Communicating climate change through narrative visualization

Shirley Leung[1], Philippe Vaillant[2], Helena van Tol[3], and Michelle Weirathmueller[4]

Abstract— **One of the greatest challenges in visualizing climate change is how to accurately display multiple sources of variable data in a way that is convincing to the general public. Most audiences have difficulty interpreting the difference between variability and uncertainty and may not grasp what constitutes major change on a global scale. One solution to this problem would be to show data from the past and present accompanied by photographic images of landscapes that represent these changes. This visualization strategy necessarily requires curation by experts and could be supported by embedding links to the raw data or relevant publications into the graphic.**

I. INTRODUCTION AND OBJECTIVES

Climate change is one the greatest environmental as well as communication challenges of our time. The underlying science is complex with large uncertainties, many variables of interest, and a multitude of diverse data sources. In order to communicate effectively, climate scientists need to tailor their messages to public audiences with varying degrees of scientific knowledge and skepticism towards scientists themselves, in addition to policymakers from very different intellectual domains. These scientists often have highly specialized, complicated tools to communicate findings with other scientists, but sorely lack simple, effective tools to communicate their findings with the public and policymakers. Well-designed visualizations can, however, facilitate better climate change communication.

One of the greatest challenges in visualizing climate change is how to accurately display multiple sources of variable data in a way that is both engaging and convincing to the general public. Many existing visualizations oversimplify concepts while others seem too complex. Effective science communicators excel at curating information to avoid either overwhelming or talking down to their audience. Our goal was thus to empower and educate our general public audience by creating an inviting interactive interface that provides access to several layers of information with varying degrees of complexity.

More specifically, our objectives are as follows:

- Use narrative storytelling visualization techniques to help our viewers gain a comprehensive and coherent understanding of climate change causes, effects, and solutions.
- Show raw time series of (at times, highly noisy) quantitative data to enable our viewers to see for themselves the measurements and evidence scientists use to draw conclusions about climate change.
- Show viewers that there is a wide array of evidence in support of climate change from many different sources.
- Show viewers that there are already observable, significant climate change effects and that we do not have to wait 100 more years to see the effects.
- Show viewers that the effects of climate change are ubiquitous and far-reaching.

II. RELATED WORK AND NOVEL CONTRIBUTIONS

Finding ways to effectively communicate climate science is an area of active research. Climate scientists typically do not have a background in the theory of data visualization or visual communication. As a result, prior climate change visualization work to communicate with non-scientists has not been subject to rigorous design and user-interaction principles.

The NASA Images of Change website [1] shows dramatic changes to the earth surface over time by showing before and after satellite images side by side. This approach provides for a simple, navigable user interface and is great at showing how drastic some climate change-driven changes have truly been. Our visualization preserves this easy navigability and high visual impact by loading before and after images side-by-side. However, this approach alone does not provide the viewer with any information on variability over time, which is an important concept. Furthermore, the images are not placed in context or associated with any quantitative or time series data. In order to better illustrate how scientists draw conclusions based on quantitative data, we intentionally emphasize the data that goes along with the imagery so that the viewer can see for themselves what quantitative, measurable evidence we have already accumulated regarding climate change.

The NASA Climate Time Machine website [2] displays gradual changes in global variables over time, but does not have an option to view before and after imagery side by side to see the dramatic changes that have accumulated gradually over time. In our design, we seamlessly integrate initial before and after imagery with gradual change imagery; the ability to see before and after imagery before looking at the changes over time associated with the accompanying time series data makes the story and changes simultaneously more salient and better contextualized.

[1]S. Leung is a graduate student in Physical Oceanography at the University of Washington shirlleu at uw.edu

[2]P. Vaillant is a graduate student in Urban Design and Planning at the University of Washington vaillant at uw.edu

[3]H. van Tol is a graduate student in Biological Oceanography at the University of Washington hmvantol at uw.edu

[4]M. Weirathmueller is a graduate student in Oceanography at the University of Washington michw at uw.edu

From the NASA Earth Observatory World of Change website [3], we retain the useful ability to click on a timeline in order to view the satellite image at a particular instant in time. However, our visualization reduces the associated overly-detailed text that goes along with each locations images, which discourages viewers from actually diving into the information. Instead, we break down our provided textual information into short annotations that pop up with images from different years and a less than one paragraph extra information section, so that this information becomes more inviting and easier to digest. Furthermore, the Earth Observatory website lacks a coherent flowing structure and is thus very difficult to navigate. The user is faced with an overwhelming number of links to click with no set order, no context as to their significance, and no easily discernible ties or connections to one another. On the other hand, our narrative visualization tells a coherent and connected story about how climate change has wide and varied effects (as well as causes and solutions) across the entire world, while guiding the viewer through a cumulative and logical progression of images and data.

