

# Colour maps for data visualization

an examination of colour mapping for data visualization in the sciences

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# Outline

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- Colour Space

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# Data Visualization

## Data Visualization

Visualization is the process of providing a visual representation of data.



Figure: Radiograph of human wrist

<sup>1</sup>Matteo, [https://mycarta.wordpress.com/2011/11/02/lending-you-a-hand-with-image-processing-](https://mycarta.wordpress.com/2011/11/02/lending-you-a-hand-with-image-processing/)

# Data Visualization

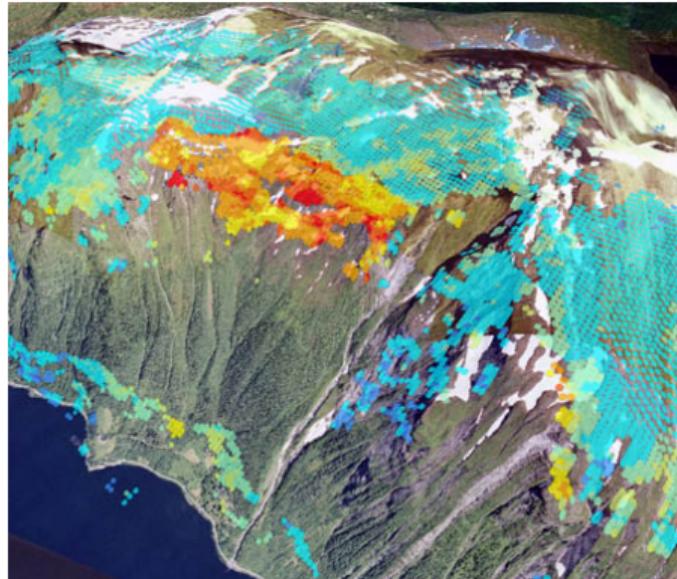


Figure: Osmundneset, located on the east side of Hyenfjord, is an example of a large unstable rock slope that was discovered with the help of InSAR. The mountainside is highly fractured over a length of approximately one kilometre. The light blue points indicate insignificant or no movement, while the yellow and red points are moving up to five millimetres per year.<sup>2</sup>

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<sup>2</sup>John Dehls, Geological Survey of Norway. "Osmundneset INSAR.", <http://www.ngu.no/nyheter/overv%C3%A5ker-skredfare-fra-ny-satellitt>

# Colourmaps

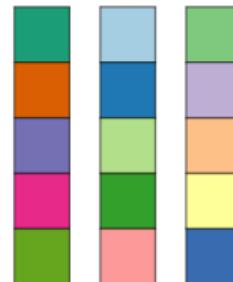
## Colourmaps

A colour map is the process of mapping colours to numbers.

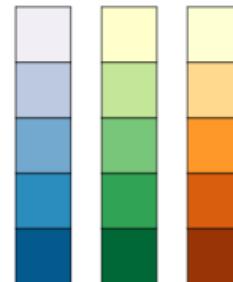
# Colourmaps

## Colourmaps

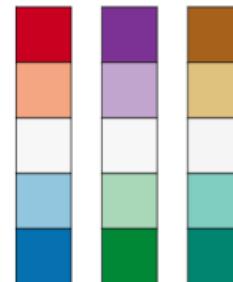
A colour map is the process of mapping colours to numbers.



(a) Qualitative



(b) Sequential



(c) Diverging

Types of colour maps. Qualitative used to represent collections of discrete unordered classes. Sequential or diverging are more suited for represented scalar variables.

# Colour space

## Colour space

Colour space is an abstract mathematical model representing colours with a unchanging set of numbers. Examples of common colour spaces:

- RGB (Red, Green, Blue)
- CMYK (Cyan, Magenta, Yellow, Key(*often black*))
- CIEXYZ, CIELUV, CIELAB

# CIELAB or CIE L\*a\*b\*

## XYZ Space

Simple linear transformation from RGB, for sRGB the equation given below.

$$[X \quad Y \quad Z] = [R \quad G \quad B] \begin{bmatrix} 0.4124 & 0.2126 & 0.0193 \\ 0.3576 & 0.7152 & 0.1192 \\ 0.1805 & 0.0722 & 0.9505 \end{bmatrix}_3$$

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<sup>3</sup> Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3-9.

