ASSOCIATIVE FORMS FOR ENCODING MULTIVARIATE CLIMATE DATA

Abstract

We are perpetually present in our environment, experiencing it with our senses. Scientific data describes the same environment quantitatively. Our goal is to use scientific and artistic methods to combine these environmental expressions and personal experience through the creation of glyphs visually abstracted from and associated with forms in nature in the representation of climate data. The use of these glyphs removes the distinctions between scientific data and sensory experience, to allow a fuller intuitive association between the two, creating an embodied experience and increasing awareness of the climate effects and changes all around us.

Authors Keywords

Glyphs; environmental visualization; visual association; art and design principles

Introduction

As humans, living organisms, perceivers, we are perpetually present in nature. We experience nature through sensory perception of everything that surrounds us: the breeze on our skin, the warmth of the sun, the scent of flowering plants, the tactile

variations in the surfaces of objects. We are constantly decoding and assimilating the clues our natural environment provides through sensory experiences and recoding them into our own experiential repertory.

Research of environmental and climatebased change through data measurement and analysis separates us from the sensory experience of our immediate environment. The current simulations and depictions of climate change data – Antarctic winds, temperatures, movement of air and water – are viewed as separate from our personal environments: distant, not part of us, not connected to us, and definitely not part of our sensory experience.

Our research objective is to facilitate the merging of our own sensory perception of the environment with the data representing that environment, through the development of a new visual vocabulary and language that speak both to the scientific and artistic representations of our environments, translating data into a sensory perception, making us perpetually present in the deeper, richer reality of our environment.

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Figure 1. A visualization containing glyphs associated with flora, fauna and mineral properties.

2 The Visual Vocabulary of Data Glyphs for Environmental Science

Current spatial visualizations of climate science often represent data with 3D glyphs. In practice, these forms are simple geometric primitives (e.g. spheres, cubes, pyramids, tubes, and arrows) that are generic by design. In one sense, this generic quality makes them appropriate for encoding whatever data is being rendered. However, in another sense, these generic geometries are limiting and problematic. They bear no relationship to the sensory aspects of our environmental experiences, and they fail to evoke any personal connection to the data. They look unnatural, even foreign or alien at times. We believe that this does not need to be the case and are investigating what might happen if the visual vocabulary used to depict environmental science took a radically different approach. Artists know that the environment around us offers alternatives to the commonly used abstract representations; embracing these rich alternatives may lead to visualizations that are more effective for interpreting the data, more engaging for stakeholder communities, and more evocative for conveying scientific findings.

Building upon prior explorations of color and affect in environmental data visualizations [1], this portfolio presents a new, complementary deep exploration of how the forms of 3D glyphs in environmental visualizations might contribute to intuitive associations, affect, and overall success in

many contexts of these spatial visualizations. Our thesis is that a new, handcrafted organic 3D glyph design, which draws specifically upon the forms, textures, metaphors, and narratives we observe in nature can not only accurately and efficiently depict data but also bridge the gap between our current experiences with environmental data and our sensory experience and memory of our environment. When viewing data portraved by the primitive geometric solids, viewers must continually refer to legends to decode representational meaning, increasing the cognitive load in decoding the data. In contrast, by enabling associations between the subject matter within the visualization and the representations of the data, there

is an opportunity to create an instant connection with known and experienced natural forms. These connections could make the visualizations more accurate and efficient, helping scientists to understand the interdependence of the variables and identify the drivers of regional environmental changes. The second contribution is that intuitive representations provide inroads to exploring the science further. Through practical application of the theories of Gibson [5] and others, we believe that expanding the visual vocabulary for data representation in this way can contribute both to the practical needs of the scientific community and the connective needs of society as a whole.

