AFFECTIVE PALETTES FOR SCIENTIFIC VISUALIZATION: GROUNDING ENVIRONMENTAL DATA IN THE NATURAL WORLD

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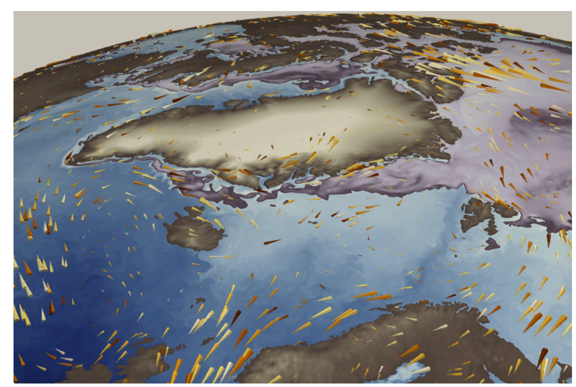
Abstract
As computing capacity increases and data grows in both size and complexity, we are capable of understanding our surroundings with increasing nuance. Visualizing this often-multivariate environmental data presents complex visual scenes to be navigated, parsed, analyzed, and communicated. We draw from both the natural world and artistic color theory to present 1) a new color system, designed to establish an affective connection between big environmental data and its original source material, 2) a tool for extracting these workable palettes from natural imagery, and 3) a selection of pre-made linear colormaps and discrete color sets drawn from natural environments.

Authors Keywords
Color; Scientific Visualization; Environment; Nature; Affect; Art

Introduction
"Between the senses and reason lies perception. At home or afield, that is where amazement resides, shunning explanation… Intoxication with color, sometimes subliminal, often fierce, may express itself as a profound attachment to landscape. It has been rightly said: Color is the first principle of Place." —Ellen Meloy

While the COVID-19 pandemic has drastically changed societal and industrial norms, it has also amplified our existing need for connection with the natural world—a need which has become subdued for many in an age of screens and big data. The widespread resurgence and recognition of this need—and, indeed, evolved sense of comfort—for time spent in nature provides an opportunity to reexamine our approach to technology-based environmental data visualization and display. As Meloy wrote in her pulitzer-nominated Anthropology of Turquoise, color is integral not only to our cognitive understanding, but also to our emotional and spiritual connection with the environment. Our visual systems are constructed for parsing extremely dense informational landscapes to make survival decisions such as escaping danger, finding food, or selecting a mate [10, 12, 13]. But these same evolved traits also enable us to perceive the nuanced beauty of a lush forest, a sunset, a coral reef, a mountain range. The combination of our color-associated predatory instincts and affective response provides us with a geographical sense of place—a borderless concept defined by our relationship to an environment [4, 7]. In order to draw more fully on color's power to make and define place in visualization, we present a new type of color system that expands the traditional palette of scientific visualization, a tool for extracting these palettes from natural imagery, and a selection of pre-made palettes available for download on sciviscolor.org. Historically, scientific visualization has engaged only a very narrow range of highly-saturated hues [11]. By mimicking palettes anthropologically and evolutionarily intrinsic to our understanding of the world, we can visually re-establish the connection between big environmental data and its source, allowing us to quickly adopt new and semantically appropriate encoding systems for improved analysis and communication.



VISAP'19, Pictorials and annotated portfolios.

Breadth and Nuance in Natural Color Palettes

When we step outside, we are confronted with a visual scene replete with greens and blues and full of life's infinite complexity. Parsing this complexity draws on the evolved abilities of our visual systems: top-down and bottom-up attentional processing, strategic grouping, exploration, value assignment and hierarchical determinants [12, 15, 16]. As many of these tasks rely predominantly on color, we are able to perceive minute differences in natural hues, especially green [13]. As demonstrated in this composite image, pine needles, prairie grass, mesquite bushes, cacti, moss, and more each carry distinct shades of green which vary drastically, even within the same plant. Primary hues are much less common in nature than secondary and tertiary hues, and are employed sparingly by flora and fauna alike to contrast with a largely analogous backdrop and to signal danger, spread seeds, or attract a mate. (See: red berries contrasting with dark green leaves, upper right).

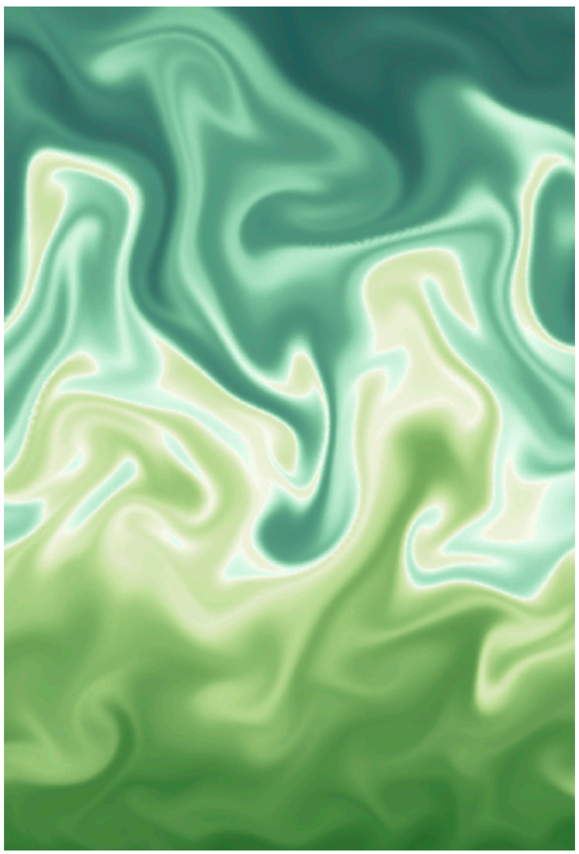
Decoding a scientific visualization, or any other kind of information-dense visual scene, draws on these same color-based evolved capabilities to accomplish these same tasks. By appropriating the earth's natural color palette, we can strategically leverage our innate sense-making operations to compose richer, more effective, and less cacophonous visualizations—a fruitful avenue which remains untapped thus far in this community.

