Designing Earth Mission Control: An Immersive Data Visualization Tool for Climate Communication and Decision-Making

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ABSTRACT

Satellite Earth Observation (EO) data is essential for tracking climate change trends and their impacts on ecosystems, however conventional methods of presenting EO data often fail to effectively communicate the intricate relationships between climate causes and effects in hyperlocal contexts. To address this challenge, this paper investigates the use of advanced data visualization techniques, focusing on the potential of Augmented Reality (AR) and Virtual Reality (VR) to enhance EO data understanding and climate storytelling. Leveraging the MIT Media Lab's Earth Mission Control (EMC) AR/VR platform, the paper details how immersive VR environments can simplify complex climate data narratives, and enhance the ability of decision-makers to analyze, interact with, and understand EO data. The paper presents the architecture of EMC's platform, including key design features such as: information dashboard carousel; map table; globe; and dynamic scenic VR environments. User feedback from diverse stakeholders reveals significant improvements in climate communication and decision-making, emphasizing the capability of leveraging immersive technologies to address global climate challenges.

Index Terms: Virtual reality, Earth and atmospheric sciences, decision support, visual simulation, climate storytelling.

1 INTRODUCTION

Satellite Earth Observation (EO) data is critical for monitoring climate change trends and its impact on Earth's ecosystems, tracking over 50% of the Essential Climate Variables (ECVs) [1]. These datasets help to evaluate historic patterns in sea level rise, air quality, global temperature, and other key climate-related metrics.

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As the need to address climate change becomes increasingly important, traditional methods of presenting data often fall short in conveying the complex interplay between climate causes and effects [2]. The use of advanced data visualization techniques can improve the ability to analyze, understand, interact with, and communicate EO data insights through visually accessible and engaging formats.

The future of EO data visualization is evolving, driven by advancements in Augmented Reality (AR) and Virtual Reality (VR) technologies by leading hardware manufacturers. The MIT Media Lab's Earth Mission Control (EMC) utilizes innovative immersive AR/VR technologies to advance EO data visualization. EMC's immersive interactive platform is designed to simplify complex climate data, allowing for enriched analysis, climate decision-making capabilities, and a deeper understanding of the impact and effectiveness of various climate projects and policies. This paper explores the systemic challenges with EO data usage and presents EMC's platform architecture, highlighting specific design features such as the information dashboard carousel, map table, globe, and dynamic scenic VR environments. These design features address the gap to further enhance climate communication and support climate decision-making.

2 SYSTEMIC CHALLENGES WITH EO DATA USAGE

Despite its immense potential, EO data faces several systemic challenges that prevent its wider adoption and utilization, particularly among stakeholders outside the EO sector. A series of consultations with 20 stakeholders from industry, government, and civil society reiterated an important insight: the real value of EO data lies in contextualizing and customizing insights for user needs.

Based on the consultations, one of the primary barriers identified is the widespread lack of awareness about the benefits and applications of EO data. Additionally, the difficulty of using EO data was another significant barrier highlighted by stakeholders. The complexity of EO data, along with the sophisticated tools required for data collection, aggregation, processing, and analysis, can often make it difficult for non-experts to use effectively. Furthermore, integrating EO data into decision-making processes remains limited, as many organizations are challenged in converting larger raw EO datasets into actionable climate insights. This emphasizes the need for a more user-friendly data platform and experiences that can inform policy, monitor and advance sustainable development, and engage broader audiences.

Addressing these challenges requires targeted efforts to enhance awareness and usability of EO data. One such way is the development of intuitive User Experience and User

Interface (UX/UI) tools and platforms that simplify EO data for diverse stakeholders. Bridging the gap between awareness and usability can help democratize the full potential of EO data to drive informed data-driven climate action across diverse sectors.

3 EMC Platform Architecture

For EO data visualizations to drive informed climate decision-making, efforts are needed to not only captivate user interest but also to foster a grasp of the complex data being presented. This involves translating intricate climate data into easily digestible insights that can influence individual and collective action towards climate resilience and adaptation.

Understanding Earth's climate system and making informed decisions about climate change impacts requires a stakeholder dialogue that transitions from global awareness to addressing hyperlocal impacts, which in turn influence the broader global system. EMC was designed to easily integrate a variety of data visualization formats that can support this global-to-local-to-global (GLG) paradigm [3].

The EMC platform was built using the Unity game engine (2022.3.10f1). It is primarily designed for the Meta Quest headset (2/3/Pro) and includes a PC companion app that allows others to view the headset experience [4]. Through OpenXR, development is possible across other platforms. Spatial audio delivers narration and background sound effects that are tied to the visual environment.

