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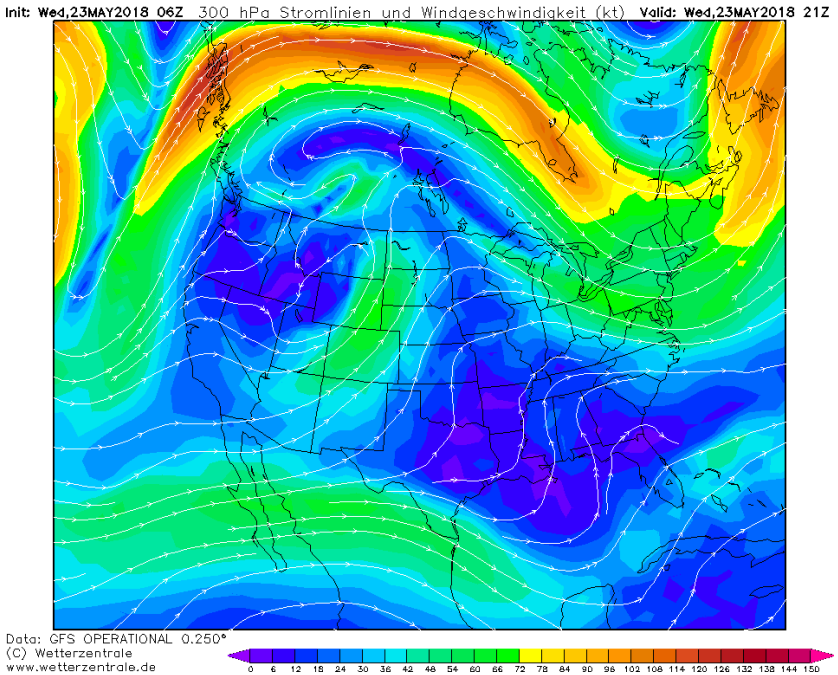
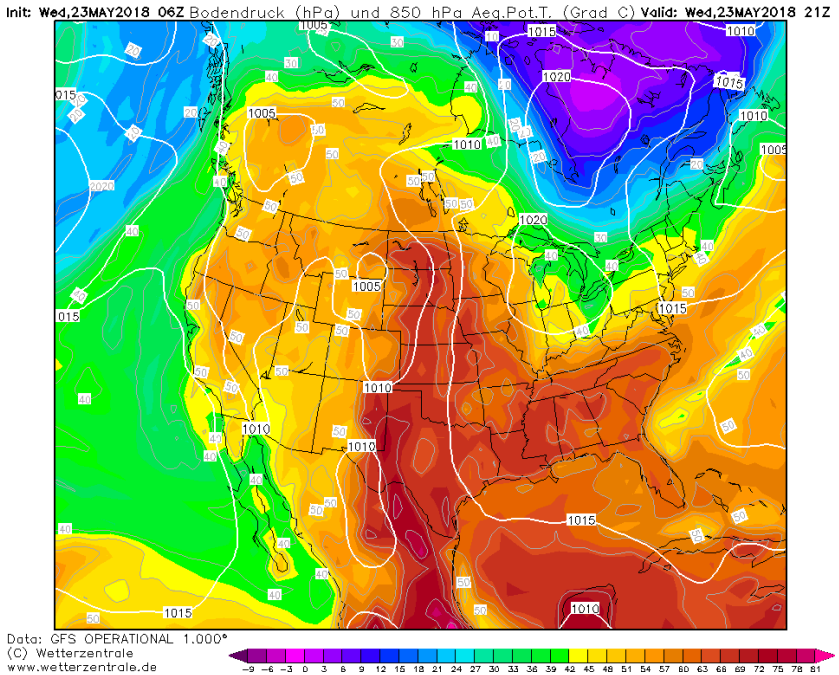
Somewhere Over the Rainbow: How to Make Effective Use of Colors in Scientific Visualizations

Reto Stauffer

http://hclwizard.org

Introduction





Two ‘random’ forecast maps from wetterzentrale.de.

Introduction

Color:

- Integral element in graphical displays.
- Easily available in (statistical) software.
- Omnipresent in (electronic) publications: Technical reports, electronic journal articles, presentation slides.

Problem: Little guidance about how to choose appropriate colors for a particular visualization task.

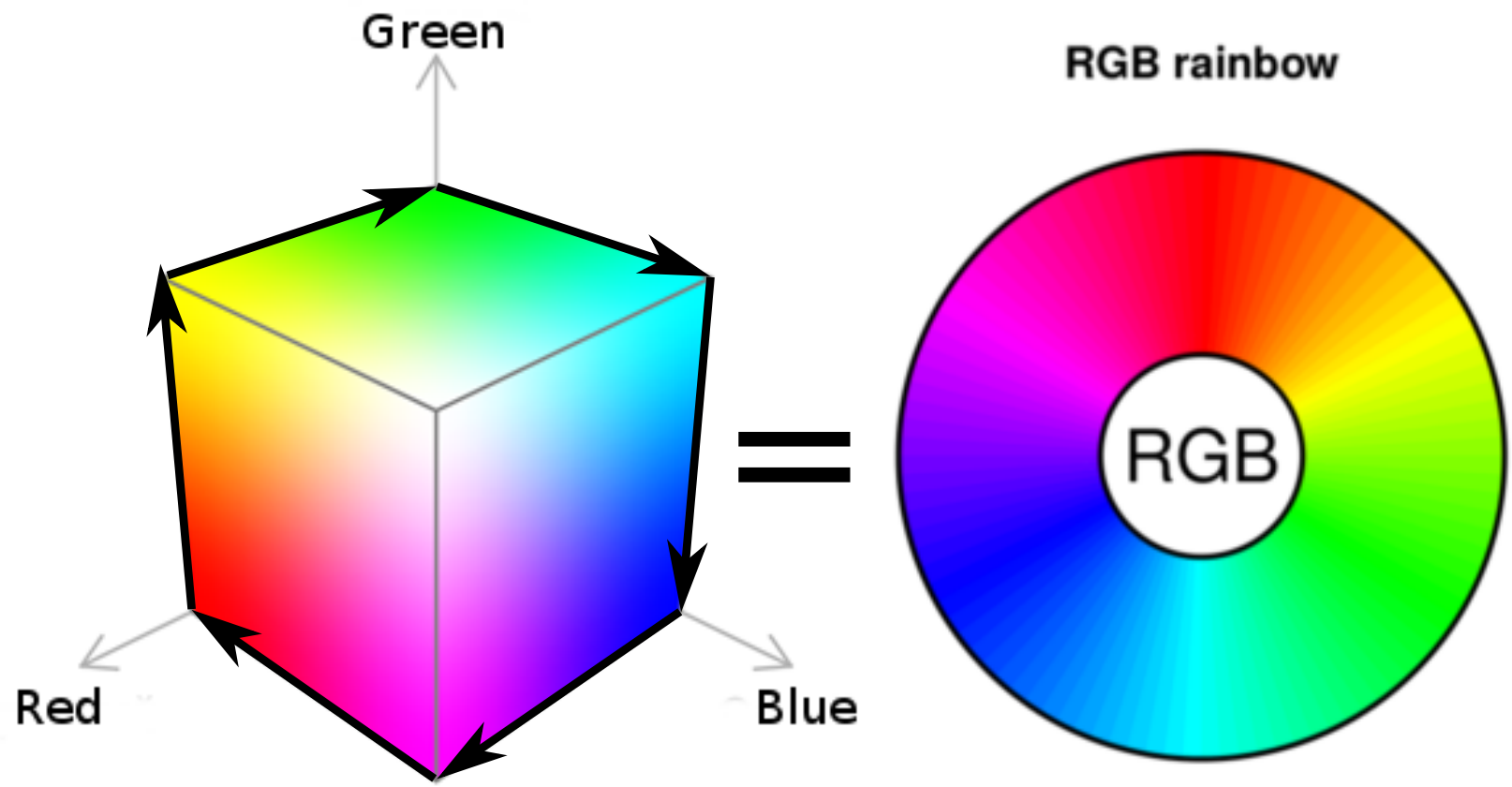
Question: What are useful color palettes for coding qualitative and quantitative variables?

Introduction

Main goal of our work:

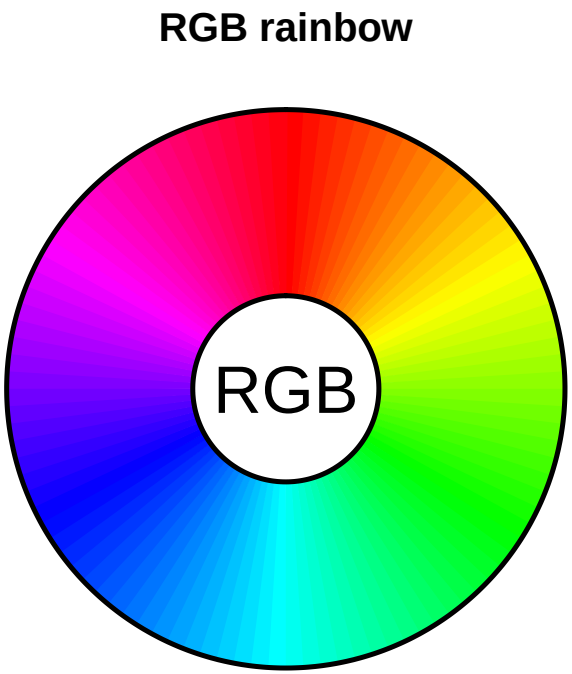
- Raise awareness of the issue.
- Introduce Hue-Chroma-Luminance (HCL) model.
  - Based on human perception.
  - Better control for choosing color palettes.
- Provide convenient software for exploring and assessing HCL-based palettes.

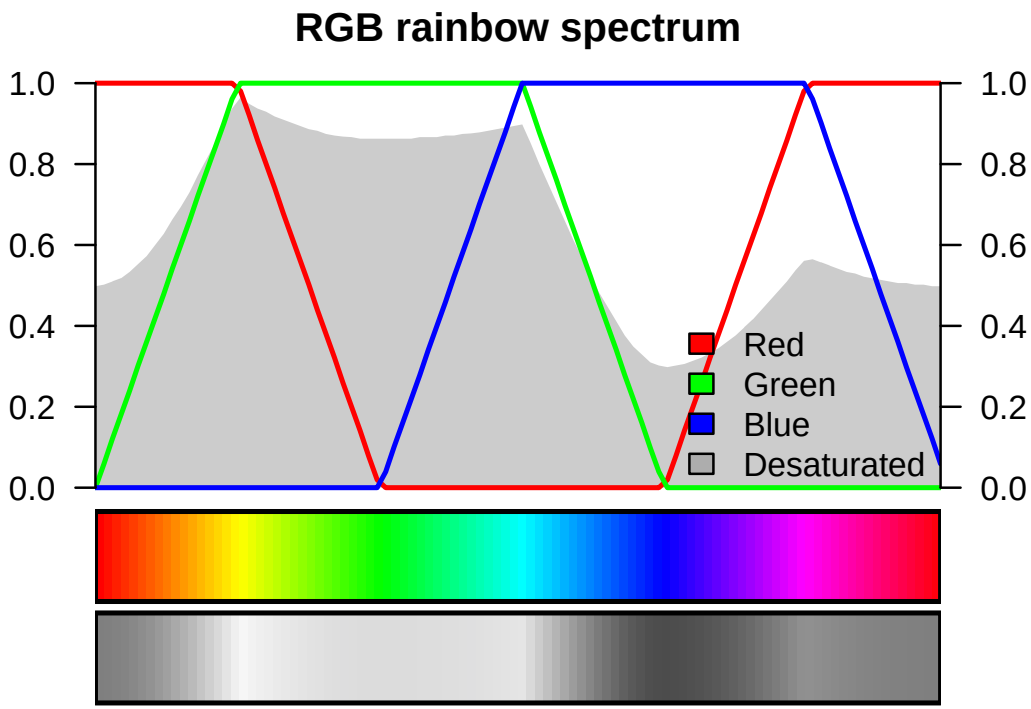
RGB Rainbow



RGB color space: And the (in)famous rainbow color palette.

