the week of August 5-12, 2018. (bottom right) Density map of cell towers based on the public domain cell tower data available though OpenCell ID (Global Open Databases of Cell Towers, www.opencellid.org, accessed on 28 July 2018, License: http://wiki.opencellid.org/wiki/Licensing). The point data of cell towers provided through this source was aggregated on a pixel level using a point density function.

The marine data coverage in 1947 essentially reflects world trade: Good coverage is only seen in the North Atlantic and along important trade routes. Securing trade and the safety of their merchant fleets was one of the main drivers behind meteorological measurements in seafaring countries, at sea and in ports. Furthermore, this coverage changed over time, in line with changing ship routes (when browsing through historical marine data coverage maps one would easily spot the opening of the Panama Canal or the temporary closure of the Suez Canal). Transportation and global economics also affect current coverage maps. For instance, commercial aviation provides large amounts of data that are used for weather prediction, which stem mainly from the most important flight corridors.

A closer look at the figure also reveals traces of World War II, such as the lack of stations in Eastern Europe. Wars were causes of measurement interruptions and archival losses, but they also led to additional measurements from war operations. In fact, 1943 saw a peak in the number of global pilot balloon ascents (Stickler et al. 2014). Military interests appear clearly in Figure 1 (top left), which shows radiosonde stations at strategic island locations and in the Arctic. Military interests and military technology were also a major driver of post-war atmospheric sciences (e.g., Doel, 2003; Edwards, 2010; Doel et al., 2017; see also Heymann and Martin-Nielsen, 2013). Global conflicts still change climate data coverage today. An often-cited example is piracy in the western Indian Ocean in the 2000s, when ships avoided the region and data coverage decreased (Smith et al., 2011).

A major impetus for climate observations was the International Geophysical Year 1957/58 (e.g., Edwards, 2010; Aronova et al., 2010). The IGY established global monitoring networks, with common standards, procedures, instrumentation and intercalibration. For example, Fig. 1 (bottom left) shows the global total column ozone network (Brönnimann et al., 2003), which was one of the first truly global networks with stations on all continents except South America (but including Antarctica), though with highest density in Europe, North America, and Japan (London et al., 1976). The IGY still reflects a colonial world: for instance, only a single column ozone station was located in the Belgian Congo in Leopoldville (today’s Kinshasa). It was one of four IGY stations run by the Belgian meteorological service in Congo (Nicolet, 1959). Several stations were operated by the Soviet Union, though using a different instrument than the other stations. In fact, international scientific collaboration in an era of cold war geopolitical interests shaped the IGY (Doel et al., 2016). At the same time, the IGY marked the start of data driven science (Aronova et al., 2010). The system of World Data Centers (which still exists) was established during the IGY (Fig. 1, bottom left), with Centers A and B collecting all data in the USA and the Soviet Union, respectively (A was organized in a more distributed, B in a more centralized fashion), and Center C in Europe, Japan, and Australia covering most but not all disciplines. Geopolitical factors also appear later in the data coverage maps. For instance, political changes and economic downturn in former socialist countries in the 1990s led to station closures.

With the GCOS established in 1992, monitoring climate change became the stated goal of a global network’s operations for the first time. In the 1990s, a global network was designed based on sub-selecting among existing networks according to climatological considerations, representativity and inter-station distance (Peterson et al., 1997). The current GCOS surface network, which is shown in Fig. 1 (top right), thus reflects a “super-network” based on national networks and established through the collaboration of many international organisations. Coverage is clearly much different from that shown in Fig. 1 (top lefft). In the oceans, an international effort known as the Argo project has become a successful source of data (Roemmich et al., 2001). Over 3700 autonomous floats drift in the world’s oceans, take depth profiles, and return to the surface to send their data before diving again.

The float distribution for August 2018 is also given in Fig. 1 (top right). Argo is part of GCOS and contributes to the project Climate Variability and Predictability Experiment of the World Climate Research Programme and the Global Ocean Data Assimilation Experiment.

In recent decades, satellites dramatically changed atmospheric data coverage. Coverage is often global (hence not shown), and the number of products is developing rapidly. This differs radically from the contexts discussed above and it could be argued that all of the above arguments do not hold for satellite data products. It should be kept in mind, however, that even satellite products stem from a specific economic and political environment that is subject to change. Additionally, there is increasing involvement of private enterprises (McCabe et al., 2017). Furthermore, data access and the ability to process huge amounts of data become additional factors for satellite data that link their use to an economic and political context.

