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GC Insights: Rainbow colour maps remain widely used in the geosciences

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Abstract. Rainbow colour maps are known to be problematic yet remain widely used in scientific communication. This study extends work by Stoelzle and Stein (2021) to investigate the extent of their use in geoscience publications. It is found that over half (55 %) of all papers surveyed from six geoscience journals from the years 2005, 2010, 2015 and 2020 ($n = 2638$) contained at least one visualisation that uses rainbow or red–green colour schemes and are therefore potentially misleading and colour-inaccessible. Recent changes to the submission guidelines for all European Geosciences Union (EGU) journals would seem to place greater responsibility in the future with editors and reviewers to identify and correct colour issues as part of the review process.

1 Introduction

Data visualisation is a crucial aspect of geoscience communication, and decisions about how colour is used to visualise data are influential in defining which messages are communicated to the reader (Zeller and Rogers, 2020). The availability of low-cost or free programming and visualisation tools, combined with the rise of online delivery, has created much greater freedom in the use of colour to encode maps and graphs in scientific journals. However, the encoding accuracy of colour has been criticised, particularly with respect to the rainbow (or jet) colour map (Rogowitz and Treinish, 1998; Borland and Taylor, 2007; Liu and Heer, 2018; Crameri et al., 2020). In general, these criticisms relate to (i) the concurrent use of red and green, which are hard to distinguish for up to 4 % of the global population with colour vision deficiency (CVD) (Light and Bartlein, 2004; Nuñez et al., 2018), and (ii) its tendency to exhibit non-uniform luminance across its length, which disproportionately, and in some cases misleadingly, draws attention to the yellow and cyan elements (e.g. Rogowitz and Treinish, 1998; Borland and Taylor, 2007; Hawkins, 2018).

While it is now considered best practice to avoid rainbow or quasi-rainbow colour maps (Crameri et al., 2020), they remain widely used in geoscience communication (e.g. McNeall, 2018; Zeller and Rogers, 2020), perhaps in large part due to the "inertia" of scientific communication, where widespread use of rainbow colour maps is a reason why scientists propagate it further (Moreland, 2016). A recent systematic review of around 1000 scientific publications from three different journals by Stoelzle and Stein (2021) concluded that 16 %–24 % of the publications used a rainbow colour map, with a similar proportion (18 %–29 %) using red–green elements without an alternative way of distinguishing them, meaning that approximately one in every two papers has colour issues.

In this study, I adopt a similar approach to Stoelzle and Stein (2021), extending their analysis to other geoscience journals, to investigate the use of rainbow and red–green colour schemes across different geoscience disciplines.

2 Methods

I undertook a manual survey of papers published in four European Geosciences Union (EGU) journals – *Earth System Dynamics* (*ESD*), *Ocean Science* (*OS*), *Solid Earth* (*SE*) and *The Cryosphere* (*TC*) – and one American Geophysical Union (AGU) journal – *Geophysical Research Letters* (*GRL*). For the four EGU journals, all papers published in 2005, 2010, 2015 and 2020 were considered. For *GRL*, a random sample of 200 papers was selected for each of these

years. In total, 1841 papers were surveyed from these five journals. An exact breakdown of how many papers were surveyed from each journal for each year is given in Fig. 1.

Following the approach of Stoelzle and Stein (2021), papers were classified using a four-way classification.

i. Black and white paper with no colour visualisations

ii. No rainbow colour or red–green visualisations or, if used, unambiguous interpretation possible with elements or labelling

iii. At least one visualisation with rainbow-related colouring or red and green elements without an alternative (i.e. non-colour-based) way of distinguishing them

iv. At least one visualisation that uses a rainbow colour map

Subsequently, classes (iii) and (iv) are collectively referred to as papers with colour issues, i.e. those containing ambiguous or non-CVD-friendly visualisations. When combined with the 797 papers surveyed by Stoelzle and Stein (2021) from the EGU journal *Hydrology and Earth System Sciences* (*HESS*), this produced an overall data set of 2638 papers spanning a range of geoscience disciplines.

