GCInsights: Consistency in Pyrocartography Starts With ~~Color~~Colour

Benjamin J. Hatchett[1,2]

[1]Cooperative Institute for Research in the Atmosphere, Colorado State University, Ft. Collins, Colorado, USA
[2]National Oceanic and Atmospheric Administration, Global Systems Laboratory, Boulder, Colorado, USA

Correspondence: Benjamin Hatchett (Benjamin.Hatchett@gmail.com)

Abstract. Fire progression maps provide operational and public information regarding wildland fire spread, size, and proximity to critical assets through time. Cartographic guidance regarding the use of ~~color~~ colour to denote the sequential nature of fire progression is limited, leading to inconsistency in fire progression maps produced for operational, research, and public applications~~. Because this inconsistency potentially limits the~~ , which potentially limit these map's accessibility and ability to effectively communicate information. In this paper, I provide ~~colormap~~ colourmap recommendations to facilitate consistent, intuitive, and accessible fire progression mapping.

1 Introduction

~~Wildland fire's movement~~ The movement of wildland fire across the landscape results from factors including weather, fuels, topography, fire history, and fire suppression activities. The most extreme cases of fire spread occur when strong winds and the orientation of topography align with accumulations of continuous fuels available to burn at high intensity and produce downstream ignitions–spot fires–meters to kilometers ahead of the flaming front. Fire progression maps (FPMs) provide a first-order visualization of a wildfire's current perimeter and spread since ignition (Figure 1). Typically, FPMs are produced daily using aircraft-based infrared data, though near-real estimates are increasingly available using satellite data ~~(Chen et al., 2022; Berman et al., 2023)~~(Chen et al., 2022; Berman et al., 2023; Liu et al., 2024).

Operationally, FPMs assist fire managers in formulating strategies and implementing tactics for achieving desired management outcomes and to understand prior management efforts. Forecast FPMs produced by fire behavior models using existing fire perimeters or ignition locations support fire management by simulating fire spread possibilities and potential smoke production (Kochanski et al., 2023). Public information officers and agency websites (e.g., https://inciweb.wildfire.gov/) ~~,~~ share FPMs with the public, media, and agency partners to provide updates on fire activity and suppression efforts. Researchers and Burned Area Emergency Response teams may use FPMs to evaluate when a particular area burned, since the time of burning in a particular location often does not coincide with the ignition or containment date. Simulated FPMs extend to pre-fire planning efforts to help prioritize fuel management strategies and locations by mapping potential growth given varying treatments and ignition locations. Taken together, the creation and dissemination of FPMs for applications throughout the fire cycle motivates the need for maps that communicate effectively.

2 Current Guidelines, Current Challenges

To provide a basis for consistency in geospatial products during wildfire incidents, the U.S.-based National Wildfire Coordinating Group (NWCG) maintains a set of cartographic standards called the NWCG Standards for Geospatial Operations "GeoOps" (Publication Management System 936) (National Wildfire Coordinating Group, 2024). GeoOps provides guidance on map product standards for wildland fire mapping with two specific recommendations for FPMs. First, it recommends using "standardised" color colour ramps (or colormapscolourmaps) to show trends instead of discrete values when showing more than five time steps. Second, it recommends the standard element of the fire perimeter data for each time period, transitioning from cool (older) to warm colors colours (more recent).

Despite this guidance, at the time of writing, the GeoOps examples demonstrate known challenges in visual communication: the use of inconsistent (i.e., "standardised" is not defined explicitly) , and potentially non-colorsafe colormaps colourmaps that are potentially inaccessible for colour vision deficient users to portray fire progressions (Figure A1). This highlights a missing, but easily remedied, aspect in GeoOps: the recommendation for sets of color-safe colormaps colourmaps that improve accessibility (Crameri et al., 2020; Stoelzle and Stein, 2021) and address 508 Compliance, a U.S. Federal Standard law enacted to create and maintain standards enabling the accessibility of electronic and information technology (i.e., web-based content or multimedia such as portable document formats) to those with disabilities (United States Congress, 1973). Further, the lack of colourmap consistency in FPMs (Figure A1, Chen et al. (2022); Kochanski et al. (2023)cf. Figure A1 and those in Chen et al., 2022, Kochanski et al. 2023, and Liu et al. 2024) represents another potential limiting factor in user cognition for maps already displaying complex information (Bunch and Lloyd, 2006) if the maps change colourmaps change substantially from day-to-day, incident-to-incident, or across applications.

