AN ABSTRACT OF THE THESIS OF

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Abstract approved:

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Natural ground color is useful for reference maps as well as maps where a realistic representation of the Earth's surface matters. Natural color schemes are less likely to be misinterpreted, as opposed to hypsometric color schemes, and are generally preferred by map readers. The creation of natural-color maps was once limited to manual cartographic techniques, but they can now be created digitally with the aid of raster graphics editing software. However, the creation of natural-color maps still requires many steps, a significant time investment, and fairly detailed digital land cover information, which makes this technique impossible to apply to global web maps at medium and large scales. A particular challenge for natural-color map creation is adjusting colors with location to create smoothly blending transitions. Adjustments with location are required to show land cover transitions between climate zones with a natural appearance. This study aims to take the first step in automating the process in order to facilitate the creation of medium- and large-scale natural-color maps for the web. A coloring method based on two grid inputs is presented. Here, we introduce an algorithmic method and prototype software for creating large-scale web maps with this technique. The prototype software allows the map author to interactively assign colors and design the appearance of the map in an automated way. This software can generate web map tiles at a global level for medium and large scales. Example natural-color web maps created with this automated coloring technique are provided.

NATURAL-COLOR MAPS VIA AUTOMATED COLORING
OF BIVARIATE GRID DATA

by

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APPROVED:

Major Professor, representing Geography

Dean of the College of Earth, Ocean, and Atmospheric Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jane E. Darbyshire, Author

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TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Natural-color maps bring together naturally-colored land cover and shaded relief in a way that makes intuitive sense to the map reader. The colors are derived from the familiar colors that are observed in natural settings. These colors are intuitively interpreted as the land cover types being shown, making them easier to understand and recall for a wide variety of map readers (Patterson 2002). This type of coloring is particularly useful for reference maps and other types of maps where a cartographically realistic representation of the Earth's surface matters. The advantages of natural color schemes are that colors are unlikely to be misinterpreted, realistic map backdrops are generally preferred by map readers (Raposo and Brewer 2014), and natural color has been found to improve recognition memory over false-color and black-and-white imagery (Wichmann et al. 2002). However, this style of map is not commonly seen covering large areas at large scales. To create such maps digitally requires skill with raster graphics software, many steps, and detailed land cover information. While this can work for small-scale world maps, it is nearly impossible to apply to global web maps at medium and large scales, because creating naturally colored land cover is presently a time consuming process when done for global web maps at large scales.

Creating natural-color maps requires more than just selecting realistic colors for land cover categories. In order for the map to appear natural, land cover colors must be adjusted with location to create smoothly blending transitions between climate zones (Patterson 2002). If no transitions are applied, the colors are only natural for one specific climate zone or land cover type. This issue also applies to maps that use hypsometric tints – representing lowlands with lush green and mountain peaks with white works well for temperate climate zones, but is misleading in arid or arctic climate zones (Patterson and Jenny 2011, Patterson and Jenny 2013). Using orthophotos as natural-color base maps is not a good alternative, due to their inherent problems. These issues include relief inversion (Bernabé-Poveda and Çöltekin 2014), cast shadows, excessive detail, areas hidden by clouds, and landscape changes over time (Patterson 2002).

The creation of natural-color web maps is not readily accessible to novice cartographers and non-experts. No automated methods have yet been developed for creating naturally colored land cover. Automating this process would make the production of natural color maps easier and more widely accessible. We propose an automated coloring technique based on grid inputs, such as regularly sampled elevation and precipitation values. This technique allows natural coloring of large areas at medium and large scales, and is therefore suitable for creating global web maps. Other advantages of this technique include automated map production and blended color transitions between global climate zones and local variations in elevation and precipitation, all while allowing the map author to retain control over the look of the finished product.

The first part of this paper provides an overview of past and present techniques for creating natural-color maps. It begins with the manual fine arts techniques made famous by cartographic artists such as Hal Shelton and Tibor Tóth, followed by modern digital techniques, such as those described by Tom Patterson. Related coloring approaches are also noted.

The second part presents a new automated technique that allows for the creation of natural-color maps by modulating user-specified color with elevation and precipitation grid data as a proxy for land cover. The method described uses a color look-up table to hold interpolated colors for all of the possible combinations of elevation and precipitation values. An interactive method for constructing the color look-up table from color reference points placed directly on a base web map in prototype software is also described. Example maps created with the automated technique are provided.

2 PAST AND PRESENT TECHNIQUES

In the past, cartographers relied on manual fine arts techniques to produce naturally colored maps. An early, superb, example of this is shown in Figure 1, a map produced in 1850 by Johann R. Stengel (1850). The production method used was a combination of pencil sketch, pen drawing, and water color painting, using various colors and color gradients (Oberli 1979). Reproduction of such maps was very difficult, as the process of chromolithography was still young, required considerable expertise, and was quite expensive.

Figure 1. An example of a natural-color map created by J. R. Stengel in 1850, using pencil, pen, and watercolor techniques (Stengel 1850, figure from Oberli 1979).