# CIELAB or CIE L\*a\*b\*

## L\*a\*b\* Space

Colour map used to approximate how humans see. Conversion from XYZ to CIELAB is given below.

$$L^* = 116 [f(Y/Y_n) - 16/116]$$

$$a^* = 500 [f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200 [f(Y/Y_n) - f(Z/Z_n)]$$

$$f(x) \equiv \begin{cases} x^{1/3} & \text{if } x > 0.008856 \\ 7.787x + 16/116 & \text{if } x \leq 0.008856 \end{cases}$$

$[X_n \quad Y_n \quad Z_n]$  is a reference white value <sup>3</sup>

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<sup>3</sup> Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3-9.

# The Rainbow Colour Map

- Commonly used
- Often the default in many visualization software
- Jet colormap is an example frequently used rainbow colormap

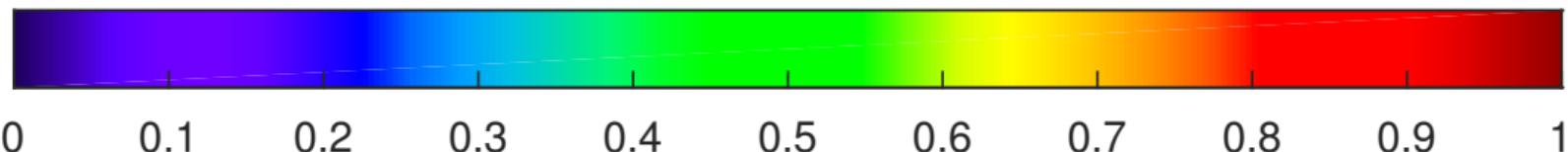
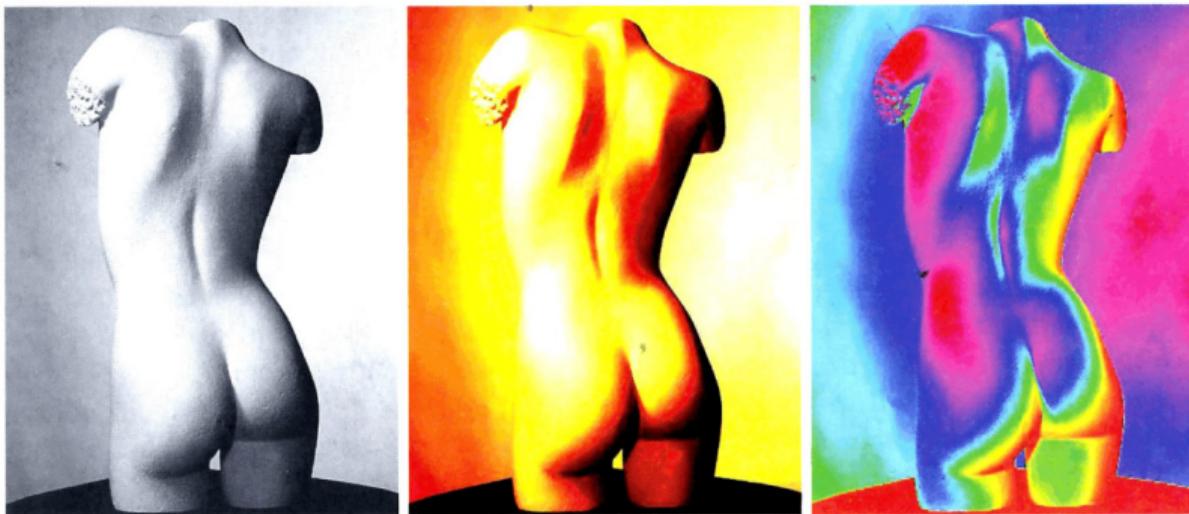


Figure: Visual Spectrum

## Visual example compared to black/white photo



Copyright: Jan Keonderink - Color for the Sciences - MIT Press - used with permission

Figure: Gray scale photo (left) rescaled using thermal (centre) and rainbow (right)

