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Introducing the global climate security atlas

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Abstract

Non-Technical Summary. There is a need to develop tools that facilitate knowledge sharing and cooperation among researchers, institutions, and countries around the world, especially concerning global, transboundary, and long-term climate impacts. The IPCC report aims to achieve this goal, and emphasizes that digitization of global maps, centralization of multidisciplinary results, and further sorting and simplification of data products are necessary to make the immense amount of information accessible to broader communities. To this end, we build a new digital atlas useful for training the future generation of climate scientists, for academic collaboration, and as a first stop in intergovernmental conversations.

Technical Summary. Climate change is a significant threat to humanity, and its impacts on natural and human systems have already been observed. Climate action requires both global and local cooperation and needs to be approached together with other world crises in a transformative, systemic, and holistic way, prioritizing long-term human and ecological well-being and short-term targeted action. Bridging the gap between climate scientists, educators, and decision-makers is crucial, which requires a multidisciplinary approach, meaningful collaboration tools, practical simplification, and visualization of research output data, and more effective communication. To address some of these challenges in communication for decision-making, as well as challenges in multidisciplinary climate teaching and research, we built a new digital atlas called the Perry World House Global Climate Security Atlas. Researchers, teachers, and policymakers are encouraged to use the Atlas to visualize global information on physical climate projections, environmental, and ecological data, as well as information on human, social, and political systems. In this paper, we motivate the need for the Atlas and summarize its potential uses, provide a summary description of the datasets, and offer suggestions on how to bridge the gap between science and policymaking.

Social Media Summary. A new interactive Atlas that brings together global, transboundary, multidisciplinary, and long-term climate impacts.

1. Introduction – importance of the problem

Climate change poses an existential threat to humanity (IPCC, 2021, 2022b, 2023), and scientists play a crucial role in addressing it (Lubchenco 1998). However, integrating climate science into decision-making and implementation remains challenging.

The Intergovernmental Panel on Climate Change (IPCC (https://www.ipcc.ch/)) provides policymakers with regular scientific assessments on climate change and has the additional aim to serve as 'a key input into international climate negotiations', which was exemplified most recently through the IPCC's contribution to the United Nations Framework Convention on Climate Change's (UNFCCC) Global Stocktake (https://unfccc.int/topics/global-stocktake). As intended, the IPCC report is the most commonly used scientific source for climate policy papers (Bornmann et al., 2022), yet the great amount of data, the exponential increase in research, and the holistic and multidisciplinary nature of climate change make it difficult to distill relevant policy information especially during the periods between IPCC reports. To summarize the multidisciplinary findings on climate hazards and impacts, the IPCC provides key visualizations such as the IPCC WGI Interactive Atlas (http://interactive-atlas.ipcc.ch) (covering the physical science) or the selection of maps under the Global to Regional Atlas (Annex I) of the IPCC WGII report (IPCC, 2022a, 2022b: impacts, adaptation, and vulnerability), this last one not accessible in an interactive way. A small proportion of the data is now stored in the IPCC Data Distribution Centre, and the intention is to have more interactive visualizations in subsequent IPCC reports beyond data storing, but this is many years ahead (See I.3.4. Lessons learned from the sixth assessment cycle (https://apps.ipcc.ch/eventmanager/documents/83/301220231149-INF.%209%20-%20Lessons%20learned%20from%20AR6.pdf)).

Our hypothesis is that the IPCC scientific information on climate impacts and vulnerability (WGII) will be more useful to global policymaking in the international negotiations space if simplified, compiled, digitalized, and visualized from a global, multidisciplinary, and long-timescale perspective. Global climate policymaking refers to multilateral climate policy decisions (when affecting many countries) or 'single-decision-making entities' exposed to

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transboundary climate risks (Bisaro et al., 2021). Our hypothesis arises from discussions with delegates and chairs in the interface of science, policy, and global security. In particular, we consulted the IPCC, UNFCCC, the State Department in the US, the North Atlantic Treaty Organization (NATO), and delegates from developing countries such as Maldives, Jamaica, Fiji, and Palau. To this end, we build an online climate data visualization project, the Perry World House's Global Climate Security Atlas (https://global.upenn.edu/perryworldhouse/global-climate-security-atlas), that can be viewed as a climate service (Climate services are defined as 'the provision of climate information in such a way as to assist decision-making', WMO Global Framework for Climate Services.) geared toward informing global decisions by using as a base the climate research and predictions outlined in the IPCC WGII.

Hence, the major motivation of the Atlas is to digitize the IPCC WGII related research to ultimately reduce the gap between climate science and global policy making (Bisaro et al., 2021; Jacobs & Street, 2020). A complementary objective is to incentivize interdisciplinary learning and teaching and to provide opportunities for coproduction of knowledge among disciplines.