The primary technique used in the mid-1900s, prior to the development of digital methods, was airbrush work combined with acrylic painting (Patterson and Kelso 2004, Tóth 2010). This required artistic training and skills, and the ability to visualize terrain as it would look from above based on a variety of geographic information sources, such as field measurements, landform and contour maps, and navigational charts (Tóth 2010). These maps could take anywhere from around forty hours to complete (Patterson and Kelso 2004) to hundreds of hours (Tóth 2010).

The most well-known cartographer that pioneered this technique is Hal Shelton (Patterson and Kelso 2004, Masia 2005, Tait 2010, Tóth 2010). His work in the 1950s – 1970s on what later became *The Jeppesen Natural-Color Map Series* was world famous (Patterson and Kelso 2004). In addition to using natural colors, Shelton aimed to depict vegetation transition boundaries with soft edges, as these transitions are not generally abrupt in nature (Patterson and Kelso 2004). Color satellite imagery of the Earth was not available prior to the early 1970s, yet Shelton's maps were so realistic and detailed that the National Aeronautics and Space Administration (NASA) used them as reference material for locating and indexing pictures taken on some of their earliest space missions (Patterson and Kelso 2004).

Another artist well known for his natural-color relief maps is Tibor Tóth. Already a skilled cartographer, he met with Shelton in 1971 and learned his painting technique, which he adapted to his own methods (Patterson and Kelso 2004, Tóth 2010). He produced many maps in this style for the National Geographic Society (see Figure 2.). In 1993, Tóth was introduced to digital production, and he has since adopted a completely digital approach to natural-color map making (Tóth 2010).

Figure 2. An example of Tibor Tóth's work (Tóth 2010, image provided courtesy of Tibor Tóth).

The use of digital tools offers a way to emulate the airbrush and acrylic painting techniques that previously dominated natural-color map creation. Tom Patterson (2002) discussed how various raster graphics techniques combined with land cover and elevation data have been experimented with and used by the U.S. National Park Service to achieve cartographically realistic, natural looking maps that are more accessible to and understandable by a wide range of park visitors (as opposed to more abstract maps). These techniques include: aquafication – the application of subtle adjustments in opacity, blending mode, and color applied to hydrographic features to give a natural appearance; texture substitution – cloning appropriate generic textures taken from aerial photographs to characterize and fill corresponding land cover areas; illuminated relief – enhancing the map relief by manipulating the hue, saturation, and brightness of certain areas; and outside land muting – a technique used to increase the contrast between the area of emphasis (such as the area within a park boundary) and the surrounding area (Patterson 2002).

In 2004, Patterson and Kelso published a guideline for creating natural-color maps using Adobe Photoshop techniques to modify the appearance of NLCD (National Land Cover Database) and MODIS (Moderate Resolution Imaging Spectro-radiometer) data. The NLCD is derived from Landsat Thematic Mapper imagery, and it consists of categorical land cover data at 30-meter resolution that covers the 48 contiguous states in the U.S.A (Homer et al. 2015). The NLCD consists of 21 categories, which Patterson and Kelso (2004) reduced via aggregation to 15 to limit the amount of information presented to the map reader. Appropriately natural (or unnatural in the case of developed areas) colors were assigned to the new categories as a way to create a natural looking small-scale map. The subset of MODIS data used by Patterson and Kelso (2004) is VCF (Vegetation Continuous Fields). The VCF data is comprised of three layers that contain forest, herbaceous, and bare land cover. Unlike the NLCD data, the MODIS VCF data covers nearly all of the terrestrial areas on earth, with the exception of Antarctica and the polar edges of countries north of 80° latitude. The three layers of VCF data can be manipulated and colored in Photoshop, then accented with supplemental data to fill in the missing land cover categories needed for a complete natural-color map. This can be a time-consuming process, depending on what the cartographer wishes to include. The techniques described by Patterson and Kelso (2004) led to the creation of the Natural Earth dataset (Natural Earth Data 2015), a well-known, small-scale, world-map level naturally colored basemap that is available for free download (Figure 3.).

Figure 3. A portion of the Natural Earth II dataset (Natural Earth Data 2015). The colors shown indicate different climate zones and the transitions between them.

The digital creation of natural-color maps typically involves the following algorithms and techniques: blur – to reduce unnecessary detail and blend transitions; color (hue, value, and brightness) and color gradient adjustment techniques; layer compositing with transparency (Porter and Duff 1984); texturing – using patterns to make large areas look more natural, such as vegetated and sandy areas (Jenny and Jenny 2013, Jenny et al. 2012); masking – a technique that allows effects to be applied to a specific area; and raster graphics effects such as shading, drop shadows, glow effects, beveling/extrusion, and embossing (Schlag 1994).

Examples of some of the techniques mentioned previously can be seen below in Figure 4. These methods are used to create a natural appearance with plausible transitions between different feature types, as well as for adding the illusion of a third dimension to some features. For example, the shaded relief is composited with the rest of the map using the multiply blend mode; forested areas are textured with a generic forest texture and raised using an extrusion raster graphics effect; water and roads are embedded into the terrain using an embossing raster graphics effect; buildings are represented with a small drop shadow effect; field patterns from aerial imagery are semi-transparent; and a mask is applied to remove built-up areas from the aerial image. Additionally, mask boundaries are blurred to avoid abrupt transitions.

