Bridging Computational Art and Climate Change: An Analysis of a Mobile Application for Raising Awareness About Climate Change Through Art

Felipe Mammoli Andrade(✉) and Artemis Moroni Sanchez Moroni

Cyberfisic Systems Division, Instituto de Ciência e Tecnologia (CTI) - Renato Archer, Rod. D. Pedro I, km 143, Campinas, SP, Brazil
{fmandrade,amoroni}@cti.gov.br

Abstract. This article focuses on the complex process of translating scientific data, specifically related to climate change, into comprehensible narratives aimed at engaging the non-expert public. Challenging the prevailing assumption that data possesses inherent communicative capacity, we analyze the complicated work involved in converting scientific data into meaningful visualizations and narratives. Furthermore, we investigate how artists have been contributing to transform the abstract aspects of climate change into tangible, emotionally resonant experiences, thereby cultivating novel forms of climate-aware public engagement. We then use this analysis to present and discuss the GaiaSenses Project, an innovative research project converging art, science, and computational technology. Through location-based audiovisual compositions driven by weather data, the project aims to establish a more intimate connection between individuals and the realities of climate change, fostering heightened environmental sensibility. By presenting and analyzing the GaiaSenses Project, this article reflects upon the transformative potential of computational creative systems in raising public awareness about climate change and stimulating climate action.

Keywords: computational art · climate change · climate art

1 Introduction

Contrary to the popular saying, data does not speak for itself. As numerous researches have repeatedly shown, making data speak involves quite a lot of work, specially for scientific data [1–3]. From designing beautiful visualizations and crafting short summaries for decision makers, to establishing trustful institutions for data validation and educating the audience to care about such data, making data speak also involves creating publics that are willing to listen to what data has to say. After all, does it really matter if data can speak for itself or not if there is no one there to listen to it? This simultaneous process of making data speak and making a public that cares about what it has to say is

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particularly clear in the history of the environmental sciences, specially those regarding climate change. As show by historian of science Paul Edwards in his study of the history of climatology and climate research institutions, the possibility to scale local data into a global reach phenomena that respects no territorial boundaries - i.e. climate change - was dependent on the capacity to build far reaching institutions that would make possible the material conditions of a global flow of weather and climate data, and knowledge [4].

Concretely, the possibility to collect weather data from around the planet, analyze it and publish reports like the IPCC Assessment Reports to foster policies like the Kyoto Protocol and Paris Agreement, is wholly dependent on the creation of institutions like the World Meteorological Organization (WMO), the Intergovernmental Panel for Climate Change (IPCC) and UNFCCC [4]. An analysis that echoes what Shapin and Shaffer (1987) have observed in their historical research on the debates between Thomas Hobbes and Robert Boyle over what means for an Air-pump to work and create vacuum, a debate that happened in XVII century Restoration England and came to be the birth of the experimental sciences: solutions to a problem of knowledge are solutions to the problem of social order [5].

While the enterprise of assuring scientific authority to the framing of climate change as a global phenomena has been largely successful from the perspective of climate sciences and its institutions, the same success has not been achieved in promoting significant political change to avoid the drastic futures presented since the 3rd Assessment Report [6, 7]. This political stagnation of climate policy is made clear by the failure of every country in the G20, the major emission offenders, in reaching any of the emission reduction goals since the Paris Agreement in 2015 [8]. Analyses like [6] have identified that for climate knowledge to be more policy-relevant there need to happen significant transformational changes in the structure and functioning of the main institution that produces scientific knowledge about climate change, the IPCC. And, due to the history of this institution, for these transformational changes to take place it needs significant pressure from both the inside, the scientists that are part of it, and from the outside, the society at large [6]. Non-expert people, an element that doesn't usually participate in the production of knowledge about climate change, but suffers the consequences of it nonetheless. This societal pressure, though, can only be exercised if the public can relate the issues raised by scientists with their common daily lives.

At least since the 90s, artists have been working with themes around climate change and global warming and trying to bridge the gap between the abstract and statistical knowledge about climate change and the experiential and daily lives of people [9]. These recent engagements of artists and the climate have been called by a varied set of names: climate change art, eco art, environmental art, climate art, atmospheric art, and many others. Despite the multiple designations, they all seem to share a commitment to raise awareness about the climate crisis and to foster an attempt to devise methods for inquiring the roles that the natural environment has in the human creative processes [9]. In other words, they strive to produce their publics [10].

Computers and computational systems have been crucial in these still early explorations. Weather by using computer systems to produce new media art exploring climate change issues, or using scientific data about the environment as material for artwork, artists dealing with climate change seems to have no option but to use computers as interaction and inspirational devices. In the myriad forms of engagement of artists with this digital objects, the abstract, statistical and global language of climate change, like "global mean temperature", "carbon budget" and "planetary tipping points", are transformed into a grammar of affect, closer to spatial and temporal scale of the human perceptual capacities. A transformation, as noted by the renowned artist Olafur Eliasson, that tries to make climate change a tangible phenomena [11].