# Visualizing a pyramid with the rainbow colourmap

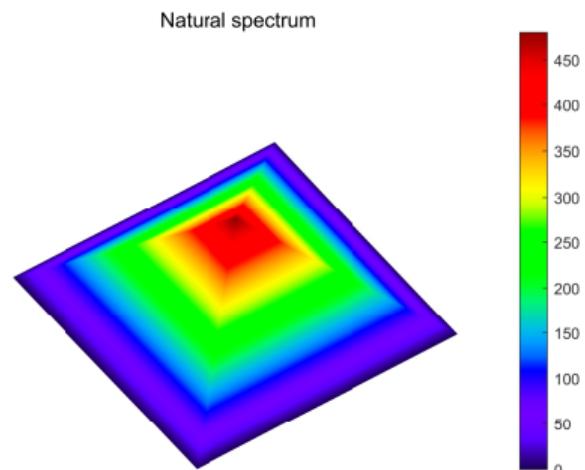


Figure: Great Pyramid of Khufu in Giza  
(pre-erosion)

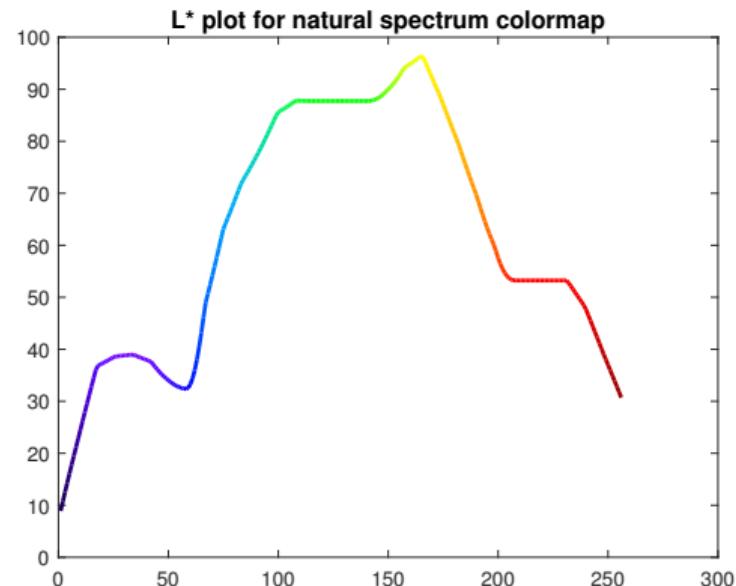
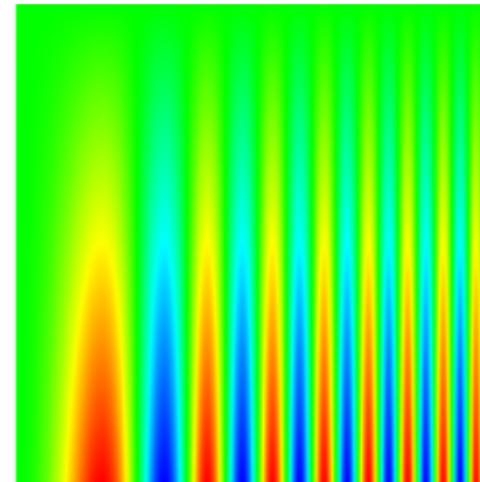
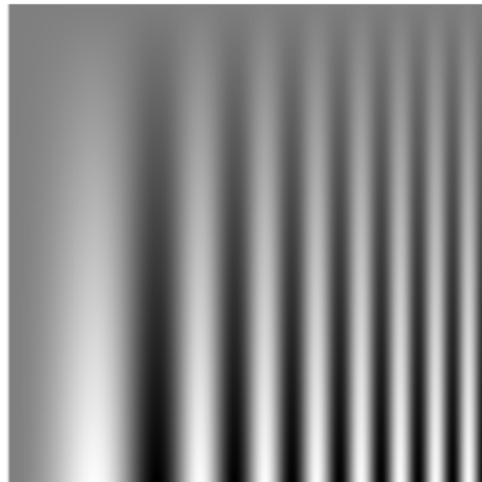


Figure: Luminosity of rainbow colourmap in CIELAB colour space

# The rainbow colour map: spatial contrast



**Figure:** A spatial contrast sensitivity function. The function plotted with the rainbow colour map loses resolution in the top of the figure.

