

# Designing objective figures and avoid color bias in science

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# The challenges of data representation

“Language is inherently biased, but through visualization, we can let the data speak for [themselves]” - Phillip Wolfram

How to avoid misrepresentation ?

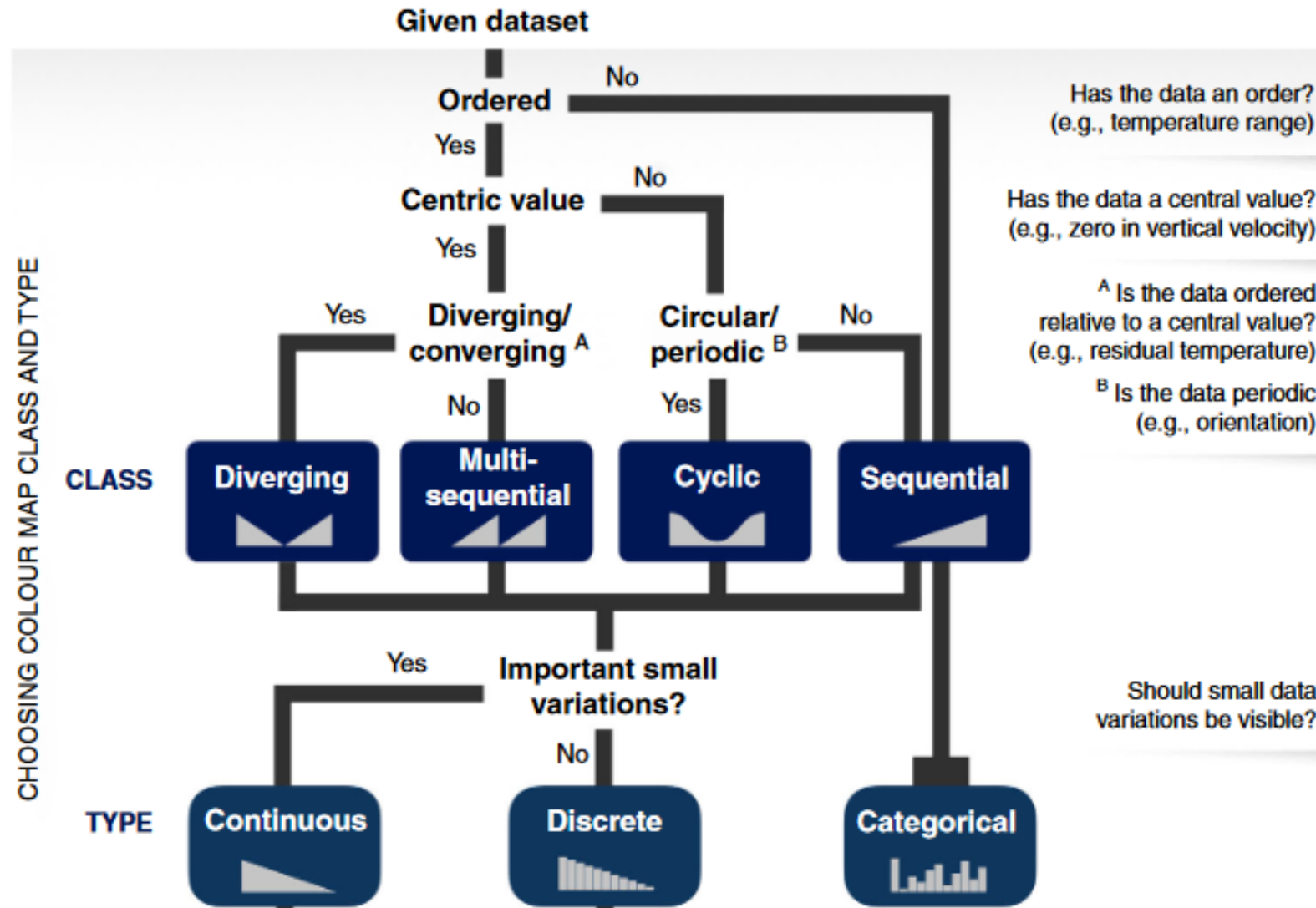
What should a colourmap convey for data representation ?

- Optimize the contrast,
- Provide an objective representation, without blind interpretation,
- Create an intuitive visual order

**1. Choose the type of colourmap according to the type of scalar to be represented**

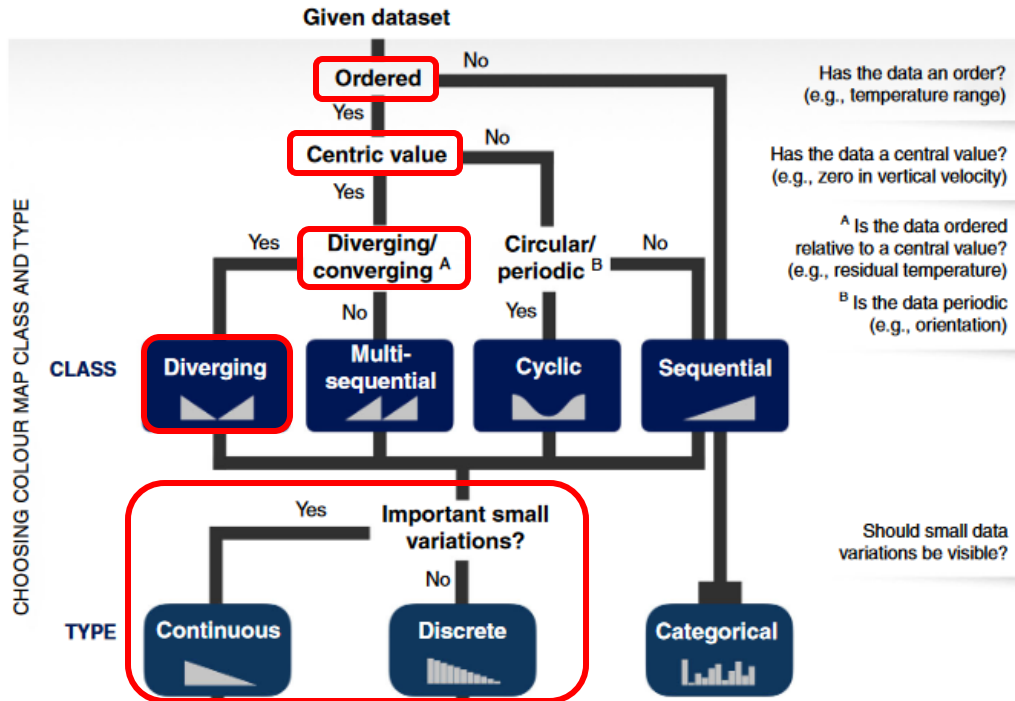
# 1. Choose the type of colourmap according to the type of scalar

Crameri et al.  
The misuse of colour in  
science communication,  
2020

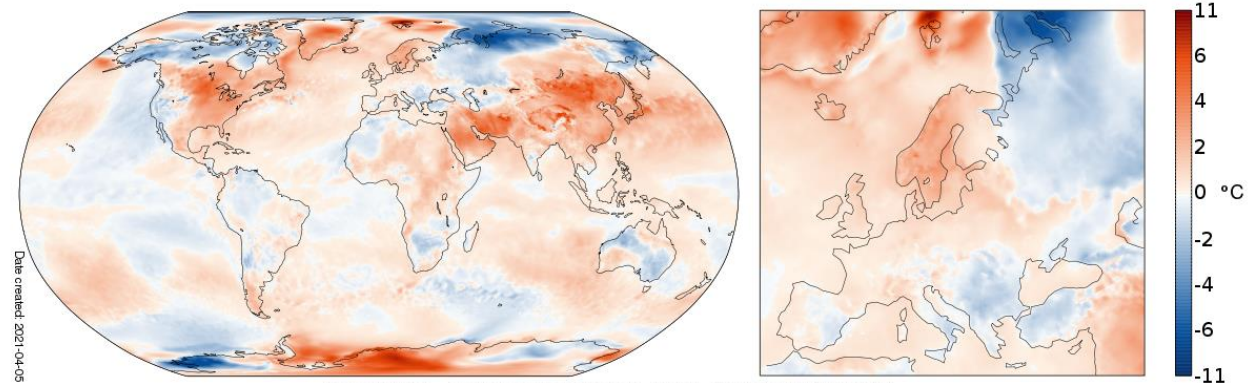


# 1. Choose the type of colourmap according to the type of scalar

Example : temperature anomaly maps



Surface air temperature anomaly for March 2021

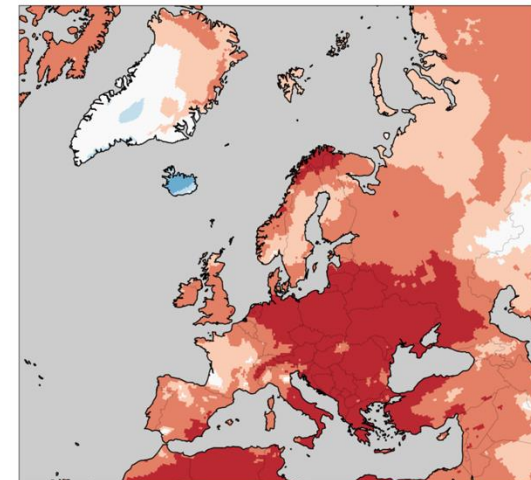


(Data: ERA5. Reference period: 1981-2010. Credit: C3S/ECMWF)