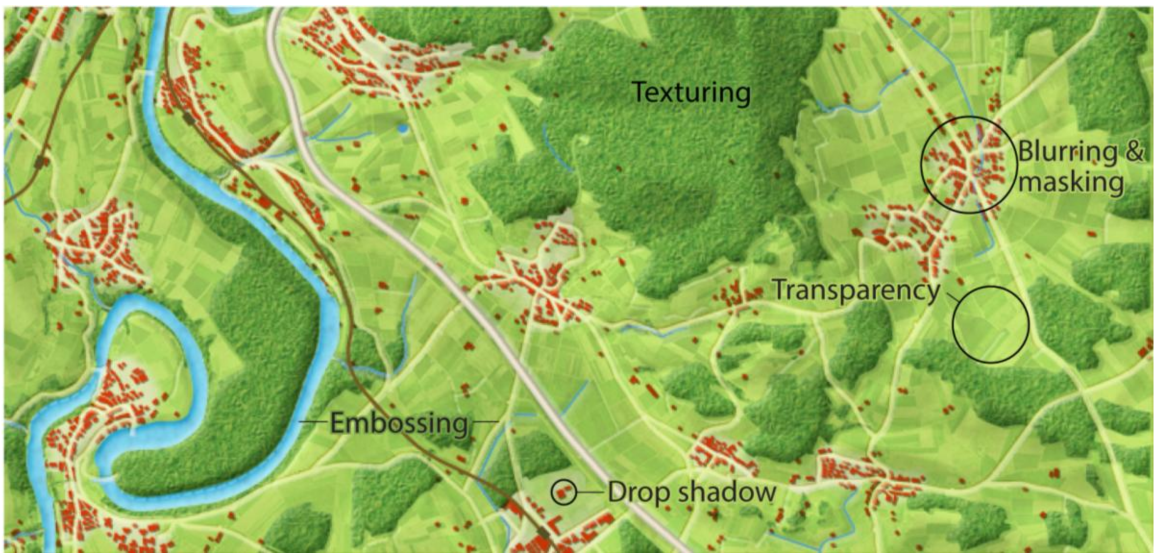

Figure 4. A section of a digitally created large-scale natural-color map with labeled examples of some of the algorithms and techniques used (Schaffhausen, Switzerland).

Cartographers have developed a variety of related techniques that vary color to illustrate continuous raster data, such as terrain elevation. Cross-blended hypsometric tinting is a technique that varies elevation colors to mimic different environments in world regions (Patterson and Jenny 2011, Patterson and Jenny 2013). This technique was developed to address the potentially misleading coloration of conventional hypsometric tinting. While cross-blended hypsometric tints are still based on elevation values, rather than using one color scheme for all regions of the world, multiple schemes are used. These vary based on regional environment, and feature blended transitions where different environments border one another. This gives a more natural appearance that is easier to interpret across all regions of the globe. Cross-blended hypsometric tints are available as a raster dataset for small-scale use (Natural Earth Data 2015).

Bivariate coloring is an approach used in thematic mapping. Two variables are plotted on one map, and a two-dimensional color legend is used to show their covariance (Meyer et al. 1975, Eyton 1984, Brewer 1994, Teuling et al. 2011, Elmer 2013). This is related to the technique outlined in this paper, as we are also using two related sets of data to color maps. However, where we are concerned with providing data-based natural land cover that is easy to interpret, one of the goals of bivariate coloring in thematic mapping is to prevent the loss of data while showing two related variables simultaneously. As a result, the legends and color schemes for these maps can potentially become complicated and difficult to read (Eyton 1984, Teuling et al. 2011, Elmer 2013).

Aspect coloring is a way of visualizing aspect classes with various hues and slope with varying saturation, while using lightness to show progression (Moellering and Kimerling 1990, Brewer and Marlow 1993). This technique allows for easy visual discrimination between aspect classes while keeping the underlying landform visible. The end result, while allowing for clear visualization of aspect and slope, is not at all natural in appearance due to the dramatic differences in hue between aspect classes.

Illuminated relief shading is a shading technique that varies color with elevation and exposure to illumination (Jenny and Hurni 2006). This approach makes significant landforms readily discernible to map readers. The final result can be somewhat natural in appearance, depending on the colors chosen, but the combination of elevation and illumination does not lend itself to identifying and coloring regions based on natural land cover. The technique we describe in the next section is related to illuminated relief shading (Jenny and Hurni 2006). We have taken inspiration from this method, and extended it by adapting it to create natural-color maps from pairs of continuous grid data, such as precipitation and elevation.

3 AN ALGORITHM FOR AUTOMATED COLORING OF BIVARIATE GRID DATA

Our algorithm uses a two-dimensional lookup table containing color definitions set by the user. As shown in the color diagram in Figure 5 (right-hand side), the colors vary with elevation on the vertical axis, and with precipitation on the horizontal axis. As a result, a specific color is defined inside the diagram for each combination of elevation and precipitation values. In order to generate a naturally colored image, the algorithm determines the color of each pixel based on the corresponding digital elevation model and precipitation grid values for that pixel.