3 Results

Overall, 34 % of the papers surveyed were found to have at least one visualisation with a rainbow colour map, with a further 21 % containing a figure that used red–green elements. This means that over half (55 %) of all the papers surveyed contained at least one visualisation with colour issues (Fig. 1). Compared to 2005, the number of papers using rainbow colour schemes in 2020 was found to be relatively consistent (31 % in 2020 compared to 29 % in 2005), though the proportion was greater in the intervening years (reaching a maximum of 38 % in 2010). There is a similar pattern when papers containing red–green elements are included, with the total proportion of papers with colour issues increasing from 37 % in 2005 to a peak of 61 % in 2015 before falling slightly to 55 % in 2020.

Comparing across the different journals, *OS* was found to contain the most papers that used rainbow colour maps, with 59 % containing at least one rainbow colour image and 75 % containing visualisations with colour issues. It was found that in every journal considered, except for *HESS* (44 %), over half of all the papers surveyed contained at least one visualisation with colour issues and, even as recently as 2020, more than half of the papers published in *GRL* (59 %), *OS* (76 %) and *SE* (76 %) used rainbow or red–green visualisations. The largest reduction in the use of rainbow colour maps was found to be in *ESD*, in which the proportion of papers containing at least one such visualisation reduced from 33 % in 2015 to 10 % in 2020, albeit based on a smaller sample size than for the other journals ($n = 46$ in 2015; $n = 69$ in 2020).

4 Discussion

Despite widespread recognition of the weaknesses of rainbow colour maps and of the wider issues associated with the use of red–green colour schemes, the results of this study suggest that both continue to be widely used in geoscience publications. The results presented here, in line with Stoelzle and Stein (2021), suggest there was a slight reduction in the use of data visualisations with colour issues in 2020. There are perhaps three main reasons for this. First, awareness of the issues associated with rainbow colour maps has grown. For example, the Crameri et al. (2020) paper "The misuse of colour in science communication" was the second-most downloaded *Life and Biological Science* article published in 2020 from *Nature Communications* (Nature Communications Collection, 2021). Second, more tools and resources have become available to support better decision-making with respect to colour schemes. For example, Stoelzle and Stein (2021) propose four actionable techniques to improve the use of colour in scientific communication, while the Scientific colour maps package (Crameri, 2021) has been downloaded more than 4700 times since 2018, with the latest version (7.0, released in February 2021) accounting for more than half of this total. Third, more journal publishers, editors and reviewers are now identifying colour issues at manuscript submission stage and requesting changes to papers that contain them (see further discussion below). Despite this, over half of the geoscience papers surveyed from 2020 still contain at least one visualisation that was ambiguous or non-CVD-friendly, and any improvement from previous years appears to be uneven across different geoscience journals and so, by implication, across different geoscience disciplines.

The continued proliferation of papers with problematic colour schemes can perhaps be explained, at least in part, by the relative lack of guidance provided by many journals to authors about the use of colour in visualisations. For example, no guidance on the use of colour schemes was found in the "Resources for authors" provided by the AGU for submission to *GRL*, including in its "Graphics requirements" (AGU, 2021), nor in the standard EGU "Manuscript preparation" guidelines used up until 2015 (e.g. *Ocean Science* via the Wayback Machine Web Archive, 2015). In such cases, there is a clear opportunity (and perhaps even obligation) for journal editorial boards and publishers to make authors more aware of colour issues or to go further by specifically advising against the use of rainbow and red–green colour scales in their publications (Stoelzle and Stein, 2021).