3 Background on Modern Global Climate Models

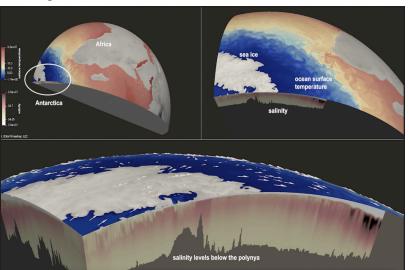


Figure 2. The US DOE Exascale Earth System Model (E3SM) [3] visualizations shown here depict global ocean temperature, sub-surface salinity, wind speed and direction, and sea ice coverage from a data set including dozens of other variables of interest to the scientists [3].

Scientists are creating increasingly large and complex 3D volumetric simulations that require interactive visualizations to explore and analyze. For example, the Antarctic Ice Shelf visualization shown in Figure 2 renders the E3SM global coupled climate model that incorporates the individual models of the planet's atmosphere, oceans, sea ice and land ice. Within each of the individual models are large numbers of variables such as the 125 variables in the biogeochemistry of the oceans.

4 Iterative Interdisciplinary Design of 3D Glyphs for Science

Our process cycled from artistic generation to user study evaluation and back again to artistic generation based on the findings of two user studies.

4.1 Iteration 1

The purpose of the first iteration within Study One was to get a broad idea of the characteristics of form that people associate with the five environmental categories we identified in the E3SM model: fauna, flora, and minerals are the fundamental categories within biogeochemistry data, and we added bodies of water and landforms. The tallies for flora and fauna in the data are rendered as animal (A) and vegetable (V).



Figure 3. Above is an example of flora source materials on the left and the abstract glyph forms on the right.

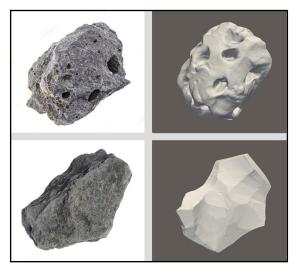


Figure 4 shows examples of mineral source materials on the left and the abstract glyph forms on the right.

Iteration 1: Artistic Generation

We created 100 glyphs drawn from visual sources related to these themes. To create the glyphs, we used the typical artistic process of abstracting forms from nature. From this original set we selected eight glyphs for each of the above categories, seeking sets that spanned levels of abstraction and visual distinction.

"To understand complex biogeochemical relationships we want to have balanced flora, fauna, and mineral glyphs normalized to show balanced relationships so that ecosystem shattering shifts can be quickly and readily identified in a clear way to be able to communicate with the public about the urgency of climate change's effects on the most vulnerable of life's unique niches."

Phillip Wolfram, Ph.D.



Figure 6 shows examples of animals as source materials and the abstract glyph forms on the right.

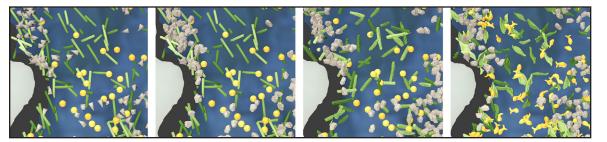


Figure 6 contains four comparative images spanning the use of traditional primitives to associative glyphs from this portfolio.

Iteration 1: Study

The artistic metaphor is only as good as the degree to which people agree on its interpretation. We evaluated the strength of association by conducting a user study, requesting participants to tag any forms they associated with the categories provided. The setup of the study is shown in Figure 7. The results of the study are shown in Figure 8. In this Figure the 40 glyphs designed for Study One are laid out such that each row contains forms designed for one of the five categories: animal (A), vegetable (V), mineral (M), bodies of water (W) and landforms (L). The tallies below the glyphs are the numbers of participants who tagged that glyph and in which category.



Figure 7. The study setup as presented to participants and one of the participants.