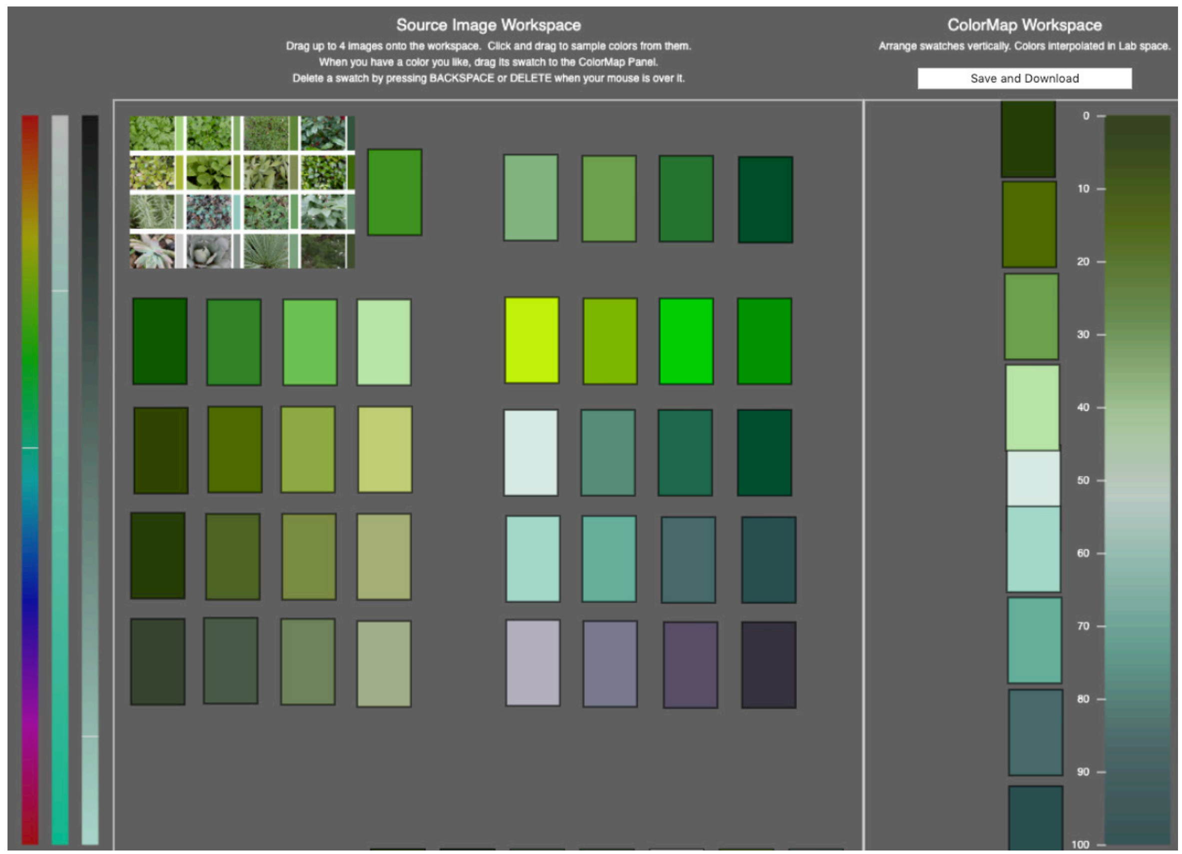
Despite the availability of dynamic natural palettes, pulling the right hues to construct color ramps for scientific visualization can be difficult, particularly for scientists with limited time. To address this need, we created ColorLoom.

The ColorLoom Interface

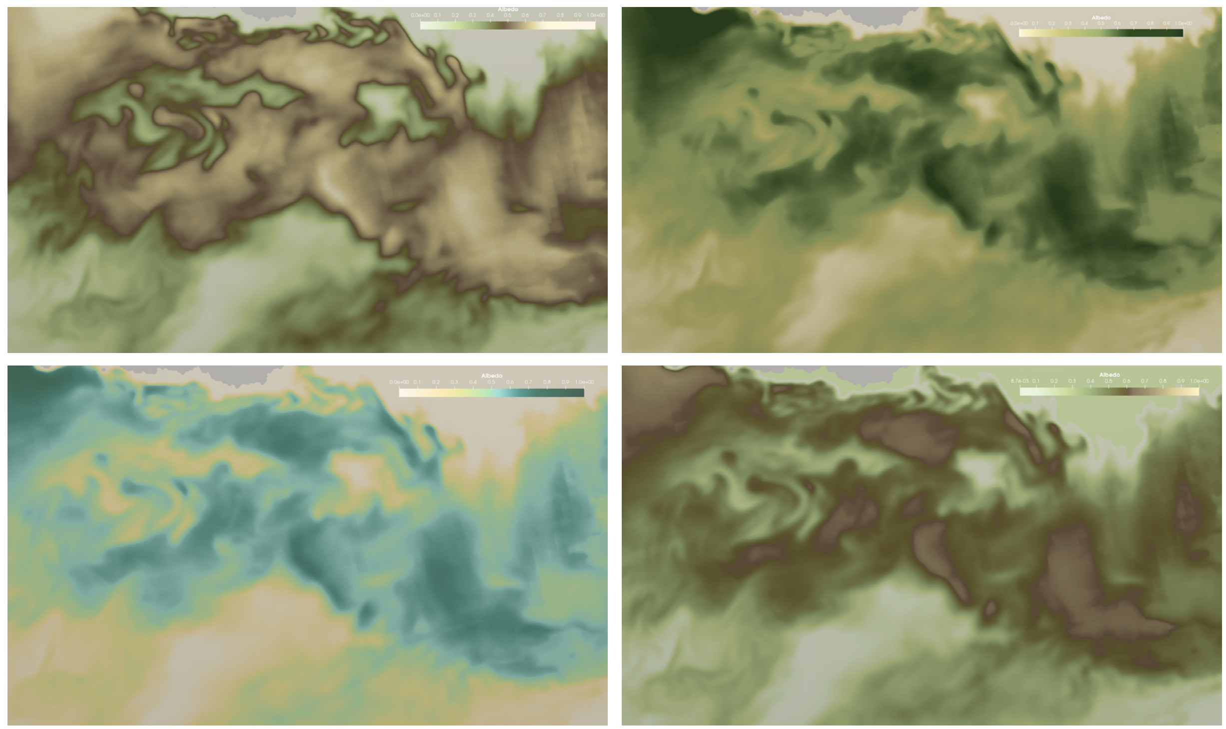
To facilitate natural color palette creation, the Sculpting Vis Collaborative developed ColorLoom. The Sculpting Vis Collaborative is a cross-disciplinary group spanning artists, computer scientists, climate researchers, visualization professionals, writers, and more. The collaborative encompases an ethos along with a set of technical tools, interfaces, and resources to advance the integration of fine arts, design, and scientific data visualization [9].

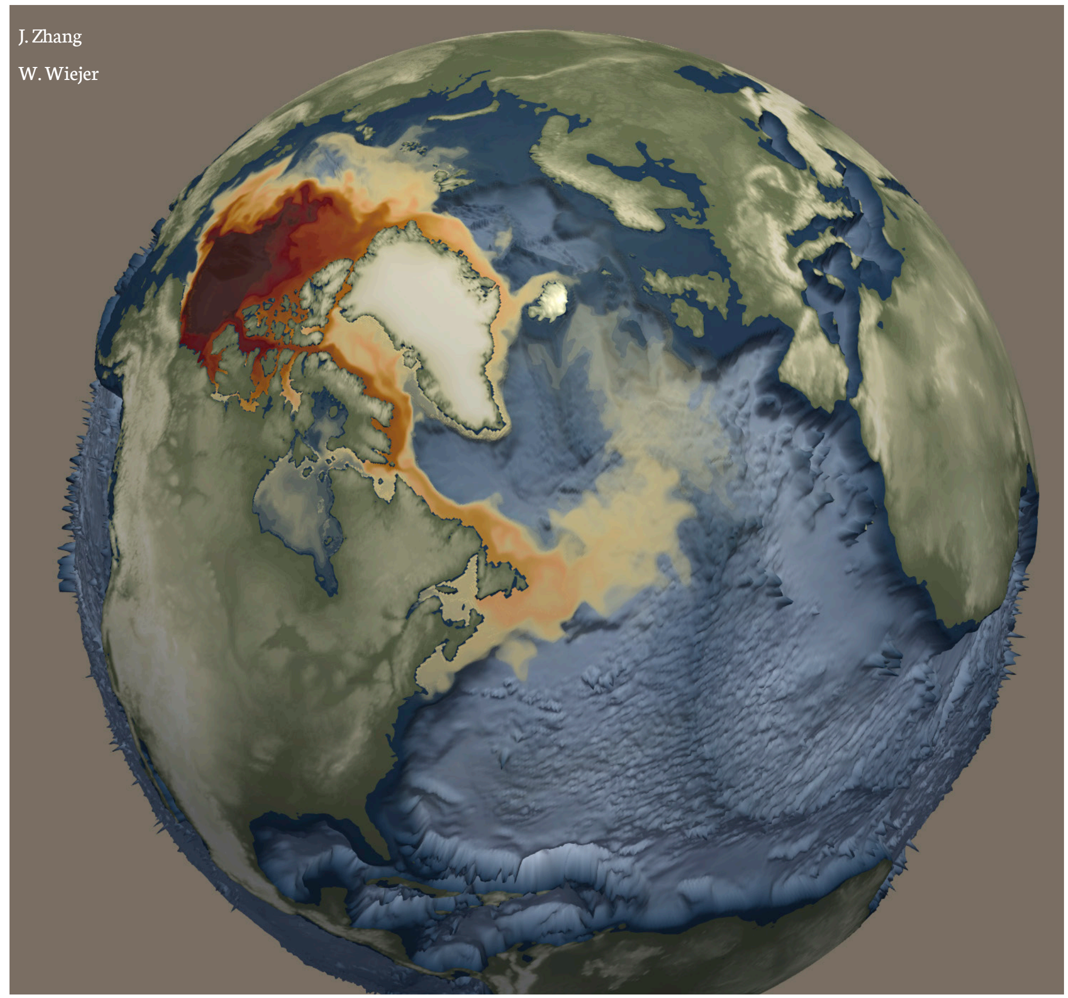
The rightmost image below is an example of the ColorLoom interface with the collection of plant imagery shown previously. When users drag and drop photos into the central workspace, ColorLoom automatically extracts a palette from each photo and provides a set of boxes with varied hues. Users can select a hue box and adjust its hue, saturation, and value in the leftmost panel. To create a continuous colormap, individual hue boxes can be freely dragged into the rightmost workspace. ColorLoom interpolates between selected hues at the points which they are placed along the vertical colormap. Images and colors can be added and ordered along the colormap and adjusted until a desired colormap is completed. The map can then be exported for use in external visualization programs. The leftmost image below shows the newly-created divergent colormap applied to MPAS-Ocean eddy data. The ColorLoom app is freely available online at http://sculptingvis.tacc.utexas.edu/applets/load_applet/color-loom/





