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R. Bujack and A. Middel and K. Rink and D. Zeckzer (Editors)

Intuitive Colormaps for Environmental Visualization

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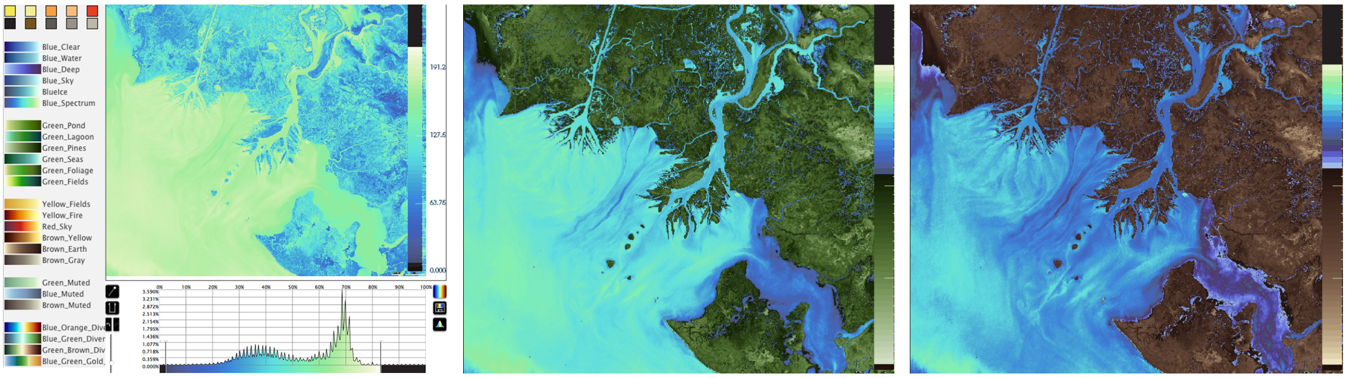

Figure 1: Illustrated here is the process of building a custom colormap for Sentinel2 CIR satellite data of the Wax Lake Delta. Starting from the left, one sees an image of the delta where brighter blue indicate regions with enhanced vegetation. Flow structures in the coastal ocean correspond to regions of enhanced sediment transport. In the central image, a separator pin divides land and water; a choice is made from the blues for the near-shore ocean and from the greens to evoke the land and foliage in the delta. In the finalized image, a brown is used in for the earth and blue variants are added to show greater detail in the water.

Abstract

Visualizations benefit from the use of intuitive colors, enabling an observer to make use of more automatic, subconscious channels. In this paper, we apply the concept of intuitive color association to the generation of thematic colormaps for the environmental sciences. In particular, we provide custom sets of colorscales for water, atmosphere, land, and vegetation. These have been integrated into the online tool: ColorMoves: The Environment *to enable the environmental scientist to tailor them precisely to the data and tasks in a simple drag-and-drop workflow.*

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Models and Principles]: User/Machine Systems—Human Factors H.m [User/Machine Systems]: Miscellaneous—Colormapping

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1. Introduction

Environmental data is growing in size and complexity, challenging the scientist who needs to communicate effectively at many levels: to peers, to policy makers, and to the general public. Communication is critical to fostering understanding and disseminating the scientific knowledge on which decisions are based.

Color is a critical channel for communicating information. Our scientific understanding of color comes from mathematical models as well as the perceptual and cognitive sciences. A complementary understanding comes from the artistic community based on observing and rendering nature onto a canvas. We tap that artistic knowledge to develop sets of sequential custom colorscales that intuitively reflect our perception of water, atmosphere, land, and vegetation. These colorscales draw on the artist's experience of color contrast and color interactions to provide discriminative power. Building on the associative color and color theory foundations used successfully in visualization [War88,HB03,Sto16], our colorscales are designed to provide more discriminative power within single hues by varying the type and distribution of hue, saturation, value, and contrast type.

(a) BlueClear (b) GreenPond (c) YellowFields

(d) BlueWater (e) GreenLagoon (f) YellowFire

(g) BlueSky (h) GreenPines (i) RedSky

(j) BlueDeep (k) GreenSeas (l) BrownYellow

(m) BlueIce (n) GreenFoliage (o) BrownEarth

(p) BlueSpectrum (q) GreenFields (r) BrownGray

Figure 2: Blue color scales for water and sky. Green color scales for vegetation and water. Brown, red and yellow color scales for earth and air. The XML files for these color scales are available on the SciVisColor website, sciviscolor.org/colormaps.