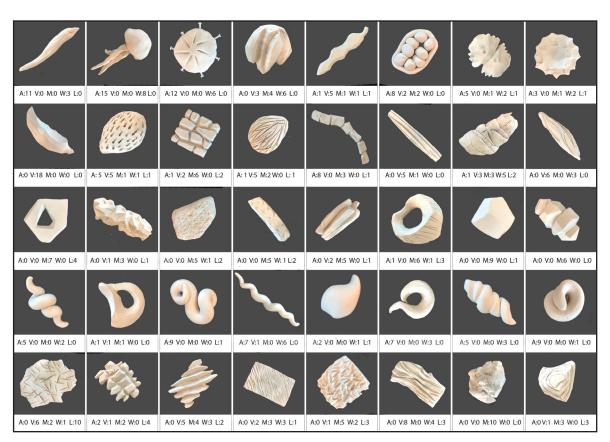


Figure 8. The 40 glyphs designed for Study One and the study results. A, V, M stands for animal, vegetable, mineral, our original categories.

Iteration 1: Results and Interpretation

The results from Study One told us we needed to go back to the drawing board. We had 22 participants. Of the 40 glyphs in Study One, only three showed a consistent association by being tagged by 50% or more of the participants. We also realized that the water and landform glyphs were rarely tagged and not consistently tagged with the category for which they were designed. For example, in the water category we had several wavy shapes. These glyphs were often tagged as animals, therefore in Study Two we incorporated this type of form into the animal set.

Despite the poor overall showing in this study, we examined the traits within the most highly associated glyphs to look for commonalities in the shapes and characteristics that would have predictive value.

Of all the glyphs in this study, those designed for the fauna category were most highly associated with the intended usage. Those in the top row all received between 11 and 15 tags; all glyphs were tagged as fauna by over half of the participants. They were the only glyphs in the study to receive over 50% of the votes in one category.

Designing glyphs referencing fauna proved to be more challenging than either the flora or minerals categories. Balancing the needed abstraction for broad application while maintaining categorical association required another iteration. By looking at common traits in the fauna glyphs from Study One we were able to successfully generate a set of forms that tested as being highly associated with fauna for Study Two.



Figure 9.
Glyphs from
Study One that
tested as the
mostly highly
associated with
the categories
of fauna, flora
and minerals,
are shown
on the left:
fauna, top;
flora, middle;
mineral, bottom.

Flora and minerals have simpler, more broadly associative forms available for source material: leaves, flowers, rocks, etc. These forms more directly translated into glyph that are broadly applicable.

4.2 Iteration 2

Iteration 2: Artistic Generation

First we narrowed our study to fauna, flora and minerals, as landforms and bodies of water are not often themselves represented by glyphs.

We then added a second set of criteria: a range in the level of abstraction of the glyph and its source, and a distribution spanning basic artistic design principles to insure visual distinction within each set.

Within each category we created glyphs that spanned from directly representative to the abstract. In Figure 10 the glyphs span a range between the highly associative, left, to abstract, right. The reasoning was that the more abstract the form, the more universally applicable it would be.

The third set of criteria involved creating visually distinct glyphs within each category. For this we tapped traditional artistic design theory, creating forms with contrasting levels of texture, complexity of shape profile, and complexity of form. See Figure 11. When populating a dense 3D visualization field with multiple variables, visually distinct glyphs are required for clear differentiation.

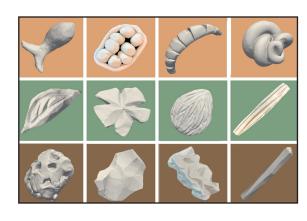


Figure 10. The rows indicate categories: fauna, flora, and mineral. The columns illustrate the range from representational to abstract, left to right.

Distilling the associated characteristics from Study One with the additional criteria, we proceeded to create three new sets representing flora, fauna, and minerals. These sets are shown in Figure 12 along with the vote tallies from the 32 participants in the study.



Figure 11. Shown here are the five types of visual contrast which we utilized to create differentiation between glyphs. They are, from left to right: profile complexity; curvilinear versus angular form; texture density; complexity of internal form; and aspect ratio.

TSAP'23, Pictorials and annotated portfolios

Figure 12. displays the glyphs designed for Study Two. Each row represents one category. The tally of votes per category appears below each glyph. Note: our study's shorthand derived from the game of 20 Questions: Animal, Vegetable, Mineral. With participants we defined the categories as fauna, flora and mineral, as early trials showed that "vegetable" narrowed the interpretation of flora.