Anomalies and extremes in surface air temperature in 2024

Data: ERA5 (1979-2024) • Reference period: 1991-2020 • Credit: C3S/ECMWF

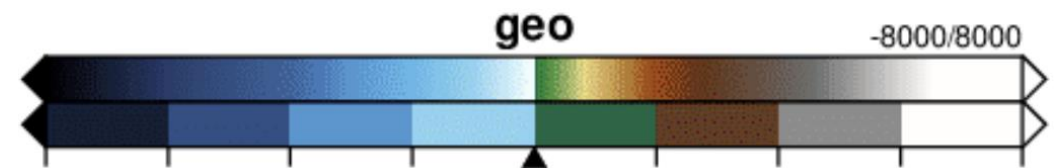
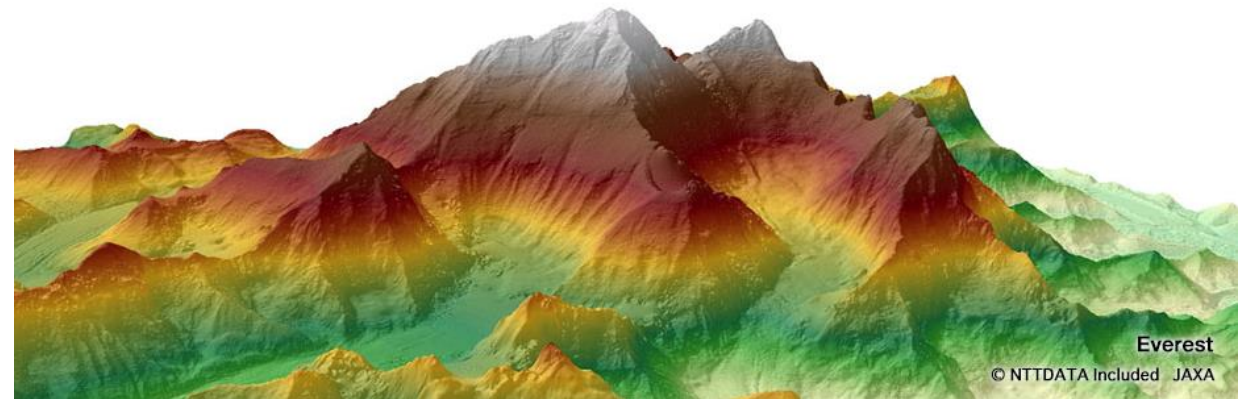
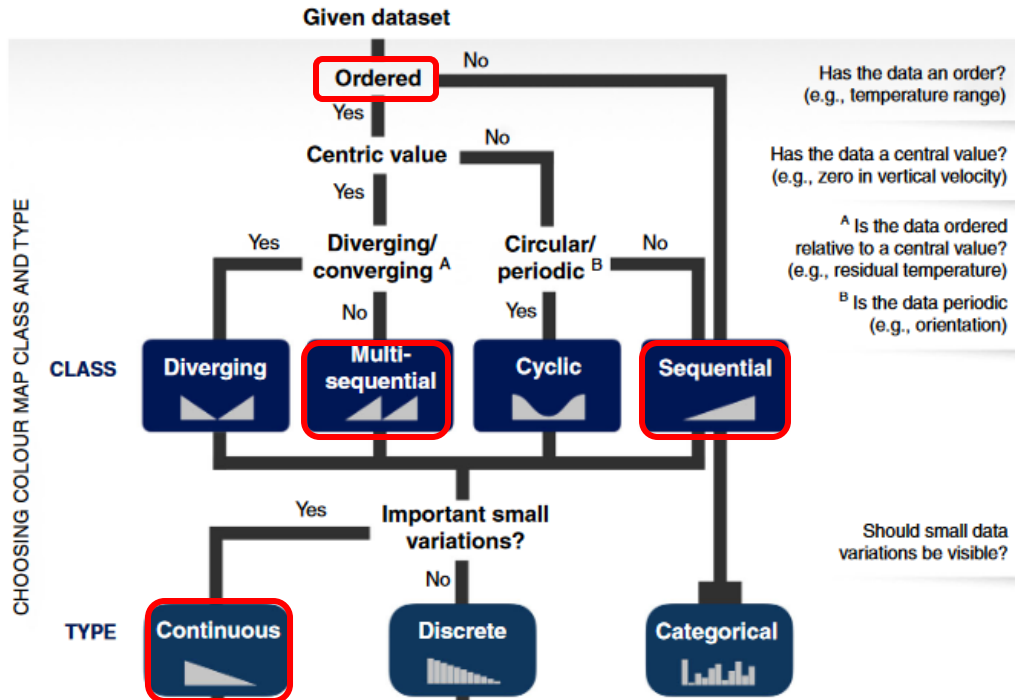


Coolest Much cooler than average Cooler than average Near average Warmer than average Much warmer than average Warmest



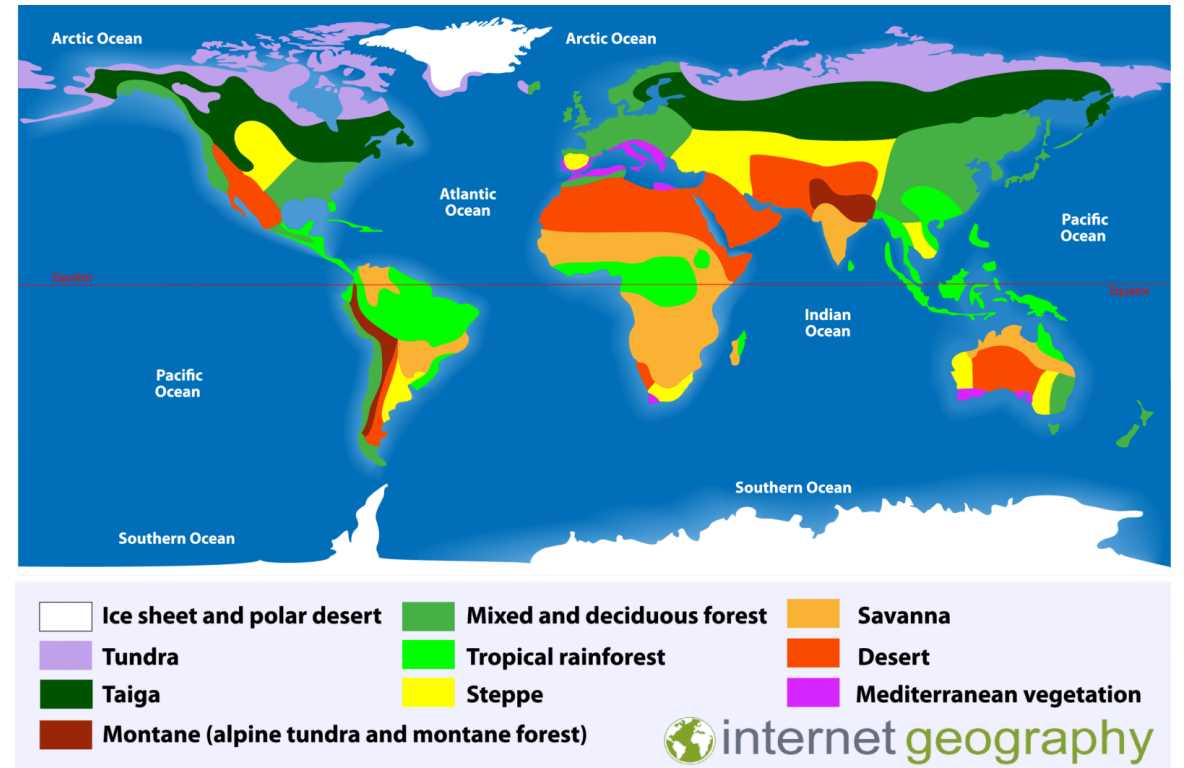
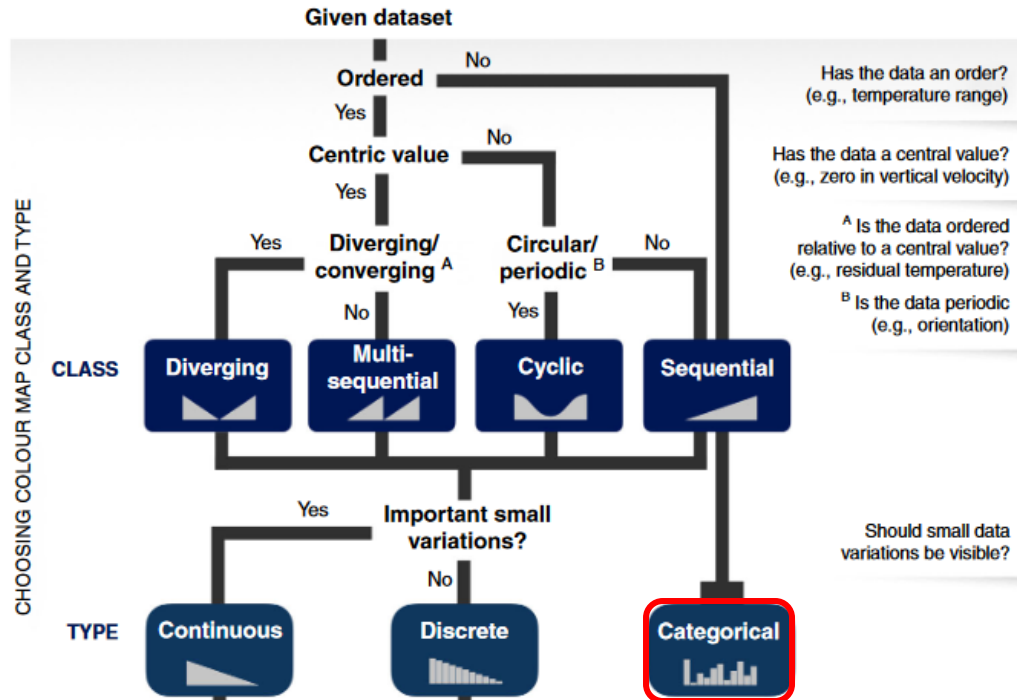
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Example : Digital Elevation Model