There are two ways for the user to create color schemes. In the first, the user selects colors from a color picker and places them directly onto the color diagram shown in Figure 5 (right). The algorithm then interpolates colors to fill in the color lookup table. Creating a desirable lookup table with this technique requires some trial and error to determine where areas of particular elevation/precipitation are located on the base map. To complement this method and reduce the trial and error aspect, a second, more intuitive technique was added. In the second method, color reference points are placed directly on the base map by the user (circles on the map in Figure 5, center). After a reference point has been set, the user can specify its color with a color picker attached to the point. For each of these points, the software extracts the elevation from the digital elevation model grid and the corresponding value from the precipitation grid data to position the point in the lookup table.

Color reference points placed on the map by the user are added to the color diagram used in the first method, so points added in both ways can be manipulated together. Points placed directly on the color diagram are indicated as squares, and those placed on the map are indicated as circles (Figure 5, right). Color reference points placed on the map can be moved on the map. When they are moved on the color diagram, they are removed from the map, because the elevation and precipitation values in the lookup table do not correspond to the map location of the point. When this happens, the shape of the point in the color diagram changes from a circle to a square.

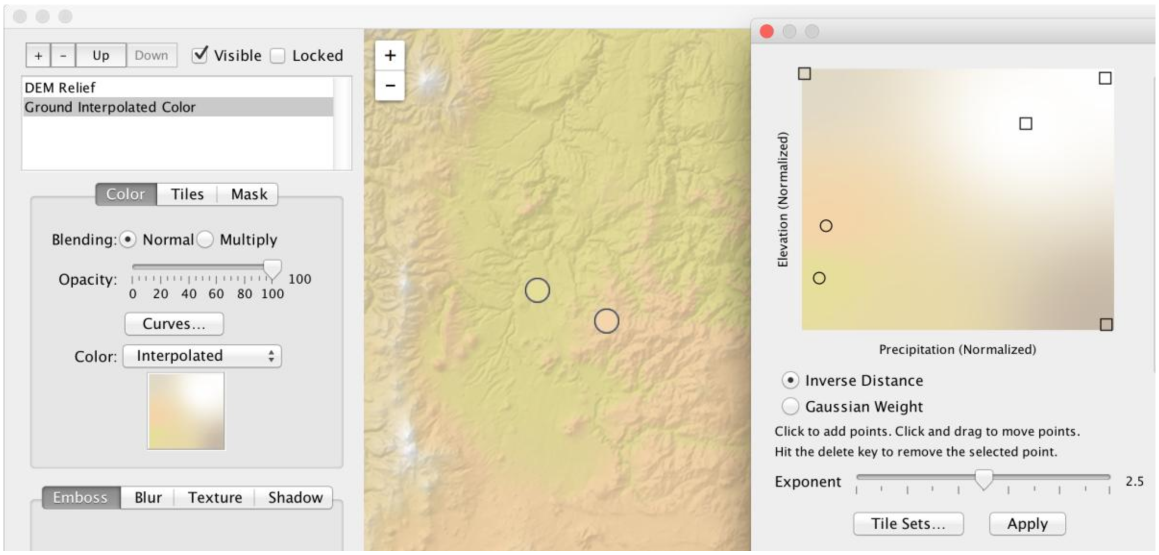

Figure 5. The prototype software: GUI for layer rendering (left), the map preview window with two color reference points (center), and the color diagram with interpolated colors showing the two types of color reference points that can be placed by the user (right).

The color points defined by the users in both methods described above are used to interpolate colors for the rest of the table. We chose to use inverse distance weighting for interpolating colors in the lookup table. The inverse distance weighting equation ($w_i = \frac{1}{d_i^p}$) uses an exponent *p* as part of the distance component *d* (the distance between color point *i* and another color point in the color lookup table), which allows the user a great deal of control over the amount of influence the color points have in the color diagram by making adjustments to the exponent *p* with a slider (see Figure 5, right). The Gaussian weighting method $\left(w_i = e^{-kd^2}\right)$, where *d* is the distance and $k = p \cdot 2$, has also been added as an alternative. We multiply *p* by 2 here to make the results appear similar to those of the inverse distance weighting method. We found that, for a color lookup table of 256 by 256 cells, the most useful range of values for *p* for both weighting methods lies between 1 and 5. The red, green, and blue color values for the lookup table cells are computed with the following standard inverse distance weighting equation:

$$rgb = \begin{cases} \dfrac{\sum_{i=1}^{N} w_i(x) rgb_i}{\sum_{i=1}^{N} w_i(x)}, & \text{if } d(x, x_i) \neq 0 \text{ for all } i \\ rgb_i, & \text{if } d(x, x_i) = 0 \text{ for some } i \end{cases}$$

Once the color lookup table has been initialized, it is used to obtain individual pixel colors for the creation of the final image. In order to extract an individual pixel color from the color lookup table, the two corresponding grid values need to be normalized. The normalized grid is computed with $\frac{v - v_{min}}{v_{max} - v_{min}}$, where v is the grid value, and v_{min} and v_{max} are the minimum and maximum values of the grid.