We are motivated to apply the concept of intuitive color assignment from researchers who have preceded our efforts (see Section 2). As has been pointed out, "The fist step to developing a systematic approach to characterizing and choosing effective visual representations of data is to look for guidance from our interpretation of the real world." [Rob90], "User interfaces that model human category judgments might enable more compelling forms of reference and selection." [HS12], and "Intuition for the meaning of a colormap can be developed through experiencing colors in nature." [TGH*16].

Research in cognition and color has elucidated important points to consider in colormapping. The natural relation of content and color allows an observer to facilitate automated processes that require less conscious concentration [Baj88]. Additionally, nameable colors tend to be easier to remember [Ber91, RDD00].

The main contribution of this paper is to provide a diverse range of colorscales enabling clearer, more intuitive representation and communication of environmental science data. We provide the scientific community with intuitively associated colorscales and palettes integrated into a domain-specific colormap customization tool, *ColorMoves: The Environment*, enabling environmental scientists to quickly and easily select and customize colormaps and color systems to meet their observation, exploration, and communication needs. Our colorscales, by exploiting the more subtle types of color contrast, can provide greater discriminative power while staying within a narrower hue range that maintains the intuitive association of color with specific natural features.

2. Related Work

2.1. Colormap Design Rules

Colormapping is a very old technique with many rules and guidelines available in the literature [SSM11, ZH16]. Common themes include *order* [SB79, WF80, Tru81], *uniformity* [Piz81, Taj83, RO86], and a *high discriminative power* [PZJ82, Taj83, LH92]. While order and uniformity can be satisfied using a straight line through a perceptually uniform color space, high discriminative power requires a long curve through a color space.

2.2. Intuitive Colors in Visualization

Robertson [Rob90], in introducing his *natural scene paradigm*, states that for the display of multiple variables in complex scenes (such as occur predominantly in the environmental sciences [BM16]), intuitive representations of the data are very important. The importance of color names for the design of color palettes is stressed and applied by Brewer et al. [Bre94, HB03].

Heer and Stone stress that the naming of colors strongly influence an observer's capacity of categorization and judgment of the physical world. They provide a framework for probabilistic color naming [HS12, Sto16]. Lin et al. [LFK*13] demonstrate how colors that semantically correspond to the displayed content increase the speed of bar chart reading and develop an algorithm to correlate a set of colors to words.

Despite concerted efforts by the cognitive and visualization communities [RT98, LB04, BTI07], some version of the rainbow remains one of the most frequently used colormaps [BM16, DBW*10, MHB*14, Win16].

The recent work of Thyng et al., [TGH*16] and of Samsel et al., [SPG*15] are notable exceptions. In the latter Samsel worked with the Climate, Ocean, Sea-Ice Modeling team at Los Alamos National Laboratory to identify how artistic color knowledge may provide greater insight into the models via more complex colormapping. Thyng et al. [TGH*16] suggest a set of colormaps, cmocean, for the visualization of ocean data. They agree with general colormap theory in that uniformity is important and that sequential, diverging, or cyclic colormaps need to be chosen to match the data type. But they also suggest two new rules. One is consistency, by which they mean that within one context two variables should not be represented by the same colormap, just as two variables would also not be assigned the same Greek symbol. The other one is intuition, meaning that cultural implications and the nature of matter and variables can enhance understanding, for example, sea ice should be visualized using blues and whites.

Our colorscales are grounded in the detailed analysis of color interaction research and the more subtle principles of color contrast theory. As with many researchers in colormap design, (e.g. [Bre94]), we build on the work or Albers and Itten [Alb09, Itt61]. It is the subtle manipulation of the types and degrees of contrast identified by Itten and further studied by Albers, that enable the subtle shifts within the colorscales to provide the discriminative power within the narrower hue range.

3. Colorscales for Associative Palettes

Environmental scientists face many challenges when it comes to the visualization of their data [BM16]. They often need to display several variables (temperature, salinity, wind speed, etc.) at once to see and analyze multi-variable correlations. Since the spatial embedding often plays an important role, they must include topographic features (e.g., geopolitical borders, rivers, or terrain information) [BM16] that require both space and colors in a visualization. The ability to see perceptual depth (discriminative power) in the data is usually a key goal. Communication to a broad audience with mixed background knowledge must be considered.

The sets of associative colorscales that we provide address these challenges while striving to follow some of the more important colormap design rules. They are designed to respect intuitive order and uniformity. These requirements are balanced against the need to create a longer line in color space so as to not sacrifice the discriminative power available in the colorscales despite the narrow hue range.