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<sup>3</sup> Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3-9.

# Challenges when using the rainbow

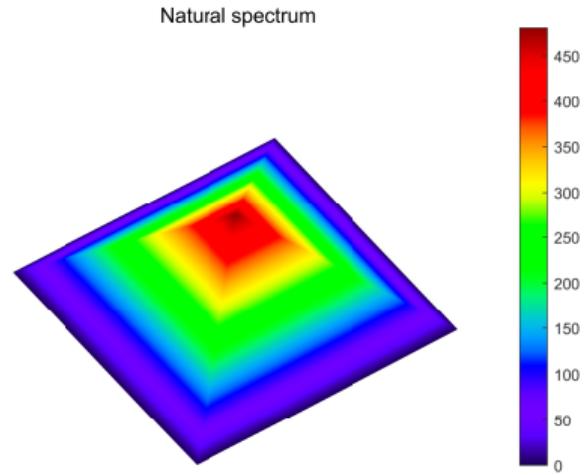


Figure: Great Pyramid of Khufu in Giza  
(pre-erosion)

- No natural order to colours, need to learn order of colours
- Colour change is not monotonic.
  - Changes in yellow appear to change faster than green
  - Luminosity varies across the colour map, increasing, decreasing and constant.
- Sensitive to deficiencies in vision.  
*(About 5% of the population are unable to distinguishing these colours)*

# Why do we use bad colours?

- Simplicity
  - RGB is a conceptually simple and easy to program
  - Default colour map in many applications
- Aesthetics
  - Using a rainbow colour bar can grab the attention of the reader!
  - When Paraview changed the default colour map, it was submitted as a bug report that the colours were too dim.<sup>6</sup>
- Inertia
  - Often scientists compare results to previously published results. If the previous results are only available in rainbow colour map, the community can get stuck with the bad colour map.

<sup>6</sup><https://www.paraview.org/Bug/view.php?id=7024>

# How to pick a better colour map

## Colour Map Requirements<sup>3</sup>

- The map yields images that are aesthetically pleasing.
- The map has a maximal perceptual resolution.
- Interference with the shading of 3D surfaces is minimal.
- The map is not sensitive to vision deficiencies.
- The order of the colors should be intuitively the same for all people.
- The perceptual interpolation matches the underlying scalars of the map.

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<sup>3</sup> Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3-9.

# Types of colour maps

## Sequential

Range from vibrant saturated colour to unsaturated colour.

Luminance is often increased as saturation decreases so they end near white.



## Divergent

Intuitive low / high

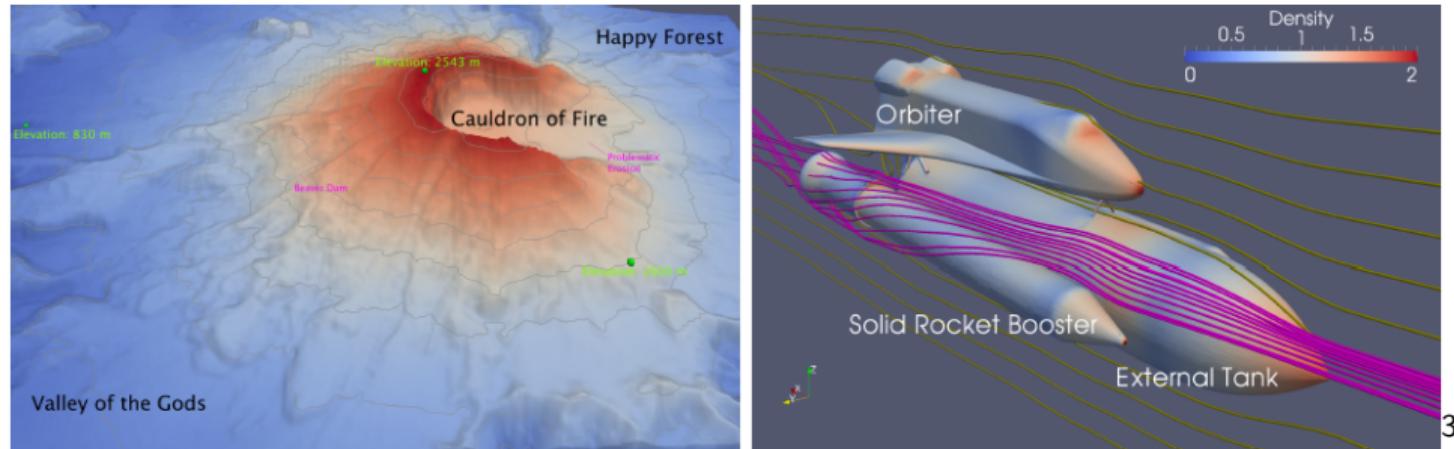
Double the perceptual resolution compared to sequential colour maps