The coloring technique was implemented in prototype software to test the automation and create example maps. The prototype was implemented in Java and has an integrated web browser for selecting and manipulating color reference points, as well as for previewing rendered web map tiles (Figure 5). The prototype software includes the algorithm functionality listed previously (blurring, layer compositing, masking, raster graphics effects, etc.). Masking can be done with the NLCD (Homer et al. 2015) or with other categorical data in raster format. This allows the previously described techniques for creating continuously varying natural colors to be applied to individual layers using specific masks, such as forested, agricultural, and urban areas, while having yet another set of techniques applied to the ground layer. For each layer, the user can create a custom color scheme based on two input grids in the color lookup table or place colors directly on the map. The prototype software also allows the user to output raster web tiles of their naturally colored map.

4 EXAMPLE OUTPUT MAPS

As discussed previously, we are primarily concerned with using our technique to display natural coloring on medium- and large-scale web maps at a global level using two continuous grid datasets (such as elevation and average precipitation) as a proxy for land cover information. This approach can be seen in Figure 6, which shows an area in Oregon. The coloring on this map was created using elevation data from the National Elevation Dataset (National Elevation Dataset 2014), and averaged annual precipitation data from the PRISM Climate Group (PRISM Climate Group 2014). The forested areas and water bodies were masked out using the appropriate categories from the National Land Cover Database (Homer et al. 2015) and colored separately from the ground area. The wetter western side of the state—displayed with more saturated green colors—can be easily discerned from the drier southeastern region—displayed with brighter green for forest and reddish tones for the ground.

This technique can also be used to display seasonal changes in land cover, as seen in Figure 7, which shows a portion of western Colorado. The forest coloring on this map was created using averaged monthly (September–November) precipitation and temperature data from the PRISM Climate Group (PRISM Climate Group 2014). Deciduous and evergreen forests were masked using the appropriate categories from the National Land Cover Database (Homer et al. 2015) and colored separately from one another. The ground area was colored using elevation data from the National Elevation Dataset (National Elevation Dataset 2014), and averaged annual precipitation data from the PRISM Climate Group (PRISM Climate Group 2014). A subtle change in the ground color can be observed from west to east, and snow-capped areas are displayed in white. Deciduous forests undergoing fall leaf color changes—displayed with brownish-orange and yellowish-green autumnal tones—can be clearly distinguished from the deeper green evergreen forests, whose foliage remains unaffected by the change in season.

The coloring technique described in this paper is not limited to natural land cover coloration. It can also be used to show bivariate information based on continuous datasets. This is the case in Figure 8, which shows two maps of the eastern half of Australia. The map on the left is a bivariate map created by Dan Bowles (Bowles 2014). Bowles manually created two custom color ramps in Esri ArcGIS software and manipulated their opacity to create a map showing how mean annual temperature varies with precipitation across Australia (Bowles 2014, D. Bowles, personal communication, October 2014). The map on the right is a bivariate map created with the coloring algorithm and prototype software described in this article. It uses the same temperature and precipitation grid data (Australian Government Bureau of Meteorology 2015), and the same shaded relief (based on NASA SRTM (Shuttle Radar Topography Mission) data (U.S. Geological Survey 2015)) as the map created by Bowles (2014). Both maps show desert and arid areas with rusty orange-brown colors, southeastern forests with cool green tones, and northern tropical savannahs with a warm green-brown shade (colors based on Bowles 2014). Although this is a small-scale example, it shows that the automated coloring algorithm introduced in this paper has the potential to be useful in simplifying the creation of other types of bivariate maps.