Figure 12. The 30 glyphs developed for Study Two and the vote tallies for each glyph in each category.

Iteration 2: Study Two

The user study methodology from Study One was applied in Study Two. The 30 glyphs, 10 per category, were randomly distributed on the table as shown in Figure 7. Participants were instructed to tag any glyphs that they associated with one of the three categories with the color chip of that category, as seen in Figure 13. Figure 12 displays the results from the 32 participants of Study Two. The tallies below the glyphs indicate the number of votes each glyph received per category. For example, the glyph in the top row, left-side column, was tagged by 19 of the 32 participants as being associated with the fauna category, three participants associated it with flora and six with mineral. Four participants did not tag this glyph as belonging to any category.





Figure 13. The study set-up on the left and a birds-eye-view of a participant's tagged responses.

Iteration 2: Results and Interpretation

The set of glyphs, their categories and study tallies are displayed in Figure 12. The three rows contain the intended associative category - fauna, flora and mineral, top to bottom.

Figures 14, 15 and 16 show the results of fauna, flora and mineral glyphs respectively. The glyph background color indicates the category: orange for fauna, green for flora, and brown for minerals. Most of the glyphs were primarily associated with the category for which they were designed.

Glyphs that received a majority of votes from a different category are shown within their designed grouping but with the background color of the category with which they were most associated by the participants. The number next to each glyphs is the number of votes it received within the majority category.

For example, the first glyph in the fauna category, top left, was tagged by 28 of the 32 participates as associated with fauna. The top right glyph, designed as fauna as it contains a reference to eyes, was tagged by 20 of the 32 participants as related to flora. The specific tallies in the other categories are shown in Figure 12.

The glyphs with a gray background received an identification in any one category by fewer than 50% of the participants.

Those glyphs were determined to be only loosely associated and therefore not useful for intuitive categorization.

Study Two yielded much more encouraging results. In the fauna category, all but one of the glyphs were tagged by over 50% of the participants as referencing fauna. Fifty percent of the fauna glyphs were tagged as fauna by over 66% of the participants.

Figure 14.
Results from
Study Two of
glyphs designed
to be associated
with fauna.

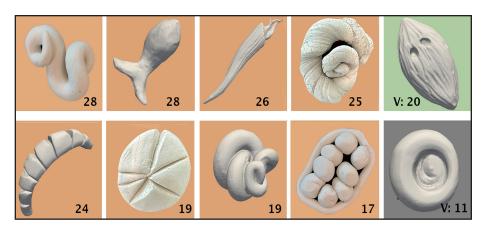
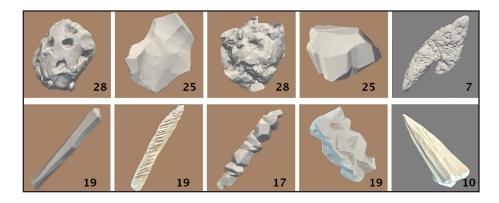




Figure 15 Results from Study Two of glyphs designed to be associated

Figure 16.
Results from
Study Two of
glyphs designed
to be associated



By applying these principles to actual data, we generated the following figures. Figures 17-19 are all the same visualization with different glyph selections. Figure 17 contains typical glyph forms. Figure 18 uses the crafted glyph forms without intentional associative application. Figure 19 applies glyphs specifically designed to be representative of fauna, flora and minerals.

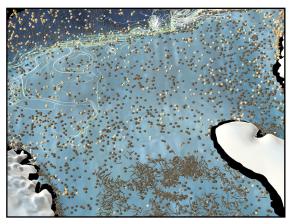


Figure 17. Visualization rendered with common geometric glyph primitives.

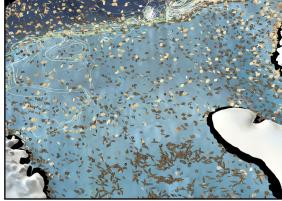


Figure 18. Visualization using hand-crafted glyphs not linked to the subject matter of the variable.