2. Our visualization project – The Perry World House's Global Climate Security Atlas

We have developed the Perry World House's Global Climate Security Atlas (https://global.upenn.edu/perryworldhouse/global-climate-security-atlas), an online climate data visualization project that brings over 200 geospatial datasets together into one place, created with the softwares ArcGIS Experience and ArcGIS online. The main purpose of the Atlas is to visualize global and transboundary climate risk and impact through digitization of IPCC related-research complemented with global social and political datasets that indicate vulnerability and exposure to climate change (see Box 1), as well as indices that showcase other intersecting crises such as biodiversity loss (IPBES, 2019), food insecurity, inequality, poverty, or conflict. The IPCC defines disaster risk as 'the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions' (see Box 1, Lavell et al., 2012), and climate impact as the 'climate effect on natural and human systems'.

The Atlas visualizes climate risk and impacts via physical climate projections (hazards), environmental and ecological data, and information on human, social, and political systems (vulnerability, exposure).

The Atlas is structured as follows:

- IPCC 2021, 2022a, 2022b information
  - IPCC, 2021: Climate Change 2021: The Physical Science Basis – a selection of physical projections on rising temperatures and fluctuating precipitation for different warming scenarios from the IPCC WGI Interactive Atlas has been added into the Perry World House Atlas to show the physical hazard component of the risk equation and allow a quick comparison with the other datasets. Whenever the purpose is to deepen the understanding of physical climate science exclusively, we recommend using the IPCC WGI Interactive Atlas.
  - IPCC, 2022a, 2022b: Climate Change 2022: Impacts, Adaptation, and Vulnerability – To fill in the gap of interactive visualizations for the WGII report, here we digitize for the first time a collection of maps from the Global to Regional Atlas (IPCC, 2022a, 2022b: Annex I). These maps assess how global temperature increases ultimately impact countries around the world with respect to food, water, health, biodiversity, infrastructure, etc. The WGII Global to Regional Atlas 'integrates and expands on the key messages in WGII chapters and cross-chapter papers to provide summaries of vulnerability, impacts, exposure, adaptation, and risk complementing the narrative in the summary for policymakers'. We tried to be loyal to the visualization and combination of data chosen by the editors of the Global to Regional Atlas when digitizing it, which is structured in a narrative fashion useful to interdisciplinary and policy audiences.
- Multiple global maps from independent published research relevant to (and in a large part described in) the IPCC reports that show the different components of risk organized by themes: climate change projections (hazard); food and water security (risk, impact, vulnerability); biodiversity loss (intersection with climate crisis); marine risks, impacts, and vulnerability; current conditions including natural disasters, droughts and pollution (natural exposure and vulnerability); social and political indices (social and political vulnerability); indices to evaluate environmental risk or ecological footprint; and geography, population, and infrastructure (exposure). We also include a 'Top layers' WebMap, which includes the layers that we found most relevant to global climate risk.
- Links to external maps, multi-sectoral indices, and other visualization efforts at the intersection of climate, biodiversity, society, and politics. The first section of this list includes all the initiatives that we have found to address the global climate services space, to our best knowledge. It is not a comprehensive list. Among these, the aim of the platform Partnership for Resilience and Preparedness is to showcase preparedness and resilience to climate change, which makes it the platform most similar to the Perry World House Atlas. One notable difference is that, as far as we know, the Perry World House Atlas is the first platform to digitize a large part of the IPCC WGII report.

Targeted users: Researchers in academia can use the tool to incentivize interdisciplinary learning and teaching and to provide opportunities for coproduction of knowledge among disciplines. Policymakers in the international negotiations space can use the tool as a first stop to learn about climate-related topics outside of their expertise.

Data visualization: Deliberate choices are made for labels, legends, colors, and symbols to ensure clarity, conciseness, and effective communication of complex information in a simple and understandable manner while staying true to the original data visualization design.

Data curation: The curation process for selecting maps aims to cover a wide range of disciplines relevant to global policy, transboundary risk and vulnerability, and broad societal objectives (e.g. SDGs) and, in particular, relevant to international security, adaptation, and long-term resilience to climate change. The selection primarily relied on the subgroup of IPCC WGII citations that focus on global properties rather than regional ones, and more recent findings from high-impact journals. The availability of maps was also a determining factor and depended on online data open sharing practices and/or the willingness of authors to share their data. Additionally, we included a large number of social and political indices compiled by the UN, World Bank, and several think tanks and NGOs, to display ecological and human vulnerability, adaptive capacity, and societal resilience.

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Box 1. The IPCC definition of risk.