By using intuitive colors, the non-scientific audience is invited to participate in the visualization, while we know from the cognitive sciences that intuitive color choices helps scientist and non-scientist alike to more quickly understand the content of a visualization.

These colormaps also help to remedy the other common problems faced by the environmental scientist. When displaying many variables, each can be shown in a different intuitive colorscale, emphasizing the contrast between the variables. When spatial context information is crucial for the interpretation of their findings, these colorscales enable sharing the visualization space. A colorscale that goes through too broad a spectrum creates issues when insufficient color channels are left for encoding all variables or auxiliary information.

Figure 3: This figure shows the construction of a green colorscale with that moves from a *warm* dark yellow-green through a mid-range *cool* blue-green and back to a *warm* light yellow-green. This allows the colorscale to maintain intuitive order while moving between warm and cool greens, shifts that create greater contrast.

The colormap design approach draws deeply from the concepts of color contrast theory. Figure 3 walks through the design process. The colormap goes beyond a simple dark to light contrast. Relying solely on luminance changes within a single hue limits the overall discriminative power. The development of GreenPond, as shown in Figure 3, combines additional shifts of cool/warm greens stepping through the linear value distribution. The greens move from warm to cool to warm. These complementary shifts of multiple types and distributions of contrast create greater discriminative power, as was found in our early color evaluation work [SPG*15].

The full set of colormaps, shown in Figure 2, are designed to provide a variety of colorscales that address specific color themes in environmental science. Blues are used for water, ice and sky/air. Greens can be for either land or water. The browns, reds and yellows cover earth and air. Within these color families are many varieties of contrast types. Colorscales have different value ranges. Some span only a section of the value scale such as YellowFields. Other move from black to white within the family, useful for a general overview of data. Color scales within one hue family also vary in saturation level and distribution.

Colorscales with a wider range of hues (BlueSpectrum, RedSky, GreenFields) can be used to get an overview of data, taking a longer arc through color space. Colorscales that span a greater luminance range with similar intensities (e.g., BlueIce, GreenPond, YellowFields) work well together in a blended colormap. To create distinct breaks along a dividing line between environments (e.g., water vs. land), use colormaps that extend to the darkest values (BlueWater, BrownEarth). Continuity can be emphasized by combining a series of colormaps, light end to light end, dark to dark.

Color contrast theory can also help to inform user choices as colorscales are combined. Types of contrast such as warm-cool are useful starting points. If two similar hues are needed, choosing one warm and one cool will highlight the differences. e.g., mixing the warm GreenPond and the cool GreenSeas. Across color ranges, a warm green (GreenLagoon) with a cool blue (BlueDeep) will maximize contrast. The yellows can also provide a warm contrast to mix with the cooler greens or blues.

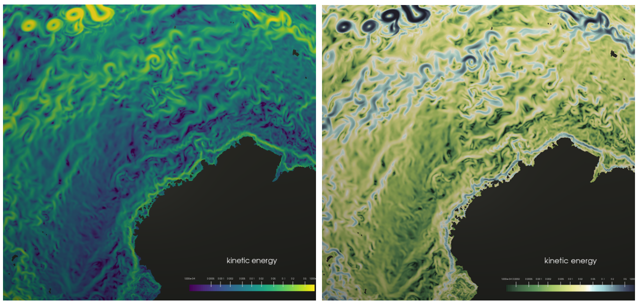

Figure 4: An MPAS-Ocean visualization of kinetic energy around the Antarctic. Viridis (left) can be compared to a custom colormap using these intuitive colorscales (right). While the hues are similar, the value range is greater on the custom map and is employed twice, once through green and once through blue. Here, the scientists welcomed the greater discriminative power created by the luminance changes. While there are benefits to both, our goal is to provide the flexibility to the scientists to assist in resolving their scientific queries.

4. Custom Colormapping

No single colormap is optimal for all domains, statistical distributions, or tasks. A previously released tool, ColorMoves [SKP*16], allows the scientist to build custom colormaps, delineating regions of interest with *pins* and *nests*. These defined regions in the data can each be given its own colorscale. The ability to interactively adjust the endpoints of these regions in real time enables the scientist to craft very data-specific colormaps. Full details on its use can be found on the ColorMoves site: `sciviscolor.org/home/colormoves`. A customized interface for the environmental community *ColorMoves: The Environment* that includes all of the colorscales discussed is available at `sciviscolor.org/colormoves-the-environment/`.

Using these colorscales within *ColorMoves: The Environment*, Wolfram of the COSIM group at LANL notes, "Separation of the ocean and land boundary in the coastal zone, allowing key detail to be manifest, is particularly important because it allows key gradients in the terrestrial aquatic interface to be found. Having these abilities will enable me to more quickly share this information."