3 Colormap Colourmap Recommendations

Near-daily fire perimeters using airborne infrared data from California's 2013 Rim Fire (17 August–24 October 2013; 104,131 ha) and 2021 Dixie Fire (13 July–27 September 2021; 389,824 ha (fully contained on 25 October 2021)) and 2013 Rim Fire (17 August–24 October 2013; 104,131 ha) serve to demonstrate alternative colormaps colourmaps that address aforementioned limitations (Figure 1 Figures 1 and B1). Perimeter data was acquired from the National Interagency Fire Center (http://www.ftp.wildfire.gov). For clarity, we I omit other standard cartographic elements of FPMs (key geographic features including topography, hydrography, and roads).

Fire progression across space over time is an ordinal process, implying sequential maps (Figure 1e-fa-b) are more logical than diverging maps (Figure 1a-bc). Further, mapping temporal data enhances the complexity of the display, implying the use of diverging colormaps colourmaps to show sequential processes may cause users to misinterpret or miss important changes Buckley (2017)(Buckley, 2017; Crameri et al., 2024). As the GeoOps notes, fire progressions include a thermal component as recently burned areas demonstrate intuitively higher temperatures. This motivates the cool-to-warm sequence, and whether such colormaps colourmaps should preserve intuitive associations (i.e., hot red-to-cool bluecool blue-to-hot red) instead of physically-consistent associations (i.e., black-body emission temperatures) remains open to discussion. Here, we