ColorLoom was inspired by Samsel's artistic practice. In both the arts and the sciences, creation is often preceded by experimentation. While working out an approach to a color system for a visualization, Samsel often assembles small collages of paintings, photos, and drawings (left). These collages create a color environment that allows Samsel to better understand how different hue, value, and saturation combinations will work together within a complex multivariate data environment. Keefe was inspired to develop a tool that applies this process to colormap generation. By extracting color directly from these paintings and collages, and using those hues to build colormaps, ColorLoom tightly integrates artistic practice with scientific visualization.





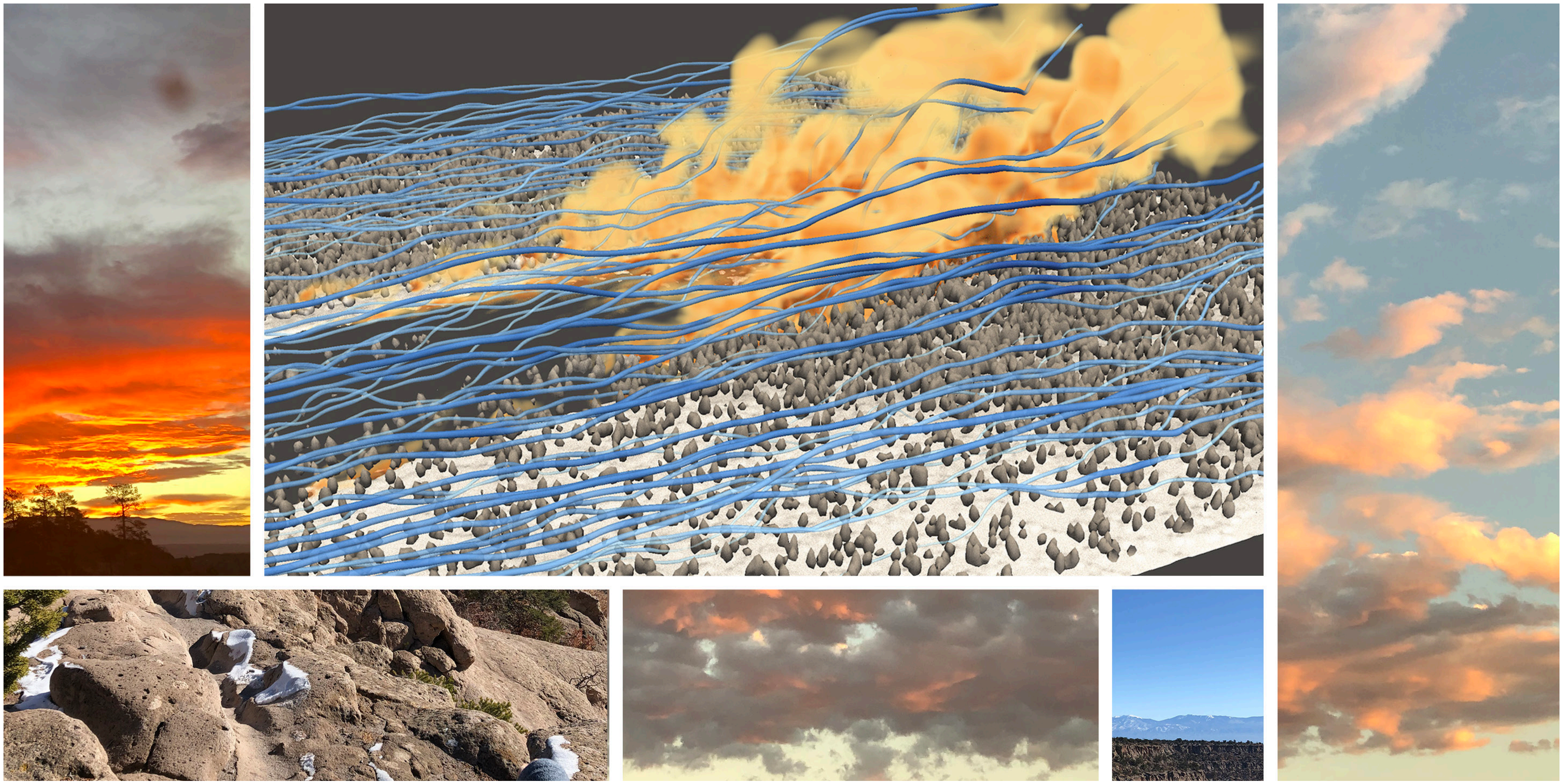
Water in the Beaufort Gyre, the Arctic's largest freshwater reservoir, has increased in freshness by 40% in the last two decades partially as a result of sea ice melt [6]. Scientists are concerned that a rapid release of freshwater could significantly impact large-scale ocean circulation. Researchers modeled an Arctic freshwater release scenario using passive tracers and dye tracking to understand how a set amount of freshwater might flow into the subpolar Atlantic.

Here, we draw from imagery from Arctic fieldwork (top left) to construct a natural palette that spans the color wheel, yet avoids confounding contrast issues through muted earth tones. Anchored in color theory, this approach to choosing appropriate hue ranges for constructing a set of linear color ramps and applying them to regions of semantic alignment allows us to direct attention to data ranges of greatest significance—in this case, freshwater diffusion over time.