The New York Times [4] also published an effective narrative storytelling climate change visualization on their website in 2009. In it, they showed model predictions of climate change effects across many different regions within the next 100 years. They employed parallel structure technique by zooming into and walking the viewer through the affected regions using a similar presentation format for each region. We employ this same parallel structure technique, which has been shown to help viewers understand information more quickly and easily [5], but we instead use real (rather than modeled) data and images to show the dramatic changes to the Earth system that have already been brought about to emphasize that climate change is already a big problem now and not just in the future. Furthermore, we attempt to provide our viewers with hope for the future by also showing images and time series of climate change mitigation projects already being implemented, such as construction of large-scale solar energy facilities and technological advances that decrease the carbon intensity of oil sands extraction.

As can be seen, in our design, we seek to create one single web visualization interface that combines effective elements from each of the prior works described above, while simultaneously adding more detailed and easily accessible information.

In summary:

- Many past communication efforts have focused on either gradual changes or before and after changes. We include the two together in order to emphasize how dramatic changes have really been but also how noisy climate data can be as well.
- Past communication efforts have tended to obscure HOW we know what we know and what climate data actually look like. We emphasize that there is a lot of data out there to support the scientific basis behind climate change and present it in a highly digestible, but accurate and honest way.
- Past communication efforts have either given viewers too little or too much information. We attempt to give viewers just the right amount so that they are neither overwhelmed (and thus reluctant to dive in) nor missing any important information.
- Past communication efforts have focused on what might happen with climate change in the future. We emphasize just how much climate change has already occurred and how it has already affected our Earth system.

III. METHODS

A. Visualization tools

We used HTML, CSS, and Javascript for our visualization. More specifically, we created the website canvas with Bootstrap (an HTML framework) and built most of our interactive features with the Javascript library D3, along with two sub-libraries, queue and topojson.

Bootstrap, in addition to providing us with an easy-to-use grid system, minimizes the risk of cross-browser rendering problems, which is a major issue in any visualization project. Topojson implements additional geospatial features into D3, and queue defers functions until all of the attached documents are loaded.

B. Interactive globe

To build our rotating globe we used JavaScript to load a Topojson file of the world along with a comma-separated file (CSV) containing positional information for each of our featured locations. Representing the globe in 3D involves choosing an adequate map projection. Selecting a map projection always involves a trade-off between the preservation of various features, such as area or distance. Fortunately, all of the most common projections are included with D3. Among those we decided to use the orthographic projection, which distorts areas and shapes around the edges but has the advantage of familiarity, since most people are accustomed to seeing the earth presented in this way. Since we are not representing data on the globe and since we are rotating the globe, hence shifting the edges, this choice seemed satisfactory. D3 projections also use an adaptive re-sampling algorithm (https://bl.ocks.org/mbostock/3795544), which improves the appearance of the projected lines by correcting problems of projected lines becoming curves in a computationally fast way (https://bl.ocks.org/mbostock/3795544). Adding the rotating behavior was just a matter of making a mouse drag event, including the angle and length of the dragging event, and determining the rotation of the projected globe along its axes.

C. Image loading time

Toggling between the exploration of the globe and the information pane was the result of simple Bootstrap functionality, but the display of the content of the information required smart approaches in loading the images and binding diverse data elements (satellite images, timeline data, annotations, and scientific papers) together in an efficient way. The challenge in interactive visualization is that, as soon as the product stops appearing fast and effortless, it might deter the audience from using it. Loading each image individually when moving through time was therefore not the best option. Our method for jumping seamlessly through time is to use a sprite sheet combining all the images of one location, and translating this sprite sheet to the correct image when moving through time. A sprite sheet is an image file containing smaller images arranged in a grid. We used a simple software package called Glue [6] to generate those sprite sheets and corresponding translation values. Glue is a command line tool that creates sprites from files and attaches metadata to it. The metadata contains crucial information describing the dimensions and boundaries of each image within the composite so that we can use JavaScript to display the relevant image sub-units.