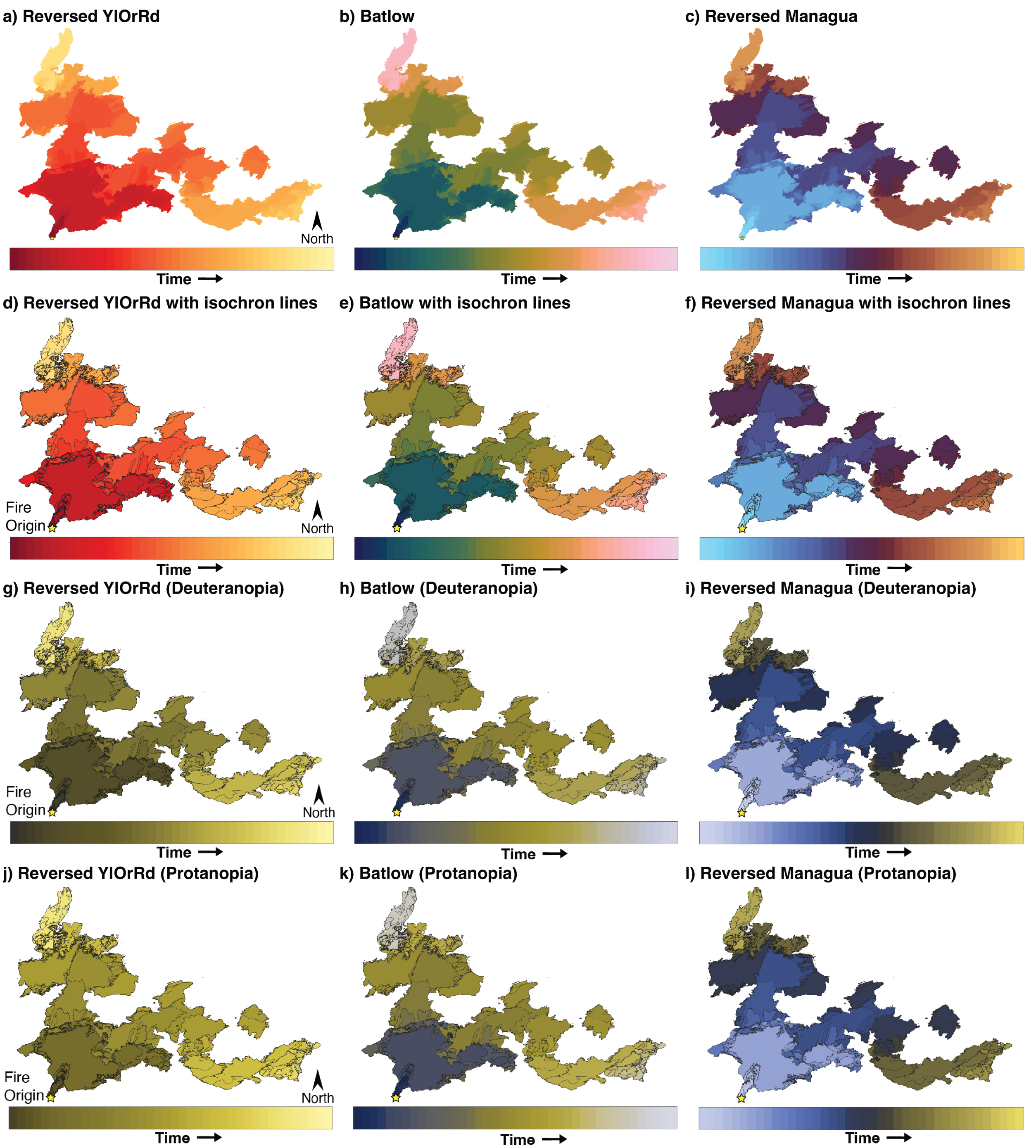

Figure 1. ~~Fire~~ (a-c) Daily fire progression maps of the ~~2013 Rim Fire (left column) and the~~ 2021 Dixie Fire ~~(right column)~~ using ~~colormaps~~ three colourmaps that are accessible for colour vision deficient viewers and ~~simple techniques to increase accessibility~~demonstrate a physically-intuitive sequential progression through time (i.e., older shown by cooler cooler colours and newer by warmer colours. (d-f) As in (a-c) but including isochrons. (g-i) Maps in (d-f) with deuteranopia (green-blind) colour blindness simulation. (j-l) Maps in (d-f) with protanonopia (red-blind) colour blindness simulation. The yellow star denotes the fire origin location.

~~select the colormaps~~ I select the sequential colourmap "~~Batlow~~YlOrRd" ~~and "Managua" from Crameri (2021), the Colorbrewer Brewer et al. (2003) sequential "YlOrBr"~~ (~~yellow-orange-brown~~yellow-orange-red; reversed to mimic the blackbody radiation ~~color curve) , and the perceptually-uniform, hue- and luminance-varying~~ colour curve) from Colorbrewer (Brewer et al., 2003) and the colourmaps "Batlow" and reversed "~~Turbo~~Managua" (Crameri, 2021) as suggested alternatives. While the sequential colourmaps "YlOrRd" and "Batlow" print well in greyscale and are accessible to readers with monochromacy, the diverging "Managua" requires additional annotation (e.g., an origin point and/or labeled isochrons) to orient readers to the correct direction of fire progression (Figure C1). The physically-intuitive nature of "Managua" (cool-to-warm-to-hot) also may allow it to show sequential fire progressions despite being a diverging colourmap and thus an exception to the guidance provided in Crameri et al. (2024).