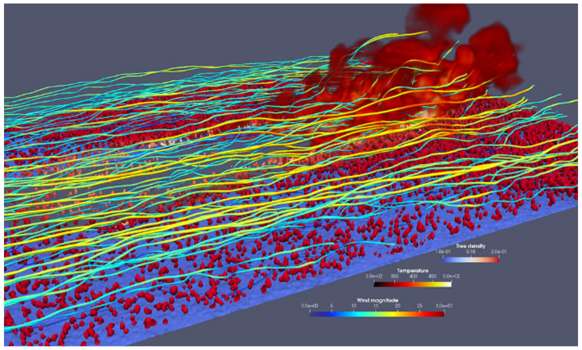
New Mexico Wildfire

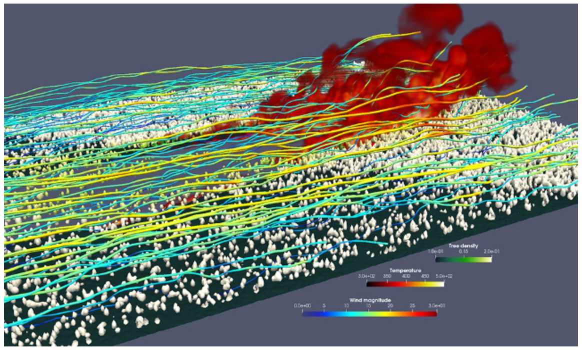
Fire scientists at Los Alamos National Laboratory (LANL) and their partners have worked for years to develop models that can help firefighters understand conditions and likely outcomes in real time. These models are extremely complex, as they must amalgamate statistical, empirical, and physical information from numerous sources [14]. Such complex models present equally complex visualization challenges. Here, we encode a rendering of FIRETEC simulation data with three variables: wind magnitude, temperature, and tree (fuel) density. These three variables are interdependent and must be individually distinguishable throughout each timestep in order to track their changes and interactions as the simulated conditions develop. To choose an appropriate palette, we need not look further than the New Mexico landscape.

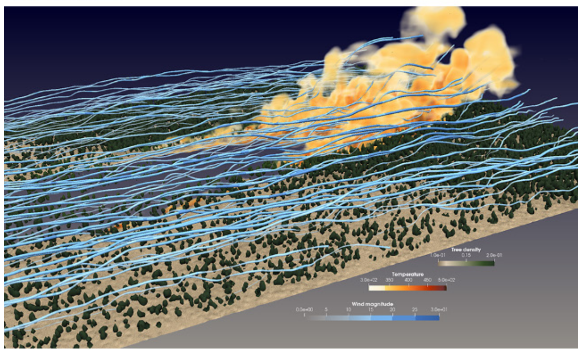
Each image below is a different element of the New Mexico environment. Hues pulled from these environments are shown in the color grid on the right, and the linear color ramps next to each image demonstrate how these hues can be used to generate diverse palettes for visualization.

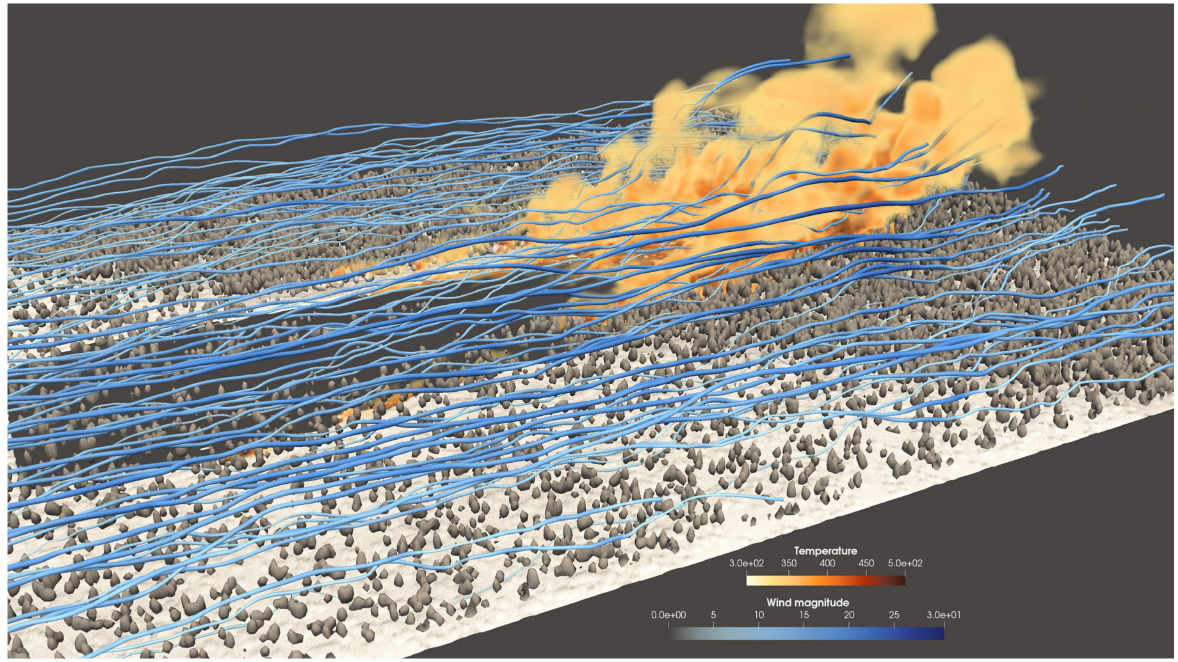


The color challenges of this dataset are more involved than those of the Arctic freshwater: multiple linear time-varying data points must reside in the same space with sufficient intra- and inter-variate contrast. To achieve this contrast, we needed multiple images of the New Mexico landscape that together provided a range of value, saturation, and both cool- and warm-leaning hues. The collection of contributing images is shown above, with the final visualization result in the center.