RGB Rainbow

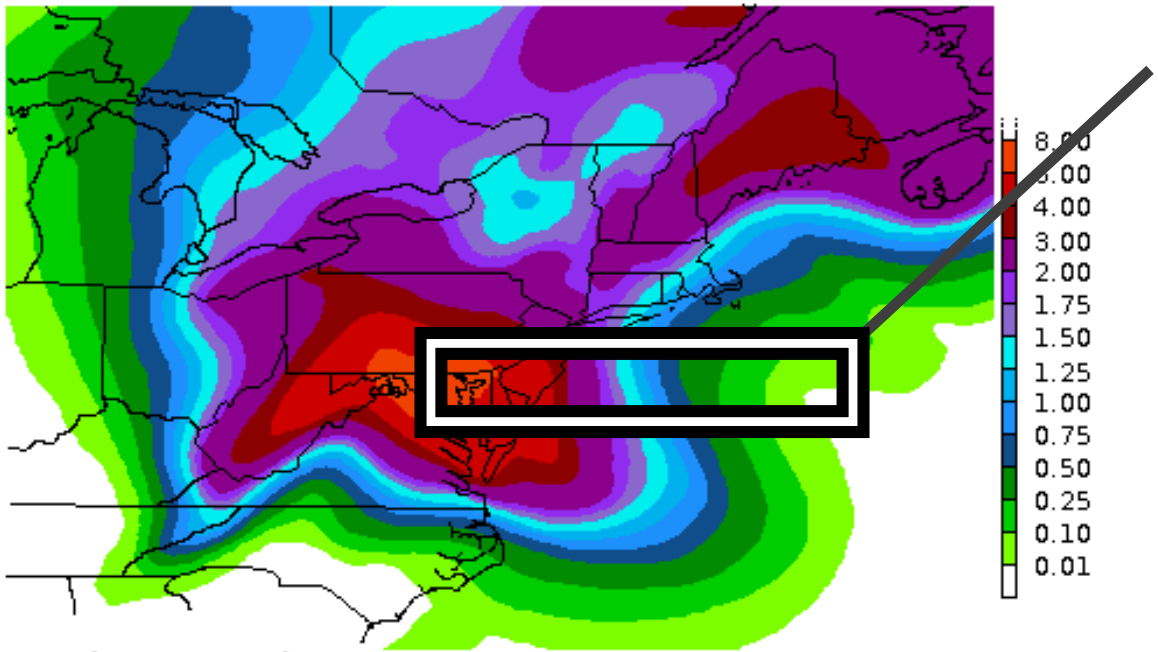




- The default color in many software packages.
- Conveniently used by many practitioners.
- Defaults only change slowly (if at all).

Question: Everybody does it – why should it be wrong?

What’s Wrong?

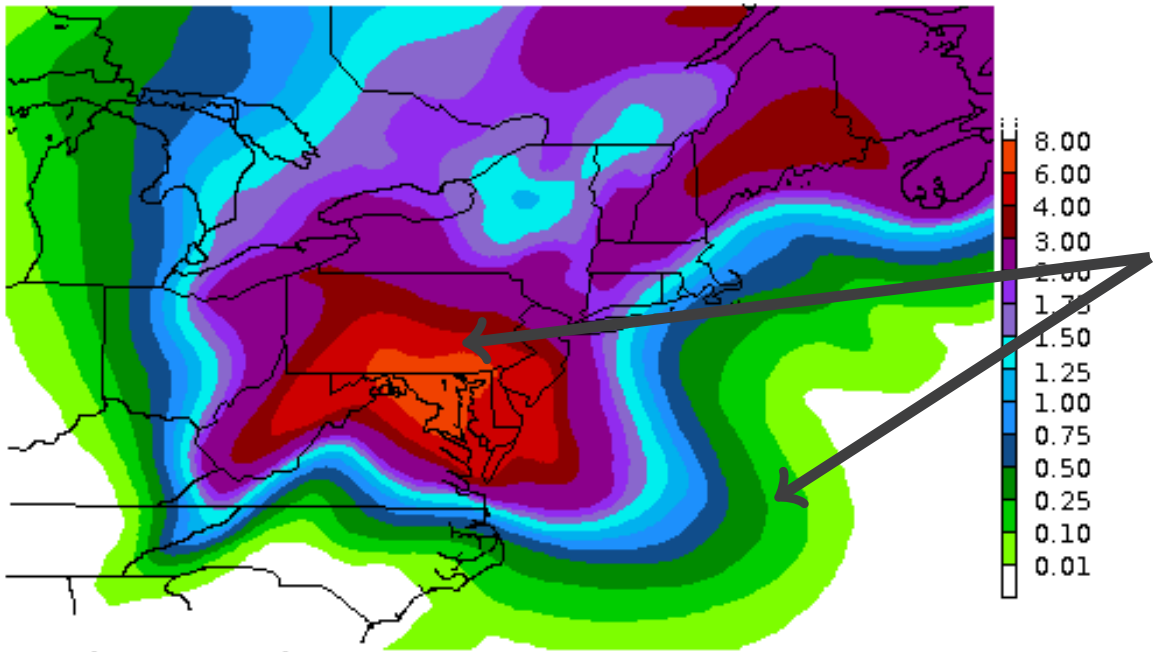


Gradients:
Very strong

Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Original figure as published by the NOAA.

What’s Wrong?



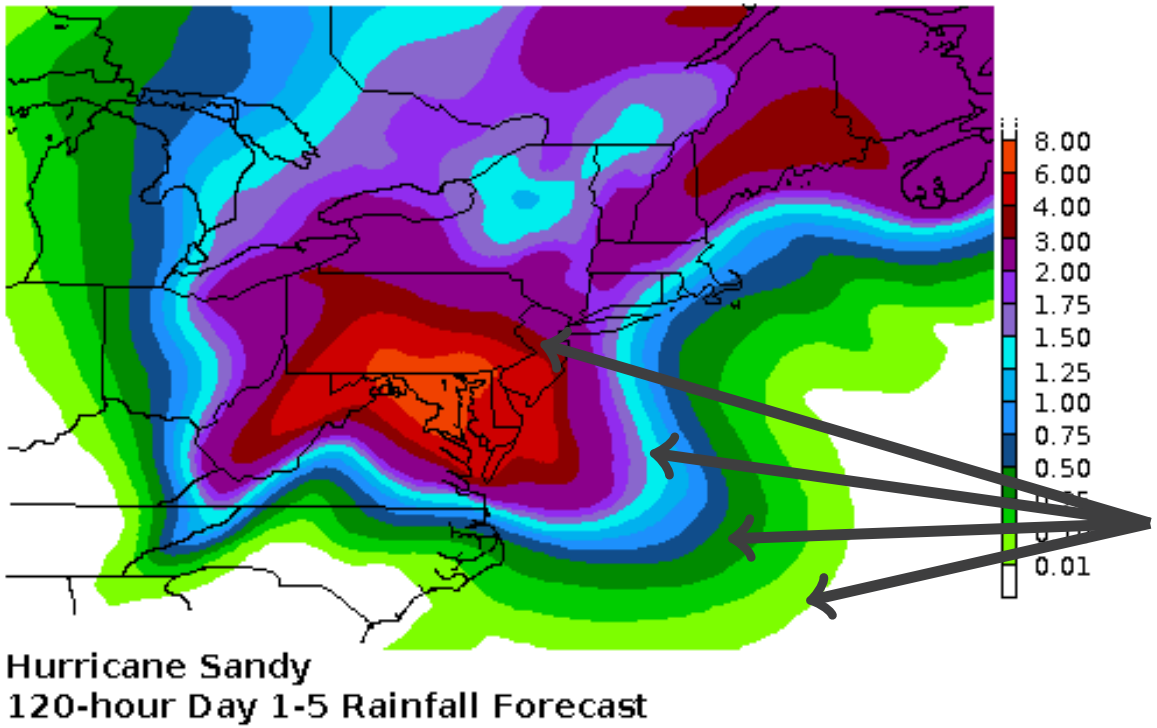
Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Gradients:
Very strong

Saturation
Highly-saturated colors

Original figure as published by the NOAA.

What’s Wrong?



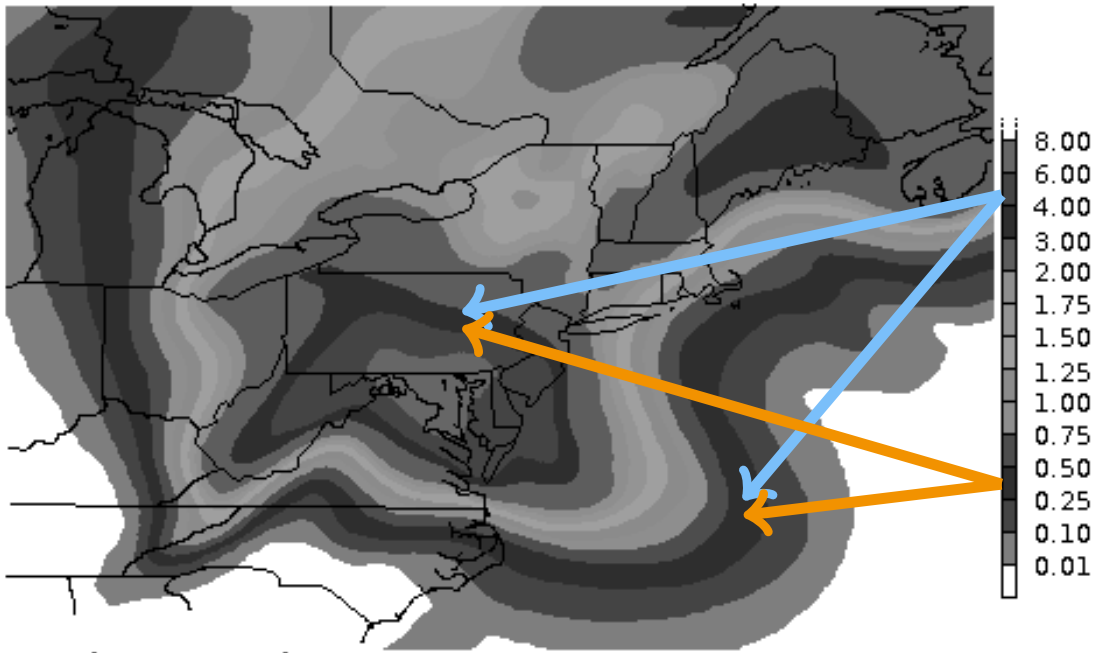
Gradients:
Very strong

Saturation
Highly-saturated colors

Discontinuous
Bright, dark, bright, dark, . . .

Original figure as published by the NOAA.

What’s Wrong?



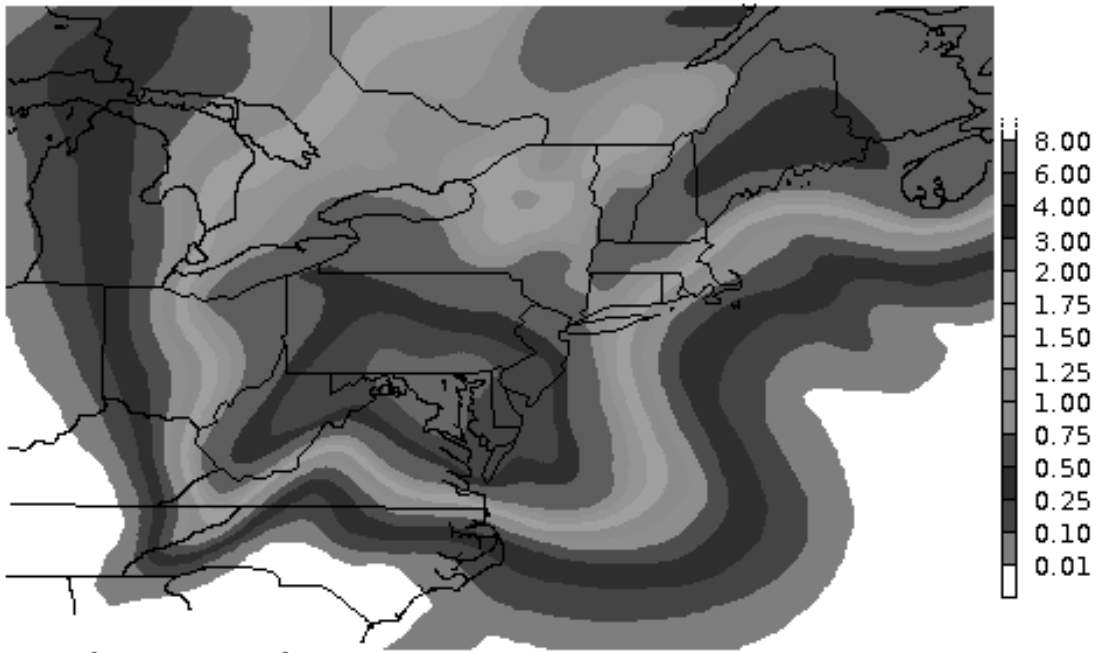
Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.

Assignment

No longer unique

What’s Wrong?



Desaturated version of the original figure.