The advantages of using intuitive colors and custom colormappings are further illustrated in Figures 4 and 5. The different data sets shown are rendered in common colormaps and in custom colormaps built from the colorscales presented. The custom colormaps allow perceptual depth into the data despite the narrow hue ranges spanned while the colors speak to the natural scene inherent in the data set.

5. Conclusions

In this paper, we have introduced sets of intuitive environmental colorscales that have been incorporated into an online tool, providing environmental scientists with a means of specifying the hue and span of color within their visualizations to enable clearer, more intuitive results.

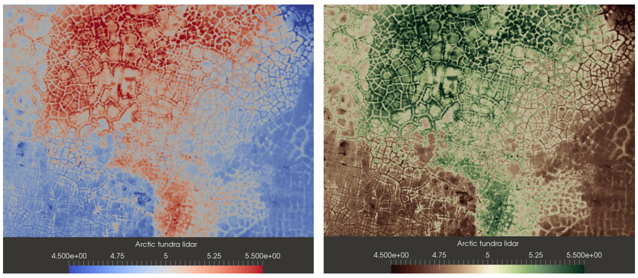

Figure 5: Arctic scientists are studying how subtle changes in the topography can lead to significant changes in vegetation type and distribution. This topographical LIDAR data without context is rather an abstract pattern. Rendering in the green and brown palette provides associative clues not available in the standard cool warm. Additionally, identifying the areas of foliage verses dry tundra is quite intuitive.

Challenge	**Solution**
Broad audience with varying scientific background	Intuitive colormaps work on many levels
Visualizations need to leave colors for the display of other parameters, spatial context, highlights, or glyphs	Narrow hue range of intuitive colorscales enables clear thematic distinction from other visualization items
Not enough perceptual depth, detail in the data	Artist-designed colorscales provide high discriminative power despite narrow hue range
The colormaps do not reflect the complicated structure of the data or do not sufficiently emphasize the central statement	The provided tool: *ColorMoves: The Environment* allows simple and precise fitting of the colormap to data and tasks

Table 1: Summary of how the suggested colorscales, tool, and workflow help the environmental scientists face typical visualization challenges.

The different ways in which intuitive colormapping can help to overcome typical challenges in the environmental sciences are summarized in Table 1. *ColorMoves: The Environment* includes all of the above colorscales plus some starting point options. We invite the community to explore their data with *ColorMoves: The Environment* and welcome feedback on the newly available colorscales.

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References

[Alb09] ALBERS J.: *The Interaction of Color*. Yale University Press, New Haven, CT, 2009. 3

[Baj88] BAJO M.-T.: Semantic facilitation with pictures and words. *Journal of Experimental Psychology: Learning, Memory, and Cognition 14*, 4 (1988), 579. 2

[Ber91] BERRY L. H.: The interaction of color realism and pictorial recall memory., 1991. ERIC. 2

[BM16] BUJACK R., MIDDEL A.: Strategic Initiatives for Flow Visualization in Environmental Sciences. In *Workshop on Visualisation in Environmental Sciences (EnvirVis)* (2016), Rink K., Middel A., Zeckzer D., (Eds.), The Eurographics Association, pp. 23–27. `doi:10.2312/envirvis.20161103`. 2, 3

[Bre94] BREWER C. A.: Color use guidelines for mapping. *Visualization in modern cartography* (1994), 123–148. 2, 3

[BTI07] BORLAND D., TAYLOR II R. M.: Rainbow color map (still) considered harmful. *IEEE computer graphics and applications 27*, 2 (2007), 14–17. 2

[DBW*10] DIETRICH J. C., BUNYA S., WESTERINK J. J., EBERSOLE B. A., SMITH J. M., ATKINSON J. H., JENSEN R., RESIO D. T., LUETTICH R. A., DAWSON C.: A high-resolution coupled riverine flow, tide, wind, wind wave, and storm surge model for southern louisiana and mississippi. part II: Synoptic description and analysis of hurricanes katrina and rita. *Monthly Weather Review 138*, 2 (2010), 378–404. 3

[HB03] HARROWER M., BREWER C.: Colorbrewer.org: An online tool for selecting colour schemes for maps. *The Cartographic Journal 40*, 1 (2003), 27–37. 1, 2

[HS12] HEER J., STONE M.: Color naming models for color selection, image editing and palette design. In *ACM Human Factors in Computing Systems (CHI)* (2012). 2