Beyond intuitiveness, ~~colormaps~~ colourmaps should consider perceptual uniformity and other components of ~~color accessibility (Crameri et al., 2020; Heggli et al., 2023; Ware et al., 2023). Labeling reference~~ visual accessibility such as contrast (Crameri et al., 2020; I . Adding contours (isochrons) could ~~incorporate accessibility if other elements of cartographic representation are desired or once continuous colormaps~~ help enhance accessibility once continuous colourmaps become difficult to interpret (~~Figure 1b,d,f). This latter issue relates to~~ Figures 1d-f and B1d-f); this would address "just noticeable differences" (Ware et al., 2023)–the smallest difference between two ~~colors–as color~~ colours–as colour differences converge towards imperceptibility on long duration (weeks-to-months) wildfires. ~~Multiple days of minimal fireactivity interspersed with occasional rapid growth days or lack of infrared data may warrant situation-specific adjustments to colormaps~~If necessary to highlight important times during the fire, isochrons could be labeled with dates.

~~Rainbow colormaps occur in FPM research (e.g., Chen et al. (2022)) and remain frequently used in scientific literature (Westaway, 2022). While Ware et al. (2023) argue that rainbow colormaps are rightly critiqued by the visualization community, when used appropriately their accessibility limitations can be addressed through better design (e.g., "Turbo"; Figure 1a-b).~~

4 Towards Consistency in Pyrocartography

Globally increasing fire activity (Sayedi et al., 2024) implies FPMs will become more important visual communication aids supporting wildland fire operations, research, and public information. However, accessibility and consistency in visual-product-based science communication is important if improving user cognition and decision making is a goal (Williams and Eosco, 2021; Heggli et al., 2023). Rainbow (or similar, such as the non-perceptually uniform adaptation called "Turbo") colourmaps remain frequently used in scientific literature (Westaway, 2022) and occur in FPM research (e.g., Chen et al., 2022; Liu et al. , 2024). Further, colourmaps displaying similar visualization challenges ("Turbo") are currently recommended for use in operations and public communication in GeoOps (Figure A1d).

Establishing a baseline set of standardised ~~colormaps~~ colourmaps targeting accessibility and consistency in FPMs, especially if incorporated into operational cartographic standards (e.g., as updates to GeoOps; T. Beauchaine, personal communication, November 25, 2024), may benefit users of FPMs before, during, and after wildland ~~fire~~fires. Because many options satisfying these basic criteria exist, I conclude by encouraging the pyrocartographic community to work towards developing a set of standardised colormaps. The four suggested colormaps (Figure 1) , one of which is an example in GeoOps (Figure A1d), colourmaps. Ideally, collaborative efforts between users and producers of FPMs would integrate social science-based methods to robustly identify the needs, preferences, usability and accessibility of maps as informational and/or decision support tools across varied end-user audiences from the general public (e.g., Morrison et al., 2024) to operational fire managers (e.g., Noble and Paveglio, 2020). By providing examples meeting contemporary visualization standards (e.g., accessible for colour-vision deficient users and demonstrating perceptual uniformity in the case of "Batlow" and "YlOrRd") and intending to be intuitive (sequential and physically-consistent with combustion), the three suggested colourmaps (Figures 1 and B1) intend to provide a starting point for such efforts.

Code availability. MATLAB code to reproduce the figures is available upon request.

Data availability. Shapefiles of the Dixie and Rim Fire perimeters is available from the National Interagency Fire Center at: http://www.ftp.wildfire.gov.