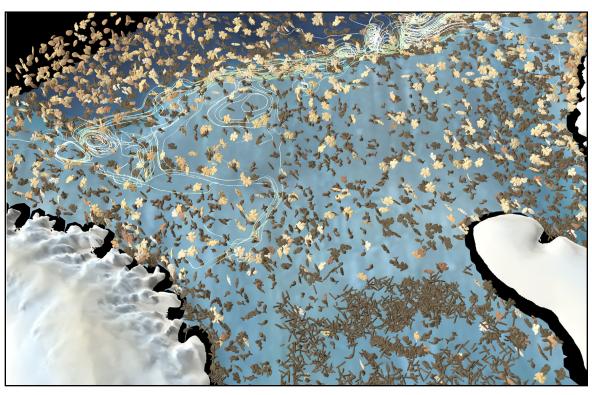
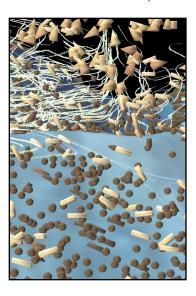


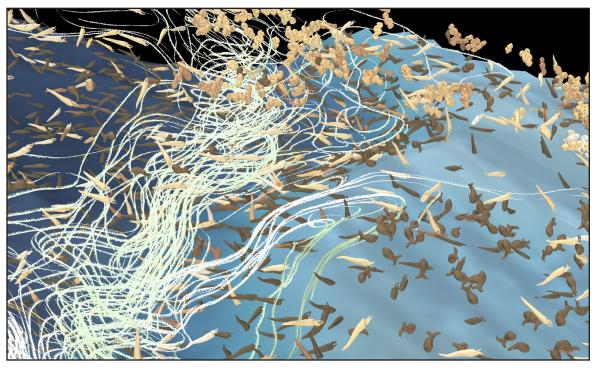
Figure 19. Visualization using hand-crafted glyphs topically associated with the variables from the fauna, flora and mineral categories.





Figures 20 and 21 are details from the above visualization. Figure 20 encodes the variables with standard geometric forms. Figure 21 applies the hand-made glyphs that are associated with the category of the variable.

VISAP'23, Pictorials and annotated portfolios



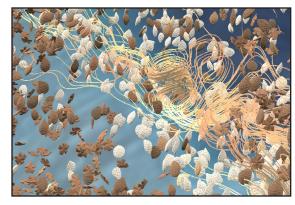


Figure 23 contains glyphs only from the flora category.

Figure 22 contains only glyphs from the fauna category, illustrating the ability to encode multiple variables within one category with visually distinct but still associative properties.

Both fauna and mineral categories contained glyphs highly associated with their intended categories, having been tagged by 66% or more of the participants. None of the glyphs designed to be associated with flora were tagged by over 66% of the participants, however all but one were selected by over half of the participants.

In the mineral category, the results showed similarly high correlation to that found in the fauna category. The only exceptions were two glyphs designed to indicate direction.

The primary contribution of this work is the methodology of multiple iterations involving both traditional design methods and targeted user studies. The secondary contribution is the actual set of glyphs. The .obj files for the glyphs are free to download from https://sculptingvis.tacc.utexas.edu/library/[2].



Figure 24 This detail from the visualization illustrates the visual distinction available within a single associative category, in this case flora..

"Visual representation is a language, one that must encapsulate the clarity of the essence of the object discussed, but via intrinsic representation balanced by brevity— making the use of appropriate glyphs essential."

Phillip Wolfram, Ph.D.

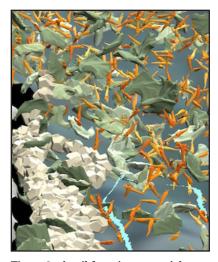


Figure 25 detail from image on right.