D. Data integration

We decided to create a simple CSV format to integrate all the data from each location. The intention in doing this was to provide enough flexibility for interested researchers to create their own versions of the visualizations using their own curated set of images and data. In this case, they will only need to replace the documents attached to the code by their own sprite sheets, location CSV file, and temporal data files. We have already had scientists express interest in uploading their own data into the graphic. The sprite sheet and the location file have already been described. The temporal data file comprises columns of local and global data at particular time stamps, columns of annotations that are useful in the understanding of the phenomenon studied, and the name and DOI of the scientific articles that studied the phenomenon. The structure and formatting requirements of this file are described in more detail in a readme file that can be found on the github repository.

E. Data Collection

For our presentation, we chose six different sites where climate change or fossil fuel consumption were the predominant effectors of landscape change. The following sites and data were chosen in consultation with a climate science domain expert to highlight specific impacts of climate change as well as the diversity of effects on the Earth's surface:

- Athabasca oil sands
  - Alberta well-to-wheels carbon intensity (g CO_2 equivalent /MJ)
  - Global carbon emissions (Tg C)
- Arctic sea ice
  - Arctic sea ice area (million km^2)
  - Global sea ice area (million km^2)
- Gansu Dunhuang solar park
  - Photovoltaic capacity - China (Gigawatts)
  - Photovoltaic capacity - Global (Gigawatts)
- Lake Chad lake level
  - Lake level measured at Bol (meters above sea level)
  - Sahel rainfall anomalies (cm)
- Sierra Nevada snow pack
  - Snow water equivalent (cm)
  - Total water storage anomaly (mm equivalent water height)
- Great Barrier Reef(?) coral bleaching
  - yl
  - yg

First we searched for satellite images of each site taken over the course of a few years. We retained the image source URL and posted it within the modal window of each location to allow our audience access to those images. Ideally, these links would come from the primary source databases for satellite images to diminish the likelihood of link expiration. However, these databases can be difficult to access and search for non-domain experts so we used series of images that had already been selected and curated by others. We then searched for data connected to the phenomenon observed at each location as well as data connecting these observations to a global or larger regional impact. We also posted links to the data sources within the modal window for each location. Ideally, the data would come from public databases, open access publications, or Sci-Hub. The link to the open access literature should also be provided as a DOI (Digital Object Identifier) link to avoid expiration. When the raw data was not provided by the literature, we converted the lines to scalable vector graphic (SVG) paths and then translated those coordinates using the values on the figure axes.

IV. RESULTS

The primary view of our visualization is split between an orthographic projection of the globe and some introductory text. The interactive globe is positioned on the left side of the screen, while the general description, instructions, and "start" button are on the right side (Fig. 1). The user can be quickly oriented to the familiar orthogonal projection of the Earth with simple gray-filled land masses and light-blue water. The yellow points at different locations stand out and invite the user to investigate those locations. The instructions may help orient the viewer, but do not need to be read for the viewer to start interacting with the visualization. Our goal was to make various intuitive interactions possible for the viewer. A tour of the sites can be initialized in a few different ways: by clicking the prominent "start tour" button, by click the up or down arrow next to the globe, or by using the up/down arrow keys. The user can also explore the different sites independently by dragging the globe and clicking on a site of interest.

Each interaction with a different site brings up a modal window (Fig. 2). The modal window can be closed by clicking the cross symbol in the upper right hand corner, by clicking outside of the modal window, or by using the escape key. The user can navigate to the next location using up or down arrow keys or navigating back to the globe and clicking another location. The title briefly describes the phenomenon observed at each site. The primary view of the modal window shows satellite images and a time series plot. Scrolling down reveals data sources as well as an informative summary paragraph.