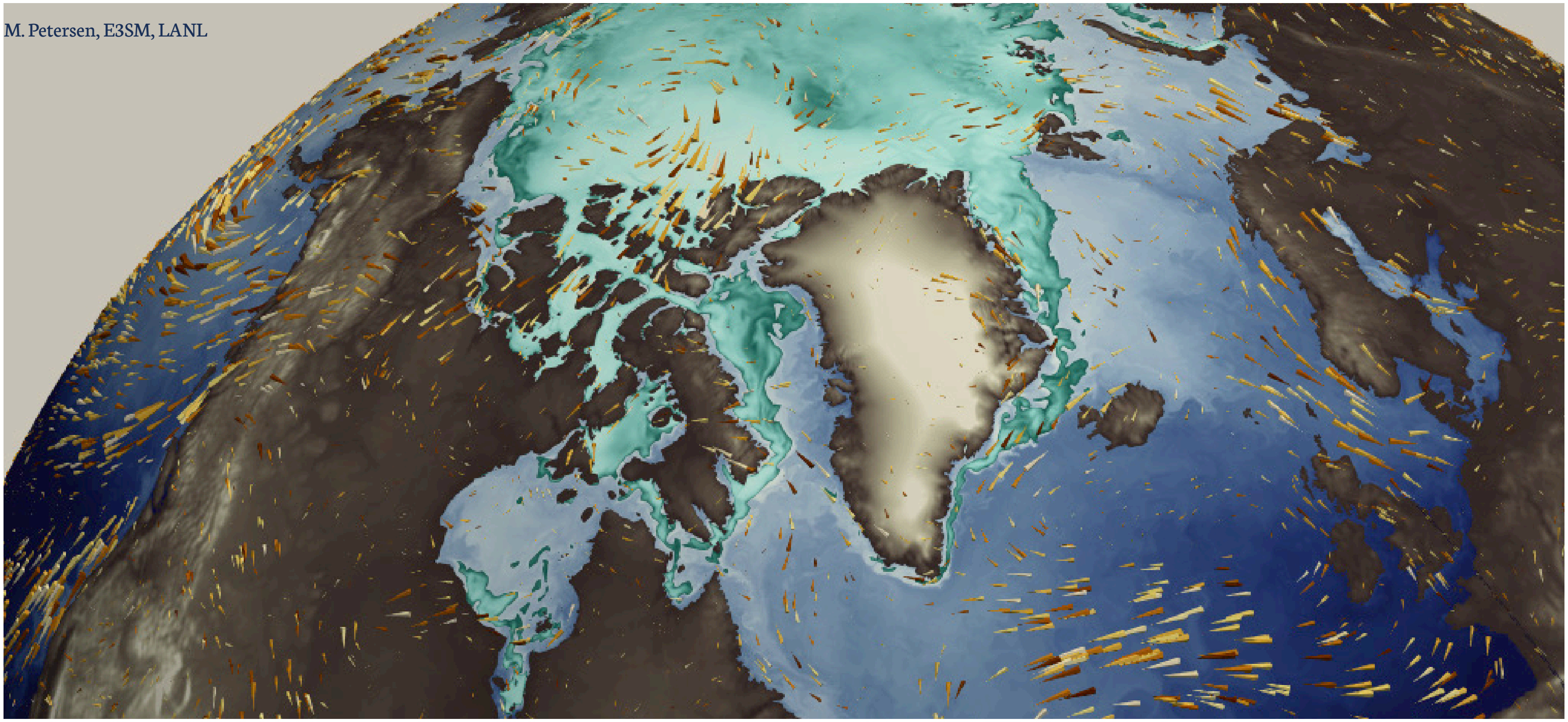






The figures here show a comparative set of visualizations illustrating the iterative design process. The top two images in the leftmost column show combinations of common default colormaps that come with most visualization programs. The number of variables competing for attention in the same space, combined with the limited hues available in these colormaps, leave these visualizations without sufficient contrast. As a result, they are visually convoluted and difficult to parse.

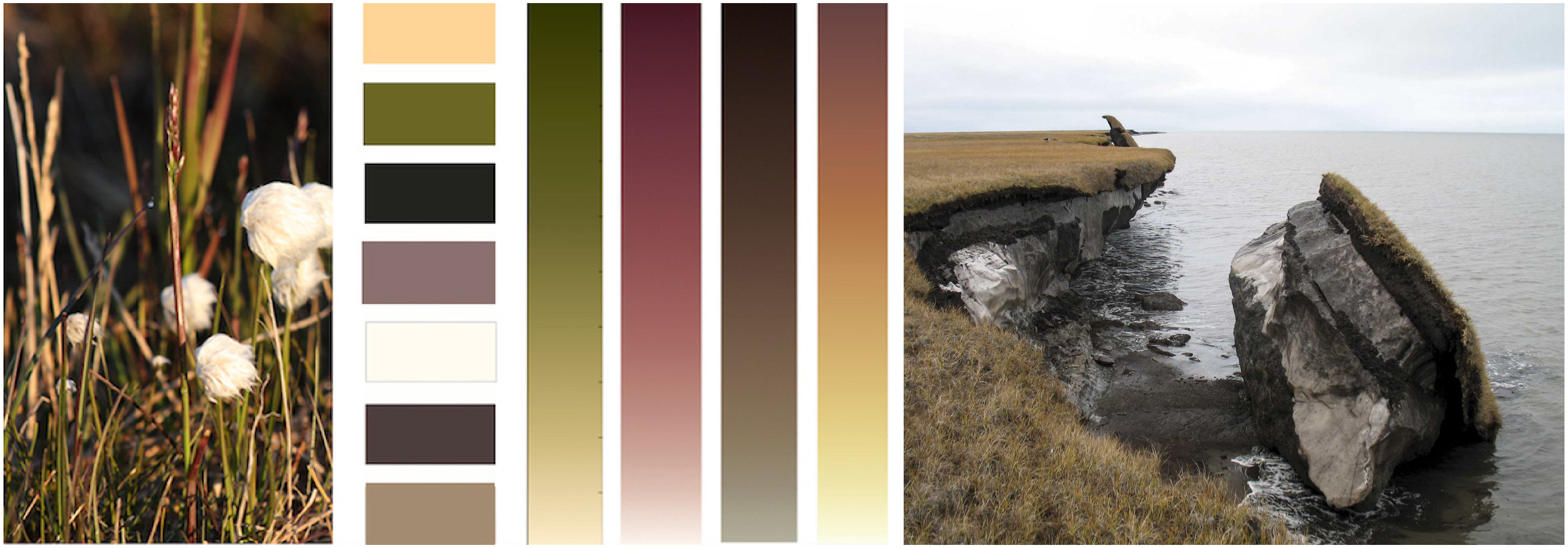
The bottom image in the leftmost column shows an iterative attempt with the same data and colormaps drawn from the New Mexico natural color palette. In this visualization, the temperature is encoded with a linear ramp pulled from the sunset image that cycles from dark purple to light yellow, moving through reds and oranges in between. This ensures that the temperature is both immediately recognizable as such and stands out from the surrounding data. We applied light blue, medium-saturated hues drawn from the New Mexico sky to the wind velocity streamlines in discrete steps, which provide some contrast with the dark green trees and orange temperature. The lack of sufficient value contrast between the trees and the streamlines in addition to the difficulty in identifying the streamlines' discrete steps led us to the final visualization (rightmost image above). By graying the trees with hues pulled from the rock image above, and applying a more saturated, linear blue colormap to the streamlines, the variability in wind velocity is more clearly visible as the value and saturation contrast with the underlying tree layer is greater.