Appendix A: NWCG Examples and ~~Colorblindness~~ Colour blindness Simulation

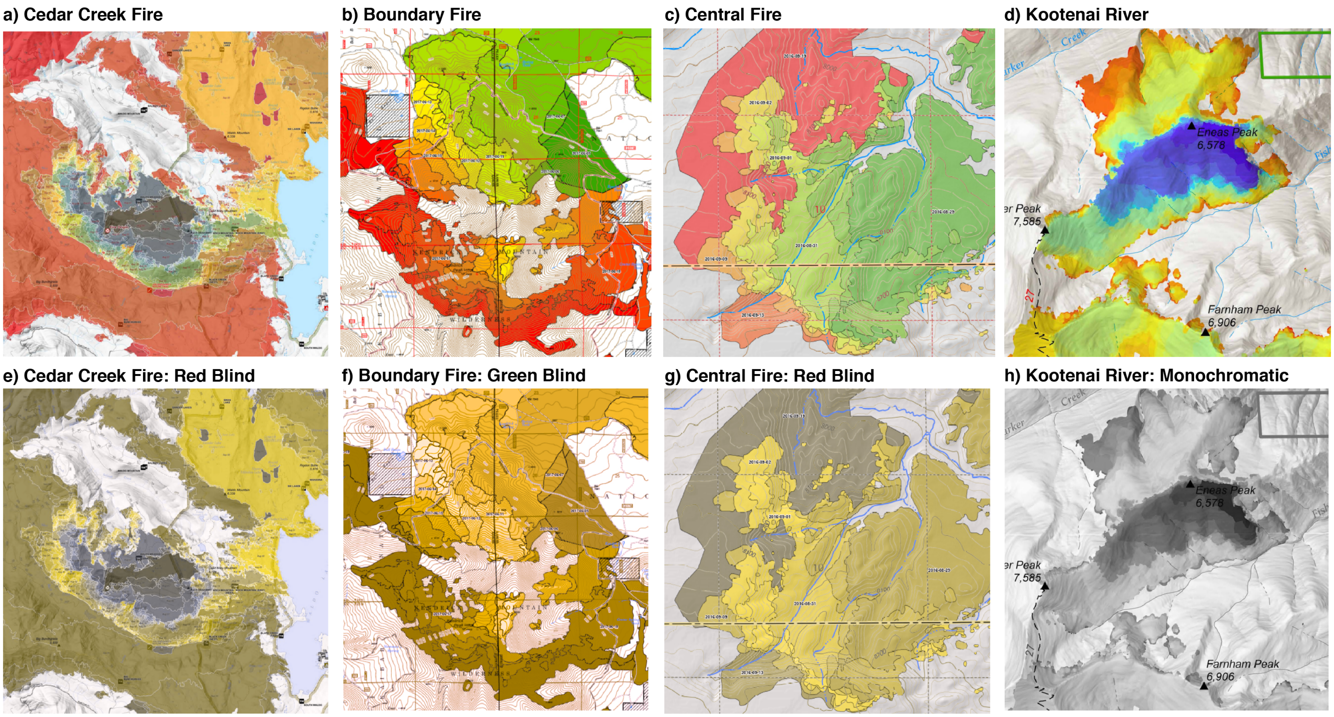

Figure A1. (a-d) The four fire progression examples provided in the NWCG Standards for Geospatial Operations ("GeoOps") Publication Management System 936 document (National Wildfire Coordinating Group, 2024) and accessed on 25 November 2024, reproduced under CC0 (public domain). Legends are omitted for clarity but ~~colors~~ colours progress forwards in time from cold (brown (a), green (b-c), or blue (d); older) to hot (red (a-d); recent). (e-h) The Coblis ~~color~~ colour blindness simulator (https://www.color-blindness.com/coblis-color-blindness-simulator/) demonstrates how these examples create varied ~~colorblindness~~ colour blindness challenges (e-g) or black and white printing challenges (h).