## Designing a new rainbow

Can we design a replacement for the rainbow colour map using the guidelines from before?

# Divergent colour maps



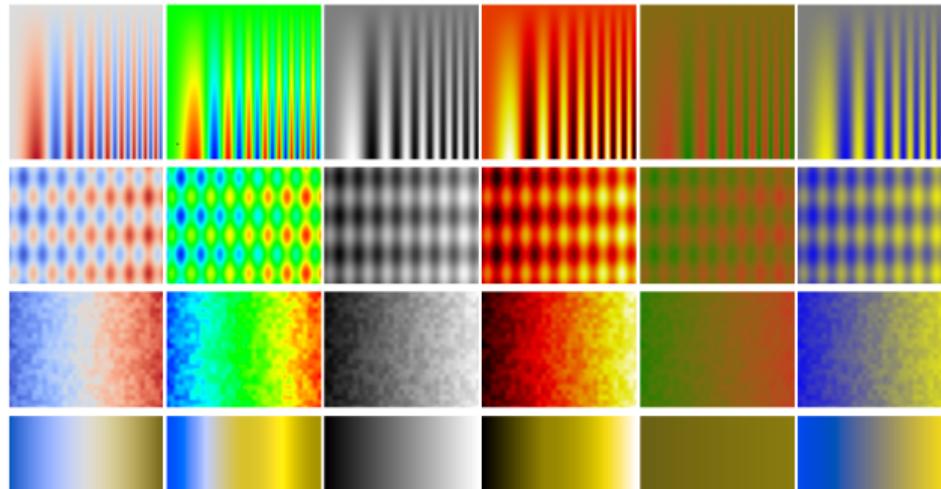
**Figure:** Examples of using a divergent colour map in conjunction to annotation

<sup>3</sup> Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3-9.

# Comparing colour maps

**The color maps are, (from left to right):**

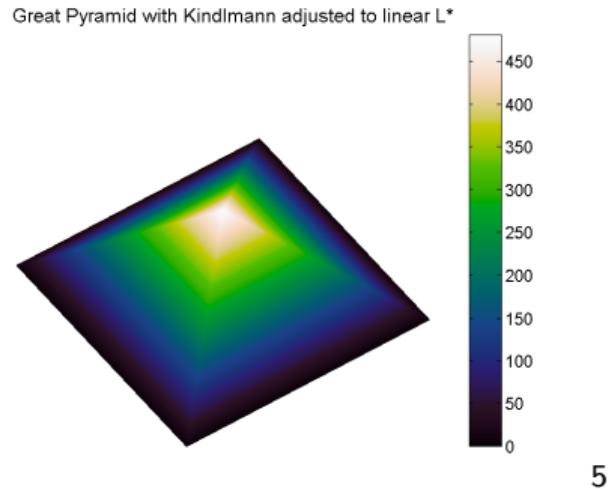
cool-warm, rainbow, grayscale, heated body, isoluminant, blue-yellow



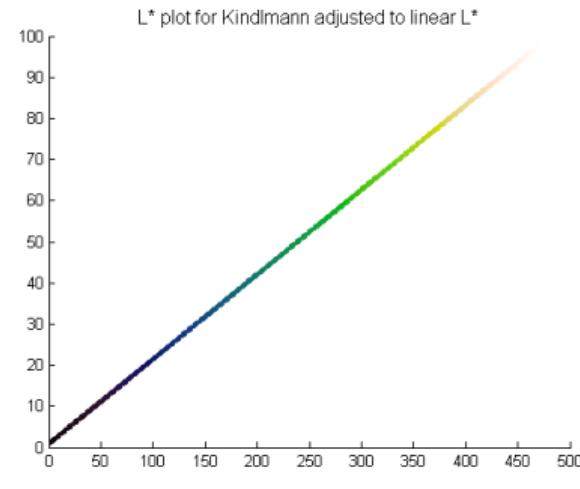
3

**The demonstrations are, (from top to bottom):**  
a spatial contrast sensitivity function,  
a low-frequency sensitivity function,  
high-frequency noise,  
an approximation of the color map viewed with deutanope color-deficient vision,  
3D shading