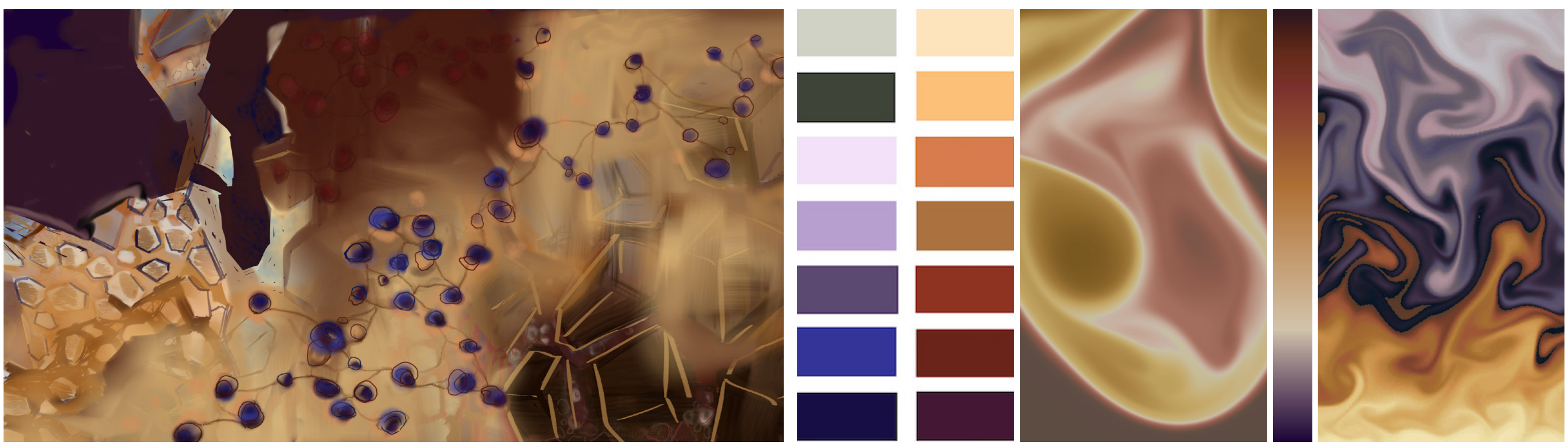
Fine Art and Expanded Natural Palettes

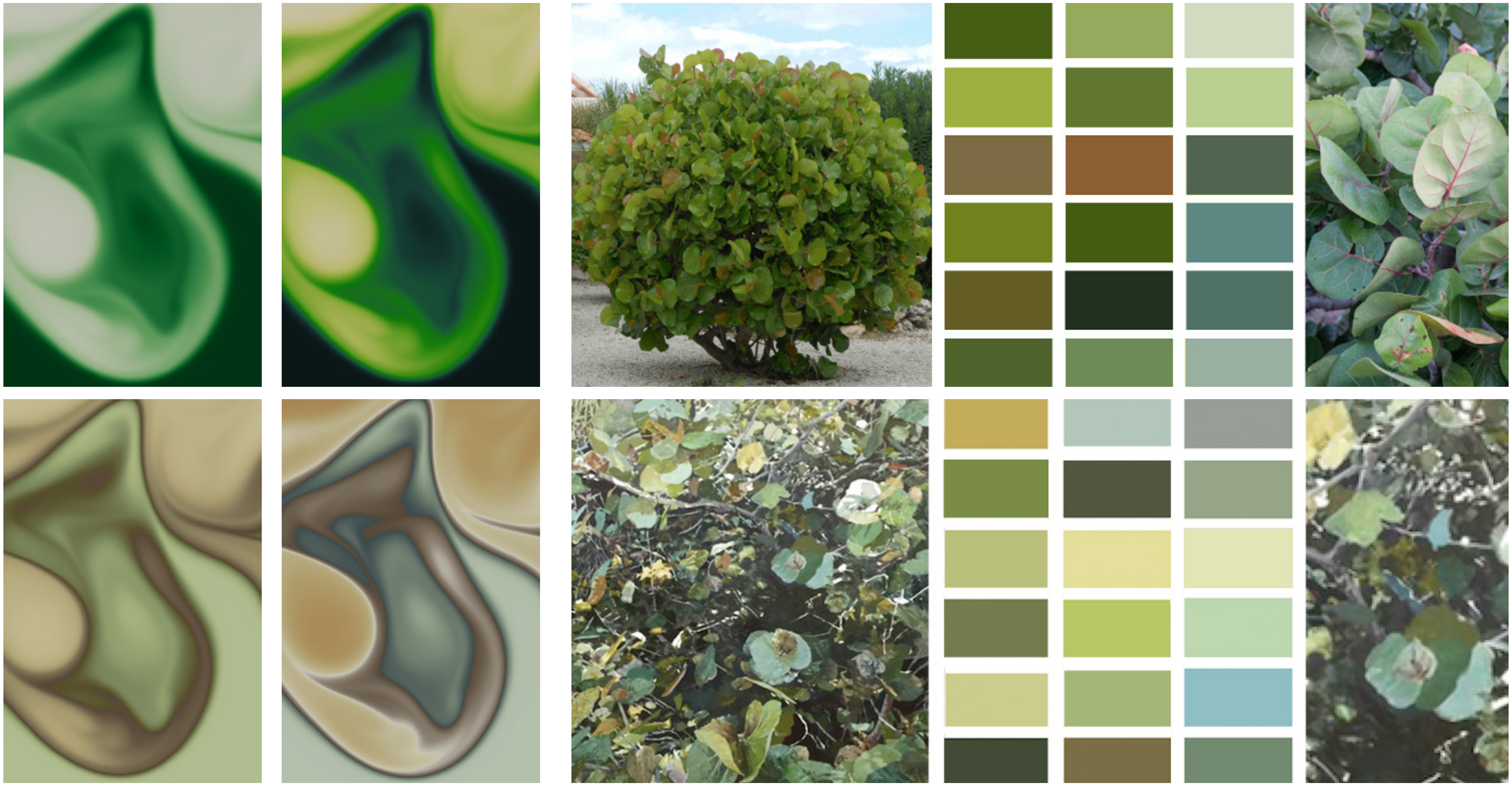
Historically, fine art has often acted as a boundary object between environment and affect—a place-making device, orienting the viewer within an emotional or physical, cultural or political space. Borrowing color from the natural world to serve their compositions and to operationalize affect, artists have been trained for centuries to selectively expand natural palettes on the basis of artistic color theory. The process of painting is the process of deep observation of shapes, spatial relationships, textures, and colors; creating a piece that resembles natural phenomena, yet is confined to the bounds and materiality of a canvas or board, requires an artist to augment contrast, saturation, and value while maintaining the relatively narrow hue bounds of terrestrial color. Integrating the arts is therefore prudent for generating effective place-making palettes for scientific visualization. When applied strategically, color theory-based natural palettes can provide nuanced differentiation between data points and intuitive, affective visual framing for communication.

The image above shows data from E3SM Ocean, Atmosphere, and Sea Ice models of sea surface temperature, ice coverage, and wind direction in the Arctic. Each element is encoded with colormaps drawn from Arctic imagery (as seen on page 5) to create a harmonious, unified data visualization, despite the complexity of multiple variables overlaid in the same space.



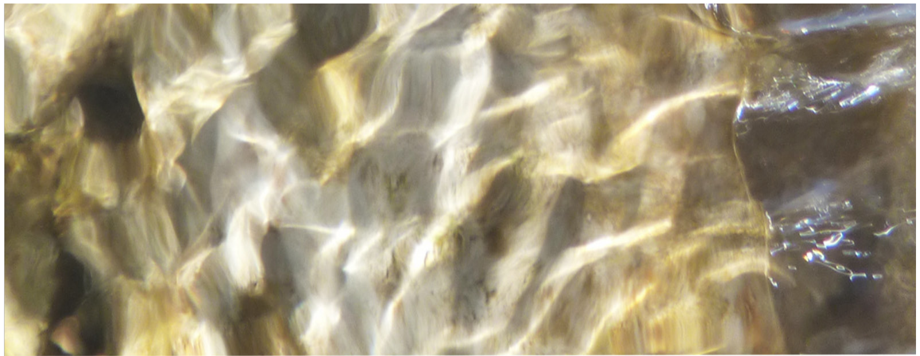
The images on this page demonstrate this concept in practice. Top center: this image shows hues extracted from an image of arctic grasses, flowers, and ice wedges (top left). Bottom left: an illustration by Samsel, using this palette as a base and expanding its hue and value ranges along with a collection of these expanded hues. The bottom right image shows two different examples of these hues applied to baroclinic data (left) and MPAS-Ocean eddy data (right).