Appendix B: Rim Fire Recommended Colourmaps and Colour Blindness Simulation

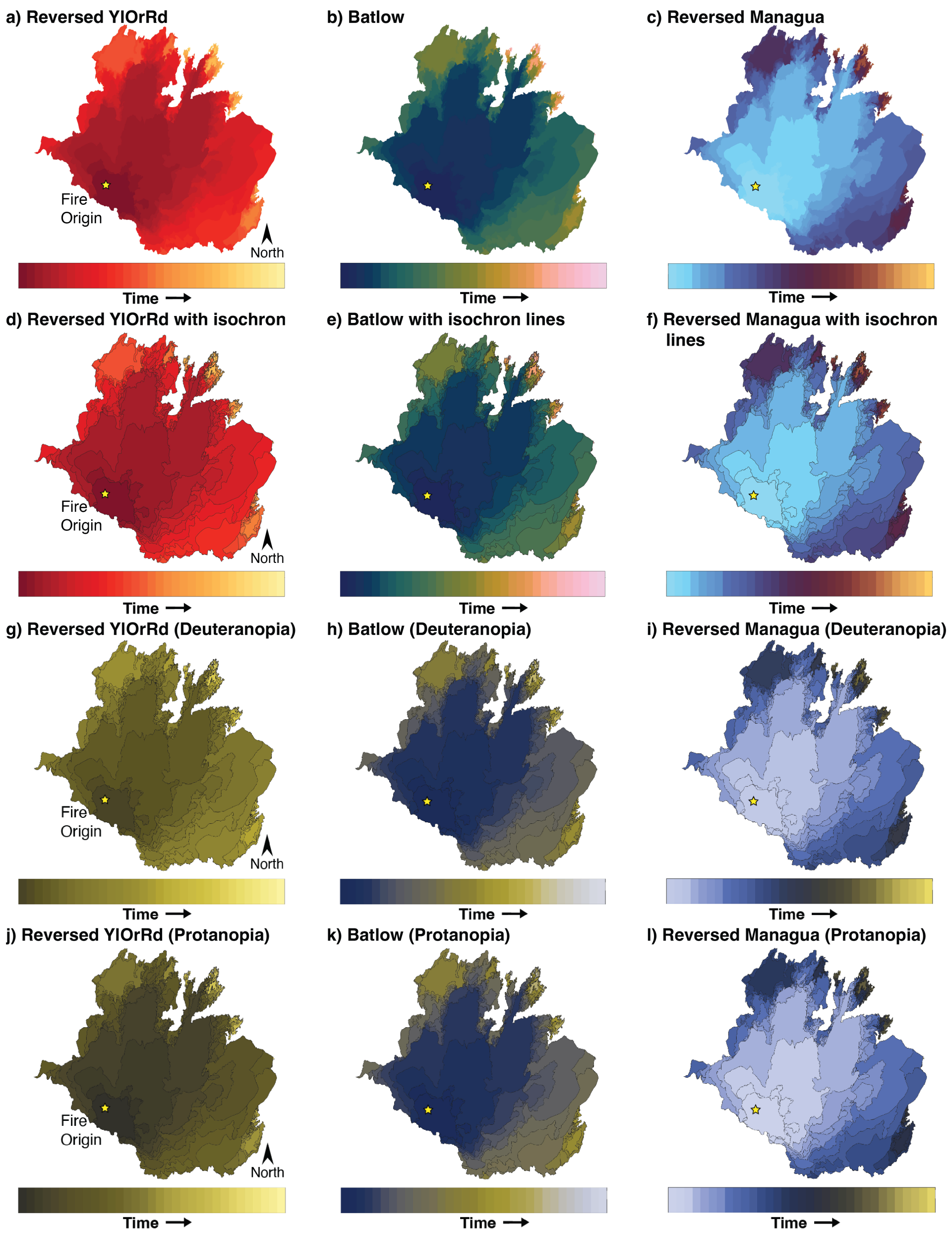

Figure B1. (a-c) Daily fire progression maps of the 2013 Rim Fire using three colourmaps that are accessible for colour vision deficient viewers and demonstrate a physically-intuitive sequential progression through time (i.e., older shown by cooler cooler colours and newer by warmer colours. (d-f) As in (a-c) but including isochrons. (g-i) Maps in (d-f) with deuteranopia (green-blind) colour blindness simulation. (j-l) Maps in (d-f) with protanonopia (red-blind) colour blindness simulation. The yellow star denotes the fire origin location.