4 Virtual Display Modalities

One of the major limitations of scientific data visualization platforms for climate communication is their tendency to focus on a single or limited number of modalities of data visualization. For example, NOAA's Science on a Sphere, NASA's Hyperwall, and the Digital Map Table (digLT) [5]. This constrains the narrative and limits the ability to tell a cohesive climate story that can seamlessly reach across global to local scales.

EMC delivers on the GLG paradigm by combining high-definition data visualization dashboards, spherical projections that support global data, 3D map tables for hyperlocal exploration, and human-scale immersive experiences—all integrated in a scenic and highly interactive VR environment. Currently, EMC includes the following virtual components that allow users to seamlessly move from one data representation to another:

4.1 Dashboard Carousel

Data visualizations, maps, infographics, and other traditional media elements are integrated into individual dashboard panels that are scaled to human-size within the immersive environment (see Fig. 1a). Each panel includes a text headline and label to describe or contextualize the visual assets. Within each panel, the user has full agency to explore the content by scrolling though extended label copy (if needed), interact with video assets (play, pause, and scrub), and expand/zoom any media element to fill the entire panel for detailed viewing. Carousel controls are composed of previous/next arrows on either side of the selected dashboard panel that allow users to move laterally through the panels.

Figure 1: Screenshots of (a) Earth Mission Control introductory dashboards (left) and (b) dashboard control buttons (right).

4.2 Globe

Critical for delivering on the global component of the GLG framework, global maps are another data visualization modality that is critical for climate communication and exploration [6]. In EMC, global datasets, like equirectangular imagery and animations from NASA's Science Visualization Studio or NOAA's Science on a Sphere, are projected onto a virtual spherical display (see Fig. 2) that can be rotated by the user. The global data visualization actively displayed on the sphere aligns to the active dashboard panel, and changes as the user navigates through the dashboard carousel. Additionally, there are location-specific pins on the globe that allow the user to select and navigate (see Fig. 2b) to a defined place to explore the climate impacts in that location.

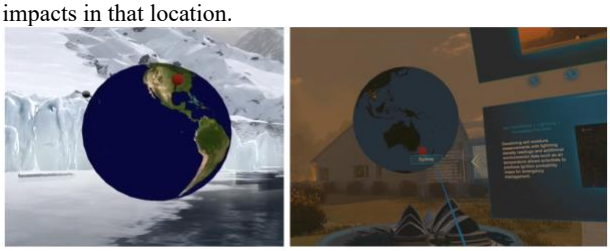
Figure 2: Screenshots of (a) EMC globe with location pins (left) and (b) location selection (right).

4.3 Map Table

Climate data is inherently geographical and multi-dimensional. In the EMC virtual environment, a map table is used to visualize geographic data, allowing users to gather around the virtual table for interactive, communal exploration and discussion. When a specific location pin is selected/activated on the EMC Globe (see Fig. 2b), the map table displays a 3D map of the selected geographic location. This provides users a clear visual approximation of the area so that climate impacts can be considered from different perspectives (see Fig. 3).


Figure 3: Screenshots of EMC Map Table featuring (a) Galveston, TX (left) and (b) New York City (right).

4.4 Dynamic Scenic Environment

While environments can be integral to creating a sense of presence and placemaking in VR, they can also deliver additional data visualization capacity by simulating climate-induced effects. EMC immerses users in a scene (see Fig. 4) where users experience an accelerated, but realistic, climate change impact that is relevant to a particular EMC narrative experience (i.e. sea level rise, wildfire, etc.). This provides users

an opportunity to build an emotional connection to climate impacts, as well as develop a sense of urgency to prepare for and address climate issues and impacts.

Figure 4: Screenshots of EMC Scenic for (a) Sea Level Rise vignette (left) and (b) Wildfires and Air Quality vignette (right).

5 The EMC Experience and Vignettes

Users initially launch into EMC with an "astronaut view" of the Earth, orbiting below them in space. Introductory dashboards (see Fig. 1a) welcome users to EMC and include general content about EO data and global climate change. The dashboard includes controls that remain present throughout the EMC experience and include buttons for rotating the globe, audio controls, and a back button to return to the introduction (see Fig. 1b).

Users navigate through EMC using handheld controllers. Only a single button, the trigger, is needed to make selections and interact with dashboard media and control buttons. Dynamic ray casting within the virtual environment provides additional visual feedback for users to easily make selections.