# Recreate the rainbow



**Figure:** Great Pyramid of Khufu in Giza (pre-erosion)



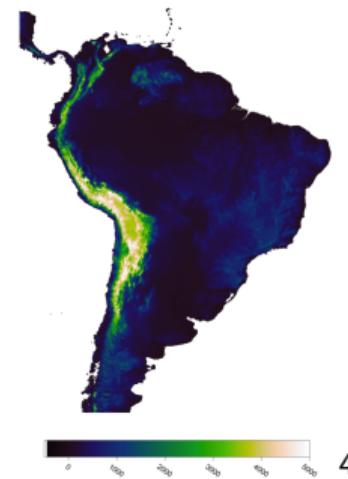
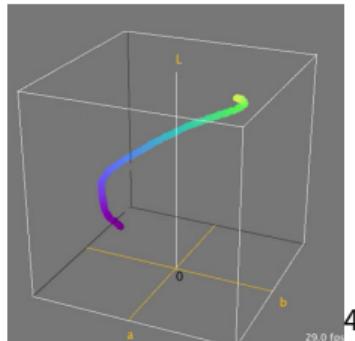
**Figure:** Luminosity of Modified Kindlmann colourmap in CIELAB colour space

<sup>5</sup> Matteo, <https://mycarta.wordpress.com/2012/12/06/the-rainbow-is-deadlong-live-the-rainbow-part-5-cie-lab-linear-l-rainbow/>

# Recreating the rainbow colour map

## CubeYF

Designed by Matteo Niccoli, designed in CIELAB to be monotonic in  $L^*$ , and a spiral in  $a^*$ ,  $b^*$ . (See animation). [▶ Link to animation](#)