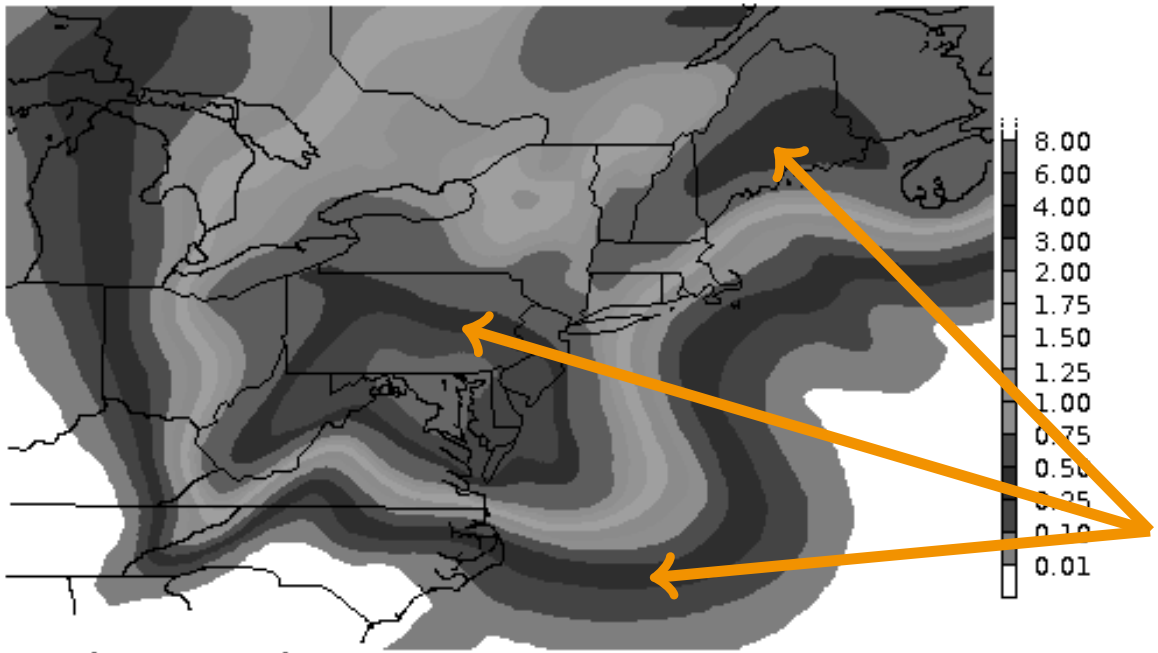
Assignment

No longer unique

Interpretation

Where is the maxi-mum?

What’s Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

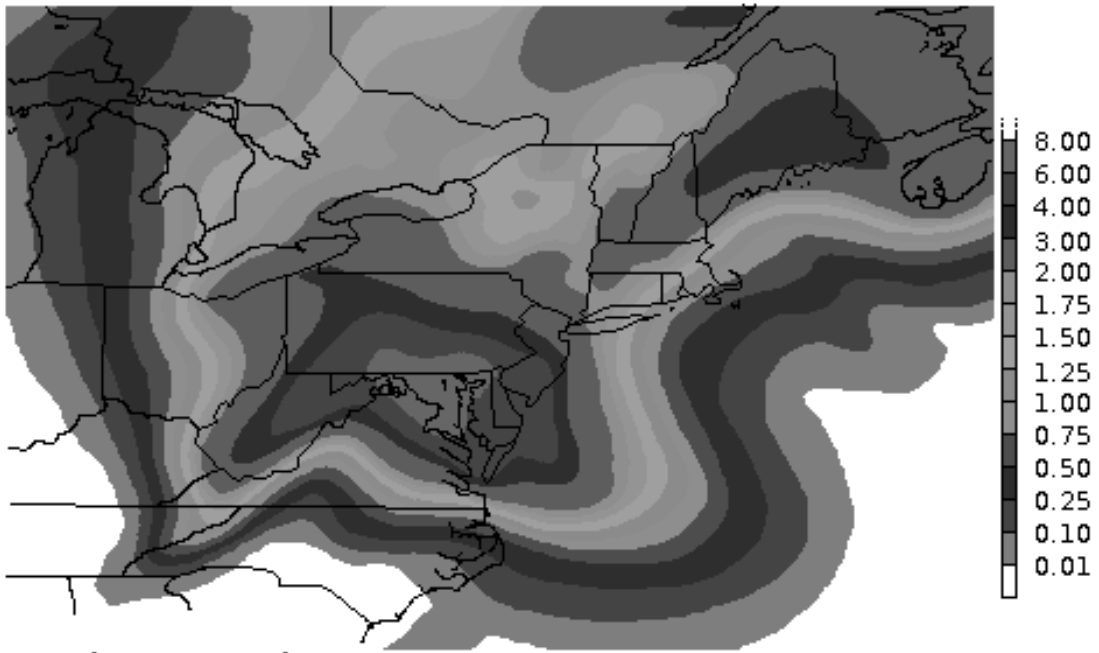
Assignment
No longer unique

Interpretation
Where is the maxi-mum?

Focus
On dark artefacts

Desaturated version of the original figure.

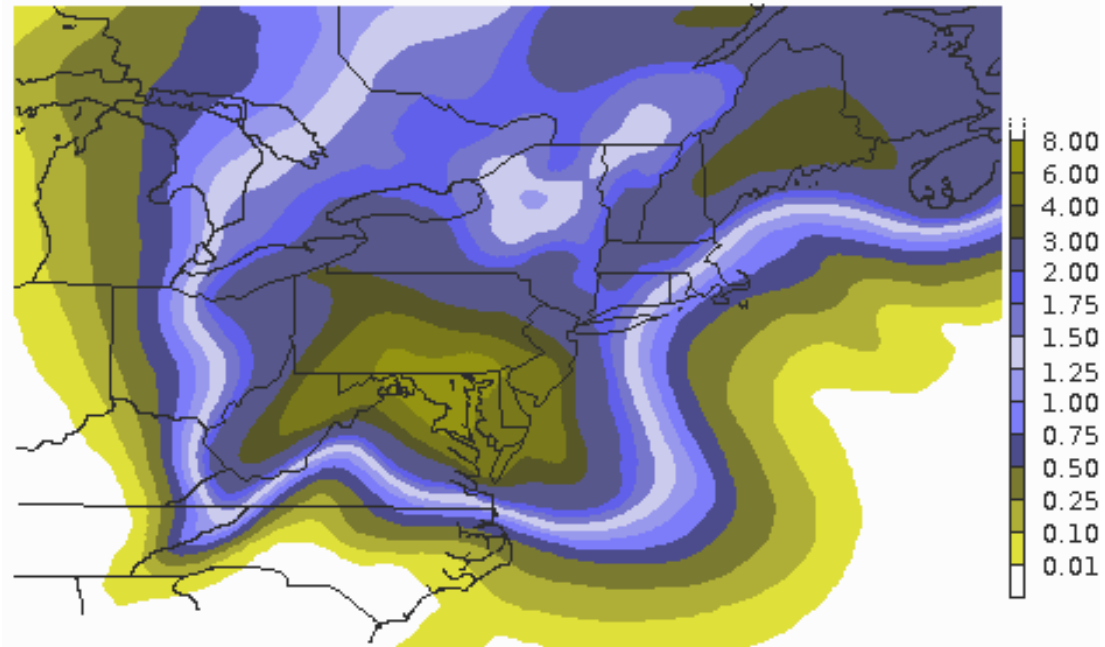
What’s Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.

What’s Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

What color-blind people see (red-green weakness).

About **5% of all Europeans** are affected.

End-user
Who is it?

Consider
Visual constraints?

Challenges

Summary: The colors in a palette should

- be simple and natural,
- not be unappealing,
- highlight the important information,
- not mislead the reader,
- work everywhere and for everyone.

In practice:

- People often do not think about it at all.
- . . . and simply use default colors.

Potential problems:

- For end users – reviewers, supervisor, collegue, customer.
- For your own day-to-day work.

The Hue-Chroma-Luminance Color Space

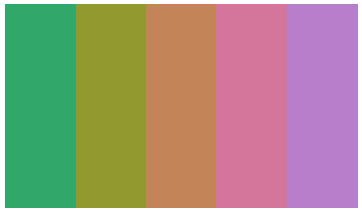
A Perception-Based Color Space

Perception-Based Way: HCL

Advantages:

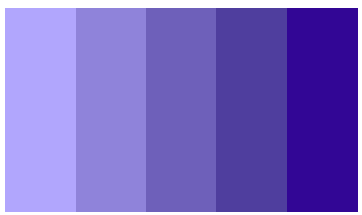
- Hue: Type of color.
- Chroma: Colorfullness.
- Luminance: Brightness.

Hue

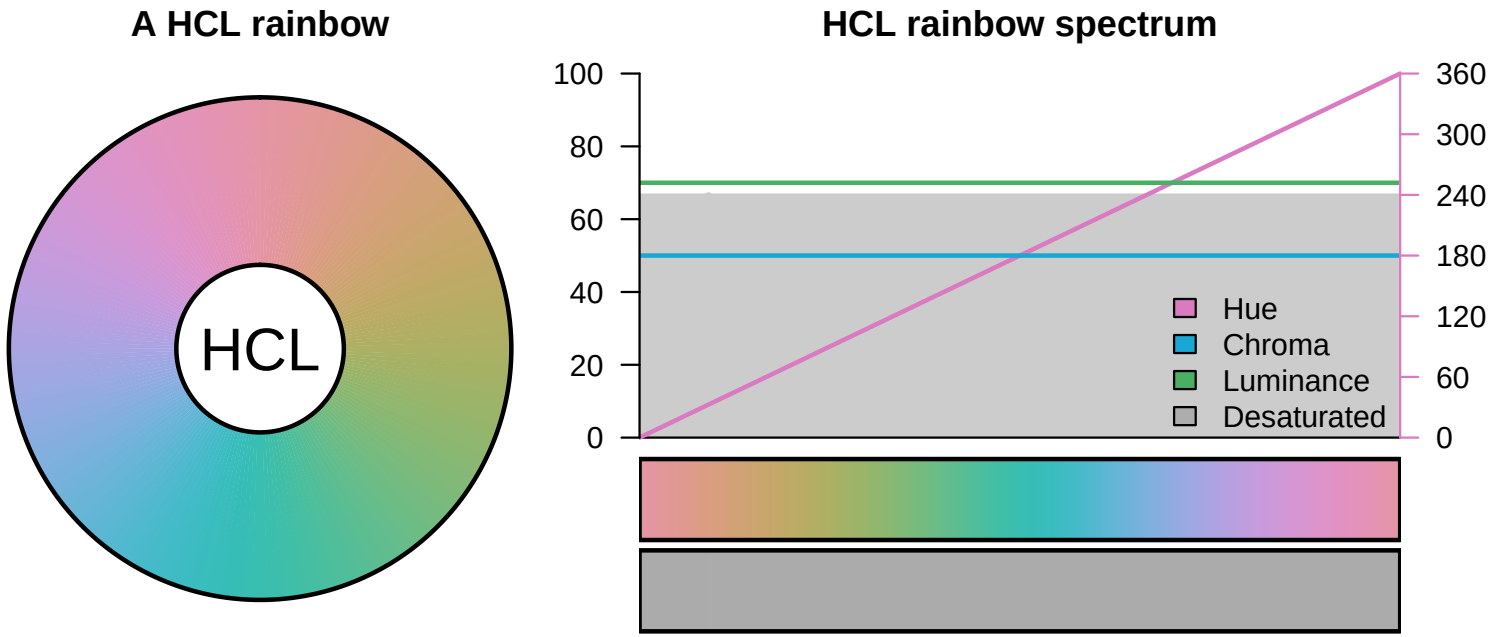


Chroma

Luminance

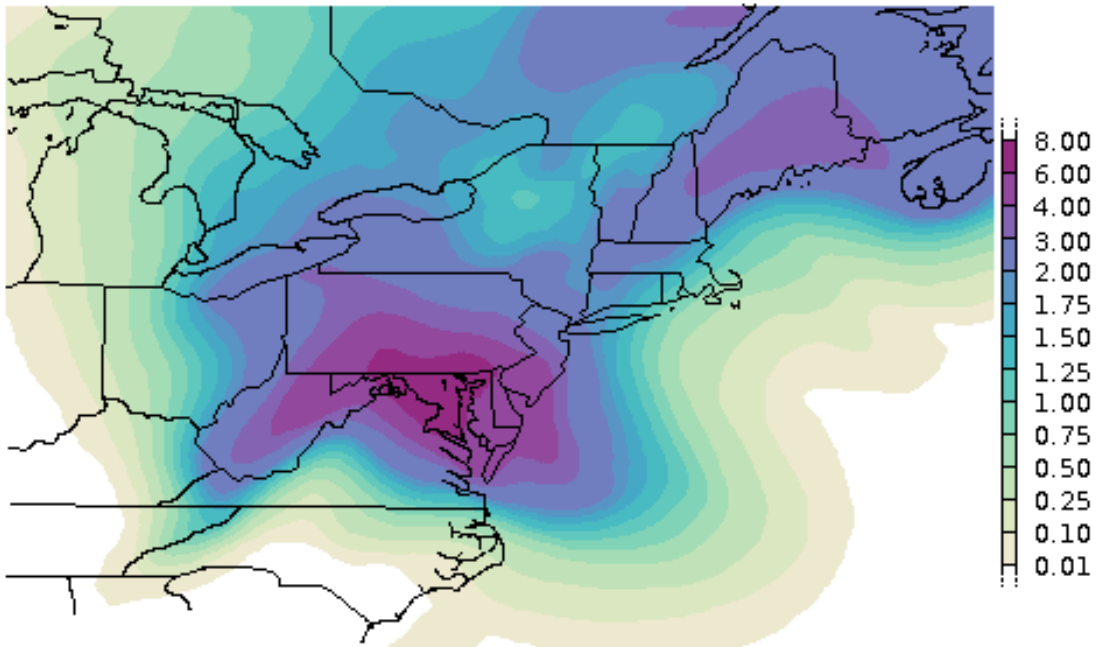


Perception-Based Way: HCL



- **H**ue (*defines the color*)
- **C**hroma (*defines the colorness*) and
- **L**uminance (*defines the brightness*)

HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

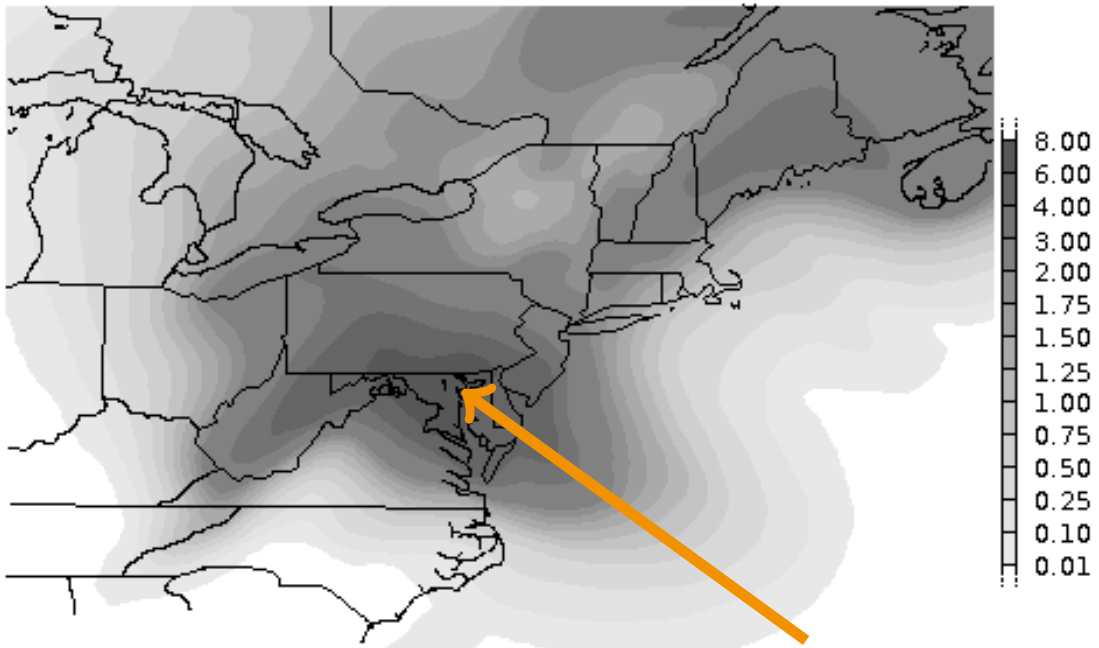
Same information, changed color scheme.

Colors:
Smooth gradients.

Information:
Guiding, no hidden information.

Works:
Screen, projector, gray-scaled device.

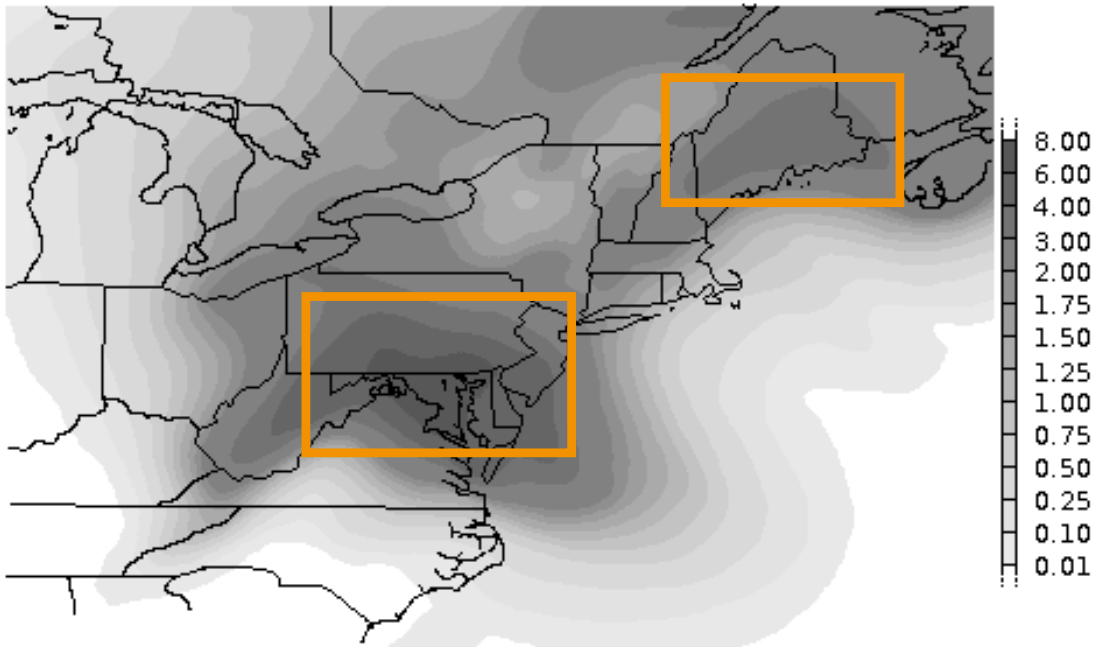
HCL Version



Assignment:
Higher values ⇒ lower luminance.

Desaturated representation of the HCL-version.

HCL Version

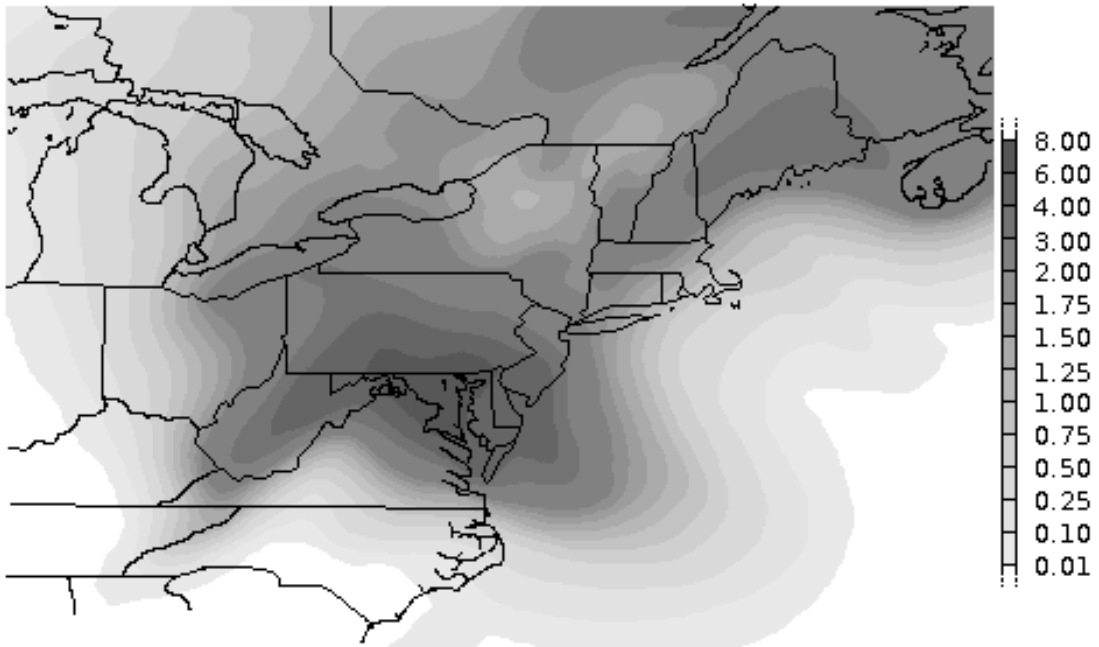


Desaturated representation of the HCL-version.

Assignment:
Higher values $\Rightarrow$ lower luminance.

Focus:
leads readers to most important areas.

HCL Version



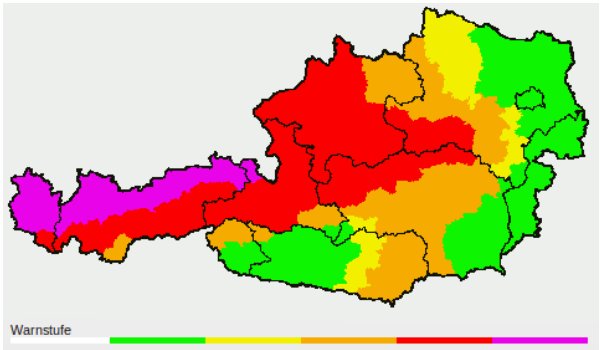
Desaturated representation of the HCL-version.

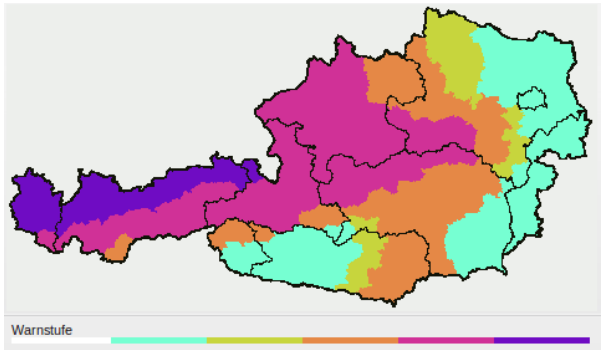
Assignment:
Higher values $\Rightarrow$ lower luminance.

Focus:
leads readers to most important areas.

Summary:
Solved a lot of problems by changing the color palette.

Warning Map Example

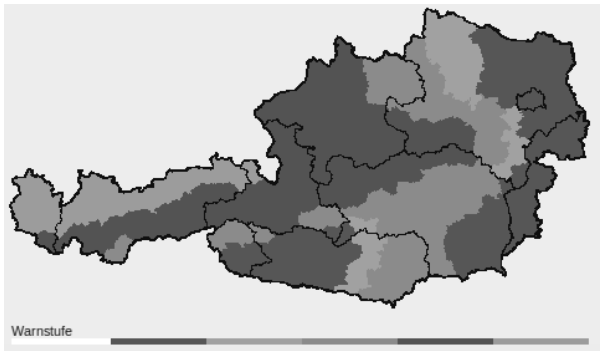


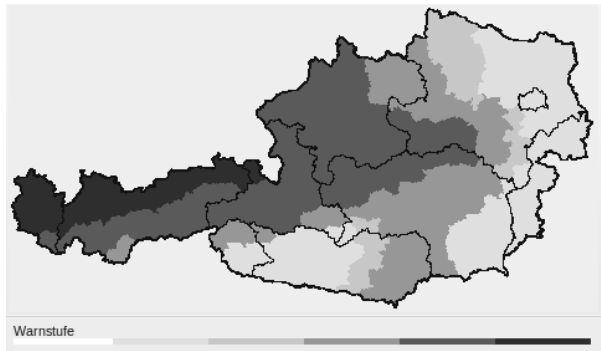


Colorized

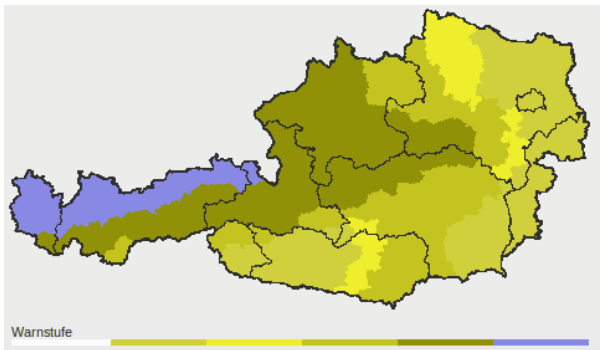
Original (left)

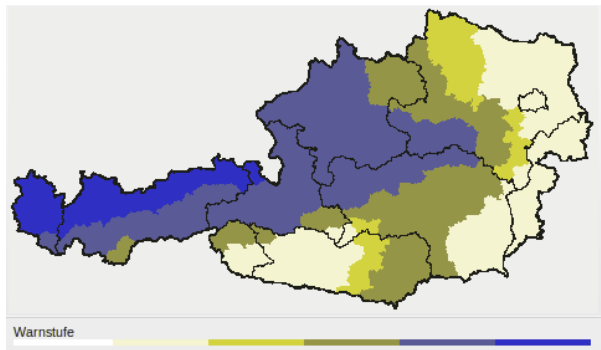
HCL idea (right)





Gray-scale





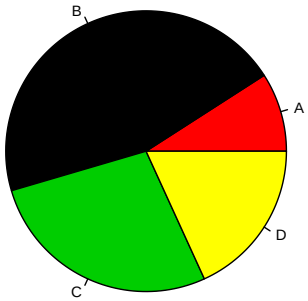
Deuteranopia

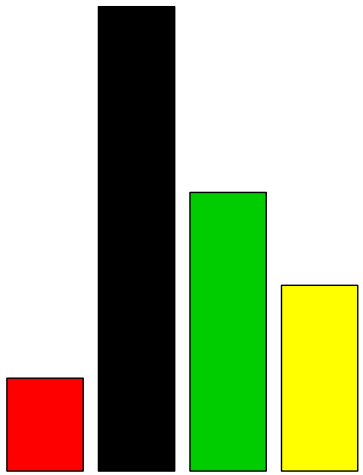
Red-Green

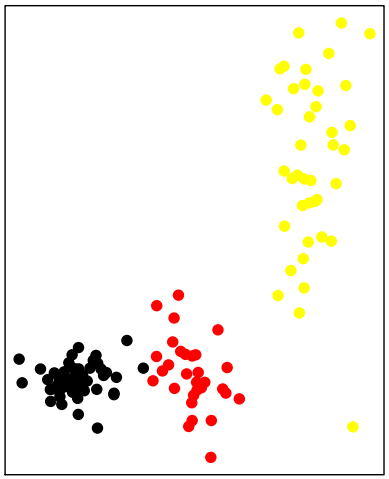
weakness

Color Palettes: Qualitative

Goal: Code quantitative data.