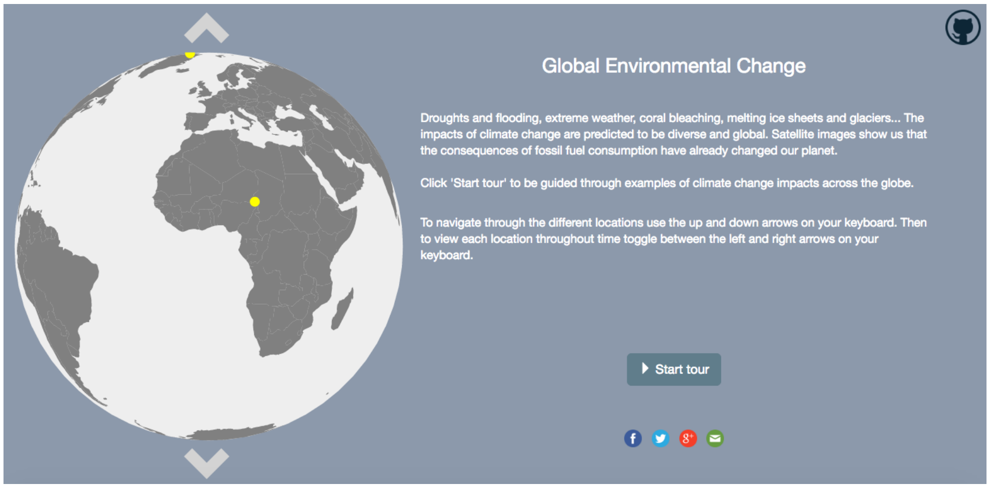

Fig. 1. Primary view of the visualization with interactive globe on the left, textual description and start button on the right.

Satellite images are paired to show an image from the past alongside a more recent image. Before and after images of landscape change are visually impactful and are an engaging technique for communicating climate change [7]. In a small user study, Lewis & Sheppard [8] presented First Nations community members with photo-realistic landscape images and simple GIS maps during a landscape management discussion. They found that the images increased the number of comments and number of physical interactions with the material. Additionally, community members were less likely to misinterpret the information presented and were better able to articulate their management opinions. In our visualization the user can click the left/right arrows or use their left/right keys to see how the landscape changed over time.

The satellite images were linked with data expressing some aspect of the phenomenon observed at each site as well as data linking the local phenomenon to global observations (eg. Arctic sea ice area and global sea ice area). Grey bars were used to show where satellite images overlap with data. Darker grey bars indicate which images are currently displayed. The before images are also linked to annotations that mention statistics or events that are relevant to the year on display.

Several different scents were used to help the user discover additional layers of information. The interactive tooltip on the globe gives the user an indication that the point can be clicked for more details 2. The up/down and left/right arrow glyph-icons indicate that the user can use those keys. The arrows become darker gray when those keys are pressed to give the user some instant feedback on the effectiveness of their interaction. Similarly, the bars on the plot become darker gray with hovering or when they are clicked. The various links and buttons also change color with hovering to indicate that they are clickable. A scroll bar in the modal window hints at more information if the user scrolls down.

V. DISCUSSION

We can assess our visualization in terms of ”expressiveness” and ”effectiveness”.

An expressive visualization communicates the facts in a set of data, and only the facts. This is particularly important for a topic such as climate change, which is often misunderstood and politicized. Despite widespread agreement within the global scientific community on at least first order causes and effects, there is persistent mistrust of climate scientists and climate-related findings [9], [8]. It is critical to find a way to present the often devastating impacts of climate change without compromising the integrity of the visualization by ”cherry-picking” the data that is shown. The causes and effects of climate change are complex and variable. There is a large degree of uncertainty, and it is important to communicate that even though results from a single location or from a single data type may be inconclusive, the picture becomes clear when the evidence is viewed in aggregate. Compared to past work, our visualization better achieves expressiveness by aggregating and then showing raw quantitative data and imagery from many locations all around the world. We also provide two sets of relevant data per location so that viewers can get a better overall idea of the many variables that contribute to our understanding of climate change. By showing all of the relevant data (but also, only the relevant data), we strategically avoid cherry-picking and promote understanding of both climate variability and trends.