# 1. Choose the type of colourmap according to the type of scalar

Example : Global map of biomes



## **2. What colours ?**



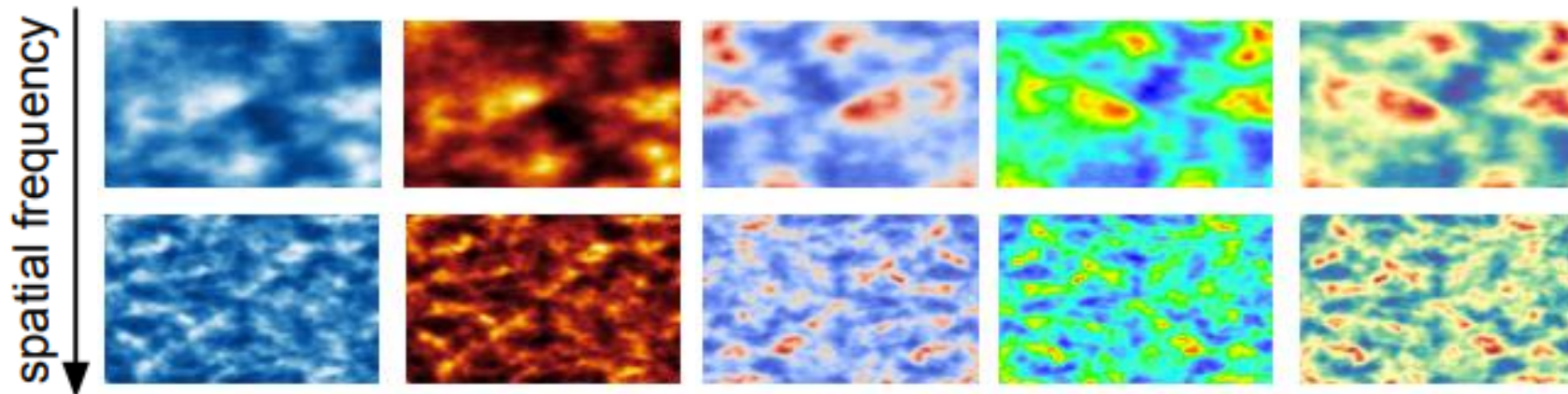
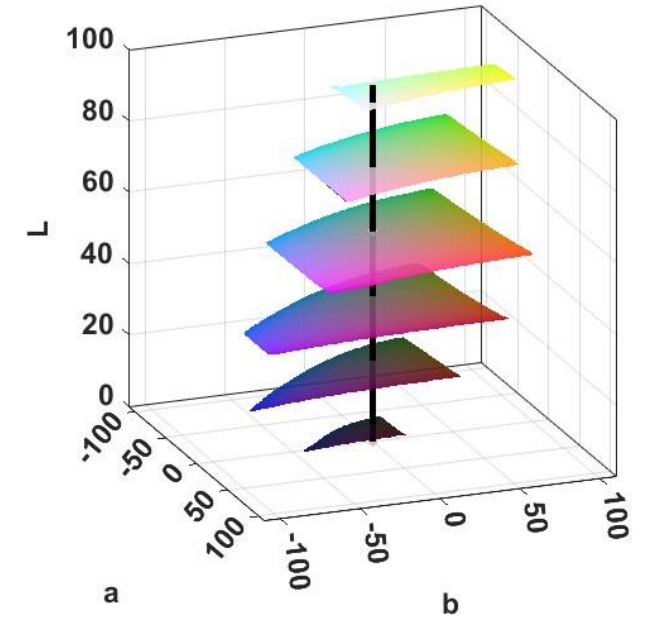
## 2.1. Optimize the contrast

- Two colours are clearly distinguishable if they are separated by more than 40 units in the CIELab colour space.

(Carter and Carter, 1982)

- For quantity estimation, use colourmap with hue changes.
- For pattern and gradient perception, especially for high frequency data, use colourmap with luminance changes.

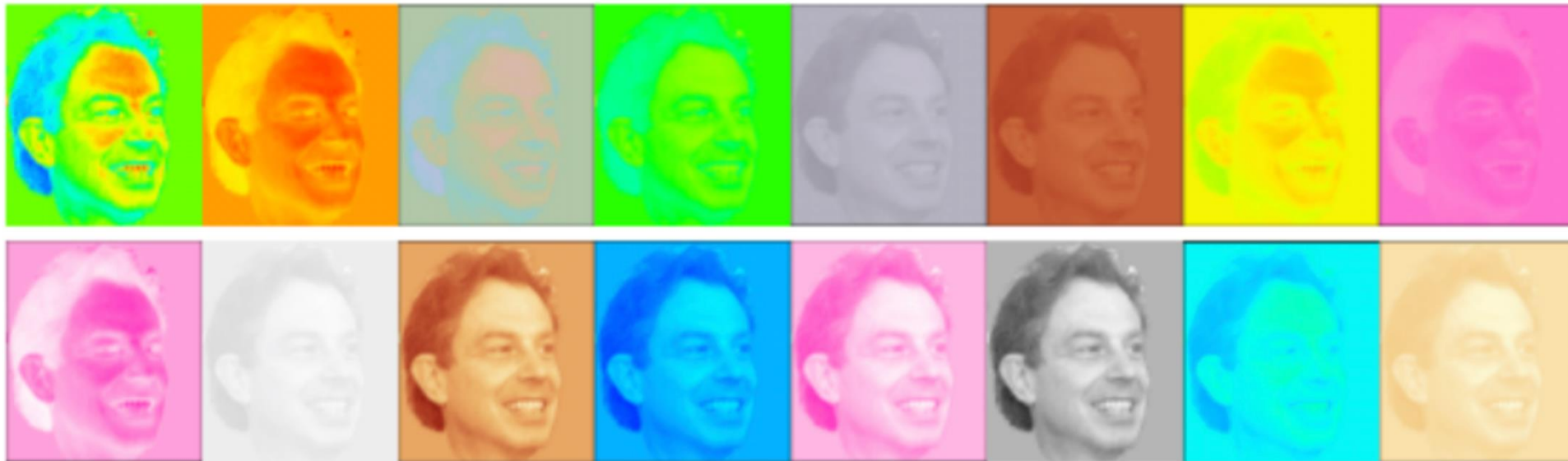
(Reda et al., 2018, Kovesi, 2015)

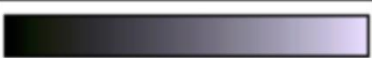









## 2.2. Convey order

The human eye is sensitive to changes in luminance to convey order.

Use colourmap with monotonic and linear increase in luminance.