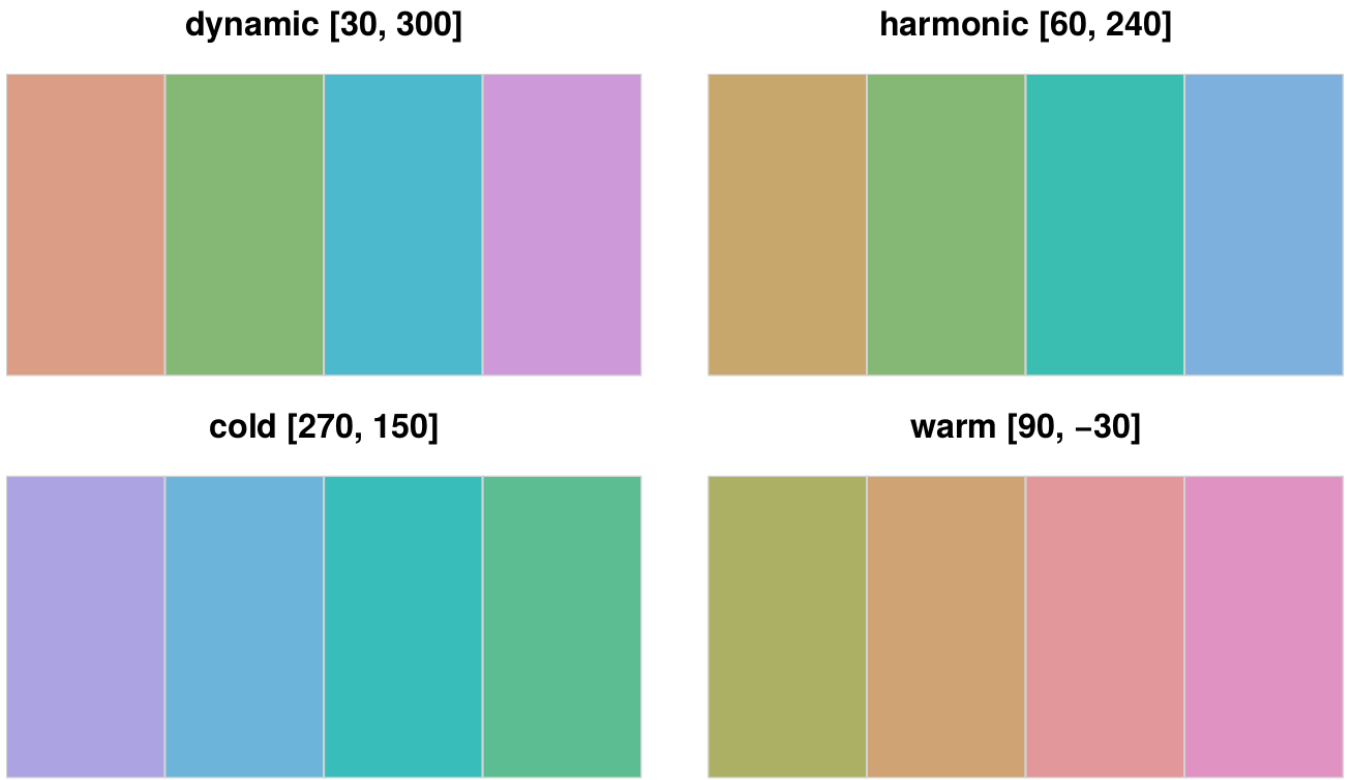






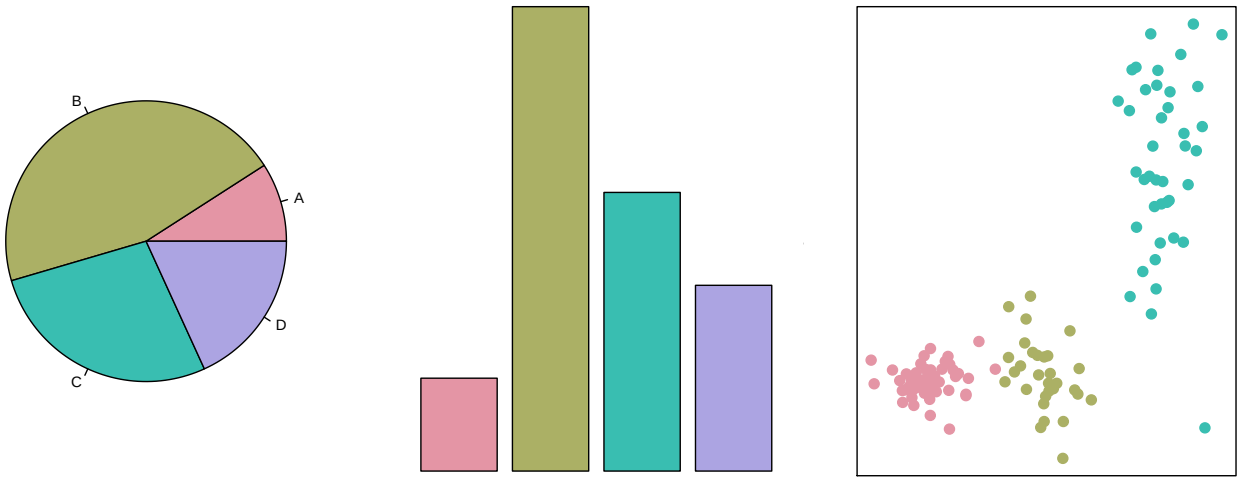
Color Palettes: Qualitative

Goal: Code quantitative data.



Color Palettes: Qualitative

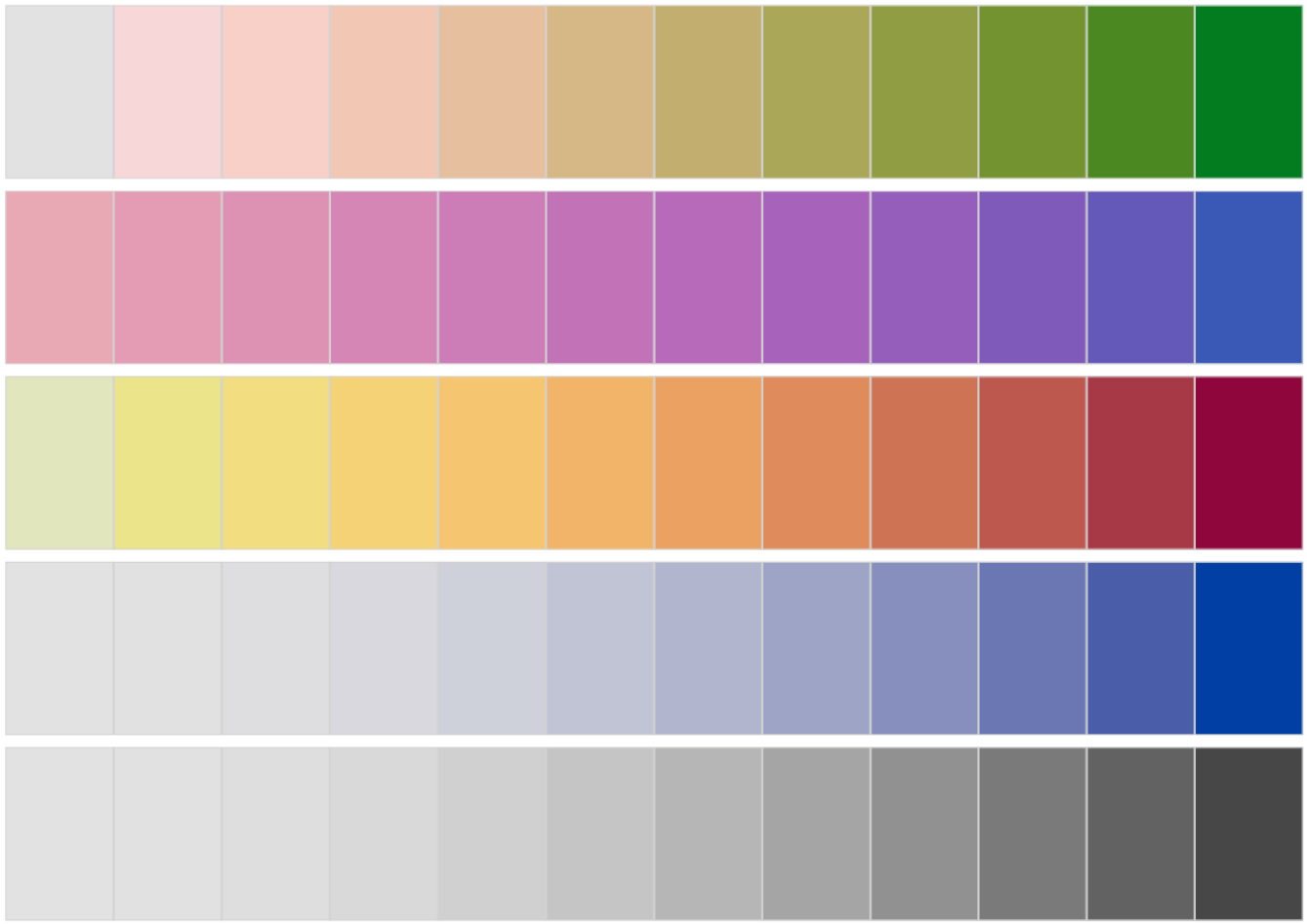
Goal: Code quantitative data.



Solution: Take colors with different hues, but keep chroma and luminance constant. E.g.: $(H, 50, 70)$

Color Palettes: Sequential

Goal: Code quantitative data (e.g., probabilities) where one side is of main interest.



Color Palettes: Sequential

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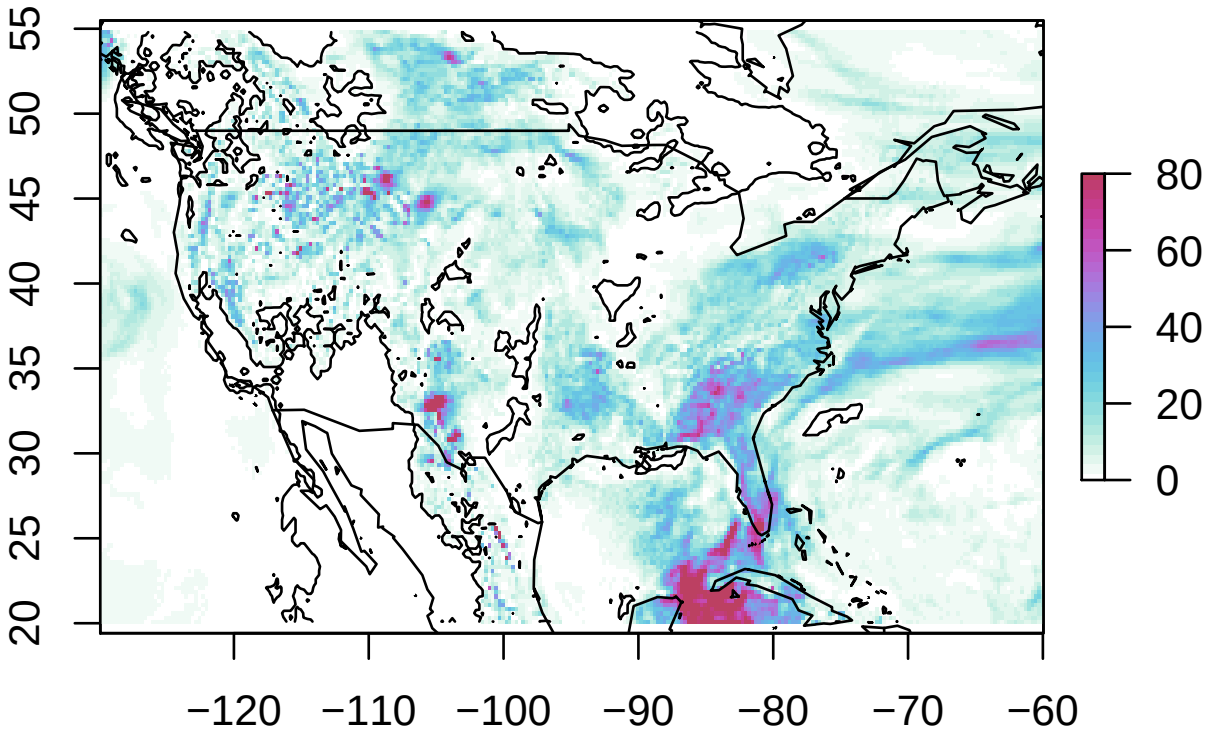

Solution: Constant hue and changing chroma/luminance. E.g., $(90 - 0, 30 - 100, 90 - 50)$.