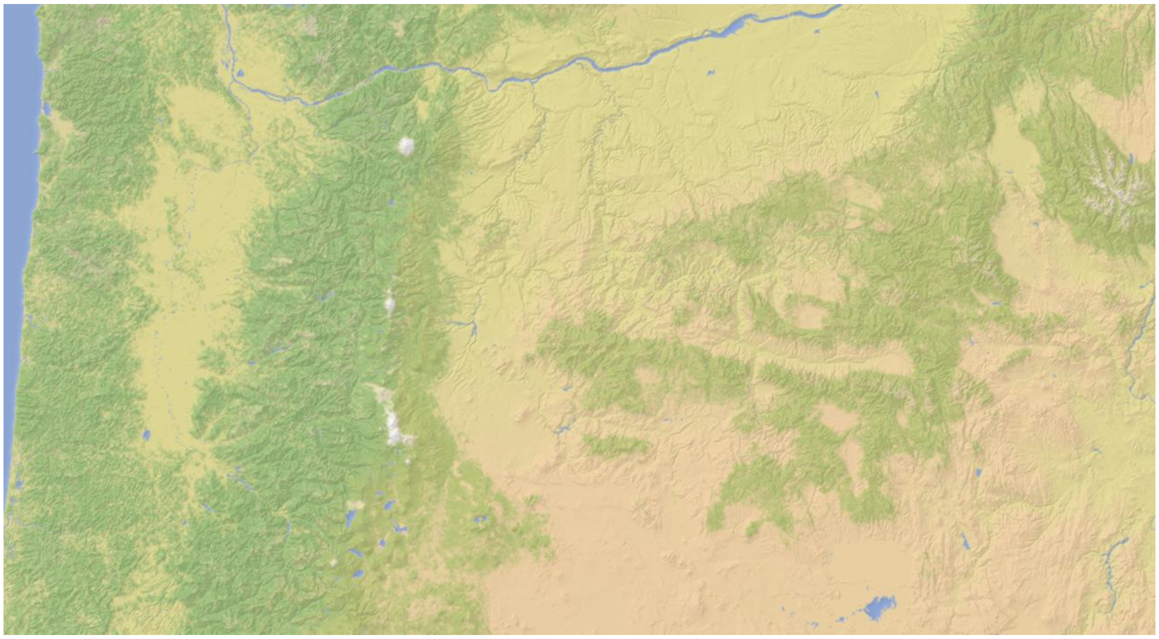

Figure 6. Example output map showing a portion of Oregon with natural colors created with the prototype software.

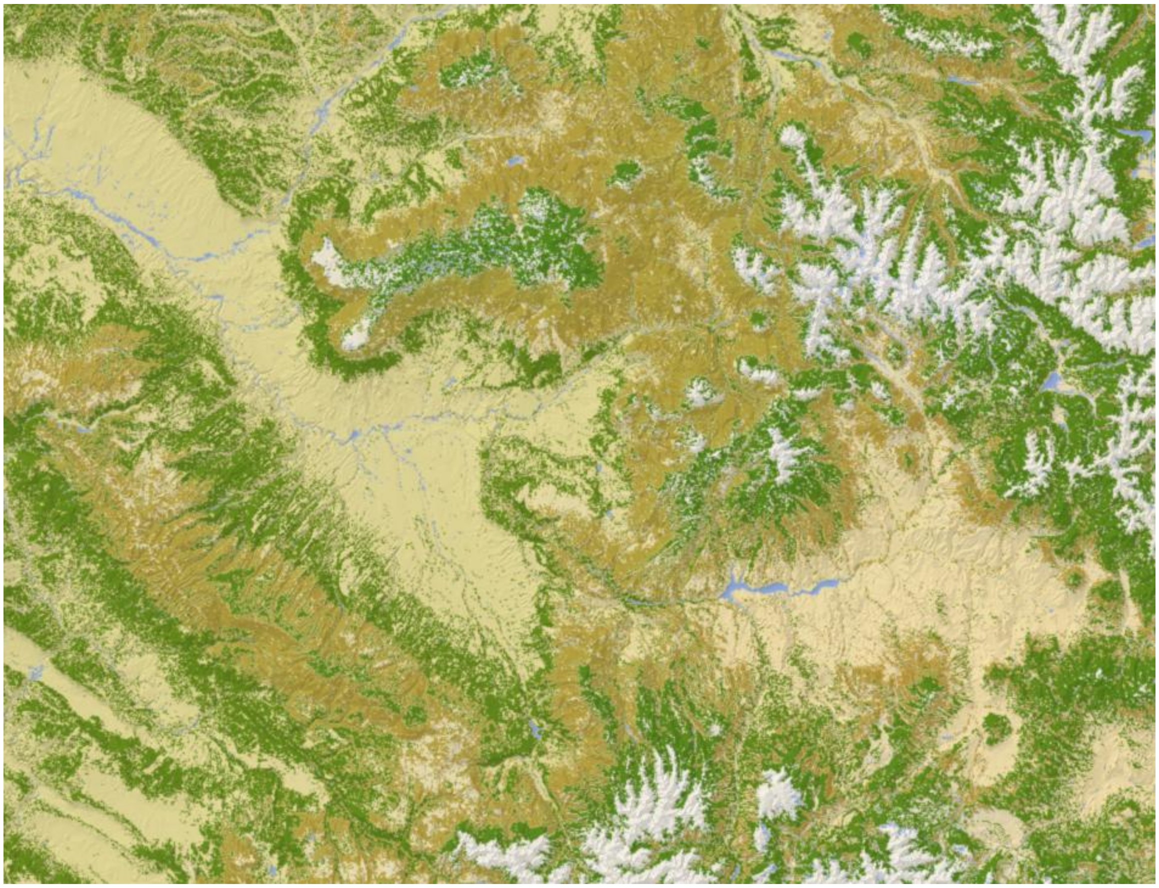

Figure 7. Example output showing fall seasonal color change in the deciduous forests of a region in western Colorado. Deciduous forests undergoing fall leaf color changes are displayed with brownish-orange and yellowish-green autumnal tones, evergreen forests are shown with a deeper green tone.