In this text, we present and discuss the GaiaSenses project, an art-science project that also aims to make climate change more tangible for non-expert people. GaiaSenses is a mobile application that presents its users with visual animations and soundscapes based on the user's geolocation and the weather conditions of their surroundings. The animations and soundscapes are driven by weather and climatic data, like vegetation constitution, fire and rainfall, derived from NOAA multiband satellite images and made available by the Center for Meteorological and Agricultural Applied Research at University of Campinas - (CEPAGRI). By repurposing scientific environmental data into novel aesthetic compositions, the project aims to provide people with novel forms of engaging with important aspects of climate change that are not usually part of our weather experience, in the hope that it fosters more public engagement towards climate action. The GaiaSenses Project is being developed at the CTI Renato Archer by an interdisciplinary team of researchers. By presenting and discussing the GaiaSenses project this text aims to inquire into the capacities that computational creative systems can have in helping us make sense of climate change and reshape the ways we relate to the environment.

This article is composed of the following sections. First, we present a brief summary of how climate change has been made visible for both experts and non-experts by contextualizing the most famous data visualization, the hockey stick, in terms of computational creativity to show that science also depends on the aesthetic production of images for their comprehension and communication. Secondly, we present two important artworks that use different strategies to make the presumed distant climate change future closer to the public: Ice Watch by Olafur Eliasson and Oceans in Transformation by Territorial Collective. We describe them and present a brief analysis of some of their affective aspects. Then, we present the GaiaSenses project, how it works and some of its compositions in an attempt to try to locate where creativity is understood to reside in the system. Finally we present a brief discussion over some effects of dealing with climate change for computational creativity research.

2 Making Climate Change Visible: Strategies from the Sciences

Climate change is a paradoxical phenomena. While there is not a single place in the world one can go to see these changes in the global climate, there is hardly anywhere one can go to escape from them. This is due to the scale of the very object that is subject to these changes, the global climate. An entity that is way beyond the human scale of perception and can only be made visible by a vast network of environmental data collection devices distributed around the planet, like weather and marine stations, people with expertise to aggregate and process these data in meaningful ways, like climatologists and ecologists, and institutions that make possible both the flow of data and knowledge about the global climate, like the World Meteorological Organization (WMO) and the

Intergovernmental Panel on Climate Change (IPCC). Historian of science Paul Edwards called this arrangement the "knowledge infrastructure of climate change", as he defined it as the "robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds" [7, p. 340]. Due to the complicated nature of the phenomena, climate change is a subject in need of particular perception and cognition support to be minimally comprehensible [12]. And this support usually comes in the form of images and charts that help narrate the climate data [13].

We would be wrong to assume that only artists engage in the aesthetic reconstruction of climate data in more visually appealing formats. In fact, there is hardly a climate change image more famous than the "hockey stick" graph (Fig. 1). First published by climatologist Mann, Bradley and Hughes in 1998 [14], the graph depicts a statistical reconstruction of the planet surface temperature variation in the last 1000 years for the Northern Hemisphere, from year 1000 to the year 2000, based on climate proxies like ice cores, corals and tree rings. The figure that resulted from the complex statistical analysis was, as Mann describes in his book, "a wiggly curve documenting past temperature changes over the entire Northern Hemisphere (the hemisphere with the most data) and indicating a sharp rise in temperature over the past century" [15, p. xvii].

Even though Mann comments that he considers that the hockey stick graph was probably the least scientifically interesting thing in the article, it was that image that spawned massive media coverage [15, p.49]. The hockey-stick was featured in Vice President Al Gore's speeches in 1999, in president Bill Clinton State of The Union speech in the 2000, in the 2001 IPCC Assessment Report for Policy Makers and in 2006 Al Gore's An Inconvenient Truth movie. But the figure actually became globally famous because it was a main point of attack for climate deniers in the early 2000s, so much so, that in 2005 the chairman of the UK House Committee on Energy and Commerce and the chairman of the Subcommittee on Oversight and Investigations demanded an investigation of the full records of the climate research, personal finance and career of Mann and his co-authors. A request that was accepted by the National Academy of Science and after investigations, came to the conclusion that nothing was wrong with the research [15, 16]. Even with this conclusion, the same researchers were victims of the 2009 email hacking event in the University of East Anglia in the United Kingdom that leaked thousands of emails and documents exchanged between climate researchers that further spawned independent investigations over the conduct of climate scientists working on climate change [17].

Mann comments that he is not sure why that specific image was the one that stirred up so much controversies that caused him to suffer incessant harassment and threats from climate deniers and oil lobbyists, since paleoclimatic reconstructions that shown a rapid increase in temperature in recent times had been done before. But he suspects that it was the high resolution of time in the graph that they managed to achieve due to his and his co-authors innovative use of proxy climate data coupled with the statistical technique of principal component analysis (PCA). While previous researches present time resolutions of centuries or decades at best, Mann's research had managed to present the temperature variations year by year, a time scale very much in line with human perception of time [15]. Which made it possible to show that it is not just that the 20th century has been warmer than the last few centuries, but that the year 1990 has been the warmest year of