Color Palettes: Diverging

Goal: Code quantitative data and highlight both ends of the spectrum (e.g., anomalies, wet/dry, probabilities, . . .).

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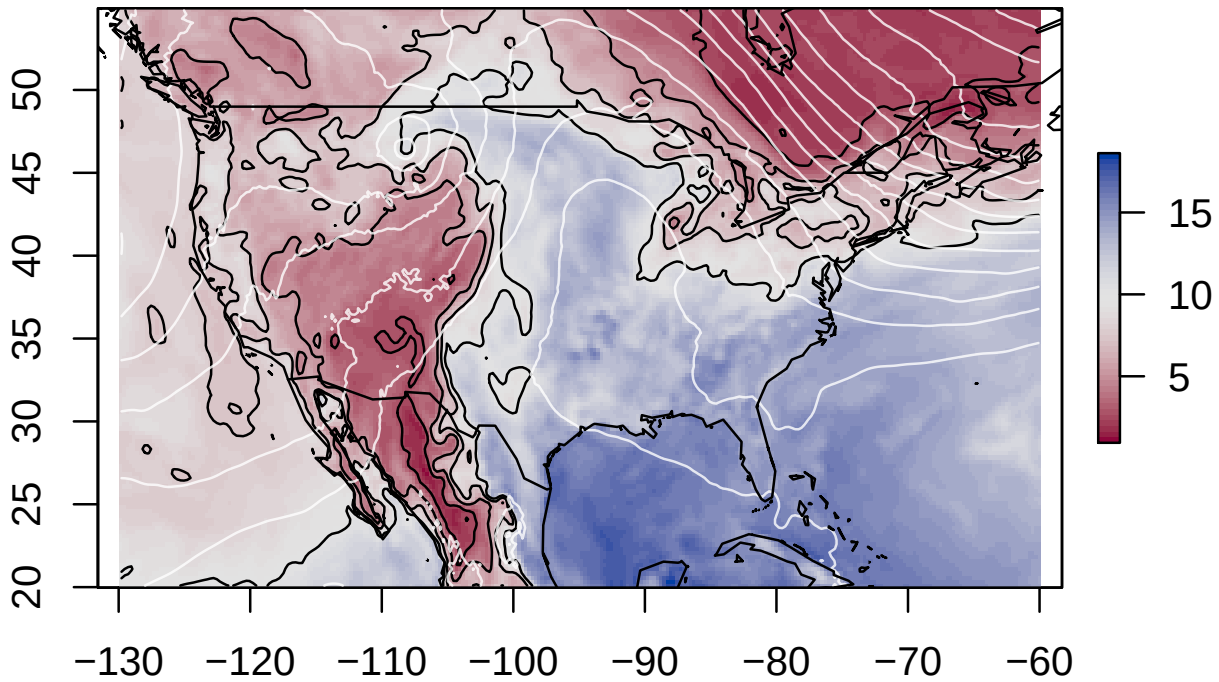
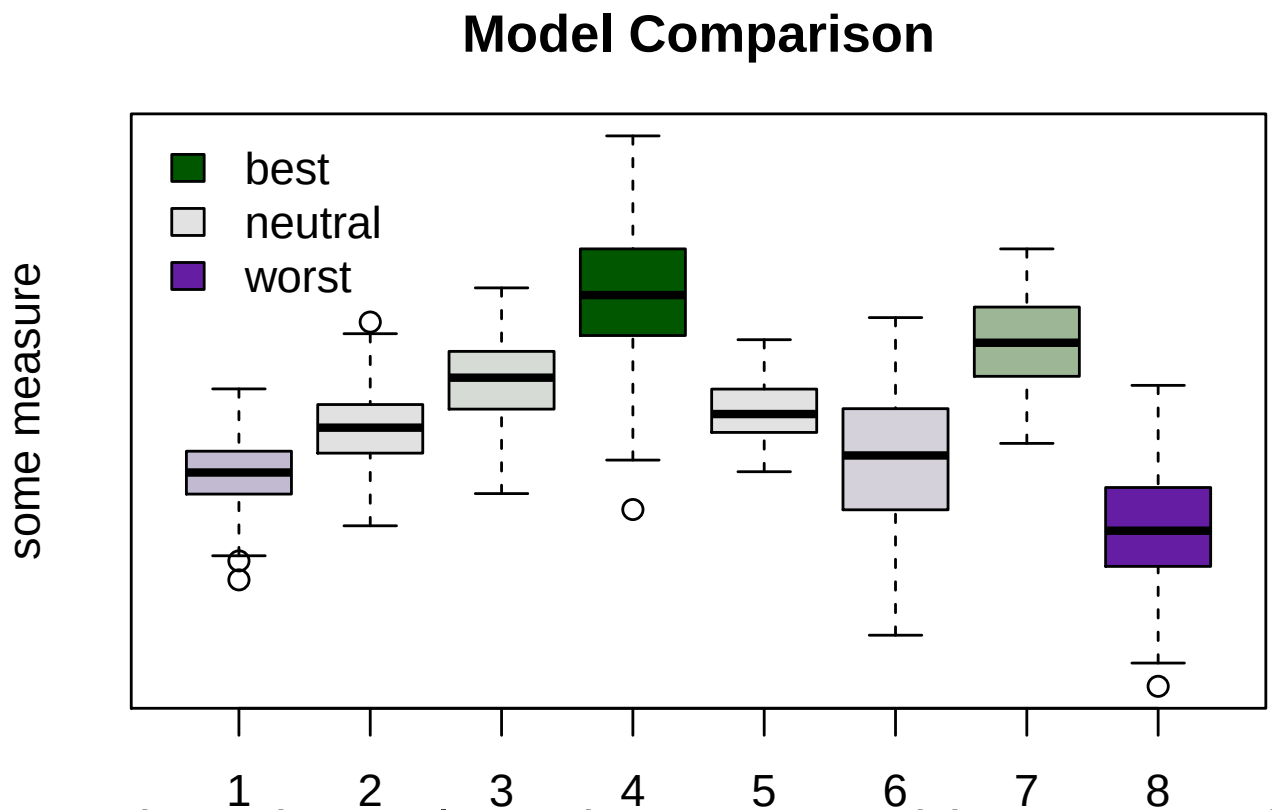


Solution: Diverging color schemes; combine sequential schemes with smooth transition.

Color Palettes: Diverging

Goal: Code quantitative data and highlight both ends of the spectrum (e.g., anomalies, wet/dry, probabilities, . . .).



Solution: Diverging color schemes; combine sequential schemes with smooth transition.

Experiences With Practitioners

In the beginning

- Hesitation of colleagues.
- “Not necessary!”
- “Why should we change existing products?”
- “Everybody does it like this . . . ”

A few days later

- Mainly positive feedback.
- Decrease of misinterpretations in classroom (“Weather & Forecast”).
- “Much easier to interpret . . . ”
- “How can I make use of those palettes (in my software)?”