From 2015 until 2021, the EGU standard submission guidelines were amended to include advice against parallel usage of red and green in maps and charts (e.g. *Ocean Sci-*

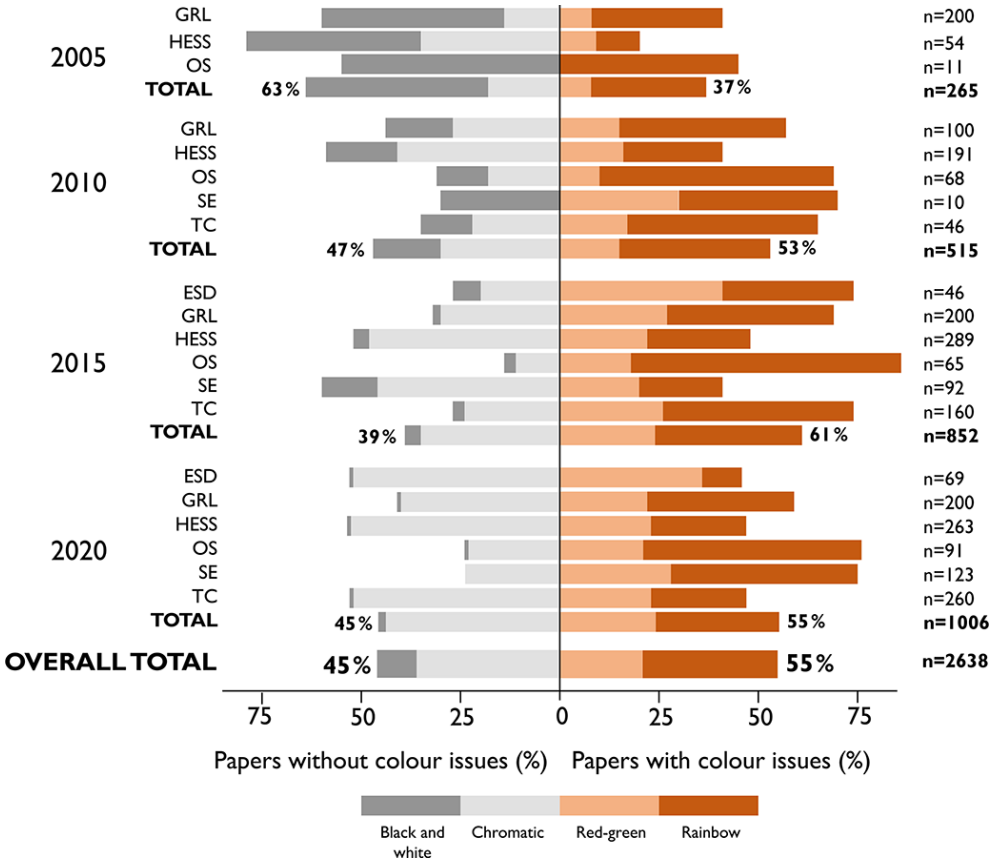

Figure 1. Proportion of papers surveyed with and without colour issues. Journals considered were *Earth System Dynamics* (*ESD*), *Geophysical Research Letters* (*GRL*), *Ocean Science* (*OS*), *Solid Earth* (*SE*) and *The Cryosphere* (*TC*) for the years 2005, 2010, 2015 and 2020. Results obtained by Stoelzle and Stein (2021) for *Hydrology and Earth System Sciences* (*HESS*) are also included.

ence via the Wayback Machine Web Archive, 2021), though this single mention in otherwise lengthy guidance text could have been potentially easily overlooked. The EGU submission guidance was further updated in 2021, with more information and resources presented prominently at the start of the "Figures & tables" section and with consideration of colour schemes included in the "Get ready" submission checklist (e.g. *Ocean Science*, 2021). In addition, authors are asked to confirm during the manuscript submission process that the colour schemes used are accessible to people with CVD. It remains to be seen whether these changes will, in future, result in a reduction in the number of papers in EGU journals containing visualisations with colour issues, but at the very least it would appear to place increased responsibility with editors and reviewers to identify and correct colour issues as part of the review process.

Data availability. The survey data set compiled here is available online at https://doi.org/10.5281/zenodo.5566884 (Westaway, 2021). This data set includes the existing Stoelzle and Stein (2021; https://doi.org/10.5194/hess-25-4549-2021) survey data for *HESS*, which is independently available at https://doi.org/10.5281/zenodo.5145746 (Stoelzle, 2021).

Competing interests. The contact author has declared that there are no competing interests.

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