5 Creating 3D Visualizations Using Associative Glyph Sets

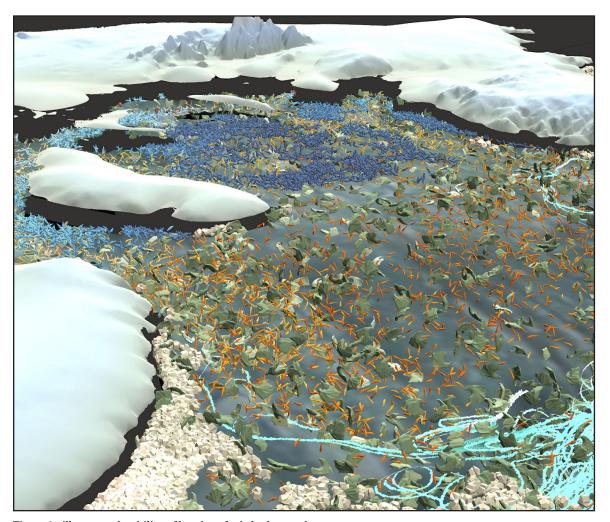


Figure 25 illustrates the ability of hand-crafted glyphs to enhance visualization by moving beyond the use of glyph primitives.

In this section we explore the findings on E3SM data from beneath the Filchner-Ronne Ice Shelf. Future work includes testing the effectiveness of association and visual distinction when the glyphs are applied to data.

In order to apply the crafted glyphs we used a system developed specifically for uploading artist-created visualization encoding. Artifact-Based Rendering [2] contains algorithms that sample volumetric data and convert it to point data, where the points are distributed by their density levels and locations within the original volumetric data. This capability drives the need for a wider glyph vocabulary as scientists are now able to co-locate much larger numbers of variables. The system enables scientists to track the movements of several variables within one visualization, watching their interaction over time in order to investigate causality.

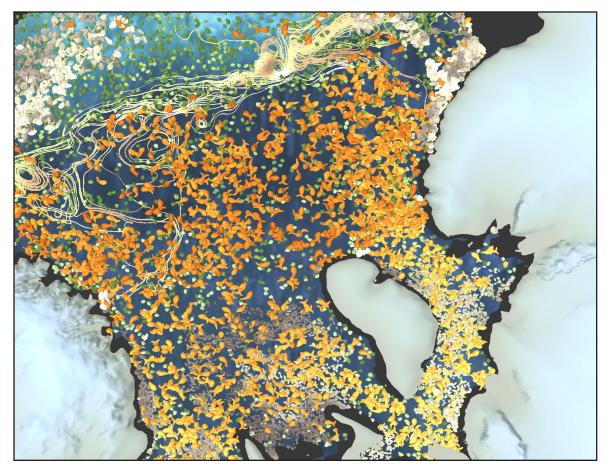
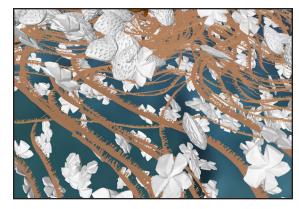


Figure 26 illustrates the distribution and the effects of color across the Filchner Ronne Ice Shelf waters.

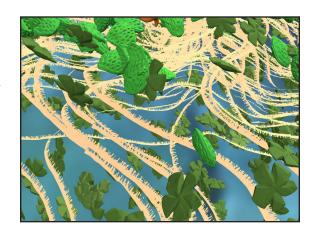
For any given location scientists often encode both categorical data and a scalar variable such as temperature. Our system enables users to apply form to encode the categorical variable, leaving color available for encoding the scalar variable.

It is worth noting that color maps that move through a value range are impacted by the internal lighting of the visualization. Isoluminant colormaps address this issue but are inherently limited in discriminatory power [4]. Thus, with the variety of forms carrying the categorical encoding, color can be used for scalar information.

Color effectively categorizes the variables by hue contrast as well as color association. However, in data sets containing several variables within one category, having multiple forms to choose from provides the variety needed for visually distinguishable encoding sets.