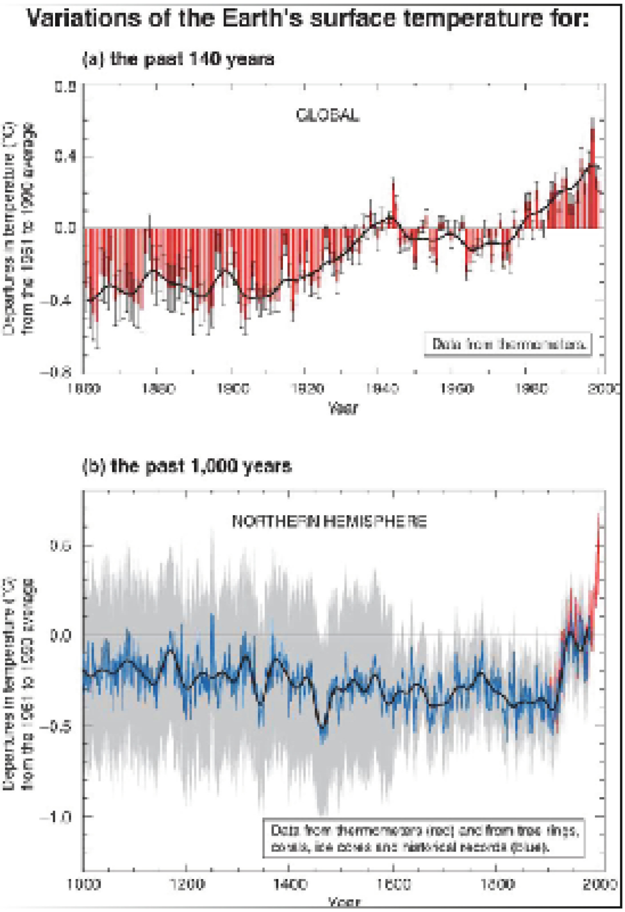

Fig. 1. Variations of the Earth's surface temperature over the last 140 years and the last millennium. (a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal time-scales). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanization over the land. Over both the last 140 years − 0.8 and 100 years, the best estimate is that the global average surface temperature Year has increased by 0.6 ± 0.2 °C. (b) Additionally, the year by year (blue curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from "proxy" data calibrated against thermometer data (see list of the main proxy data in the diagram). The 95% confidence range in the annual data is represented by the gray region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium. Source: IPCC AR3 Working Group I: The Scientific Basis p. 3, 2021.

the last thousand years. A picture that made every more clear the anthropogenic aspect of global warming by showing, in the human scale of time, the geological effect of human actions over time. A picture so enticing that, as Mann recounts, it had featured on a large number of magazines, articles, as cover art and as art in protest banners [15].

As the controversy over the hockey stick makes clear, it was the image and its aesthetic capacity to affect, and not just the climate data, that spawned the heated debates. Although Mann describes in some detail the process of producing the graph, how it was slowly composed by incorporating climate data that were already collected elsewhere and how the PCA technique was used to make all the data interoperable, the author does not comment on the specific software tools used to produce the image. Nonetheless, it is not too hard to imagine that the image was created using techniques similar to the ones used today in programming languages that offer scientific visualization tools, like Mathlab, R, Python. By appropriating [18] categorization of computational art for analyzing this particular scientific image, a categorization that describes computational art as "a spectrum of activities defined by the margin of control of human artist on the final output, or, to reverse the viewpoint, the level of autonomy of the computational system" [18, p157], it would not be too far off to suppose that the hockey stick belongs to the leftmost side of the spectrum, where an artist have complete control over the process and uses code as medium.

In the terms of Boden's cognitivist theory of creativity, it would be hard to determine if the hockey stick would better fit the combinatory or the exploratory category, but in a retrospective analysis it had a transformational effect in both the conceptual space of climate science and in the societal world at large [19]. An example that reframes categorization theories as situated and historically localized practices [20]. As [17] comments, these controversies had a significant effect on the public trust in science and surveys showed a decrease in public trust in what scientists have to say about the environment both in the US and Europe [17, p548]. An important transformational effect however, was in the worldview of Mann himself. He mentioned that after the events, it became clear to him that climate change science is inextricably connected to politics [15]. A point that many artists and scientists try to make clear to non-expert publics.

The hockey stick story shows the significant societal effect that aesthetic experimentation with climate data can have, even when inside the aesthetic rules of scientific representations. In the next section, we present two artworks that deal directly with climate change and discuss some aesthetic and technical strategies that they use to try to bring the planetary scale of climate change down to the human scale of perception.

3 Making Climate Change Tangible: Strategies from the Arts

3.1 Making the Distant Close - Olafur Eliasson's Ice Watch (2015)

The monitoring of ice sheets is a main index to assess climate change. The extent of ice sheets in the poles, especially in Greenland and Antarctica, fluctuate naturally due to seasonal changes and weather variations, like temperature, precipitation and humidity. The expected behavior is that melted ice would drain into the sea, later evaporate and, due to the water cycle, would eventually fall as snow atop the ice sheep, keeping its amount in a dynamic balance. But with climate change, the planet warms due to the continued emission of CO2 worldwide, making the warm seasons longer, thus interrupting the time the melted ice needs to go back to its ice sheet. This accumulation of lost ice is an important metric to assess sea level rise worldwide, one of the main risk factors of global climate change. Since 1992 Greenland and Antarctica have each lost more than 100 billion metric tons of ice per year on average [21].