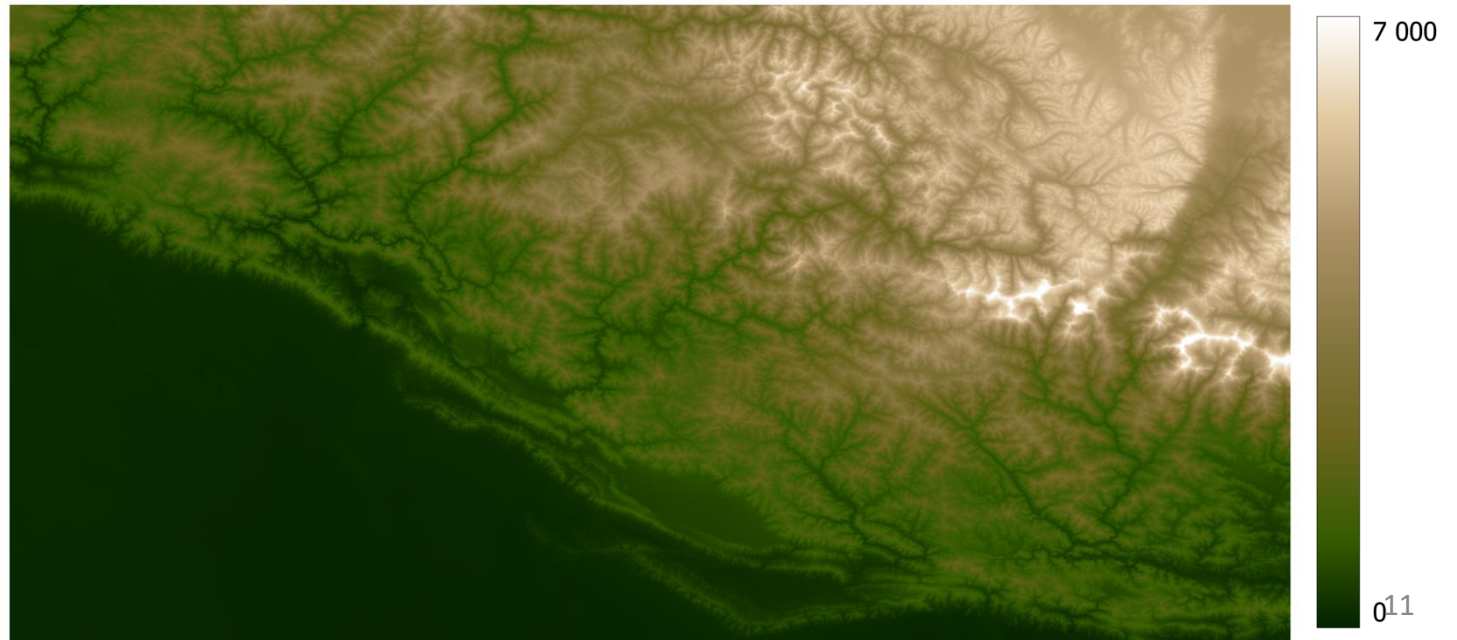
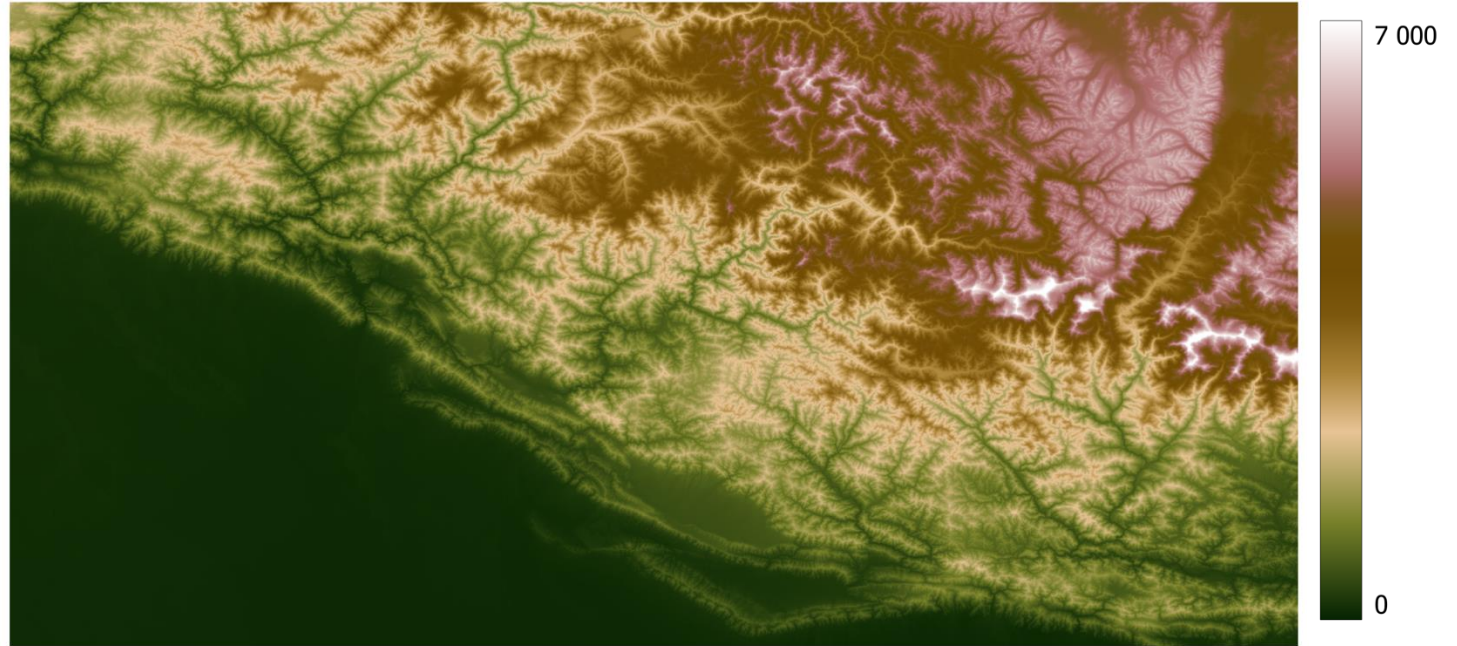
			
LAB Grayscale	Heated Body	Isoluminant Rainbow	Rainbow
			
HSV Grayscale	HSV Saturation (increasing)	HSV Saturation (decreasing)	LAB Isoluminant Saturation

Rogowitz et al. The « Which Blair Project »: a quick visual method for evaluating perceptual color maps. 2001

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Use colourmap with monotonic and linear increase in luminance.



SRTM DEM, Nepal

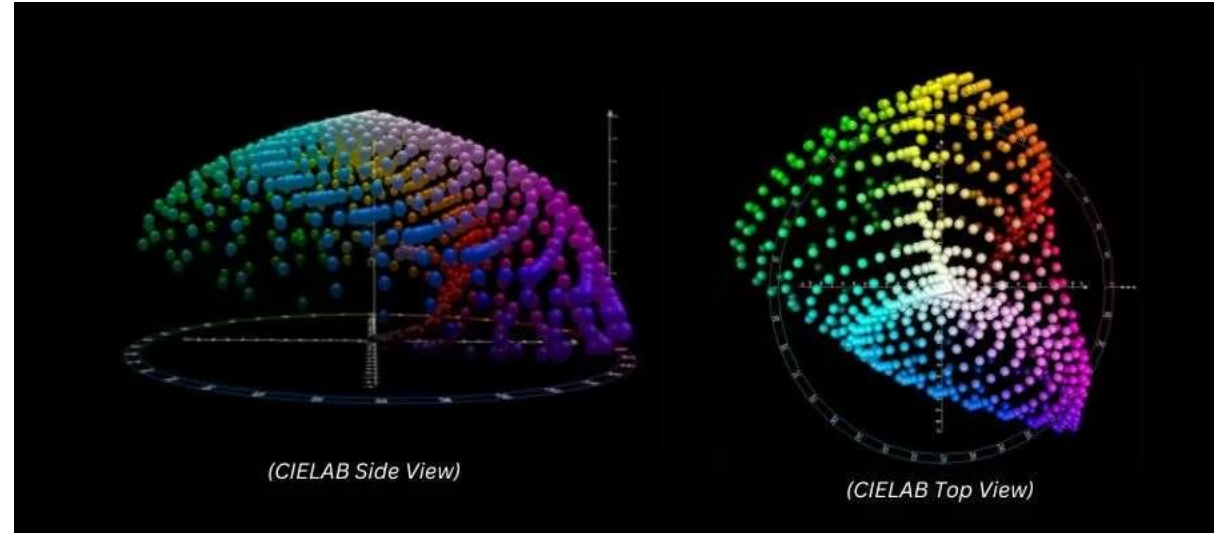
### **3. Avoid bias in the representation**

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2 types of color spaces :

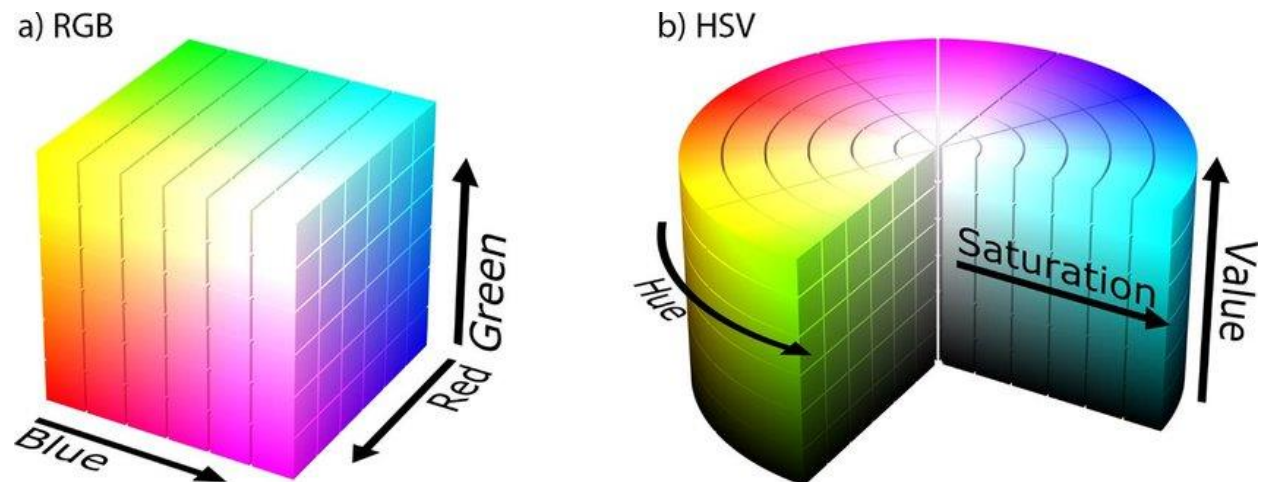
#### Absolute

- Based on human perception
- Perceptually uniform: equal distances in space are perceived as equal changes in colours