The EMC platform has been used to produce immersive experiences—or vignettes—that take users to environments that are actively experiencing the impacts of climate change. Users can currently select from two vignettes, Sea Level Rise (see Fig. 4a) or Wildfires (see Fig. 4b), by hovering their cursor over the globe and clicking to select a vignette. As vignettes continue to be produced and added to EMC, a more expansive selection menu will be added.

Upon selecting an EMC vignette, users enter a sweeping, immersive scenic environment that is visually undergoing a climate impact that is aligned to the theme of the vignette (e.g. Scenic environment of Antarctica when the Sea Level Rise vignette is selected). Introductory narration describes the urgency of the climate theme. The initial dashboard carousel includes general and global scale data and information about the theme.

As the user navigates through the dashboard carousel, the content on the globe changes to align with the topics on the dashboard panels. In addition to exploring the content in the dashboard carousel, users can rotate the globe. Upon the selection of a location pin on the globe, the map table will display a 3D map of the location, and the dashboard content will change to include hyper-local data and visuals that contextualize the climate impacts for the selected location. This allows users to transition from a global to localized examination of place-based climate impacts.

Users can exit the vignette and return to the introduction by selecting the "Back" button, which initiates a closing sequence, developed to advocate for a hopeful climate future for all.

6 User Testing Across Diverse Stakeholder Groups

Initial user testing has been conducted over the past 12 months and is expected to continue to provide valuable insights into the specific needs and preferences of different stakeholder groups. The focus will be on three key groups: (i) the general public and educators; (ii) industry; and (iii) policymakers.

6.1 General Pubic and Educators

For the general public and educators, the main goal is to raise awareness about climate issues and improve climate-related educational content. The aim of immersive, hyperlocal visuals is to empower the user group with the knowledge to advocate for climate action. This is done through contextual storytelling and hopeful narratives that translate complex climate data into accessible and engaging learning experience for non-EO experts.

6.2 Industry

For industry stakeholders, EMC allows for the use of EO data for developing climate strategies, monitoring Environmental, Social, and Governance (ESG) effectiveness, and ensuring compliance with climate and sustainability regulations. The ability of EO data to provide real-time monitoring and long-term trend analysis offers industry sectors the ability to monitor and verify significant environmental footprints such as tracking carbon emissions, assessing resource use, and evaluating the environmental impact of their operations. While there remain challenges such as the integration of EO data into existing corporate systems, initial feedback from the user group emphasizes the need for robust platforms that provide clear, actionable climate-insights to support sustainability reporting and compliance verification.

6.3 Policymakers

Initial testing with the policymakers underscores the critical role of EO data in forming data-driven climate policies and sustainability compliance monitoring. Further discussions on standardized data formats and interoperability between different data sources is needed, with policymakers emphasizing the importance of user-friendly platforms such as EMC that present complex EO data in a clear, concise manner.

7 Key Insights from User Groups

7.1 Emotional Response to Data

Initial user testing of EMC has revealed that using immersive simulation for climate-related events such as rising sea levels and advancing wildfires provoke a significant emotional response in users. Emotional responses to environmental changes highlight the human element of climate action, making it a powerful catalyst for engagement and support, as well as emphasizing the need for urgent action. This reinforces previous findings that immersive experiences elicit stronger emotional responses [7].

7.2 Hyperlocal Climate Data

A key design choice of EMC is the hyperlocal presentation of EO data. While numerous global climate models exist, the importance of transitioning from a global perspective to a hyperlocal focus through various modalities in EMC resonates with users. This approach ensures that climate insights are relevant and effective, addressing the specific challenges and opportunities present in different areas.

7.3 Democratization of EO Data

Advanced data visualization tools are expected to meet the strong call for standardized data formats and interoperability between different data sources. By layering EO data with advanced data visualization, EMC democratizes access to critical environmental information, providing powerful tools for

environmental and socioeconomic advocacy as well as strategic planning for climate resilience.

8 Conclusion

Early testing and development of the EMC platform has demonstrated its potential to integrate EO data with virtual visualization technologies to design experiences that address climate communication and engagement needs for a variety audiences—particularly policymakers, industry, and educators. Moving forward, iterative user testing, design improvements to the EMC platform, and the production of new, climate impact-focused vignettes will position EMC at the nexus of climate data visualization, immersive technologies, and climate science communication and decision-making.

Supplemental Materials

All supplemental materials are available online at https://www.media.mit.edu/publications/designing-earth-mission-control-an-immersive-data-visualization-tool-for-climate-communication-and-decision-making/. In particular, they include (1) all figure images, (2) videos capturing the EMC experience, and (3) a full version of this paper.

Figure Credits

Figures 1 thru 4 image credits: MIT Media Lab.

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