This monitoring relies on complex aggregation of historical satellite imaging and data from marine buoyancy stations and is usually visualized in line charts depicting the decline of ice sheet mass over time. Despite being a central risk element for populations worldwide, it is a phenomenon that is happening in very remote places, like Greenland and Antarctica, in the glacial landscapes that are mostly unknown for non-expert people and at a scale particularly hard to comprehend. It is as an attempt to raise awareness about these often remote and abstract phenomena that characterize global climate change that the artist and United Nations (UN) Climate Ambassador Olafur Eliasson presented the installation Ice Watch in 2015.

Ice Watch is an interactive installation developed by the Danish-Icelandic artist Olafur Eliasson in collaboration with geologist Minik Rosing and presented in Paris for the occasion of the 21 COP Climate Summit in 2015 and subsequently reprised in London and Copenhagen. In 2015, the installation consisted of twelve immense blocks of glacial ice arranged in a clock formation at the Place du Panthéon in Paris, and left to melt away during COP21.

From December 9th to December 14th 2021, while the talks that would later become the Paris agreement were happening inside COP21 and the ice melted, the passing by people were encouraged to interact with the ice blocks the way they see fit, in an effort to inspire public action against climate change. A large number of people were drawn by the intriguing blue hue of the glacier ice and the chance to see it and contemplate it [22] (Fig. 2).

A number of photos show people interacting with it in a myriad of ways, touching it, hugging it, sitting at it, drinking the melted ice water, taking pictures, dancing near it and even moving it as it becomes smaller and lighter. As reported by the writer Rebecca Solnit and recovered by [9], "it's a beautiful, disturbing, dying monument to where we are right now… People are coming by fascinated, most needing to touch the ice" [9, p. 144]. A response that seems to be aligned with the artist's original expectation in the press release: "Put your hand on the ice, listen to it, smell it, look at it – and witness the ecological changes our world is undergoing. […] I hope that Ice Watch arouses feelings of proximity, presence, and relevance, of narratives that you can identify with and that make us all engage" [24].

As [9] notes, the way the ice fragments established a relationship with the broad theme of climate change is not just due to its origin in the receding glacier of Greenland, but also due to its trajectory to the exhibition. Weighting a total of 80 tons, the twelve blocks were harvested from free-floating icebergs in a fjord near Nuuk in Greenland by divers and dockworkers from the Royal Arctic Line. They were then placed in six 40 foot refrigerated containers in Nuuk, Greenland, and transported to Aalberg in Norway by a container ship. In Norway, the containers were moved to Paris by truck and arranged at the plaza using forklifts and a crane [9]. A journey that amounted to a total of 30 tons of CO2e in carbon footprint [Olafur emissions report]. The very physical transportation of

Fig. 2. Ice Watch Installation in Paris. Source: Ice Watch Paris Press kit.

the key actors, the ice blocks, to a place of decision about the global climate as the COP21 performs the whole issue of climate change. As they travel, they get enmeshed in the global logistical network that connects every part of the planet, and that is significantly responsible for global CO2 emissions [9]. At the end of the journey, the ice blocks are a kind of 10 ton miniatures of global climate change.

When the public interacts with the melting ice, the geological scale of climate change and the human scale of sensing collapse onto each other. By breathing next to the ice blocks, one breaths the ancient air trapped between the snow layers that form the glacier ice, by touching it, one is made part of the milenia long process that forms glaciers by the slow deposition of snow that is compressed by its own weight, and by witnessing them melt, one can see, like in a natural time lapse video, the future that awaits humanity in the next century [9]. In Ice Watch, the control that the artist has over the final artwork is distributed to the weather forces of both the surrounding environment and surrounding publics, like the heat from the atmospheric temperature and the heat emanating from people's body.

The installation works not only because the artist provides unmediated access to a rare natural phenomena, the melting of glaciers, but because the artist was capable of arranging a complex set of technical mediations that allows for the ice blocks to be moved from Greenland to Paris before it fully melts. The efficacy of this artwork lies, of course, in this capacity to transport, alongside the ice block, the environmental relations that would only happen in a remote place, like Greenland, to a crowded place like Paris. And at a crucial time for climate politics, the COP21.

The Ice Watch does not seem to be closely related to computational art at first, but it can be thought of as an ingenious way of visualizing fundamental data about the changing climate, the melting of glaciers, but directed at non-expert publics. It functions as an analogy to climate scientists watching the planet change inside their computer models by analyzing data tables and charts. But instead of affecting its publics by a "visual analytics" [25] like the hockey stick graph, it affects its publics by making concrete the abstract phenomena of melting glaciers and bringing close to home the distant research sites in the coldest parts of the northern Atlantic Ocean. These aesthetic strategies are central to the objective that Olafur Eliasson sets for his own work, as he comments: "As an artist I hope my works touch people, which in turn can make something that may have previously seemed quite abstract into reality […] and Ice Watch makes the climate challenges we are facing tangible" [22]. The expectation, as the author comments, is that by allowing this intimate connection to be forged, the experience of connection will inspire public action.