Risk = Hazard × Vulnerability × Exposure

Hazard: the physical driver of the risk. E.g. heatwaves, droughts, floods

Vulnerability: the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events. E.g. poverty level, electric network reliability, conflict, lack of adaptive capacity (governance, early warning systems)

Exposure: the presence (location) of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected by physical events and are thereby subject to potential future harm, loss, or damage.

Atlas usability: Currently, the maps displayed in the Atlas can be analyzed comparatively, as almost all data is in raster format and therefore not suitable for multiple overlays. We recommend limiting the selection to one dataset at a time. To compare different layers, we recommend opening different tabs. In the future, based on feedback from policymakers and other users, we plan to add a hotspot finder, by combining layers of vulnerability, hazard, and exposure to determine the level of risk.

Data availability: The Atlas references the original paper or source in each case. We include here a Supplementary Document with data sources and description of the data shown in the Atlas. We also uploaded the original data depicted in the Atlas (not published elsewhere) to the data repository Scholarly Commons hosted at the University of Pennsylvania. For images, data formats are mostly .netcdf,.tiff, or R frames. For country and point (lon, lat) data, the original data are given in a list format (e.g..csv,.xsx).

The Atlas contributes to an underexplored niche in climate services (Bisaro et al., 2021) with four major characteristics:

(1) Digital compilation of diverse scientific findings on global climate impacts and vulnerability – we digitized most of the maps in the IPCC WGII Annex I and added many more maps cited elsewhere in the IPCC WGII report. Our project fills a need for a digital compilation of independent papers studying the climate impacts and vulnerability of food, water, biodiversity, or health, topics that are most directly relevant to long-term multidisciplinary global policymaking. Compiling the data from independent research sources is time consuming, and historically, one could only obtain data from individual researchers on request. More recently (as journals and funding agencies are increasingly requiring data sharing), the original sources and the code needed to recreate the published research are provided, but unfortunately in many cases not the final map output. To facilitate compilation work for subsequent IPCC reports, we encourage scientists to always share in their publications the data necessary to reproduce their published figures and also the final maps in a commonly used format and open to everyone.

    We also ask journals and research institutions to make open data sharing and hosting a standard practice. Open access to journals, which is fortunately becoming a standard procedure in most journals (e.g. Open Science, UNESCO (https://www.unesco.org/en/open-science)), is also needed to foster a more transparent and inclusive scientific community.
(2) It highlights multidisciplinarity in global crises beyond climate. The Atlas is designed to be a place to find relevant global maps in multiple disciplines that intersect with climate change, such as biodiversity loss, inequality, conflict, or food insecurity. The upcoming era of climate services and communication, previously constrained in scope, must now embrace the multidisciplinary essence of climate issues, and address broader societal challenges (Jacobs & Street, 2020). For complementarity, we provide links to many existing (more narrowly focused) global visualization websites in the Atlas web page under External links (https://experience.arcgis.com/experience/8bacbb10ee82480a9dfb3198f5a1d160/page/Links-to-External-maps/).
(3) Focus on a global environmental perspective – our database is useful for understanding globalized, transboundary, and multidimensional risks that require global or multilateral cooperation. Therefore, the Atlas can be a first step in understanding where and what actions should be prioritized at the global scale and can be combined with existing tools that focus on local risk assessment.
(4) Long-term (decadal to multidecadal) focus – it is crucial to increase the availability of tools focusing on the global and mid- to long-term (decades and longer), especially for topics that are intrinsically holistic, have a strong dependence on globalization, and require great transformational action. By considering the long-term implications of climate and environmental crises, governments can make informed short-term decisions that lead to more long-term resilient infrastructure, sustainable development, and effective climate policies to ensure a sustainable and habitable planet for generations to come. This is especially relevant in a diplomatic environment that is short-sided, siloed, geopolitically complex, and accustomed to incremental and local rather than transformational and transboundary practices.

The first aim of our digital Atlas is to support inter- and multidisciplinary and multi sectoral research, teaching, and communication at the intersection of climate, environment, and societal impacts and hence provide a platform and tools for discussions and meaningful collaborations that ultimately help critically inform our collective path forward. Possible users are academia and educational institutions. The Atlas can be used to expand the array of risk management strategies (Jacobs & Street, 2020), better understand benefits and tradeoffs across disciplines and to assess the status of global research by identifying gaps in data, research topics, sectors, and incentivizing research on places underexplored or on topics whose risks have been consecutively underestimated in subsequent IPCC reports, such as extreme weather events or low-probability but potentially high-impact events and tipping points (e.g. the five Global Reasons for Concern described in the IPCC report are now assessed to occur at lower global warming levels than those assessed in previous reports, IPCC, 2023). The Atlas can also be used to visually identify climate change risk hotspots, regions that are highly responsive and/or are more vulnerable to the threats arising from the projected climate change and other crises compared to other regions because of high (physical, social, economic, or environmental) vulnerability, high climate sensitivity, or low adaptation capacity (e.g. driven by security stresses, lack of infrastructure). Finally, the Atlas serves as a guide for teaching global change and the interconnectedness of multiple global crises at the undergraduate and graduate levels. In her 2023 'Global Climate Change' and 2024 'Climate and Big Data' classes at Univ of Pennsylvania, Prof. Irina Marinov used the Atlas as a starting point for student projects on interdisciplinary climate case studies.