hclwizard.org

A Perception-Based Color Space

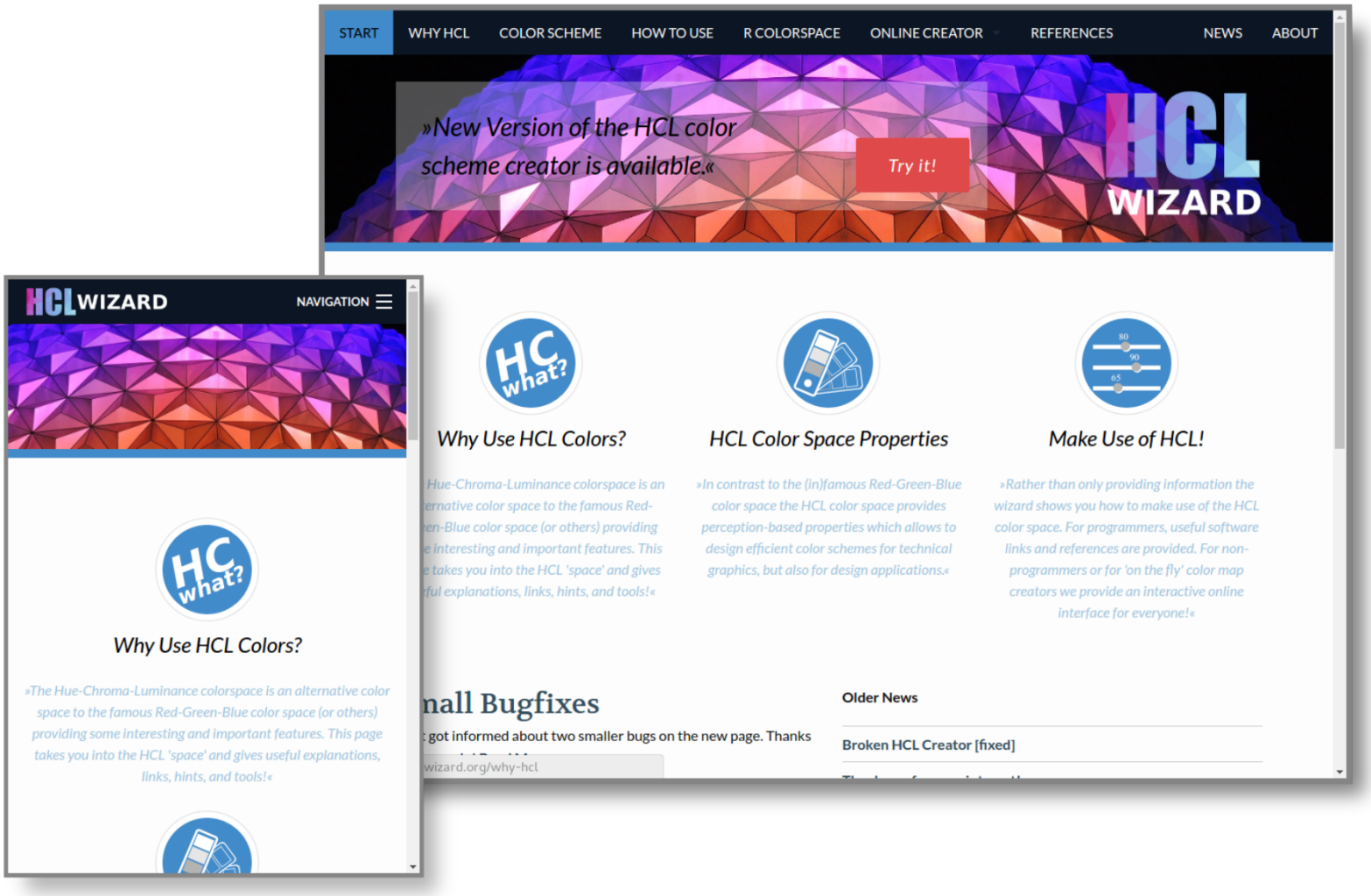
hclwizard.org

The R `colorspace` package

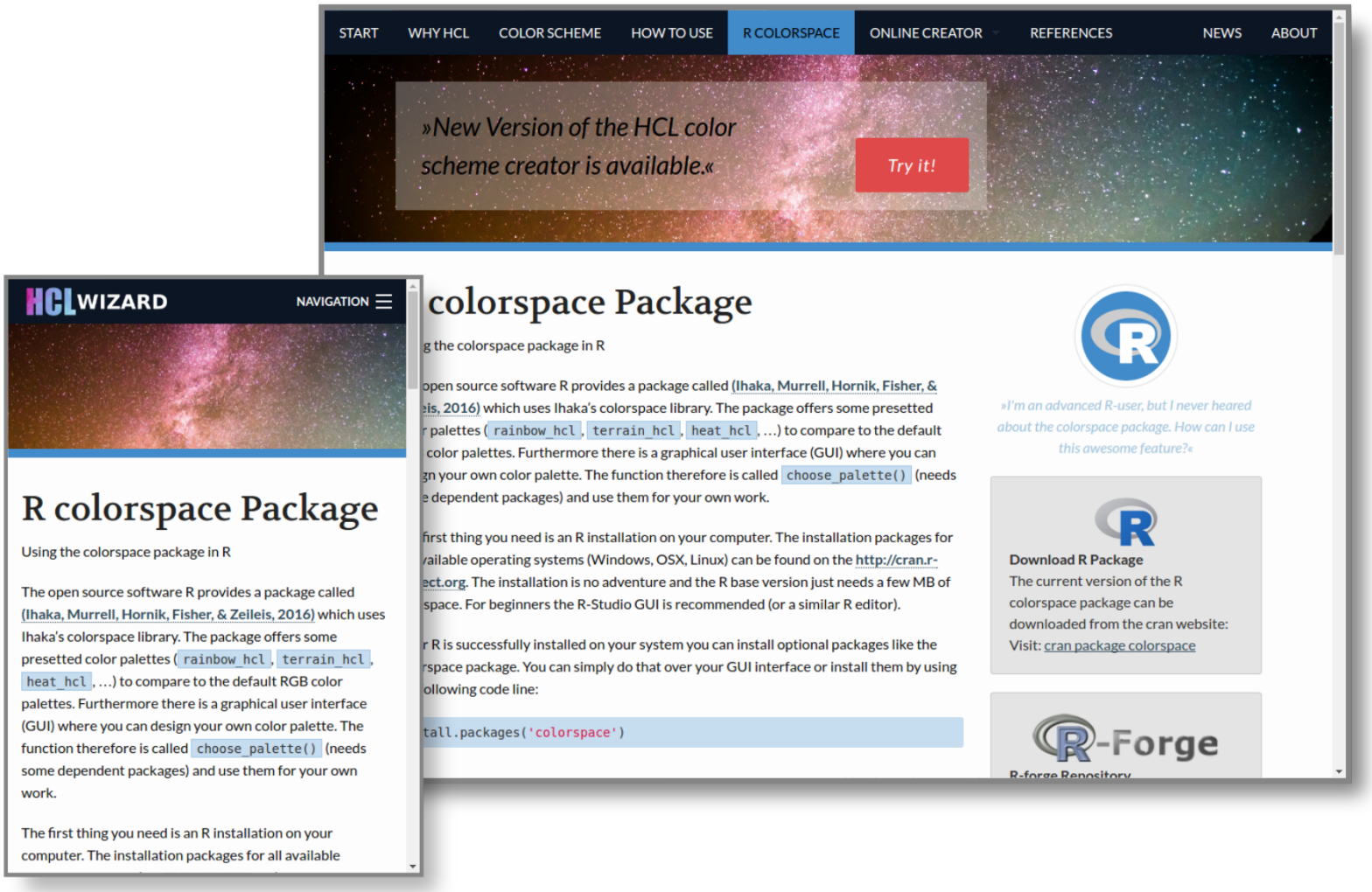
- Available on c-ran.
- Provides methods to explore, choose, and assess HCL based color maps.

For non-R users: We set up a website to provide the same interface to everyone. Just visit: `http://hclwizard.org`.

hclwizard.org



hclwizard.org



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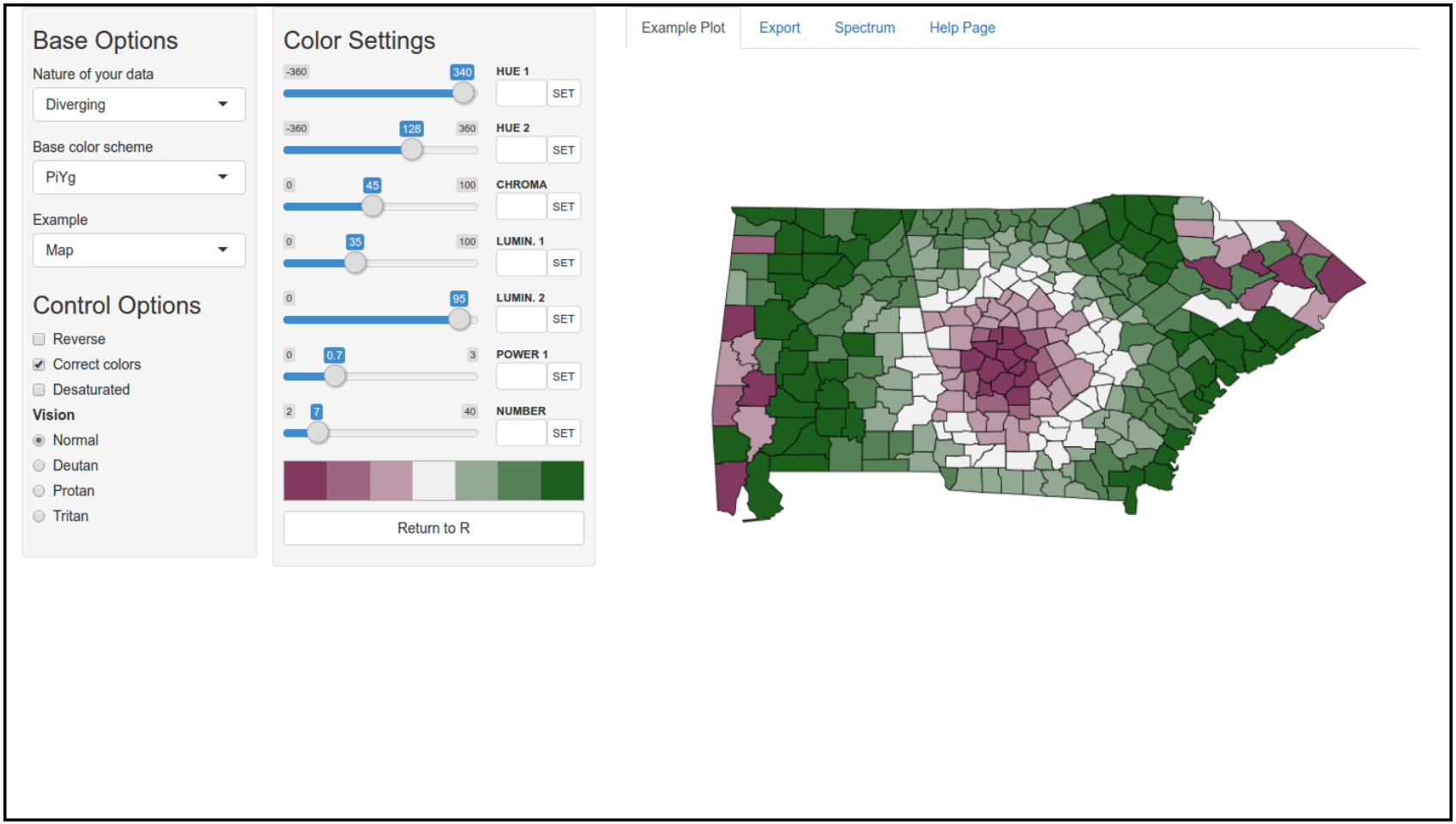

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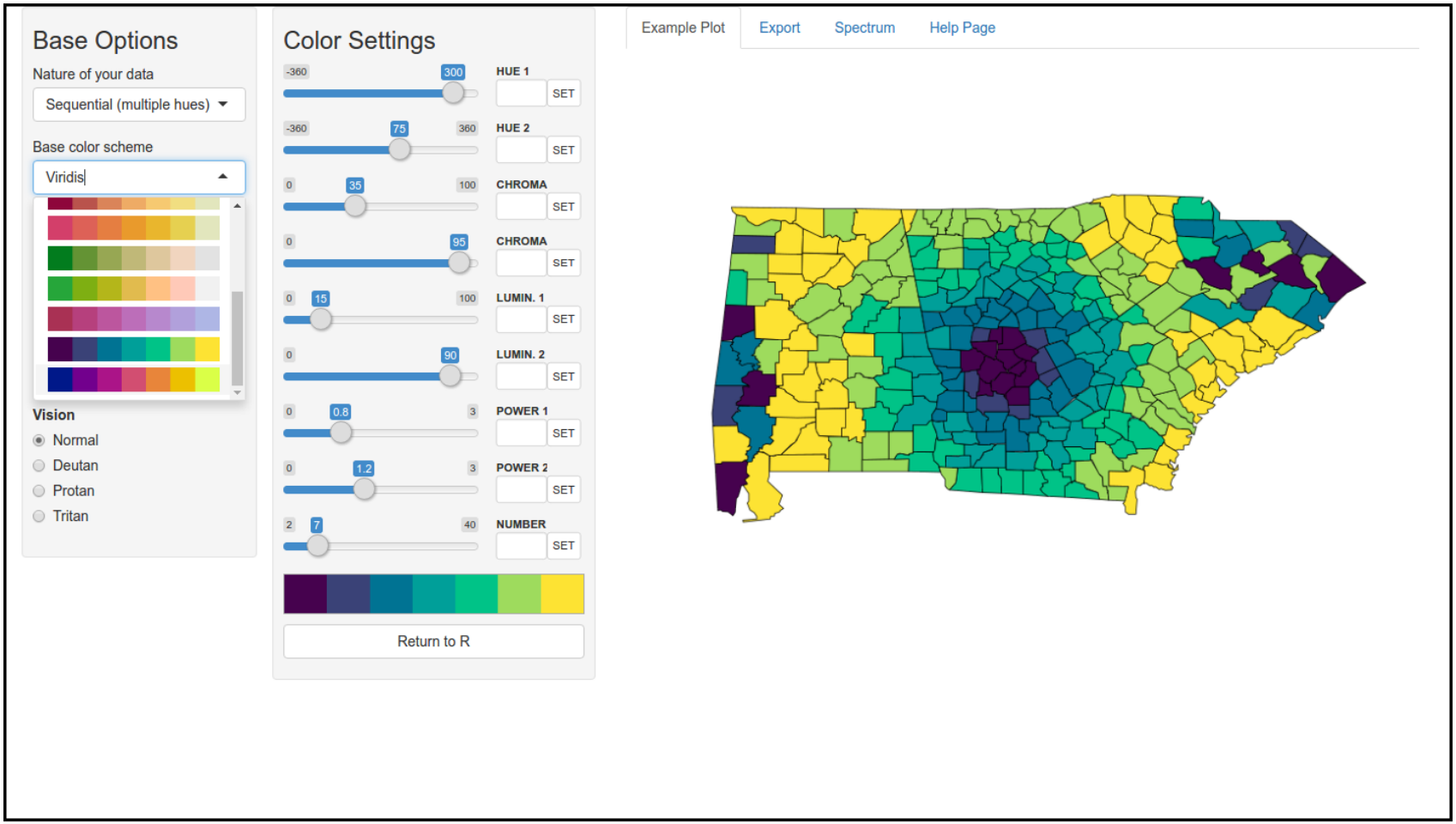

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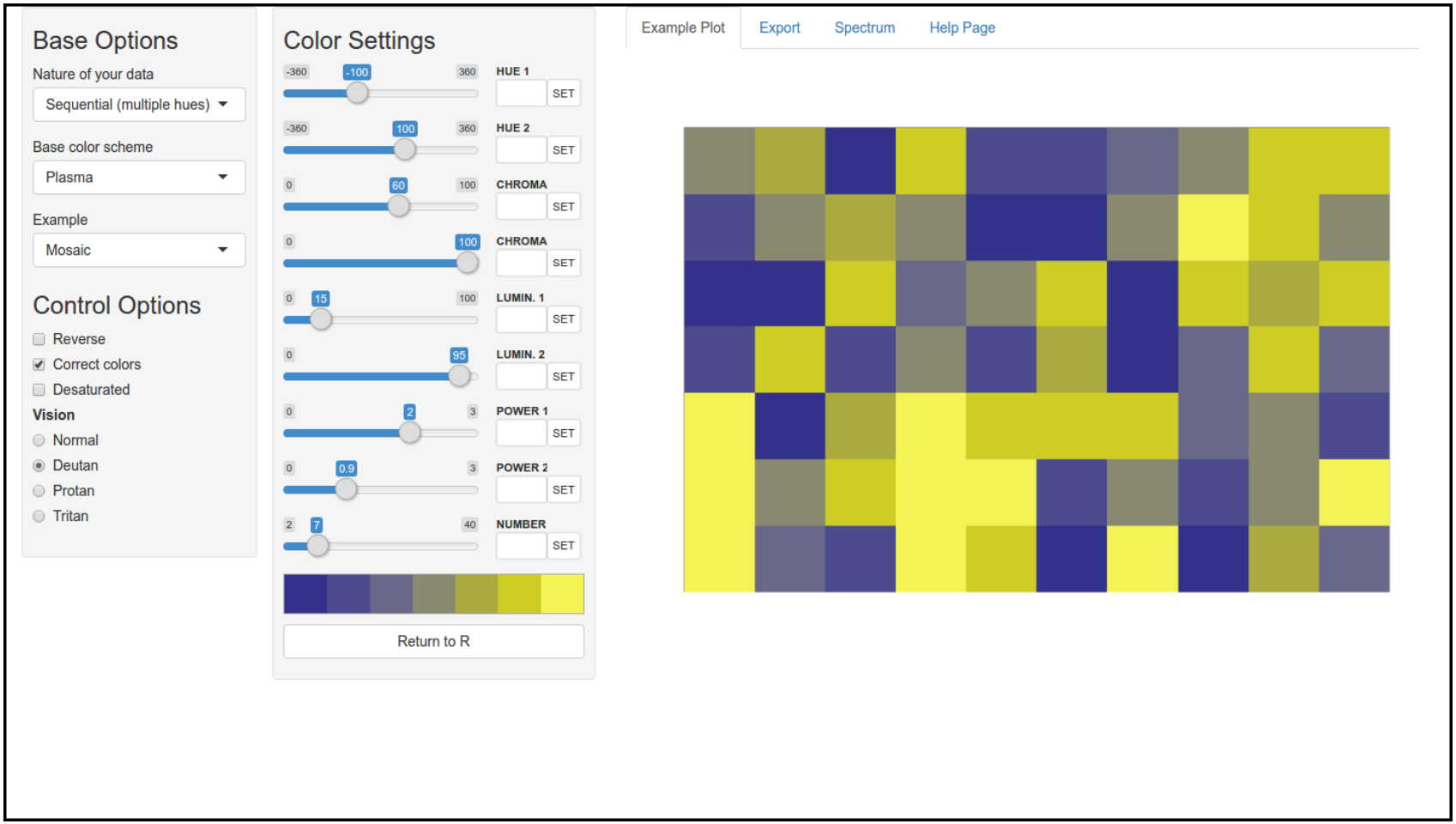