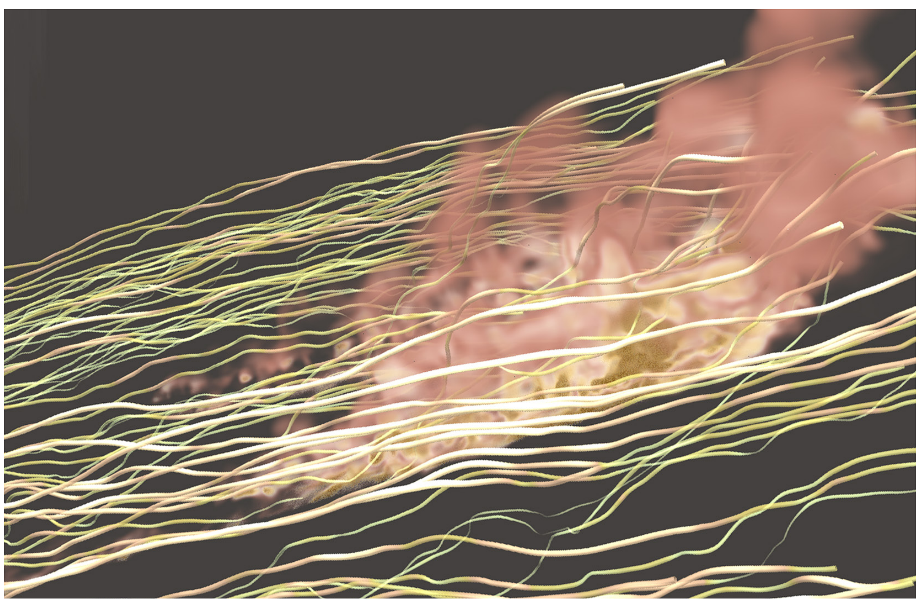




The figures above are a second example of artist-expanded palettes. The collection of images on the ride side of the top row shows a sea grape bush on the left with a close-up of its leaves on the right. A selection of colors pulled from both images illustrates the diversity of greens and green-adjacent hues available in our immediate environments. The right side of the bottom row features a painting of sea grapes by Bruce Marsh. Here, Marsh has drawn directly from natural imagery to make his work look and feel hyper-realistic, but has expanded the value range of a core set of green, yellow, and blue hues to provide enhanced visual differentiation and detail in the painting. The four visualizations on the lefthand side of the figures above show a progression of green palettes applied to the same bari clinic data. The upper left is encoded with a standard linear green colormap. The upper right shows a customized expanded version of a linear green colormap which provides a wider hue, value and saturation distribution. The bottom left image shows the data encoded with colormaps created using the sea grape image and the bottom right with hues from the sea grape painting.

When Marsh's analogous palette is applied to continuous colormaps, the range, depth, and subdued qualities of the hues work in concert to generate a quiet affect, encouraging exploration and rooting the visualization firmly in a sense of natural Place.

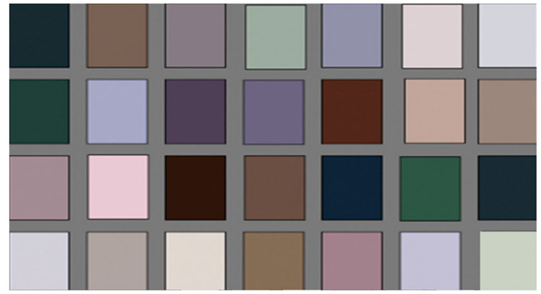


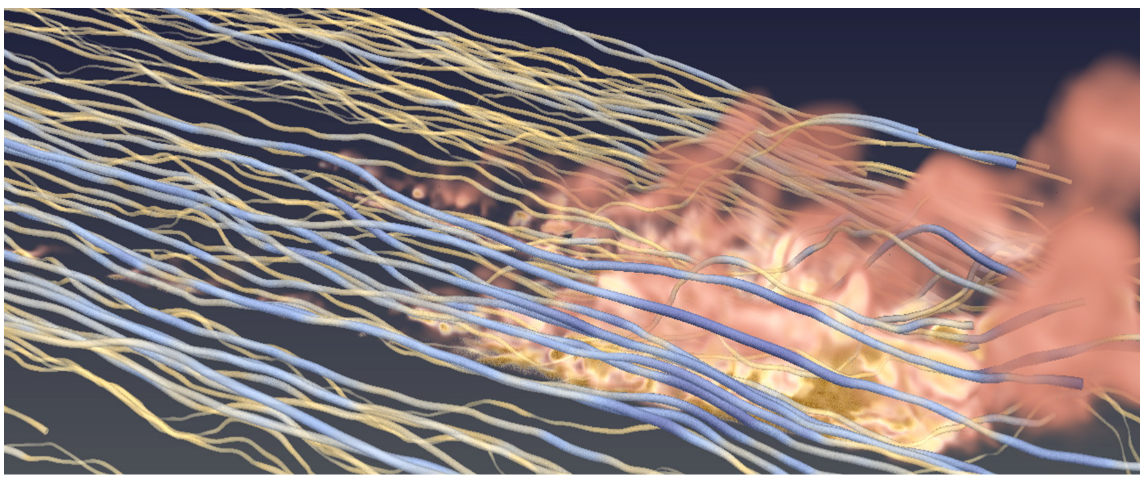
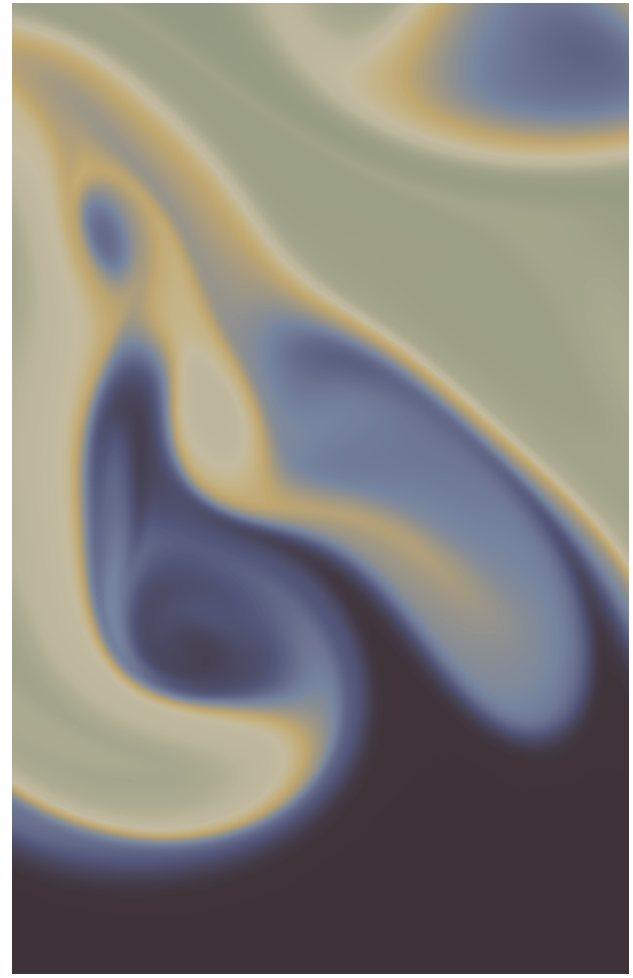