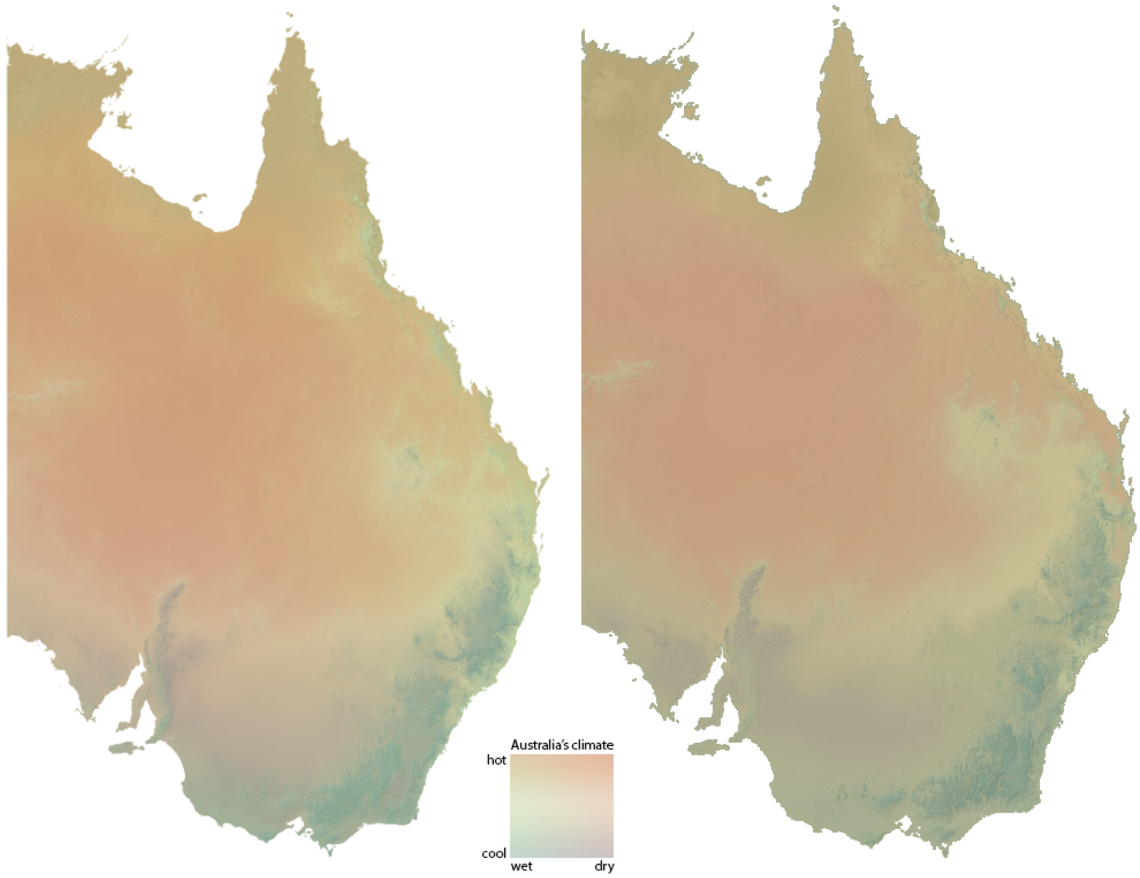

Figure 8. Comparison of two bivariate maps of the eastern half of Australia showing how annual mean temperature varies with precipitation. The map on the left was made using Esri ArcGIS, and the map on the right was created using the algorithm described in this paper. Both maps were based on the same temperature and precipitation grid data. The map on the left and the legend are provided courtesy of Dan Bowles (adapted from Bowles 2014).

5 CONCLUSION

We have created example maps (Figures 6–8) and shown that the proposed technique can successfully create natural-color maps by modulating color with elevation and precipitation as a proxy for natural land cover. Elevation and precipitation data are used because these datasets are readily available in grid format at various scales for many areas, whereas high resolution land cover data is available for some countries, but not at a global scale. This technique can be used to create natural-color web map tiles covering large areas. The color gradients created with the proposed technique vary smoothly with climate zones and are effective at portraying land cover in combination with shaded relief.

The color lookup table and interactive placement of points on the map allow for the quick and easy creation of natural color schemes based on real-world data for medium- and large-scale web maps. The speed and ease with which these natural-color maps can be created makes this style of mapping much more accessible to novice cartographers and people without graphic design software expertise. The prototype software we discuss in this article is available for free download on GitHub (https://github.com/OSUCartography/MapComposer). Additionally, a modified version of the technique presented is available for use in the PyramidShader software package (Eynard and Jenny 2015), which is also available on GitHub (https://github.com/OSUCartography/PyramidShader).

In addition to creating natural map coloring with elevation and precipitation grid data (as shown in Figure 6), the algorithm described in this paper can also be used to display other types of continuous bivariate information (Figure 7). It could also be expanded to include additional grid inputs, which would allow the user to create multivariate map color schemes automatically.

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APPENDIX

Data Pre-processing Requirements for the Prototype Software *MapComposer*

The prototype software described in this thesis is available for free download from GitHub (https://github.com/OSUCartography/MapComposer). However, some data pre-processing is required before the user can create natural color schemes in the software. This appendix provides a list of the basic steps used to format input grid data prior to using it with the prototype software.