3.2 Making the Unimaginable Imaginable - Territorial Agency's Oceans in Transformation (2020)

With Ice Watch, Olafur Eliassion hoped to forge connections between the individuals and the planet by providing an intimate sensory experience to an index of climate change that is hard to imagine from a distance. In Oceans in Transformations (2020), the architecture collective Territorial Agency tackles the difficulty of imagining our climate future using a different set of techniques. Instead of bringing a miniature of climate change, Oceans in Transformation brings together numerous datasets of human effects on the planet into a single map, providing an impactful picture of modern history and the future to come.

Oceans in Transformation is an art-research project that traces the human impact in the oceans by collecting and collating data from 79 different datasets in one large map that tries to show a picture of what is known about the oceanic system and what it could look like in the future [26]. The project was developed by the architecture collective Territorial Agency, founded by John Palomino and Ann-Sofi Rönnskog and it was commissioned by the Thyssen-Bornemisza Art Contemporary (TBA21) - Academy. The three year project culminated in an exhibition in 2020 at the Ocean Space at the old Church of San Lorenzo in Venice, Italy, and was the recipient of the S + T + ARTS'21 prize promoted by the European Commission for project where appropriation by the arts has a strong potential to influence or alter the use, deployment, or perception of technology [27].

In Venice, the core of the exhibition was an installation composed of 37 large LCD panels distributed in 7 groups (Trajectories), where each group depicted a large animated map of a transect of the planet and the numerous human activities that happened in this zone [28].

The grouped LCD panels depict maps that the artists called the "sensible zone" [28], a small vertical section of the planet that spans from 200 m below the ocean level to 200 m above the ocean level. A section that concentrates the most biogeochemical activities - life - of the planet's biosphere, the section that historically contains the highest level of human activity and environmental impact, and coincidentally, the section that will be most affected by the 3 m–6 m rise in the sea level projected for the next century.

In one of the groups, the North Sea to Red Sea Journey (Fig. 3), a transect cuts from the North Atlantic, across the continental shelf of the North Sea (passing through

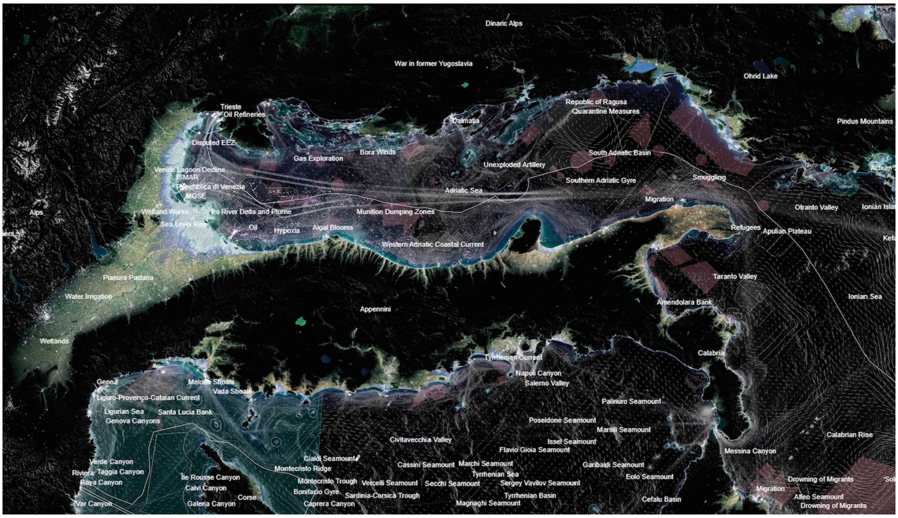

Fig. 3. An example of the visual composition present in the exhibition Oceans in Transformation. In this case, the sensible zone of Italy. Source: [26]

the UK, France and Italy), it goes through Venice and its lagoon, across the Adriatic, it connects to the Suez Canal and finally ends at the Red Sea. The transec shows an enormous map, where only the sensible zone (200 below and 200 above the sea level) is colored and the rest is dark. In this area, 79 different datasets with data ranging from 1900 to 2020 are superimposed considering the geolocation of their data, like a long exposure photograph taken from a satellite over 120 years [26]. In the map, the green territories are land from sea level to 200 m above it, the white lines are the trajectories of transport ships, the tiny white dots are fishing ships, red squares and circles are oil and gas exploration stations. On the land, the different intensities of light represent the urban expansion of cities, and in their interface with the sea, the white to light blue to dark blue color gradient represent the projected sea level rise for climate scenarios of + 1,5 °C, +2 °C and +3 °C above pre industrial levels. And the sea rise distribution is a result from sea rise projections combined with a digital elevation model DEM derived from the Shuttle Radar Topography Mission SRTM [28].