#### Non-absolute

- Based on devices (cameras, printers...)
- Non perceptually uniform

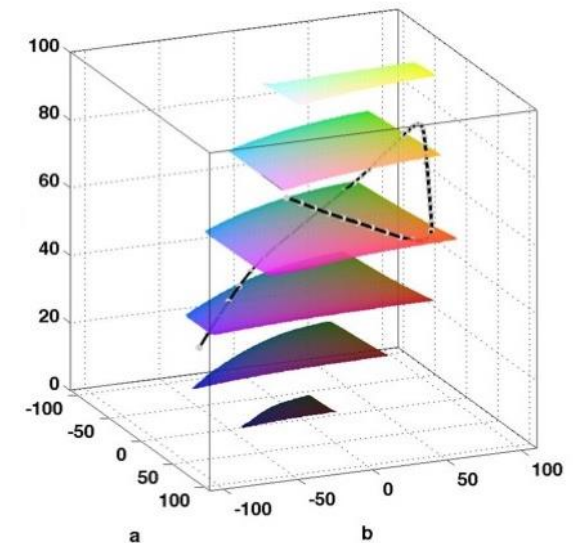
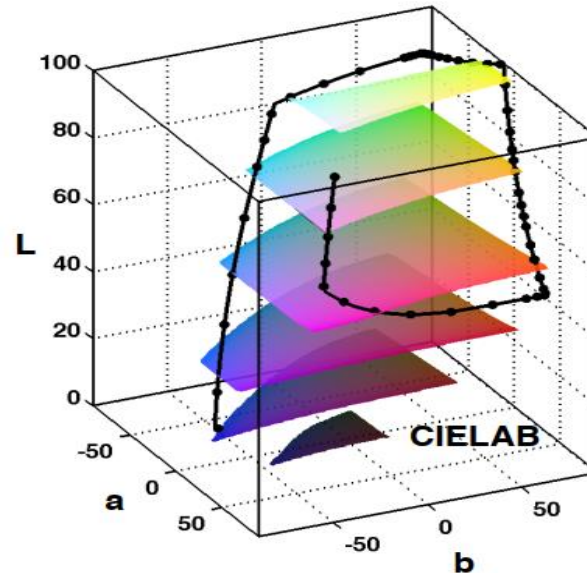
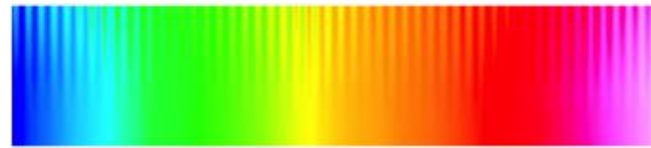
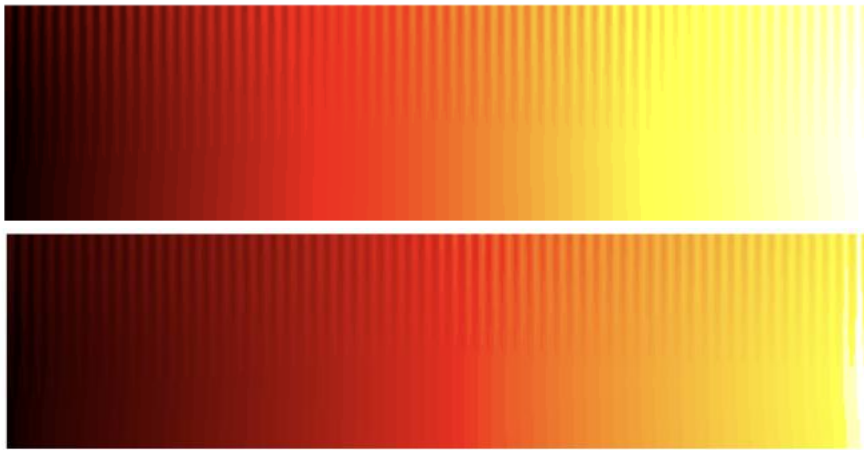


### 3. Avoid bias in the representation

Perceptually uniform colourmaps are defined such that equal steps in data are perceived as equal changes in colours.

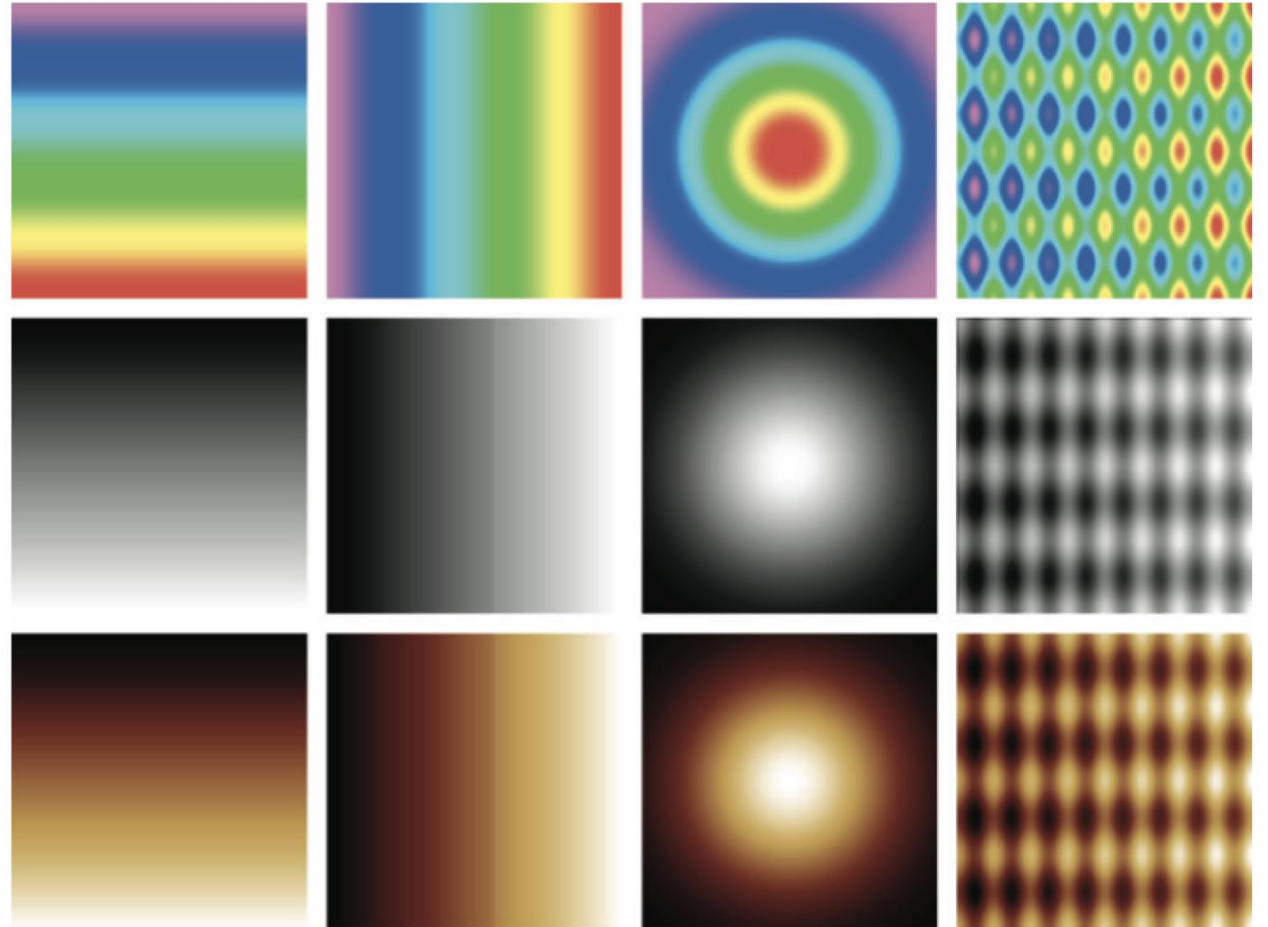
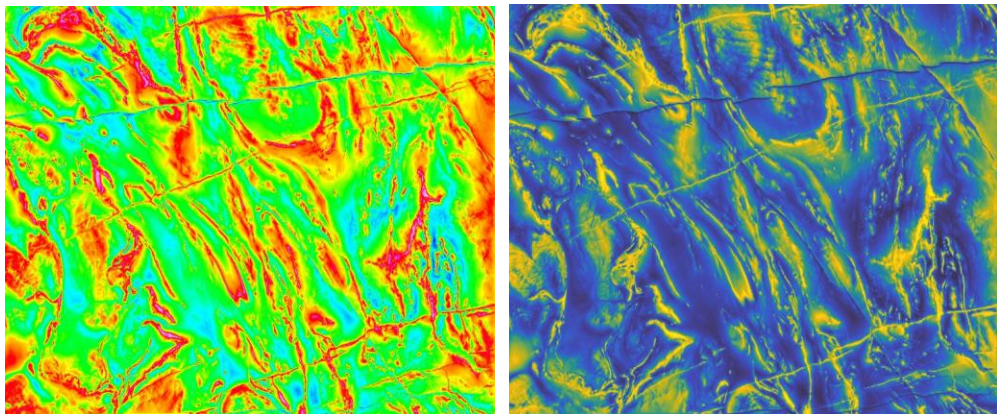
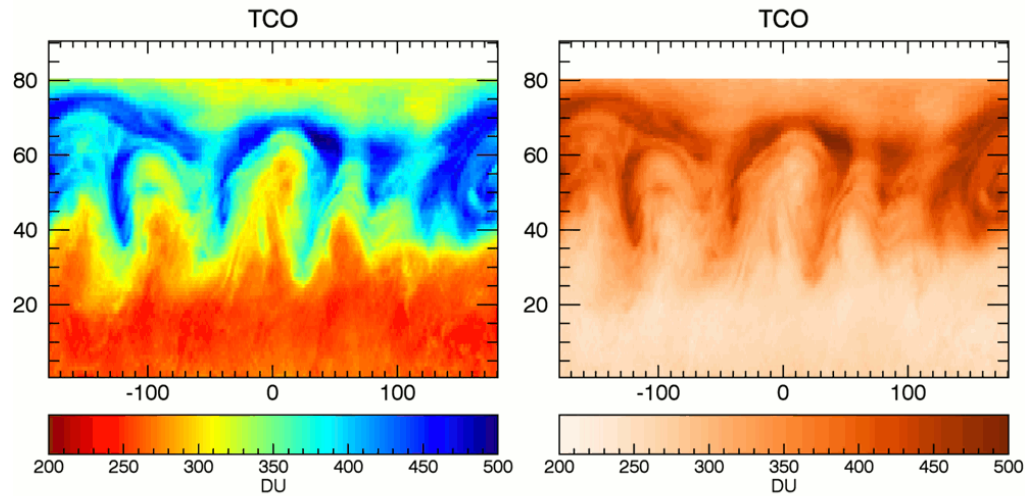
They prevent segmentation or concealed variations in the data representation.