Affect in Natural Color Visualizations

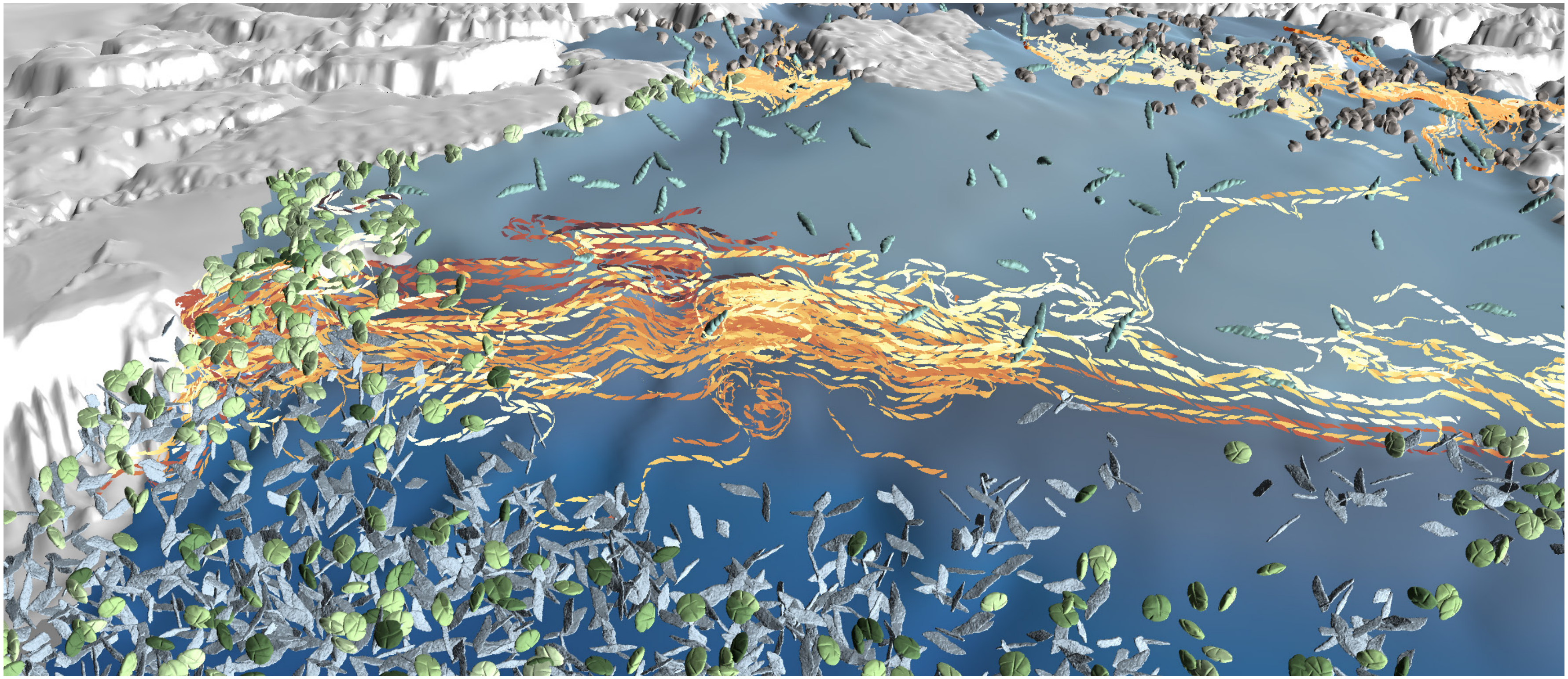
The language of color is both a primordial vessel for communication and also an inextricable element of the environment. As a result, color sits at the intersection of geographical place and affect: it is a contour of culture, a definer of space, and a visual carrier of the self. In the arts, color contrast theory is employed to navigate the complex relationships and dynamics between colors within a defined space in order to elicit specific affective responses [2, 5]. A deep understanding of these relationships is the foundation for experimentation: palette expansion, exaggeration, and dichotomies of subject matter and viewer association become tools for creating new approaches to visual communication [2, 5].

The topmost image in the column to the left is a photo of sunlight in a shallow area of a stream. The four photos in directly below the stream image show cacti (left three images) and a pine tree (rightmost image), alongside colors pulled from each image respectively. The collection of hues below the foliage images is a linear colormap overlaid with discrete hues drawn from the cacti and stream, demonstrating the striking differences in color contrast and hue appearance based on each discrete hue's environment. Finally, the bottom image of the column shows these hues applied to the same FIRETEC data from previous pages.

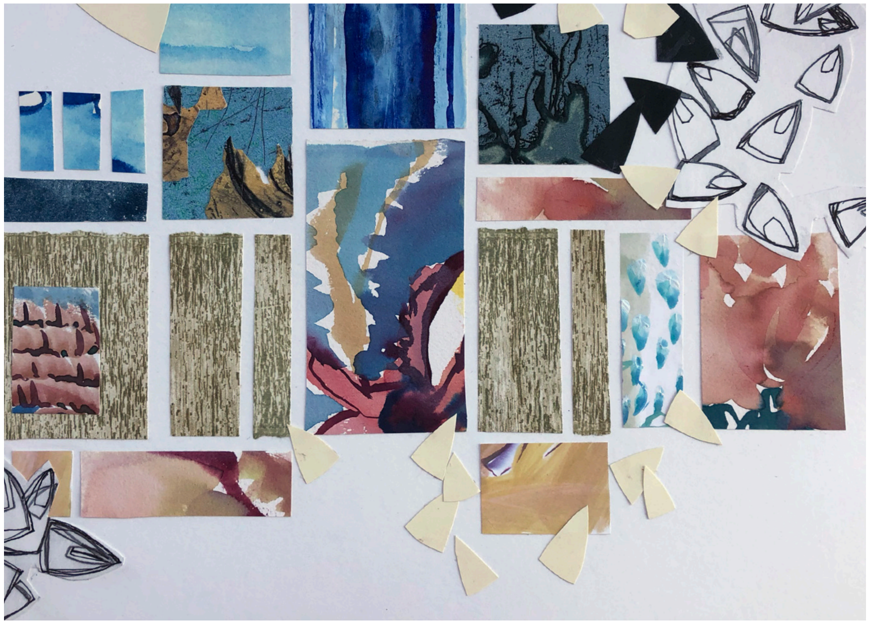



These images show the application of hues from a completely different environment—the ocean—to FIRETEC data as well as baroclinic data. The collection of discrete hues borrowed from the cuttlefish image on the upper left generate a new kind of tranquil affect for the fire data. The Skies and Rocks palette, the Cactus and River palette, and the Cuttlefish palette each produce a unique visualization with a unique affect for the same set of data, demonstrating the subtle but powerful effects of color on mood and association in visualization.



E3SM Ocean, DOE https://climatemodeling.science.energy.gov/projects/energy-exascale-earth-system-model.



While color plays a significant role in the production of affect, it is part of a larger equation of shape, texture, and spatial relationships. Our work with the Sculpting Vis team focuses on expanding the vocabulary of scientific visualization by directly integrating artistic practice into the visualization workflow [8, 9]. Further questions remain as to how these elements may contribute to establishing a grounded connection to geographical Place, and to what extent a cohesive visual language that pulls equally from the sciences and the fine arts improves affective connection and communication to diverse publics.

The image above shows a visualization of Antarctic water masses beneath the Filchner-Ronne Ice Shelf created using the Sculpting Vis tool for incorporating artistic vocabulary directly into scientific visualizations: Artifact-Based Rendering (ABR) [8]. The figure on the right shows one of Samsel's collages that contributed to the palette deployed in the Arctic visualization above.

Conclusion

Our work draws from both the arts and the sciences to enable humanistic approaches to environmental data analysis. By borrowing from the natural world, we can assemble palettes for scientific visualization that leverage our evolved visual predispositions and generate strong associative affect. These visualizations are grounded in a clear sense of geographical Place, re-establishing a wavering visual connection between big data and its original source and improving communication for a multiplicity of audiences.

Acknowledgements

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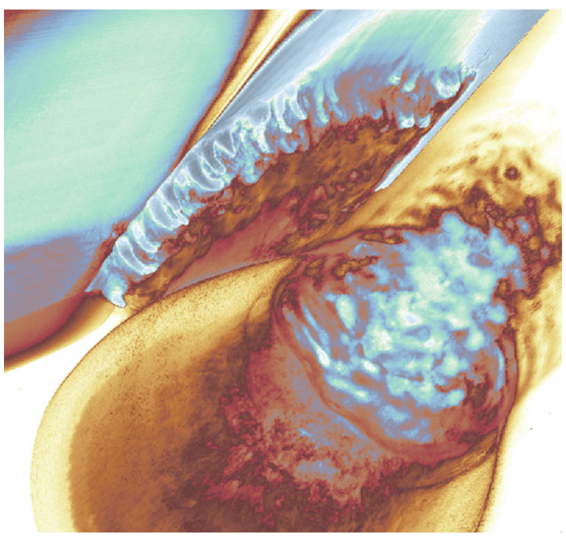

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