The Ocean in Transformation project uses only open access data and a list of the 79 datasets used can be found in the project website [26], along with the specific portion of the data that was used. As commented by John Palomino in an interview about Oceans in Transformation, although all data was open access, downloading them and making them interoperable was incredibly laborious and time consuming, since the data sets spanned through numerous different scientific fields that do not share data standards between them and rarely had the same space or time resolution. As shown by the artists, knowledge about the ocean is still incredibly fragmentary, with large portions of the oceans still unstudied. The little data available, observes John Palomino in an interview, is scattered in many different websites that are usually known only by experts in the field and systems with complicated processes of data requests [29].

The aesthetic language born out of Oceans in Transformations has the purpose of making visible the enormous human impact in a space usually associated with emptiness, the ocean, by making the most of the land not visible. As Fig. 3 shows, the ocean is not empty, on the contrary, it is incredibly busy with human and non-human activities, and incredibly at risk. And by bringing together many disparate datasets about the oceans, it makes it possible for the public to grasp, visualize and imagine the future of the crucial, but often neglected oceanic system. By seeing the world from the point view of the oceans, from the point view of the sensible zones, it is possible to comprehend that we, humans, are actually part of a collective that shares similarities by means other than land.

Differently from the Ice Watch, the control the artist has in the final product is extreme, but this extreme control is used to highlight the gaps in our knowledge about the ocean by showing that despite this control, it is the data availability that defines the possible aesthetic composition in the panel. Gaps in data become gaps in the knowledge that become gaps in the possibility to fill the visual composition.

By analyzing the two artworks above, Ice Watch (2015) and Oceans in Transformation (2020), it is possible to extract two principles that could contribute to the effectiveness of creating climate change artwork with computational means. First, based on Ice Watch (2015), the notion that no matter how precise the scientific data about changes in the environment are, they are usually understood as too abstract by the non-expert public, since the global climate is a non-tangible object. Thus, it is crucial to foster other ways to visualize climate data that are more embodied and allow for sensible connections, as the artists observe in their essay accompanying the artwork: "there is a huge gap between what we know and what we feel. How can we translate knowledge into action, and really change our behavior? Of course, it is necessary to present the facts and data supporting climate change science, but this is not where action begins. Only by embodying knowledge can we gain a sense of responsibility and commitment" [23, p4].

In Oceans in Transformation (2020), the artists make clear that the usual cartographic imaginary that guides our view of the world is not enough to comprehend or even imagine the extent of the human impact on the planet, especially in the oceans. And that the fragmented aspect of knowledge about these impacts contributes to this alienation. To actually grasp the extent of the magnitude of climate change in the world, it is crucial to develop new aesthetic propositions that offer alternative perspectives on the environments we inhabit. And as they show, these alternatives do not need to abandon scientific knowledge and procedures, on the contrary, the extensive use of tools like Geographic Information Systems (GIS), Satellite Images and ocean datasets, can actually open possibilities to experiment with environmental data in novel aesthetic ways.

4 The GaiaSenses Project

The previous sections have shown related works of climate art that try to raise awareness about the changing climate by providing an aesthetic experience for the public in the form of an event. In the GaiaSenses project, the strategy is to provide its public with periodic aesthetic experiences so they can perceive the climate and the weather in different ways, making aspects of climate change more present in their daily life.

The GaiaSenses Project proposes the development of an application for mobile devices that periodically delivers audiovisual compositions to its users, based on the weather conditions of their surroundings. Based on the users geolocation data, the application will periodically generate an animation and an accompanying sound using data from the weather satellite GOES-16, made available by the Center for Meteorological and Agricultural Applied Research at University of Campinas (CEPAGRI) and data platforms like Google Earth Engine and OpenWeather. These compositions will be short videos (20–30 s) or interactive images bringing attention to specific weather and environmental events happening near the user's location, like rain, fires, or vegetation composition, and users will be able to share these compositions online in social media platforms. By providing a periodic composition, the project aims at making climate change a more present element in the daily life of people, a topic that is not only remembered in moments of environmental disaster [30].

The audiovisual compositions will be made by using these localized data as inputs to generative algorithms and other creative computing techniques. Currently, the visual components are produced by specific animation algorithms implemented using the javascript library p5.js, a library for creative coding similar to Processing. The project currently has 12 visual animations implemented that are powered by real time weather data such as temperature, quantity of rain, lightning occurrences, wind speed, wind direction, cloudiness and fire occurrences. Each animation receives a combination of these weather data that modifies its behavior. For example, Fig. 4, the animation Storm Eye: it receives temperature data, wind speed and wind direction. And they affect the animation as follows: 1) the temperature controls que color pallet of lines, from blue (cold) to red (warm); 2) the wind speed controls the velocity in which each curve circles around the screen; and 3) the wind direction controls how disperse the curves are from the center of the composition.

The audio compositions work in a similar way. The audio components are implemented in Pure Data, a visual programming language for creating interactive and real time music based on audio synthesis and processing, much like a modular synthesizer. The music compositions also respond to specific weather data that alters the composition behavior. In the Lluvia composition, for example, the amount of rain (mm/h) controls the pitch, tempo and audio channel, in a way that the heavies the rain one can hear a fast and spatial sound event, much like in the rain, where one can hear the droplets hitting the ground from every direction. Other examples of compositions can be seen on Fig. 5.