They are built from a linear interpolation of dots on a path through an absolute colourspace.



### 3. Avoid bias in the representation

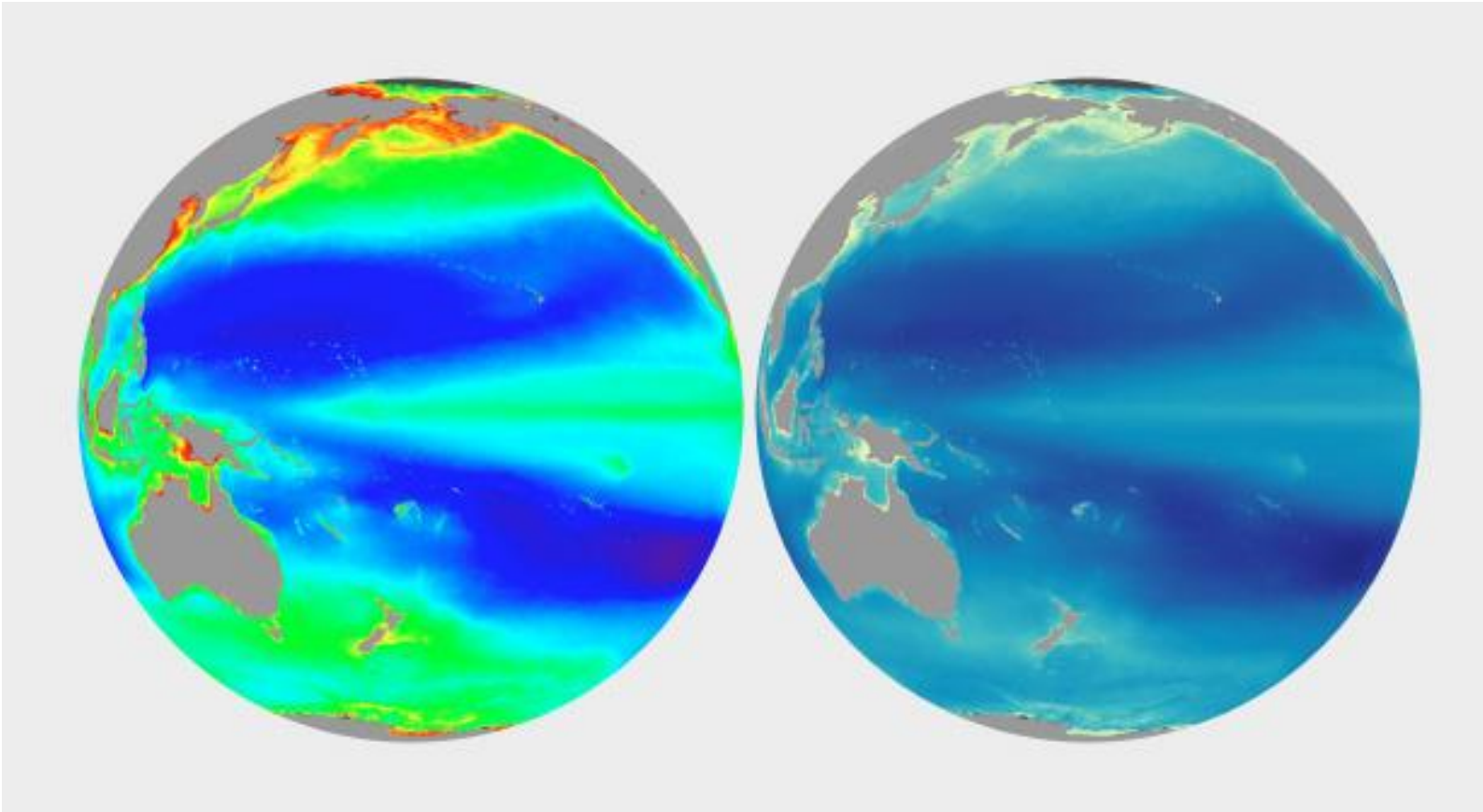
The rainbow colourmap is often used by default in software. It must be banned as it is non-uniform.



### 3. Avoid bias in the representation

The rainbow colourmap is often used by default in software. It must be banned as it is non-uniform.

map of ocean phytoplankton distribution



The Original Default "Rainbow (Jet)" Colormap



The Recent Default "Viridis" Colormap



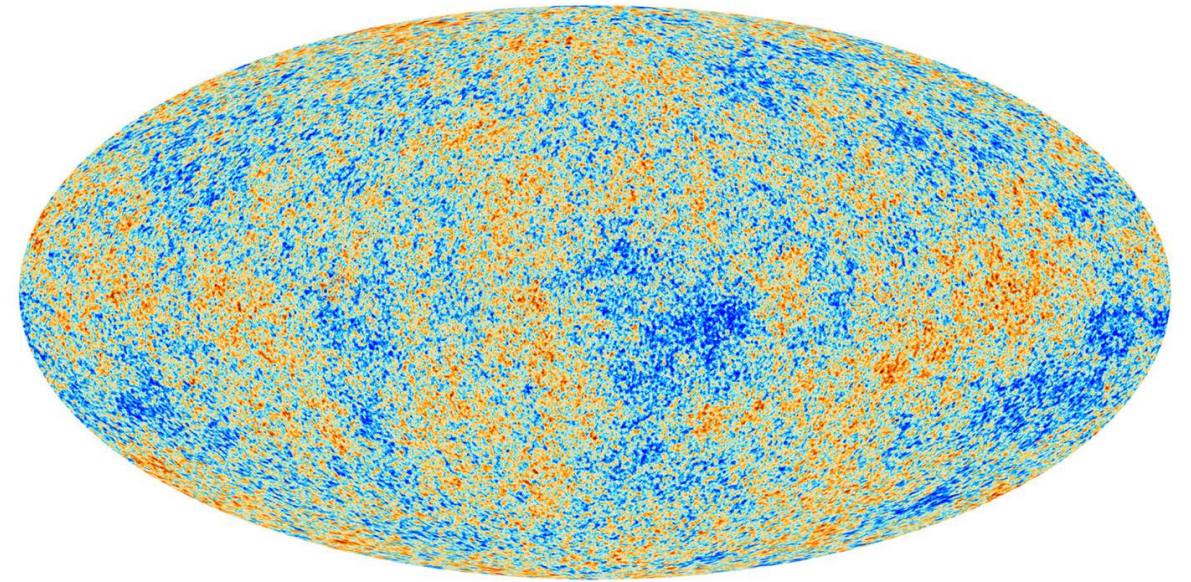
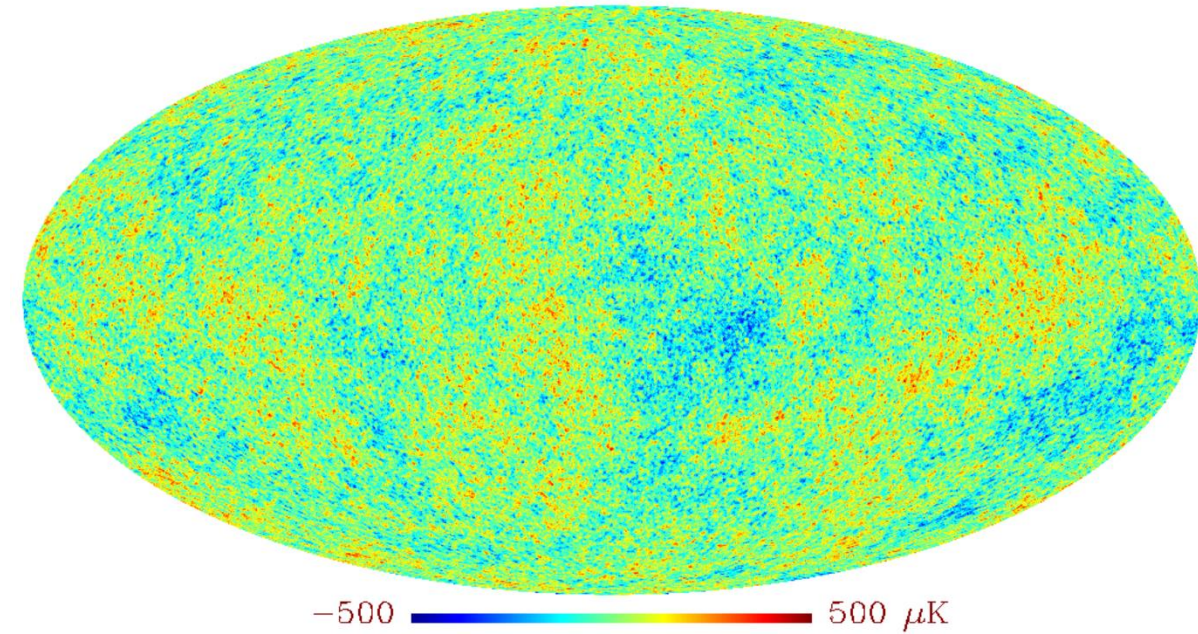
NASA