# Cube YF

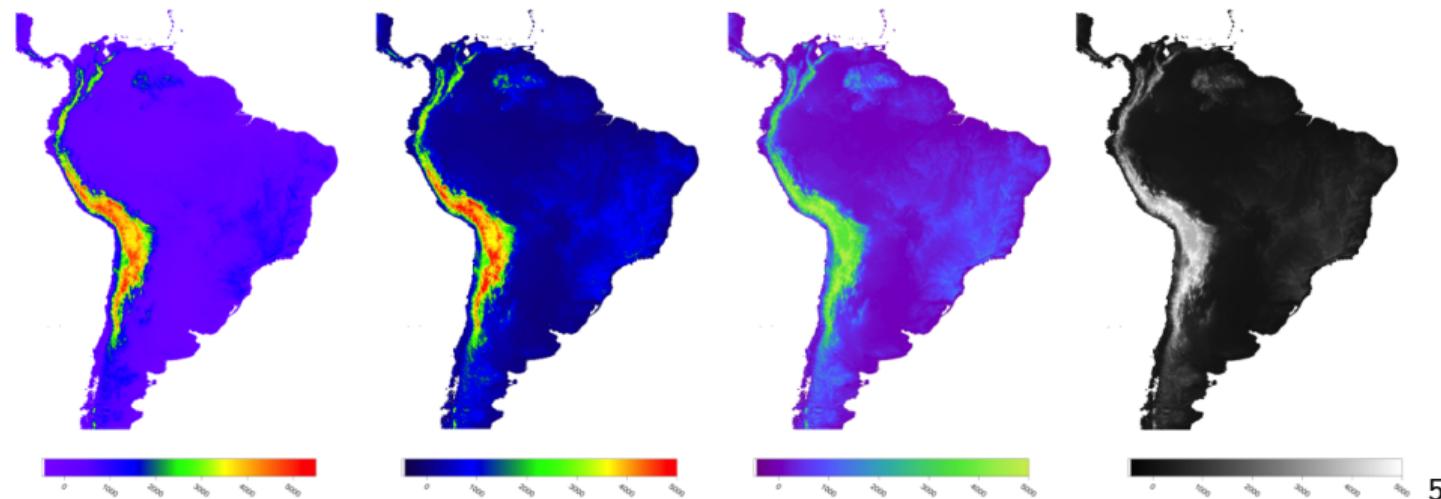
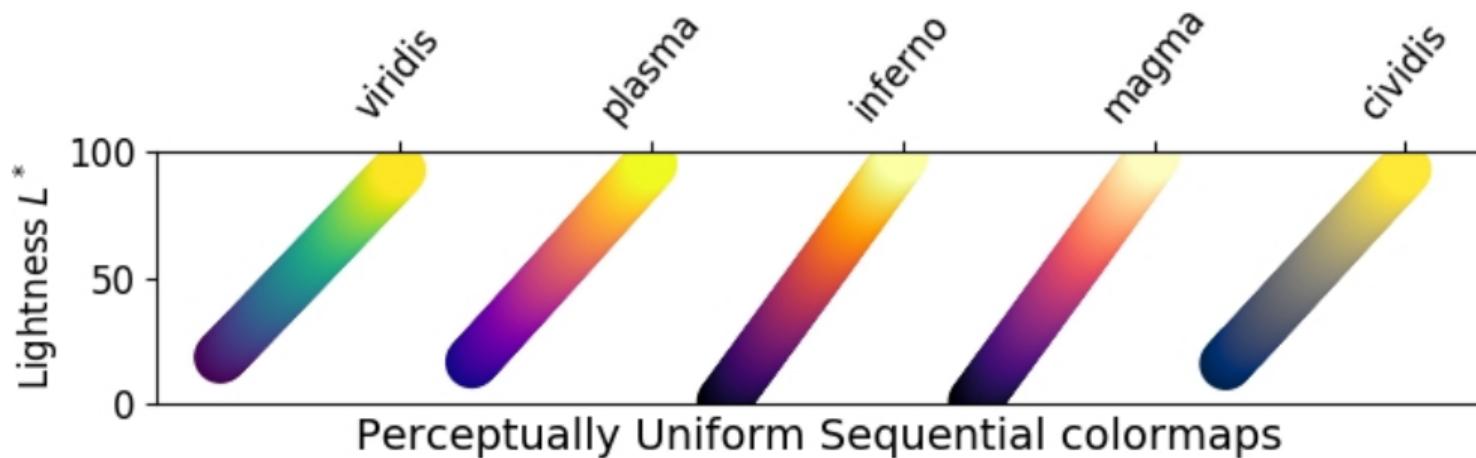
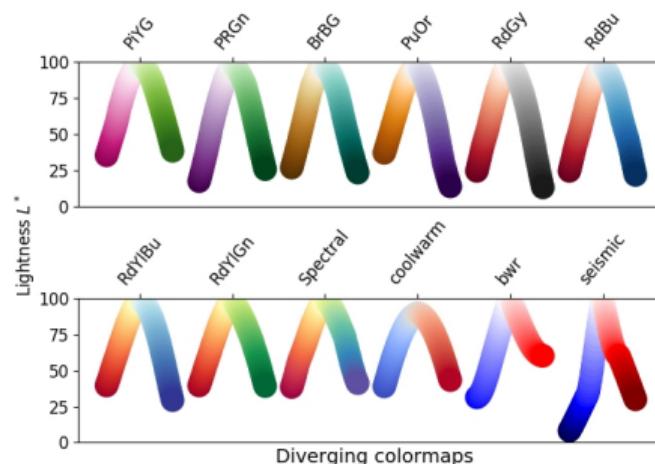
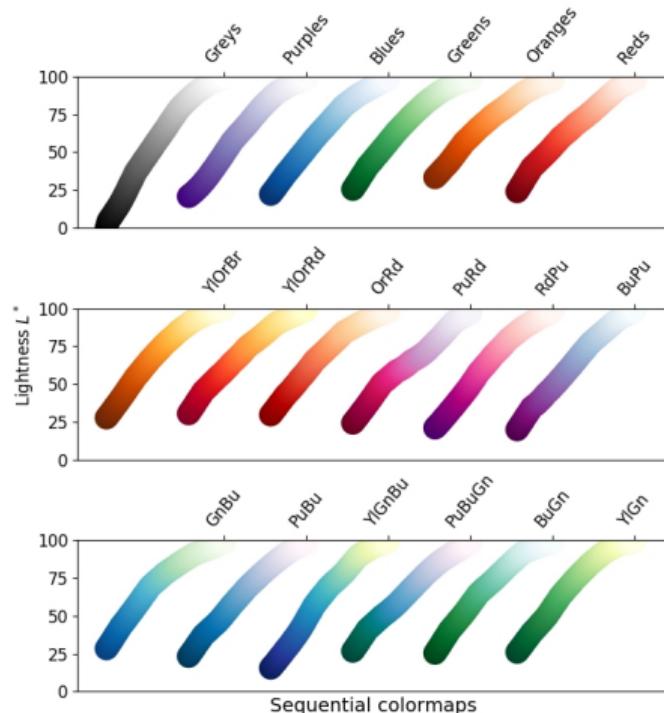