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A second aim of the Atlas is to support climate international negotiations at the global level on the decadal timescale. 'Climate change is transforming and redefining the global security and development landscape' (Tarif et al., 2023). Even though the original motivation for the Atlas was to provide visual information of climate risk to non-climate-experts in the international security space, the Atlas is also useful to policymakers that base their decisionmaking and risk assessment on the IPCC WGII Impacts Reports on topics such as adaptation to climate change, global food security, or global health, among many others. We propose that this Atlas can be used by global actors such as the UNFCCC or the UN Security Council. The Atlas can help narrate that climate change is a global security threat when combined with other environmental and societal crises, visually identify hotspots of climate risk, identify areas that share similar vulnerabilities or hazards, better define the global goal of adaptation, or assess adaptation needs and prioritization, especially when combined with other initiatives such as the Global Adaptation Mapping Initiative (https://globaladaptation.github.io/#page-top), which aims to map where and how adaptation is happening. For example, we used the Atlas to facilitate and guide the narrative on the policy brief 'Refining the Global Goal on Adaptation ahead of COP 28' (Cabre et al., 2023). This Atlas may also be used by policy and political actors such as think tanks, NGOs, and nonstate stakeholders as well as for US policymaking (e.g. National Security, State Department) to, for example, highlight risks around sites of interest such as military bases and alliances and bring attention to long-term risks typically not considered (multiple decades ahead). Note for example that NATO is developing a similar tool.

3. Discussion

To foster greater collaboration and advance research concerning global, transboundary, and long-term climate impacts, there is a pressing need for the development and implementation of additional tools and mechanisms that facilitate knowledge sharing and cooperation among researchers, institutions, and countries worldwide.

The IPCC WGI and WGII reports aim to do this, but digitization of global maps, centralization of multidisciplinary results, and further sorting and simplification of data products are one of the steps necessary to make the immense amount of information from these reports accessible to broader communities. To the best of our knowledge, the Perry World House Atlas is the first attempt at digitizing the IPCC WGII report starting with the Global to Regional Atlas (Annex I), useful for teaching and training the future generation of climate scientists and useful for academic collaboration. It also serves as a first stop in intergovernmental conversations. In future work after receiving feedback from IPCC coordinators and policymakers, we plan to expand the Atlas to include a climate-change 'hotspot finder' as a function of time, socioeconomic scenario, and level of warming. Forecasting such hotspots can be used by scientists, policy and decisionmakers, first responders, and disaster response agencies for climate adaptation and mitigation practices.

We recommend that scientific organizations and researchers become more involved in science diplomacy (Gluckman, 2022; Jacobs & Street, 2020). The language used by climate and environmental scientists, typically very niche-focused and technical, needs to become more relevant to both policymaking and educational purposes for example by adding a section targeted to generalists in scientific publications, with emphasis on simplifying the main conclusions, key factors, relevant time scales, clarifying the main causes and types of uncertainty, and pointing to unlikely high impact scenarios in a simpler language. According to North et al. (2022), the IPCC should also engage more practitioners with policy implementation experience in the future to ensure that the science is presented in a way that is more valuable for decision-making. There is also a clear need for increasing interdisciplinary funding in traditional climate science-funding agencies (e.g. NSF, NASA, NOAA), where funding is typically still separated along traditional disciplinary boundaries.

The Perry World House Digital Atlas is an open access resource for researchers, students, and educators and relies on researchers making their final research output (e.g. global maps) open access. We are grateful to the researchers who have thus far made their published, digitized maps available to us and end with a call for researchers across fields to make their final digitized products available to the broader community and to the Atlas effort. Additionally, we call on teachers and educators to share with us any open educational resources that make use of information in the Atlas – we plan to create our own lessons and make such materials broadly accessible by implementing an 'educational activities' section of the Atlas in the near future. To make sure that this tool gets to the science-policy space, we are presenting the initiative in scientific conferences, and will organize a session at the Perry World House at the University of Pennsylvania and at a side event at COP29 in the university pavilion.

The core of our project is open science. As such, we hope that the Digital Atlas can lead to increased research efficiency, transparency, broader knowledge dissemination, more collaborative, and interdisciplinary research, and a higher degree of public and policy engagement with climate science. We welcome community feedback, suggestions and engagement with our project via email or the Atlas link.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/sus.2024.18.

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