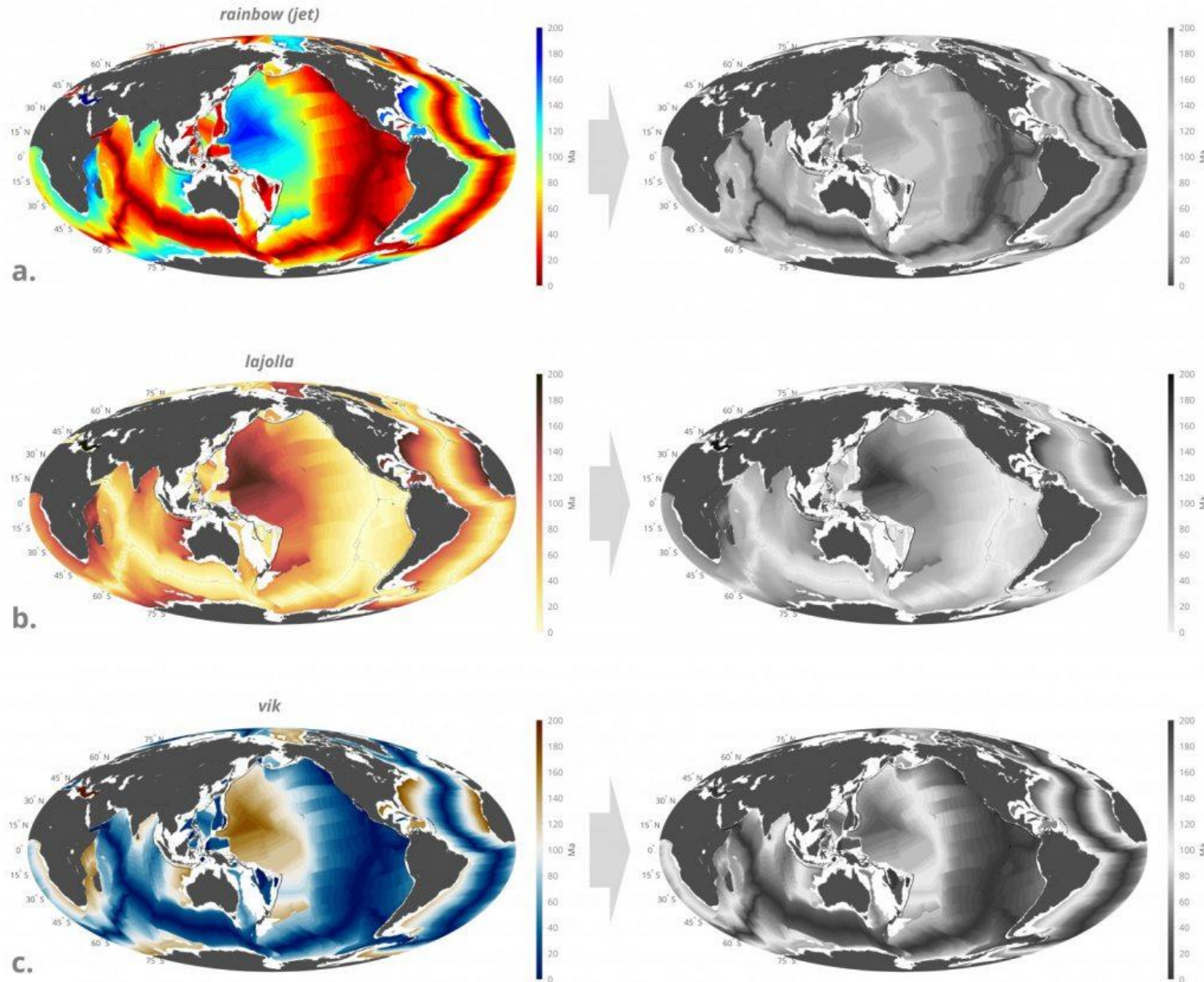
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CMB map



### 3. Avoid bias in the representation



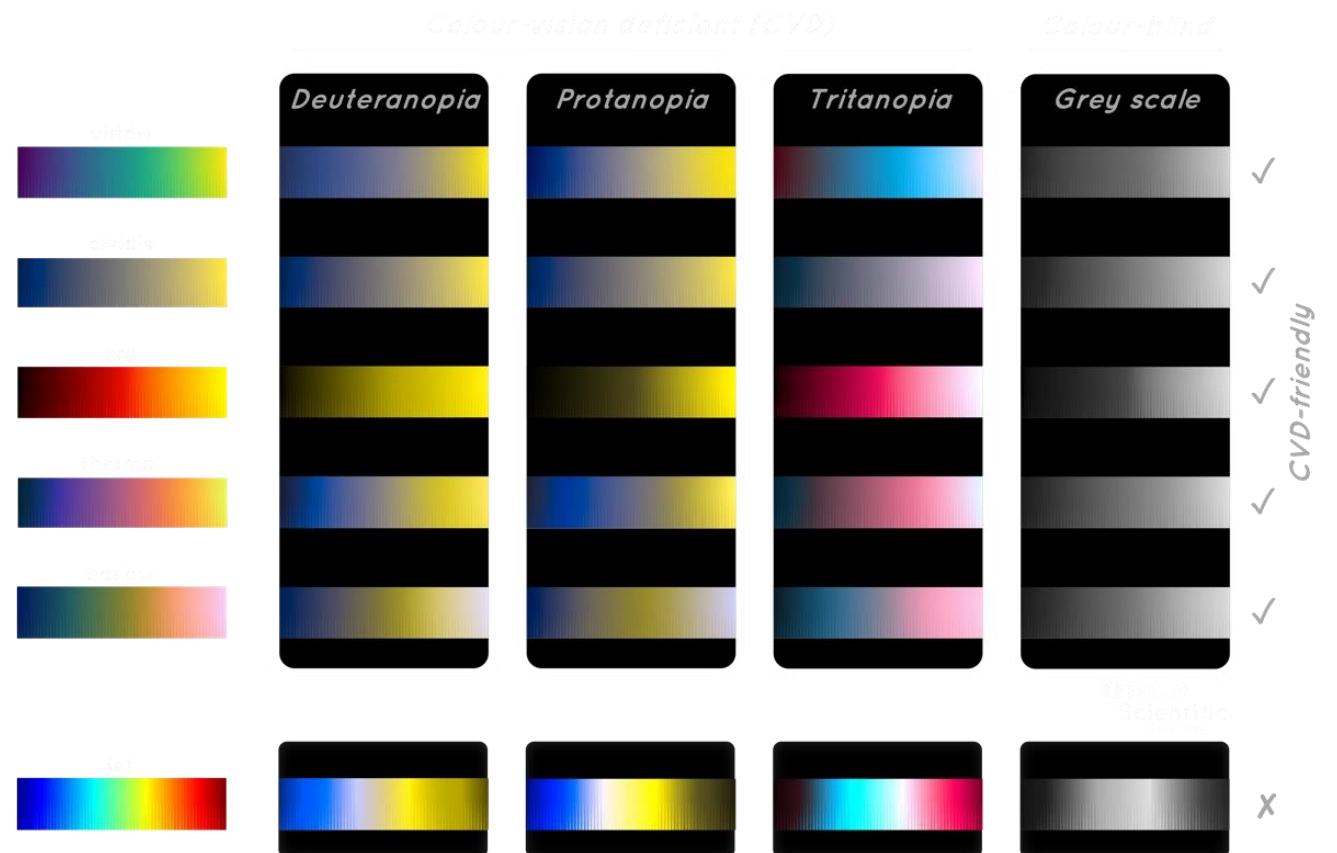
Always keep in mind that the figures you publish may be printed in black and white.