To produce the data to drive these animations, the project has a data processing service in a backend implemented in Python, using the Flask web framework, to leverage the rich data processing ecosystem available for Python. The data processing service works by downloading and transforming data from a desired location, it downloads Rainfall data from the OpenWeatherAPI, Fire data from the CSV files openly available in INPE website, and lightning data from the GOES-16 satellite also openly available in a AWS service. After downloading, the backend processes the raw data into metrics to determine what kind of animation will be produced for a specific location based on the seriousness of weather events happening in the requested region. This decision is based on extracting certain parameters from the raw data like the quantity of rainfall, fire temperature and lighting occurrence, and comparing them to thresholds [31, 32]. Thus, the user will

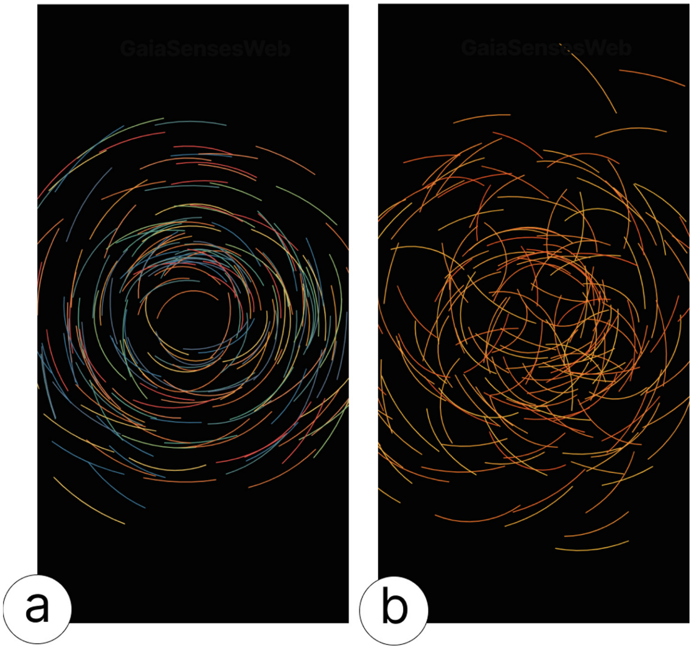

Fig. 4. Storm Eye composition in two different weather conditions. a) temperature: 24 °C, wind speed: 4 m/s, wind direction 20°; b) temperature: 32 °C, wind speed: 14.2 m/s, wind direction 271°. Source:

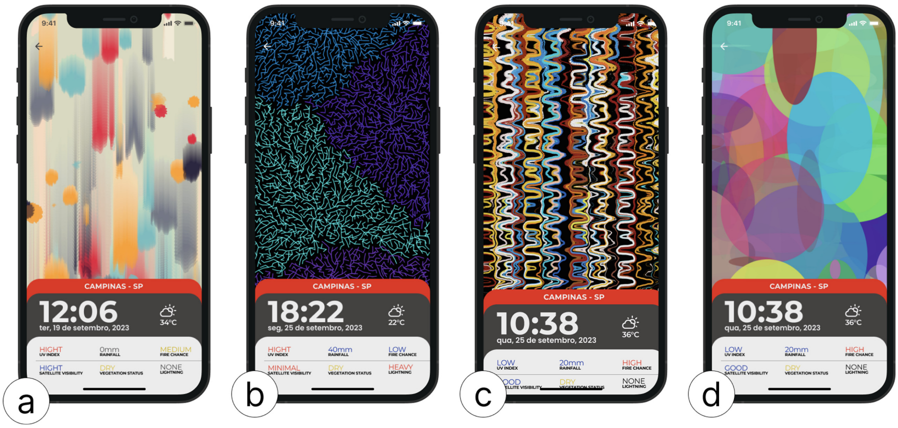

Fig. 5. Screenshots of GaiaSenses App showing some compositions. a) Brush, driven by humidity data; b) Lightning Tree, driven by lightning occurrences data; c) Zigzag, driven by rain and lightning occurrence data; d) Lluvia, driven by rain data. Source:

receive a composition that corresponds to the most serious weather event happening in their requested location, fostering a sense of local relation to the climate and weather systems.