Alternatively, we have made a modified version of our coloring method available in the PyramidShader software package (Eynard and Jenny 2015), which is also available on GitHub (https://github.com/OSUCartography/PyramidShader). Using PyramidShader requires much less preparatory data work. The coloring technique in PyramidShader requires two grid datasets that have the same size (columns and rows), cell size, and projection. Both datasets must be in the Esri ASCII grid format (.asc). Shaded relief can also be added to the map. The rest of this appendix details the production of natural-color web map tiles using MapComposer.

Data required

- 2 continuous grid datasets for creating the natural color scheme (such as elevation, precipitation, temperature, etc.) in GeoTIFF format (raster conversion can be done in ArcMap or similar GIS software if necessary)

- DEM (for shaded relief) in GeoTIFF format (raster conversion can be done in ArcMap or similar GIS software if necessary)

Notes

- If the datasets you wish to use are in multiple parts (such as DEM quads), mosaic them into a single GeoTIFF (.tif) raster file in ArcMap or other GIS software.

- Optional: Clip the datasets to the desired extent in ArcMap or other GIS software.

Preparing the data for coloring

The datasets to be used for coloring must be normalized to 0–1. The normalized grid is computed with $\frac{v-v_{min}}{v_{max}-v_{min}}$, where v is a given grid value, and v_{min} and v_{max} are the minimum and maximum values of the grid. Normalization can be done using the Raster Calculator tool in ArcMap, or similar functionality in other GIS software.

Tiling the data

Tiling the data for use in MapComposer requires the use of a customized Python script that uses GDAL (Geospatial Data Abstraction Library). This script is available on GitHub in the MapComposer documentation directory. The script reads in GeoTIFF files and produces BIL (Band Interleaved by Line, .bil) tiles with associated header (.hdr) files. All tiled output is in the Web Mercator projection.

The Python script must be run in a terminal. Some tips for using the script are given below.

- Optional arguments:
    - Limit the zoom level of the tiled output using:
        - -z ‘minimum zoom level’-‘maximum zoom level’
        - For example: `-z 7-10`

    - Adjust the resampling settings using:

- -r with one of the following options:
  average, near, bilinear, cubic, cubicspline, lanczos, antialias
- The default setting (no argument specified) works for continuous datasets, but for categorical datasets like the NLCD, use nearest neighbor to avoid interpolation and preserve the categorical values.
- For example: `-r near`

▪ Example statement for running the script:
  Note: The script will create a new folder to store the tiled data in, which is represented as `outputFolderName` below.

```
python filePath\gdal2tiles4dems_1_0.py filePath\fileToBeTiled.tif
-z 7-10 –r near filePath\outputFolderName
```

Using the processed data in MapComposer

After pre-processing the data as described above, it can now be used in the MapComposer prototype software. Instructions for basic MapComposer functions and use of the coloring technique described in this paper are given below.

To create a new layer: From the Map menu, select ‘Add Layer’ (or click the ‘+’ button above the layer stack pane).

To remove a layer: Select the layer by clicking on it. From the Map menu, select ‘Remove Layer’ (or click the ‘-’ button above the layer stack pane).

To rename a layer: Double click the desired layer in the layer stack. Type in the new name and press the ‘Enter’ key to save changes (changes will not be saved if ‘Enter’ is not pressed).

To create shaded relief: Select a layer to use for shaded relief, and click the Tiles tab. Click the folder icon to browse to the desired (un-normalized) DEM tile set. In the message window that pops up, select ‘grid’ (the ‘image’ setting is for PNG web tiles). If the custom Python script was used to generate the tiles, check the box for TMS (Tile Map Service). If the zoom level range was limited the when generating the tiles, it will be necessary to go to that range of zoom levels to see the tiles in the map preview window.

To create interpolated color: Make a new layer, then click on it the layer name in the layer stack area. Click on the ‘Color’ drop-down menu, select interpolated, and double-click the colored square below it to bring up the color diagram. To specify the pair of datasets to be used, click the Tile Sets button, then click the folder button to browse to the desired set of tiles for each axis of the color diagram. If the custom Python script was used to generate the tiles, check the boxes for TMS. Press ‘OK’. Place the desired colors in the diagram as indicated by the instructions in the window.

To use tiles hosted on the web: Enter the web address into the Tiles tab with the desired layer selected.

To create a mask: Use categorical raster data, such as the NLCD (National Land Cover Database). Follow the data pre-processing steps given previously prior to masking. Select a layer to apply the masking to, and click the Mask tab. Click the folder icon to browse to the desired tile set. If the custom Python script was used to generate the tiles, check the box for TMS. It may be necessary to check the 'Invert' box to get the desired masking effect.

To save and load settings: Go to the File menu and select 'Save Map Settings'. This saves all of the current map document settings as an .xml file. To load saved settings, choose 'Open Map Settings' from the File menu, then navigate to the saved .xml file.

To export web tiles: Go to the File menu and select 'Export Tiles'. PNG web tiles will be exported for all zoom levels (0–22). If the zoom level was set to a limited range when using the custom Python script to generate the input tiles, the custom output tiles will only be visible at the originally specified range of zoom levels (as shown in the map preview window in MapComposer).