Figures 27 above and 28 below vary only by color. The white glyphs in the top image enable comparison of the impact of form and texture. Below the flora are colored by two different green colormaps. The variety of form provides the visual contrast.



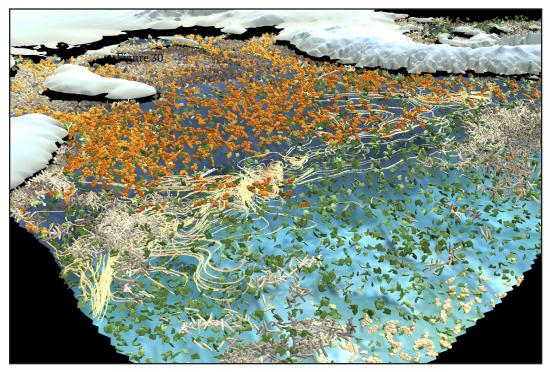
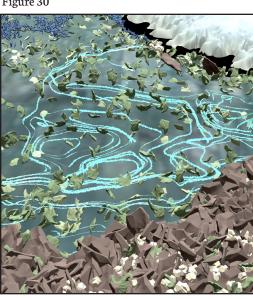


Figure 29

Figure 30

Prior work [1] explored the affect of shape and its impact on visualization of scientific data. Figures 29 to 31 combine the affective properties of form with the associative categories of form to begin to provide the intuitive, scientifically accurate and visually engaging imagery able to capture and hold attention across audiences. Creating a vocabulary that incorporates the potential to convey the science in a language that speaks of our environment and to our humanity is the long-term goal. This section of the portfolio presents progress in that direction, showing the potential of this approach while also illustrating the scope of work ahead.



Figures 29 to 31 demonstrate the value added by employing an artistic vocabulary to data visualization. The objective here is to produce artistic images able to draw audiences via curiosity, the trait that underlies the human drive

Figure 31



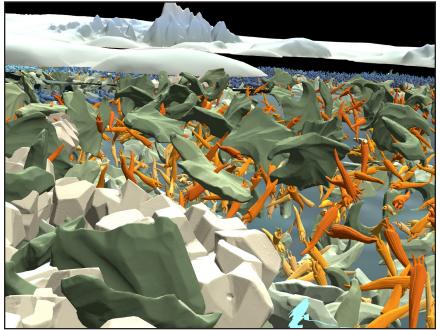
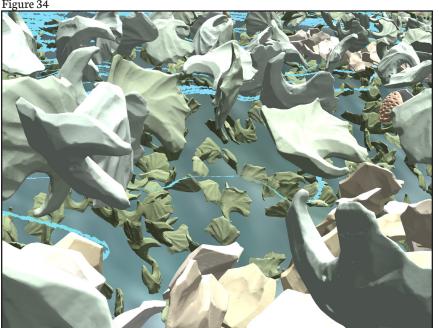