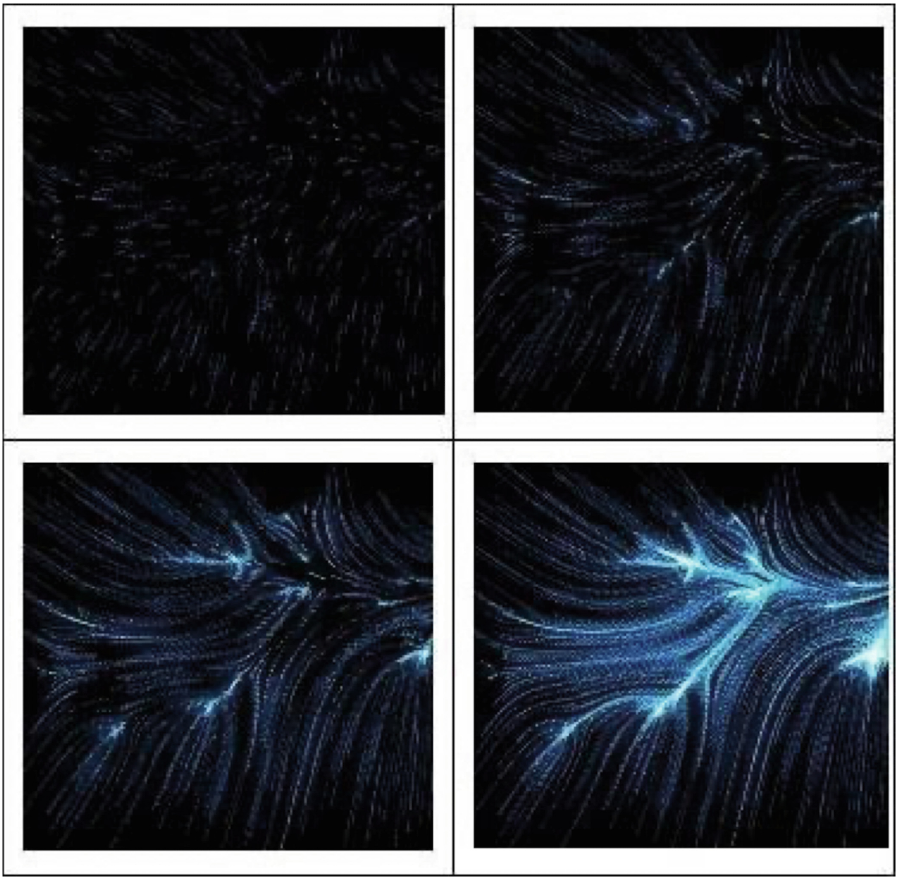

Fig. 6. Frame sequence of an animation using lighting data. Source: [31]

Figure 6 shows a sequence of frames of an animation driven by lightning data. In this animation, the data processing service downloads lightning data from the GOES-16 AWS repository, that make files available in netCDF format, the netCDF file is transformed into a CSV table containing latitude, longitude and the date and time of lightning occurrence, then, the CSV file is filtered according to the requested location and time period. Finally the data is sent to the frontend application that renders the animations in the user's mobile device.

In Fig. 6, the animation prints in the user's screen the location of every registered lightning event in a way that the more alarming the lightning event in a place, the more attracted they will be to each other, forming the bright areas seen in the image.

In [18] computational art autonomy spectrum, the GaiaSense is probably in the leftmost section, where the artists retain control over the output and use code as a medium. But when accounting for the decision making process and specific visual content of each animation and soundscape, the creative decisions are not made by the programmers alone, but also by the specific natural conditions, collected by weather satellites like the GOES-16 and the animation algorithms, thus distributing the creative agency of the artist/programmer over the final output to non-human elements like the environmental forces and the algorithms driving the animations.

Similar to the Ice Watch, the GaiaSenses provides a novel way to make climate data perceivable in the scale of the human senses, mostly by vision and hearing. And similar to the Oceans in Transformation, by joining previously dispersed data sources, it creates an aesthetic grammar to help people to engage intellectually and imaginatively to the often dry, but important climate data. A development that displaces the autonomous scale of computational art proposed by [18] at least a little to the right, towards a more dynamic integration between human and machine creativity.

5 Discussion and Future Work

This article presented the GaiaSenses project and discussed it in context to other instances of climate art created using computational means. By presenting other forms of aesthetically experiencing climate change, from more to less scientifically inspired, we intended to contribute to the still emerging discussions of how to use digital and computational art to raise awareness about climate change and inspire political action. In the discussed artworks, Ice Watch and Oceans in Transformation, we identified certain strategies that could be fruitful as reflexivity elements in the development of computational art dealing with climate change, and particularly in the GaiaSenses project. Particularly the principal of making abstract scientific scales more concrete and bringing together disperse scientific knowledge in creative aesthetic forms. As a result, we suggest that: as the advent of computing has prompted new ways of understanding and inquiring about human creativity [19], the acknowledgement that climate art makes about the active role that the environment has in making art, can make important advancement in accounting for more elements in the human creativity, beyond the psychological and social aspects. In an analogous way, the agency that the environment takes from us in this new climate condition, showing that nature is not just the passive background of human history, is similar to the dislocation of cognition that the computer has caused, claiming that cognition is not something that happens in isolation, only inside the the mind. It is, of course, extremely early to propose such ideas, but they seem relevant to at least touch on, due to not only the climate road ahead, but to our climate present.

As noted by [33], the computational creativity field has yet to engage with the matter of climate change, since there are very few people in the field tackling such relevant themes [30, 34]. According to [33], this engagement is a great opportunity since the field has historically focused on aspects that are now crucial to deal with the climate crisis, like supporting and enhancing decision-making processes, automatically generating creative scenarios and promoting interdisciplinary partnerships with artists, scientists and decision makers. How the field will be able to contribute, as the authors notes, is now a matter of discussion, research of trial and error. A methodology that the computational creativity field seems particularly apt to execute and a topic that it will be less and less likely to be avoided.

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