[Itt61] ITTEN J.: *The Art of Color: The Subjective Experience and Objective Rationale of Color*. Van Nostrand Reinhold, New York, NY, 1961. 3

[LB04] LIGHT A., BARTLEIN P. J.: The end of the rainbow? Color schemes for improved data graphics. *Eos 85*, 40 (2004), 385–391. 2

[LFK*13] LIN S., FORTUNA J., KULKARNI C., STONE M., HEER J.: Selecting semantically-resonant colors for data visualization. *Computer Graphics Forum (Proc. EuroVis)* (2013). 2

[LH92] LEVKOWITZ H., HERMAN G. T.: The design and evaluation of color scales for image data. *IEEE Computer Graphics and Applications 12*, 1 (1992), 72–80. 2

[MHB*14] MIDDEL A., HÄB K., BRAZEL A. J., MARTIN C. A., GUHATHAKURTA S.: Impact of urban form and design on mid-afternoon microclimate in phoenix local climate zones. *Landscape and Urban Planning 122* (2014), 16–28. 3

[Piz81] PIZER S. M.: Intensity mappings to linearize display devices. *Computer Graphics and Image Processing 17*, 3 (1981), 262–268. 2

[PZJ82] PIZER S. M., ZIMMERMAN J. B., JOHNSTON R. E.: Contrast transmission in medical image display. In *1st International Symposium on Medical Imaging and Image Interpretation* (1982), International Soc. for Optics and Photonics, pp. 2–9. 2

[RDD00] ROBERSON D., DAVIES I., DAVIDOFF J.: Color categories are not universal: replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General 129*, 3 (2000), 369. 2

[RO86] ROBERTSON P. K., O'CALLAGHAN J. F.: The generation of color sequences for univariate and bivariate mapping. *IEEE Computer Graphics and Applications 6*, 2 (1986), 24–32. 2

[Rob90] ROBERTSON P. K.: A methodology for scientific data visualisation: choosing representations based on a natural scene paradigm. In *Proceedings of the 1st conference on Visualization'90* (1990), IEEE Computer Soc., pp. 114–123. 2

[RT98] ROGOWITZ B. E., TREINISH L. A.: Data visualization: the end of the rainbow. *IEEE spectrum 35*, 12 (1998), 52–59. 2

[SB79] SLOAN K. R., BROWN C. M.: Color map techniques. *Computer Graphics and Image Processing 10*, 4 (1979), 297–317. 2

[SKP*16] SAMSEL F., KLAASSEN S., PETERSEN M., TURTON T. L., ABRAM G., ROGERS D. H., AHRENS J.: Interactive colormapping: Enabling multiple data range and detailed views of ocean salinity. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016), CHI EA '16, ACM, pp. 700–709. `doi:10.1145/2851581.2851587`. 4

[SPG*15] SAMSEL F., PETERSEN M., GELD T., ABRAM G., WENDELBERGER J., AHRENS J.: Colormaps that improve perception of high-resolution ocean data. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (2015), CHI EA '15, pp. 703–710. `doi:10.1145/2702613.2702975`. 3

[SSM11] SILVA S., SANTOS B. S., MADEIRA J.: Using color in visualization: A survey. *Computers & Graphics 35*, 2 (2011), 320–333. 2

[Sto16] STONE M.: *A field guide to digital color*. CRC Press, 2016. 1, 2

[Taj83] TAJIMA J.: Uniform color scale applications to computer graphics. *Computer Vision, Graphics, and Image Processing 21*, 3 (1983), 305–325. 2

[TGH*16] THYNG K. M., GREENE C. A., HETLAND R. D., ZIMMERLE H. M., DIMARCO S. F.: True colors of oceanography. *Oceanography 29*, 3 (2016), 10. 2, 3

[Tru81] TRUMBO B. E.: A theory for coloring bivariate statistical maps. *The American Statistician 35*, 4 (1981), 220–226. 2

[War88] WARE C.: Color sequences for univariate maps: Theory, experiments and principles. *IEEE Computer Graphics and Applications 8*, 5 (1988), 41–49. 1

[WF80] WAINER H., FRANCOLINI C. M.: An empirical inquiry concerning human understanding of two-variable color maps. *The American Statistician 34*, 2 (1980), 81–93. 2

[Win16] Windyty, SE, wind map & forecast, 2016. URL: `https://www.windyty.com`. 3

[ZH16] ZHOU L., HANSEN C.: A survey of colormaps in visualization. *IEEE Transactions on Visualization and Computer Graphics 22*, 8 (2016), 2051–2069. 2