Appendix C: Greyscale (Monochromacy) Simulation

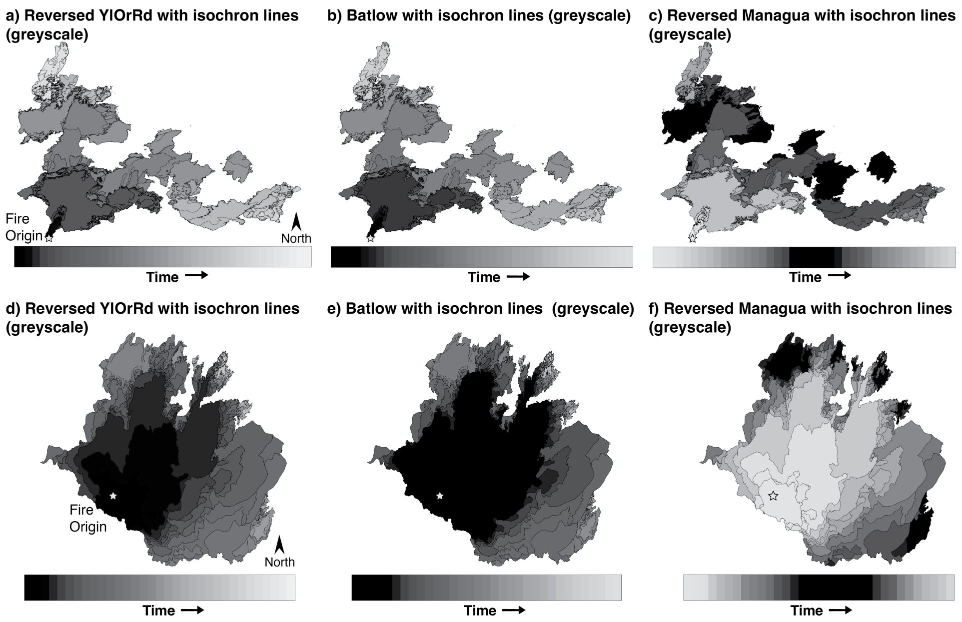

Figure C1. (a-c) Daily fire progression maps of the 2021 Dixie Fire using three colourmaps that are accessible for colour vision deficient viewers and including isochrons shown using greyscale to simulate black and white printing or monochromacy colour blindness. (d-f) As in (a-c) but for the 2013 Rim Fire. The star denotes the fire origin location.

Author contributions. B.J.H. is the sole contributor.

Competing interests. I declare no competing interests.

Ethical statement. No human subjects nor sensitive data were involved in this research, thus no ethics approval or informed consent was sought.

Disclaimer. The statements, findings, conclusions, and recommendations are those of the author and do not reflect the views of NOAA or the U.S. Department of Commerce.

Acknowledgements. This research was supported in part by the NOAA cooperative agreement NA19OAR4320073, for the Cooperative Institute for Research in the Atmosphere. I thank Fabio Crameri and Richard Westaway for providing thoughtful, detailed, and constructive comments that greatly improved this manuscript.

References

Berman, M. T., Ye, X., Thapa, L. H., Peterson, D. A., Hyer, E. J., Soja, A. J., Gargulinski, E. M., Csiszar, I., Schmidt, C. C., and Saide, P. E.: Quantifying burned area of wildfires in the western United States from polar-orbiting and geostationary satellite active-fire detections, International journal of wildland fire, 32, 665–678, https://doi.org/doi:10.1071/WF22022, 2023.

Brewer, C. A., Hatchard, G. W., and Harrower, M. A.: ColorBrewer in print: a catalog of color schemes for maps, Cartography and geographic information science, 30, 5–32, 2003.

Buckley, A.: Methods for Mapping Temporal Data, in: Esri User Conference Technical Workshops, San Diego, California, https://proceedings.esri.com/library/userconf/proc17/tech-workshops/tw_396-490.pdf, 2017.

Bunch, R. L. and Lloyd, R. E.: The cognitive load of geographic information, The professional geographer, 58, 209–220, https://doi.org/https://doi.org/10.1111/j.1467-9272.2006.00527.x, 2006.

Chen, Y., Hantson, S., Andela, N., Coffield, S. R., Graff, C. A., Morton, D. C., Ott, L. E., Foufoula-Georgiou, E., Smyth, P., Goulden, M. L., and Randerson, J. T.: California wildfire spread derived using VIIRS satellite observations and an object-based tracking system, Scientific Data, 9, 249, https://doi.org/10.1038/s41597-022-01343-0, 2022.