Figure: South American Elevation coloured by, from left to right, ROYGBIV, classic rainbow, cubeYF, and grayscale

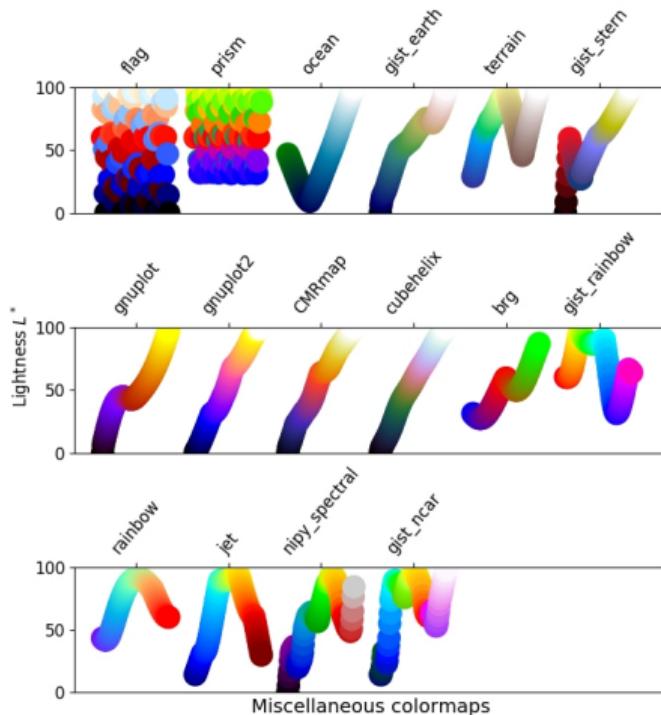
# Perceptually Uniform Sequential colourmaps



# Sequential and Divergent Colourmaps



# Miscellaneous Colourmaps



# Colourmaps in animations

Example of a simple wave animation using various colourmaps.

Folder of video files

# Conclusion

- Colour map choice can be critical when visualizing data
- Choosing the wrong colour map can distort the visual interpretation of the data
- The Rainbow colour map should not be used
- Numerous alternatives available
  - Divergent colour maps
  - Open source functions for generating divergent colour maps available in python, matlab, R, mathematica, gnuplot, excel spreadsheet

# References

- Matteo, <https://mycarta.wordpress.com/2011/11/02/lending-you-a-hand-with-image-processing-basic-techniques-1/>
- John Dehls, Geological Survey of Norway. "Osmundneset INSAR.", <http://www.ngu.no/nyheter/overv%C3%A5ker-skredfare-fra-ny-satellitt>
- Moreland K, Diverging Color Maps for Scientific Visualization (Expanded), In Proceedings of the 5th International Symposium on Visual Computing, December 2009. DOI 10.1007/978-3-642-10520-3\_9
- <https://www.paraview.org/Bug/view.php?id=7024>
- Matteo, <https://mycarta.wordpress.com/2012/12/06/the-rainbow-is-deadlong-live-the-rainbow-part-5-cie-lab-linear-l-rainbow>
- <https://matplotlib.org/tutorials/colors/colormaps.html>