## 4. Consider color vision deficiencies

- Red and green are difficult to differentiate for most of the blind people.
- Use blue and yellow instead.
- Online tools can help you check that your colourmap is suitable for them.

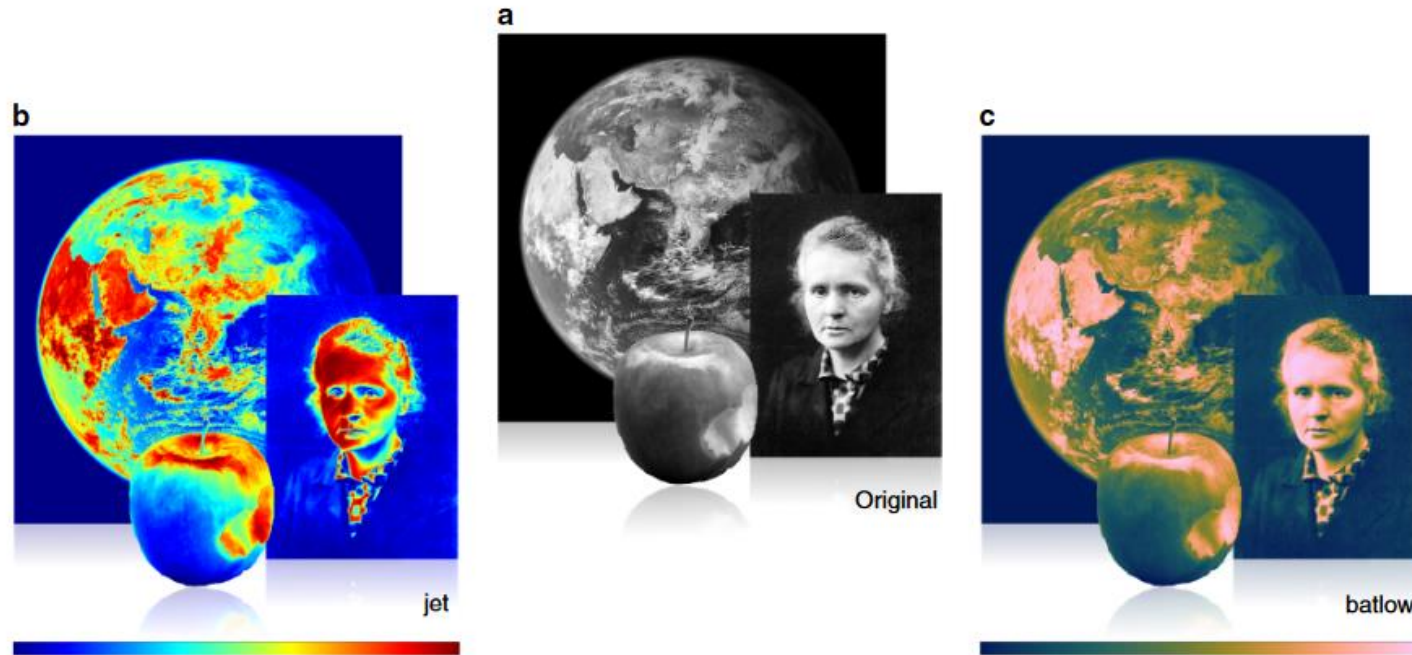
<https://davidmathlogic.com/colorblind/>

<https://www.fabiocrameri.ch/colourmaps/>



# Conclusion

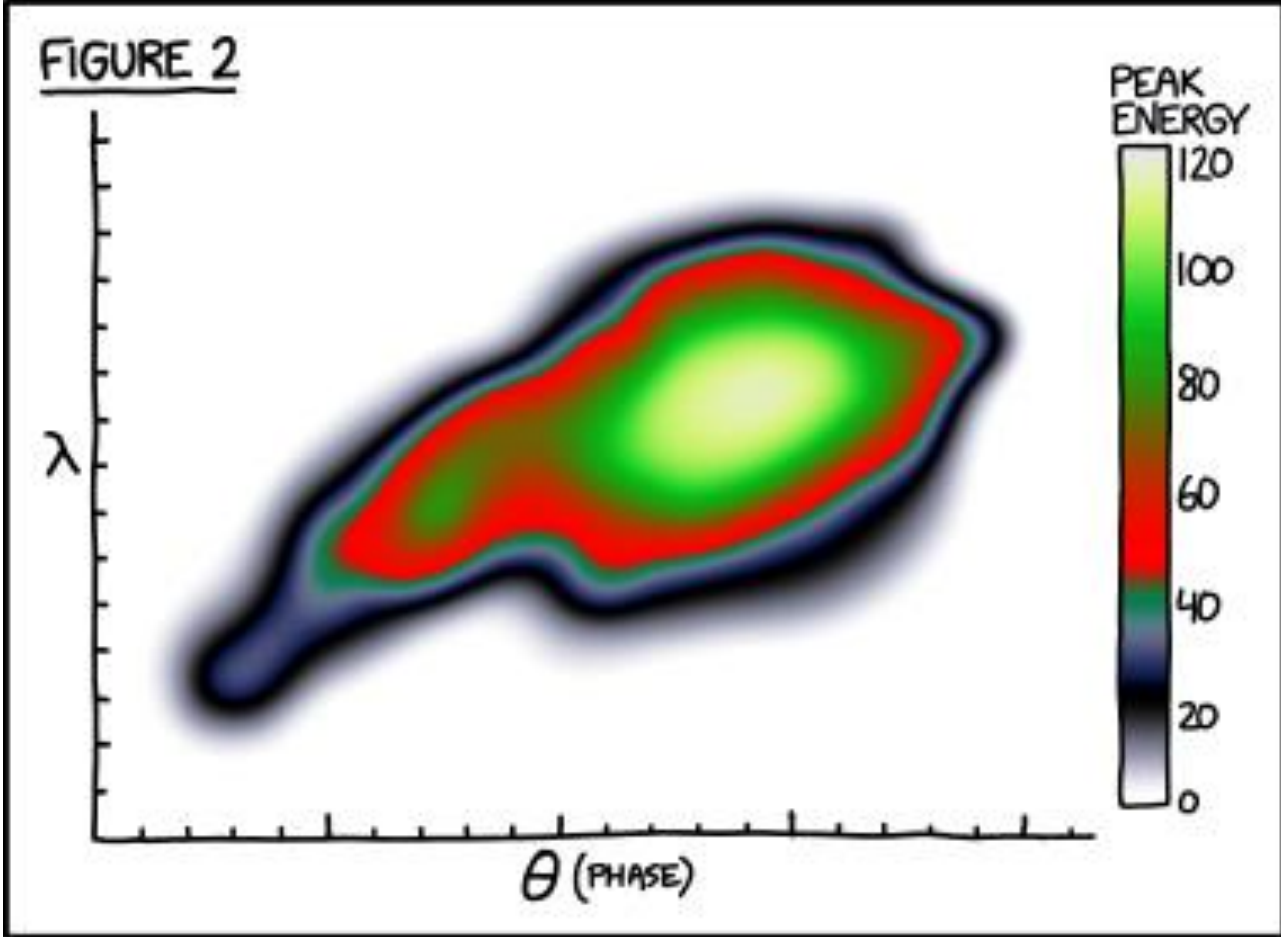
**Stop blindly use default colourmaps in software. Adapt your colourmap to your data (type, order, spatial frequency...). Use perceptually uniform ramps to avoid bias in representation.**



Fabio Crameri







<https://www.fabiocrameri.ch/colourmaps/> (Fabio Crameri)

<https://colorcet.com/index.html> (Peter Kovesi)



EVERY YEAR, DISGRUNTLED SCIENTISTS COMPETE FOR THE RAINBOW AWARD FOR WORST COLOR SCALE.

**UNIVERSAL COLOUR KEY FOR SCIENTIFIC GRAPHS**  
ERRANTSCIENCE.COM

-  DATA I LIKE
-  DATA ON FREEZING EXPERIMENTS
-  EVIL DATA THAT DISAGREES WITH ME
-  THIS IS DATA I'M UNSURE ABOUT BUT WANT TO MAKE LOOK PRETTY
-  DATA I WANT TO MAKE UNREADABLE ON A WHITE BACKGROUND
-  UNICORN RELATED DATA