Crameri, F.: Scientific colour maps, https://doi.org/10.5281/ZENODO.5501399, 2021.

Crameri, F., Shephard, G. E., and Heron, P. J.: The misuse of colour in science communication, Nature Communications, 11, https://doi.org/10.1038/s41467-020-19160-7, 2020.

Crameri, F., Shephard, G. E., and Heron, P. J.: Choosing Suitable Color Palettes for Accessible and Accurate Science Figures, Current Protocols, 4, e1126, https://doi.org/https://doi.org/10.1002/cpz1.1126, 2024.

Heggli, A., Hatchett, B., Tolby, Z., Lambrecht, K., Collins, M., Olman, L., and Jeglum, M.: Visual communication of probabilistic information to enhance decision support, Bulletin of the American Meteorological Society, 104, E1533–E1551, https://doi.org/https://doi.org/10.1175/BAMS-D-22-0220.1, 2023.

Kochanski, A. K., Clough, K., Farguell, A., Mallia, D. V., Mandel, J., and Hilburn, K.: Analysis of methods for assimilating fire perimeters into a coupled fire-atmosphere model, Frontiers in Forests and Global Change, 6, https://doi.org/10.3389/ffgc.2023.1203578, 2023.

Liu, T., Randerson, J. T., Chen, Y., Morton, D. C., Wiggins, E. B., Smyth, P., Foufoula-Georgiou, E., Nadler, R., and Nevo, O.: Systematically tracking the hourly progression of large wildfires using GOES satellite observations, Earth System Science Data, 16, 1395–1424, https://doi.org/10.5194/essd-16-1395-2024, 2024.

Morrison, R., Kuligowski, E., Dootson, P., Griffin, A. L., Perry, P., Pupedis, G., Begg, C., and Gardner, A.: Understanding the challenges in bushfire map use and effective decision-making amongst the Australian public, International Journal of Wildland Fire, 33, https://doi.org/https://doi.org/10.1071/WF24071, 2024.

National Wildfire Coordinating Group: Standards for Geospatial Operations, https://www.nwcg.gov/publications/pms936, Last Accessed: 2024-11-04, 2024.

Noble, P. and Paveglio, T. B.: Exploring Adoption of the Wildland Fire Decision Support System: End User Perspectives, Journal of Forestry, 118, 154–171, https://doi.org/10.1093/jofore/fvz070, 2020.

Sayedi, S. S., Abbott, B. W., Vannière, B., Leys, B., Colombaroli, D., Romera, G. G., Słowiński, M., Aleman, J. C., Blarquez, O., Feurdean, A., et al.: Assessing changes in global fire regimes, Fire ecology, 20, 1–22, https://doi.org/https://doi.org/10.1186/s42408-023-00237-9, 2024.

Stoelzle, M. and Stein, L.: Rainbow color map distorts and misleads research in hydrology – guidance for better visualizations and science communication, Hydrology and Earth System Sciences, 25, 4549–4565, https://doi.org/10.5194/hess-25-4549-2021, 2021.

United States Congress: Section 508 of the Rehabilitation Act of 1973, 29 U.S.C. section 794d, 1973.

Ware, C., Stone, M., and Szafir, D. A.: Rainbow colormaps are not all bad, IEEE Computer Graphics and Applications, 43, 88–93, https://doi.org/10.1109/MCG.2023.3246111, 2023.

Westaway, R. M.: GC Insights: Rainbow colour maps remain widely used in the geosciences, Geoscience Communication, 5, 83–86, https://doi.org/10.5194/gc-5-83-2022, 2022.

Williams, C. A. and Eosco, G. M.: Is a consistent message achievable?: Defining "message consistency" for weather enterprise researchers and practitioners, Bulletin of the American Meteorological Society, 102, E279–E295, https://doi.org/https://doi.org/10.1175/BAMS-D-18-0250.1, 2021.