An effective visualization presents information in a way that is readily perceived and accurately interpreted. We wanted the user be able to very quickly understand the primary messages we were trying to convey (as discussed in section I): (a) there are multiple lines of scientific evidence in support of climate change, (b) the Earth system and landscape has already undergone significant alterations due to climate change, and (c) the effects of climate change are far-reaching and global. Research has shown that the order in which information is presented can profoundly affect not only the users' experience, but also the conclusions they draw from the presented data [10], [11]. As the user moves through the components of the visualization, it helps keep transitions low-cost by minimizing the number of changes from one

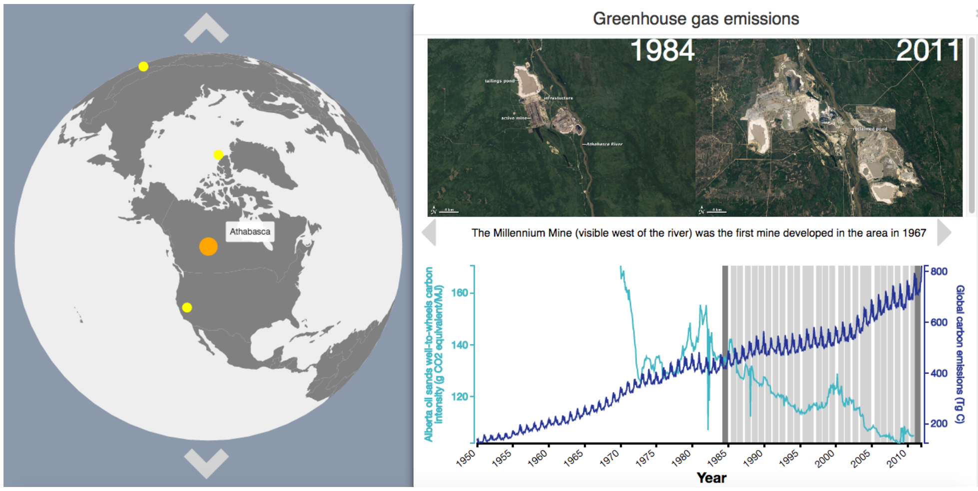

Fig. 2. Modal window view provides information about each site to the viewer.

view to the next. One way to achieve this is to use parallel structure [5]. We implemented parallel structure in our visualization by maintaining a consistent modal window layout and navigation from one location view to the next. In order to further improve the effectiveness of our visualization, we also added many ways in which the user could interact with the data in real-time. Examples include stepping the satellite imagery through time using the left/right arrow keys, clicking on the y-axis labels to isolate and focus on only one data set at a time, and clicking on particular years of interest to learn about interesting and relevant events that occurred in that year as well as revisiting the imagery corresponding to that year. This interactivity allows users to explore the data at their own pace and makes the entire visualization more engaging because they can highlight and revisit the most personally salient data and imagery. Compared to some past work, we also presented less textual information. Instead, we curated and highlighted only the most important facts and events via annotations that pop up in association with certain images to prevent the user from being overwhelmed with dense textual information. We included a small, less prominent summary section that appears at the bottom of the modal for those who do want to dive more deeply into the information. And we gave the users access to complete information through links to publicly available resources. By setting up all of these different layers of information and ways in which users can interact with it, the climate change data we present becomes more personal, memorable, and easy to understand, leading to greatly increased effectiveness compared to past climate change visualizations for the general public. Informal user studies showed that users were highly engaged in the data exploration process and oftentimes found the data together with the images useful, surprising, memorable, and convincing.

VI. FUTURE WORK

In creating our visualization, we focused primarily on the overall design and functionality. Future iterations would benefit greatly from informal user tests. More feedback from both scientists and non-scientists would be useful.

One of the initial goals of the project was to ensure that the code was open source so if anyone wanted use or expand on our work, they could simply fork our repository on Github. We would like to continue to explore ways to ensure that our project can be easily utilized and edited by users without extensive prior experience in web programming. Although we kept that goal in mind during the design and implementation of our project, our primary focus up until this point was on front-end usability.

We received valuable feedback when presenting our visualization prototype at the end-of-term poster session. Advice came from both domain scientists and also data visualization experts.