Figure 32





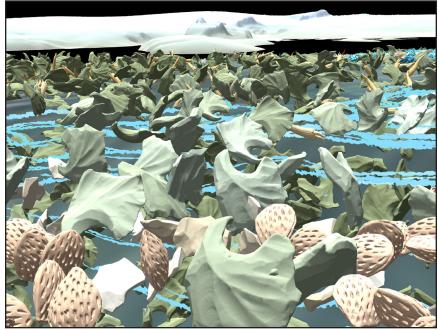
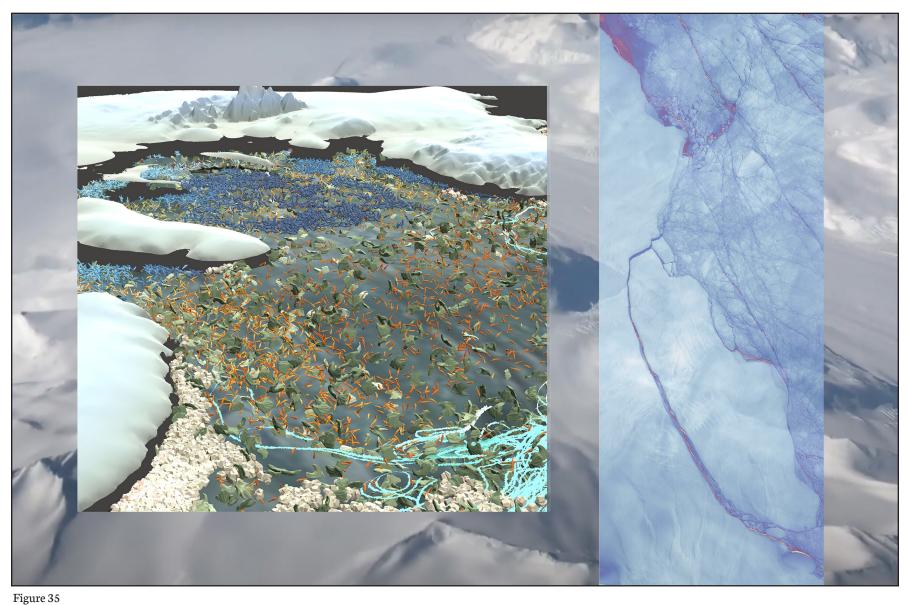


Figure 33

6 Context and Metaphor

The glyph development presented here is part of a broader effort to expand the visual language across scientific visualization. However, the more pressing need identified by climate scientists is the need to engage the public and promote discussion about our changing climate. Figures 32, 33, and 34 demonstrate the ability of form to convey emotion. These images portray the chaos and movement perpetually churning within the ocean, illustrating the riches available to science communication if we use a fuller vocabulary tapping the artistic disciplines. In Figures 35 and 36 the collages include context for the science represented, metaphors speaking to the predicted outcomes from the research and tapping the wonder inherent within the natural world, all designed to facilitate discussion and thought about the challenges ahead.



Art is often described as a conduit for societies to engage with the most challenging threats of the day. Artists are described as context makers, providing context by providing images that bridge the topic and our human experience. Figures 35 and 36 are collages that provide context for the science content. Here in Figure 35 the surrounding images speak of the fragility of our polar environments.

Figure 36 focuses more on the context for the data than on the data itself. Here is a reference to the data collection method: a remotely controlled submersible that travels beneath the ice shelves to collect data on temperature, the speed and direction of current, salinity levels and more, all aimed at assisting us in understanding the melt rate of these critical Antarctic features that have the potential to impact coastal communities across the globe threatened by sea level rise.

Submersible photo: Rob Robbins, USAP

Earlier iterations of the climate visualizations employing handcrafted associative glyph forms have been presented in planetariums as shown in Figure 37, theaters, conferences and galleries. Future work includes expanding into narrative presentations designed for broad audiences and wider distribution, the need for which is well documented [6].

Conclusion

Perpetual presence - nature is everywhere. Within natural systems there is invisible ongoing activity, webs of interaction and impacts, most not visible to the human eye. Yet the invisible perpetual processes are driving changes on our planet that will affect not only us all but all of nature on the planet.

The goal of this work is to link the study and representations of earth's physical and biological processes - often occurring at remote locations, and driven by factors not visible to the human eye - to our experience of the environment in which we live.

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All of the visualizations shown here use the Energy Exascale Earth System Model project, E3SM, sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research.

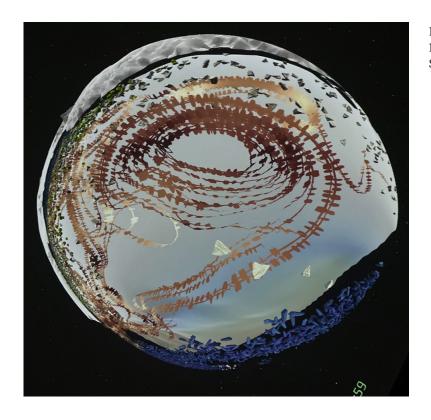


Figure 37 Planetarium presentation of Southern Ocean currents.

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