In addition to planned networks and satellites, climate data also emerge from new technological opportunities. For instance, precipitation data can be gained from microwave links that serve mobile communication (Messer et al., 2006), temperature data are obtained from vehicles, and snow and visibility data from webcams. These opportunities might again alter data coverage maps. As a placeholder for the changes in climate data coverage yet to come, Figure 1 (bottom right) shows mobile phone coverage (in the form of the density of antennas) as a measure for the global penetration of mobile phones. While this is clearly not (yet) a meteorological network, it illustrates that in the future, coverage maps might reflect population, mobile communication, traffic, or general mobility in addition to information from networks based on weather stations. The resulting coverage map is again different from the other two maps.

Why is it a problem?

The previous paragraphs show that data coverage is not a random sample of the Earth's surface nor a planned product, which may at first appear rather trivial. However, this skewed distribution reflects a large range of factors related to political and economic aspects, as well as technological progress and opportunities. Why is this a problem?

First, unequal data coverage complicates the generation of infilled global data sets that are used for downscaling to local scales or for comparison with climate models, among other applications. There are various techniques to take care of this, but poor coverage inevitably translates into larger uncertainties. Moreover, different data origins suffer from different types and sizes of uncertainties and systematic errors (for example, biases and uncertainties in sea-surface temperatures measured from ships are related to the country of origin; see Kennedy, 2014), which further complicate the process. Therefore, the provenance of the data matters for the technical procedure of obtaining best estimates. Scale is another important issue (see also Heymann and Achermann, 2018). For instance, since the 1853 Brussels conference, marine climate observations have been a global undertaking to serve global seafaring, whereas other measurements such as those of evapotranspiration (Thornthwaite, 1948) typically had a more regional emphasis such as agriculture (eventually developing into subdisciplines with a corresponding spatial focus such as microclimatology or topoclimatology). The global station distribution for soil moisture measurements not only shows nations states, but also regional authorities and programmes (Ochsner et al., 2013).

Second, unequal climate data coverage has political implications such as the procedural injustice in climate policy due to the imbalance of observations (see Huggel et al., 2016). Developing countries with only short climate records suffer from a disadvantage when trying to prove adverse climate effects. When sophisticated methods are used to generate globally complete, technically „objective“ long-term data products such as reanalyses, this imbalance is partly alleviated, but the imbalance in the underlying data remains or at least transforms into larger uncertainties, as discussed above (see Parker (2016) for a discussion of epistemological differences between reanalyses and observations). Unequal spatial coverage is not just a data problem, but also one that affects climate justice. In addition, scholarly attention in climate change research suffers from a “streetlight effect”, with colonial history being an important factor (Hendrix, 2017).

Third, climate data products carry imprints of social, political and economic contexts, which should not be dismissed as irrelevant or nonexistent. As an example, we can examine development cooperation. Early colonial climate data (see Fig. 2 for an example) contributed to shaping world views, depicting the tropics as an imagined space and to the notion of environmental determinism (Livingstone, 1999; Mahony and Endfield, 2018). They were an instrumental part of colonialism. Although the measurements themselves do not convey attitudes, some of these data, influencing our decisions today, still carry colonial roots. By producing full-coverage data products of past climate and analyzing climate processes over the former colonies, western science today has to be careful not to „re-colonize“ their atmosphere (Gregory, 2001). Being aware of data histories may sensitize for this aspect. Despite the enthusiasm for open data in so-called developing countries, questions of data policy, ownership, co-authorship, and location of data holdings should be discussed under this point of view. For instance, precipitation data based on mobile communication links seem promising for developing countries (Tollefson, 2017), but might raise proprietary concerns.

FIGURE 2 Colonial data form part of current products on which decisions are based. German aerologists in the East African colonies in 1908, measuring vertical wind profiles using balloons (Brönnimann and Stickler, 2013, photo provided by Hans Steinhagen, Lindenberg)

Fourth, the changing global data coverage maps in Figure 1 are also the expression of (and thus point us to) a more profound change in global environmental governance. Today, the operators of observation systems and the providers of climate information may be different bodies acting in different political environments. The nation state, still the responsible operator of many climate monitoring networks, is no longer the sole provider of climate competence. Climate services often emerge in an international context and (in developing countries) in large partnership projects, although the World Meteorological Organization encourages their operation through National Weather Services (WMO, 2014; Hewitt et al. 2012). Multinational bodies assist decision makers (e.g., the Intergovernmental Panel on Climate Change) and provide climate services to primary users (e.g., Copernicus Climate Change Services C3S), leaving to the national weather services the role of transforming knowledge for use by national stakeholders (Brasseur and Gallardo, 2016). This reflects changes in global governance strategies, where climate services have become part of global environmental governance (Jasonoff and Martello, 2004). From a globalization-critical view (Hardt and Negri, 2000) one could argue that climate services facilitate control over nature, which becomes a commodity whose just distribution is at stake (Okereke and Charlesworth, 2014). On a more general level, with the rise of modern science, only measurable and quantifiable outcomes are considered scientific. Climate data that are stripped off their context fit this scheme, whereas the quantitative methods allow the transformation from observing, measuring and calculating numbers to managing, governing and constructing the modern world (Rose, 1991; Callon, 1998).