- *Site navigation:* Once users were oriented to the keyboard controls for navigating the visualization, they found subsequent exploration to be straightforward. However, it was clear that the text-based instructions on the home page were not particularly helpful. More guidance could be presented to the user upon opening the modal view. A brief pop-up instruction or tooltip could be presented for the initial view, since once the user understands the navigation, it is applicable to all locations.
- *Integration of annotations:* The annotations helped users to gain contextual insights into the links between the data and the images. It would be helpful to more explicitly link those annotations to specific locations on the image, where applicable. Also, the grey time-step bars in the chart view should be "scented", to let users know that they have additional information.
- *Draw viewer's attention to important features:* Satellite images are the most appealing and persuasive graphical element in our visualization. To draw the viewer's attention, these images could be a lot bigger if plot height was decreased a little bit and if the modal window took up more screen space after it is opened. The globe could

shrink and become more distant once the modal is open.

- *Improved aesthetics:* One user suggested that enlisting some help from a graphic designer could improve our colour scheme.
- *A more guided experience:* Although the level of interaction in our graphic is appropriate for users interested in doing their own exploration, it might be beneficial to have an alternate version that provides fully-guided experience. For example, some users might benefit most from a playable video that quickly steps through each location and explicitly tells them what to see and how to interpret the images and data.
- *Built-in collaboration and user input:* In order to better understand how users interact with our visualization, it might be useful to include a method for people to give feedback or to ask questions. This type of interactivity could help inform future implementations in terms of both design and content.

VII. CONCLUSION

The challenge in communicating climate change is enormous. The data is multifaceted, the audience is global and diverse, and the stakes are very high. Data visualization and information graphics can be useful tools in this communication effort if they are used effectively. More research into how different audiences perceive climate change visuals is urgently needed. Because there are so many different types of climate change data, domain scientists have some responsibility in communicating their findings. Training in data visualization techniques and theory could go a long way in addressing this gap. We hope that our visualization can be of future use and inspiration to climate scientists that want to communicate their findings.

ACKNOWLEDGMENT

We would like to thank Dargan Frierson for helping us brainstorm about the overall design and message, and for assisting in the selection of potential locations. We also appreciated the feedback and suggestions received as part of the end-of-term poster session.

REFERENCES

[1] National Aeronautics and Space Administration (NASA), "Images of Change," 2016. [Online]. Available: http://www.nasaimages.org/

[2] ——, "Climate Time Machine," 2016. [Online]. Available: http://climate.nasa.gov/interactives/climate-time-machine

[3] ——, "World of Change," 2016. [Online]. Available: http://earthobservatory.nasa.gov/Features/WorldOfChange/

[4] New York Times, "Copenhagen Climate Conference graphic," 2009. [Online]. Available: http://www.nytimes.com/interactive/2009/12/05/world/climate-graphic-background.html

[5] J. Hullman, "CSE 512 Lecture 20: Narrative Visualization," pp. 24–26, 2016. [Online]. Available: http://courses.cs.washington.edu/courses/cse512/16sp/lectures/CSE512-Narrative.pdf

[6] J. Bastida, "Glue software repository page," 2015. [Online]. Available: https://github.com/jorgebastida/glue

[7] S. R. Sheppard, "Landscape visualisation and climate change: the potential for influencing perceptions and behaviour," *Environmental Science & Policy*, vol. 8, no. 6, pp. 637–654, 2005.

[8] J. L. Lewis and S. R. J. Sheppard, "Culture and communication: Can landscape visualization improve forest management consultation with indigenous communities?" *Landscape and Urban Planning*, vol. 77, no. 3, pp. 291–313, 2006.

[9] J. Hansen, M. Sato, and R. Ruedy, "Perception of climate change," *Proceedings of the National Academy of Sciences*, vol. 109, no. 37, pp. E2415–E2423, sep 2012. [Online]. Available: http://www.pnas.org/cgi/doi/10.1073/pnas.1205276109

[10] J. B. Black and G. H. Bower, "Episodes as chunks in narrative memory," *Journal of Verbal Learning and Verbal Behavior*, vol. 18, no. 3, pp. 309–318, jun 1979. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0022537179901737

[11] N. Pennington and R. Hastie, "Explaining the evidence: Tests of the Story Model for juror decision making." *Journal of Personality and Social Psychology*, vol. 62, no. 2, pp. 189–206, 1992. [Online]. Available: http://doi.apa.org/getdoi.cfm?doi=10.1037/0022-3514.62.2.189