Proposal: Learn from the “why” and “what for”

The context-dependence of climate data is not only a problem, but also an opportunity. We propose that climate science and climate services could learn not just from the climate data, but also from its context. Measurements were made with specific intentions, which matters not only for data processing, but provides direct information about the science-society interface.

Why did society start measuring, and for what purpose? The answer is manifold: to make trade safer, forecast the weather and provide warnings, cope with new responsibilities of nation states, document factors affecting human health, praise God, describe uncharted territories, support artillery, provide strategic advantage, document the wealth of colonies, benefit agriculture, mining, and tourism, better operate air traffic, enhance living conditions in conurbations, foster basic science, and document climate change. Knowing the “what for” gives us valuable, direct information about the climate-society interface. It would be important to analyse how and by whom current data needs are actually defined; we cannot do this here. But even if, at first sight, the current needs differ from previous needs, they can arguably be better understood in a historical context. For instance, infrastructure safety was and is an important “what for”, and although the nature of infrastructure might change, the locations as well as the hazards might be similar. Emerging climate services can benefit from this information not only when designing products, but particularly when communicating them to society (see below).

Technically, the metadatabases underlying global data sets (Thorne et al., 2017) cover at least a small part of the “why” in the form of data type and data provenance information, which is accessible to experts. This information may, however, not be directly helpful for non-expert users, even when transformed into actual data products.

What we are arguing for in this paper is rather straight forward. Climate services can make use of climate data empathy (i) to provide additional information about data products, (ii) to enhance the effectiveness of communication, (iii) to raise awareness about the contingency of environmental data and its relevance for applications.

As to (i), the “why” and “what for” should be part of the user guides, user interaction and training, similar to providing information about the digital data formats or error bars. Apart from websites and documents on a general level (or this paper), specific short text notices accompanying specific data products targeted to the non-expert user could be useful. These could state, e.g., when the underlying data are largely from airport stations, or when a product is based on national weather service stations merged with satellite estimates, or when station coverage mainly reflects coastal sites that may not be representative of inland basins. This sort of information could improve the use of climate data in other fields.

As to (ii), climate data empathy could lead to better communication strategies, particularly when combined with empathy for other observation practices and knowledge traditions (see also Brasseur and Gallardo, 2016). Traditional or indigenous knowledge is recognized as important for climate change adaptation (Kumar, 2014). A recent study on the development of climate services for Peru concluded that traditional knowledge should be incorporated (Rosas et al., 2016). Yet, climatologists sometimes argue that traditional knowledge - if not considered biased and unscientific immediately - is at least in need of massive correction under climate change. Even then, the communication of this correction might benefit from understanding the perception encapsulated in the traditional knowledge. Cultural views of climate and climate change differ widely (see Hulme, 2017; Mahony and Endfield, 2018), but climate change communication and the provision of products and particularly of graphics by modern science (this paper is no exception) are mostly rooted in western culture (Brönnimann, 2002; Schneider, 2014). Combining data products with contextual knowledge as well as traditional knowledge may not necessarily lead to other data products, but possibly to other communication strategies, perhaps also assisted by results from linguistic analyses (Willis, 2017) to enhance the transformation of knowledge into action.

As to (iii), climate data is by far not the only field in which environmental data are increasingly detached from their context, and thus this phenomenon also affects other fields with environmental applications. Raising the awareness about the contingency of environmental data in general (from soil contamination data to biodiversity censuses) might thus be generally beneficial for making environmental decisions. It also calls for a stronger role of human dimensions in climate science, which should not only enter at the stage of impact research, adaption planning, or economic measures, but should be onboard already at a much earlier stage. The success of global historical reanalyses has generated new awareness of the importance of the underlying data, including data rescue (Allan et al., 2016). This is an opportunity to further raise awareness of the importance of context knowledge.

Conclusion

Climate data products are not just best-estimates of physical variables. They are simultaneously societal products with a specific context, which are important in their own right. Climate data scientists generally know the context of their data in great detail, and give their utmost efforts to minimize its effects on data products and their uncertainty. However, the knowledge about data context too often remains with the original scientists and is not communicated along with the data product, leading to lost knowledge. We argue that this context is important for users of the products and should be provided. Such a change would make climate services more comprehensible and effective.

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