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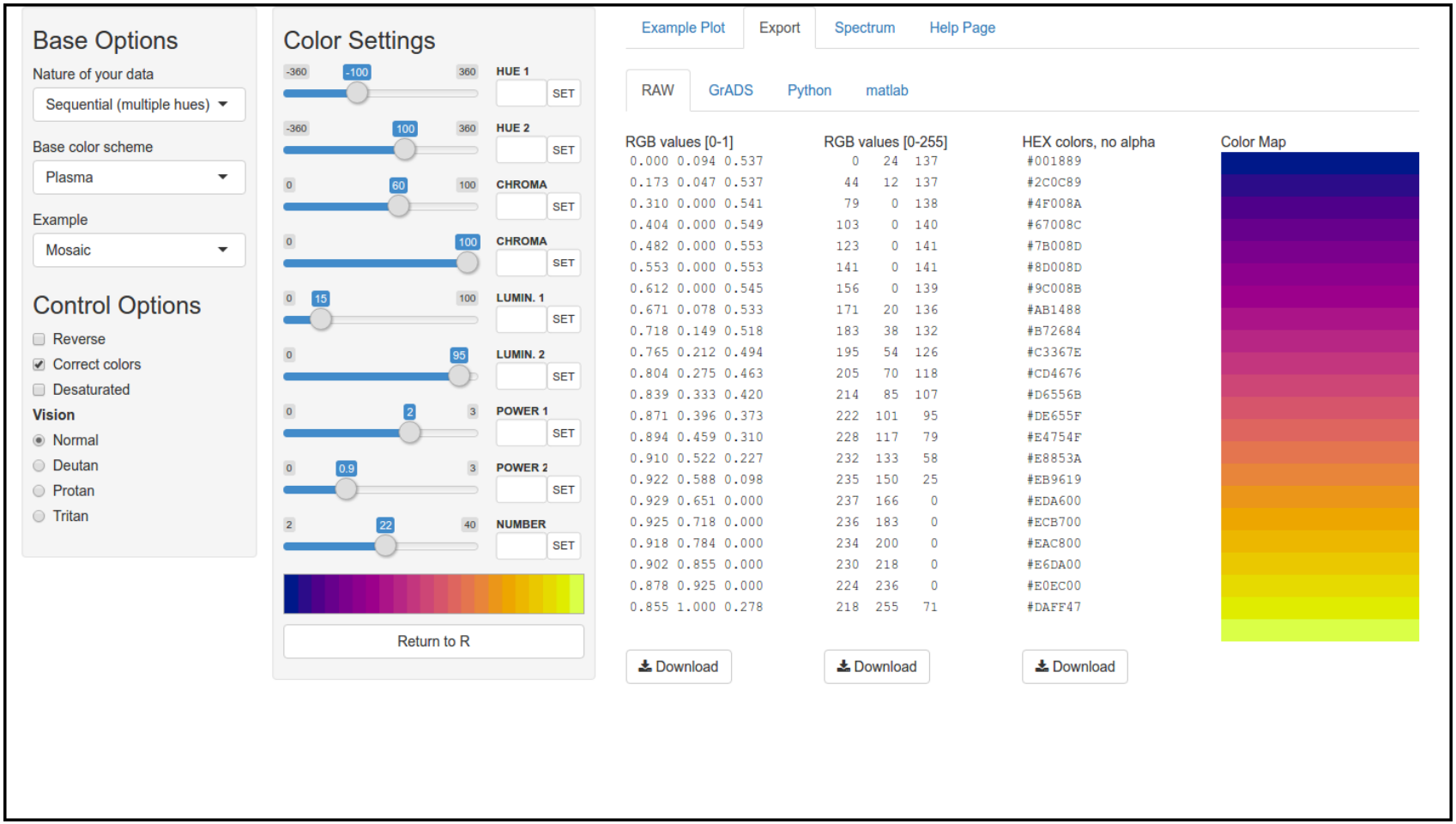

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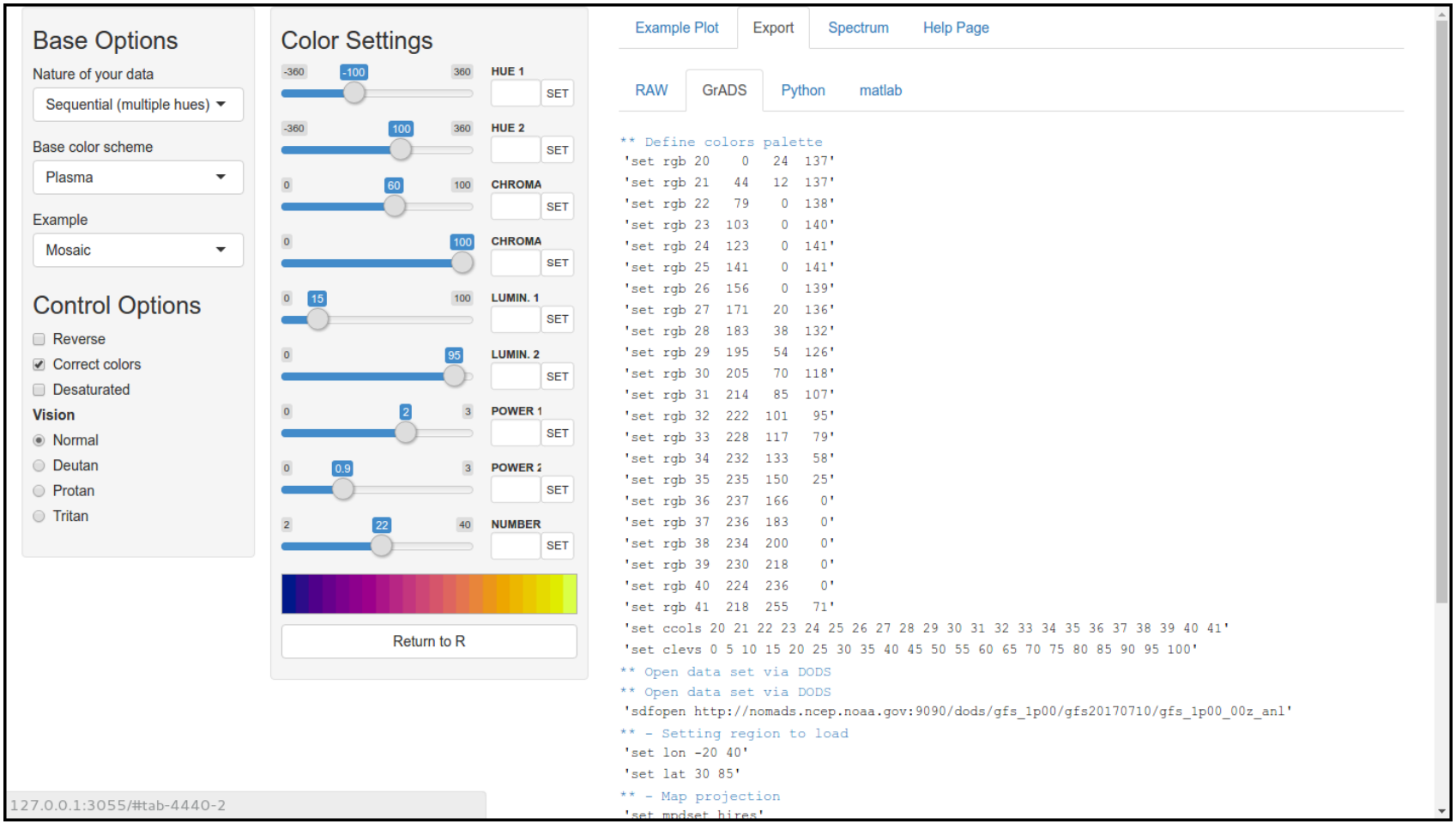

The R colorspace Package

A Perception-Based Color Space

R colorspace

```
> library('colorspace')
> # Interactively choosing color palettes
> #
> # Variant A:
> # pal <- choose_palette()
> #
> # Variant B (requires shiny and shinyjs):
> # pal <- hclwizard()
```

R colorspace

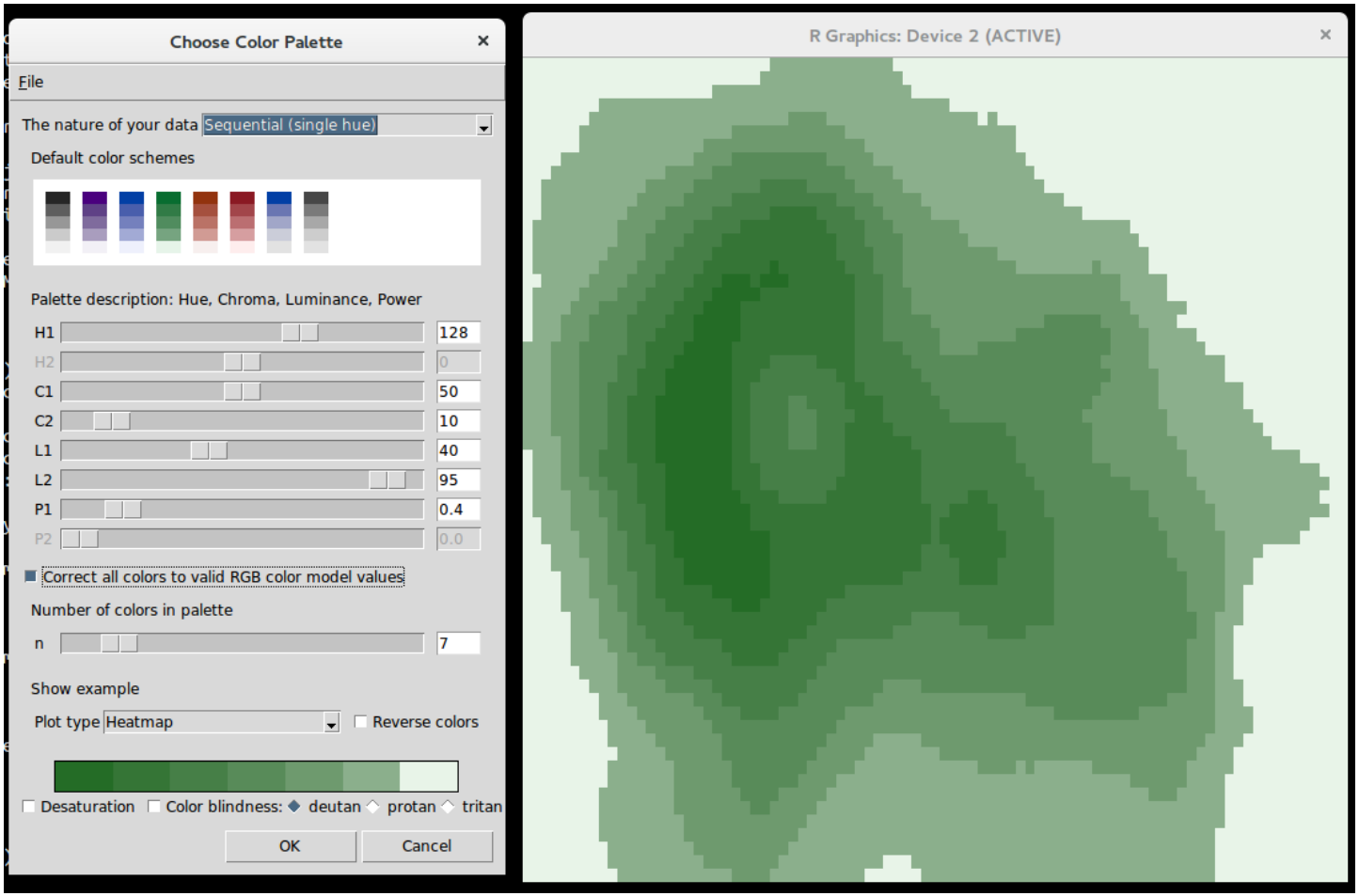

Figure: Screenshot of the tikz choose_palette interface.

R colorspace

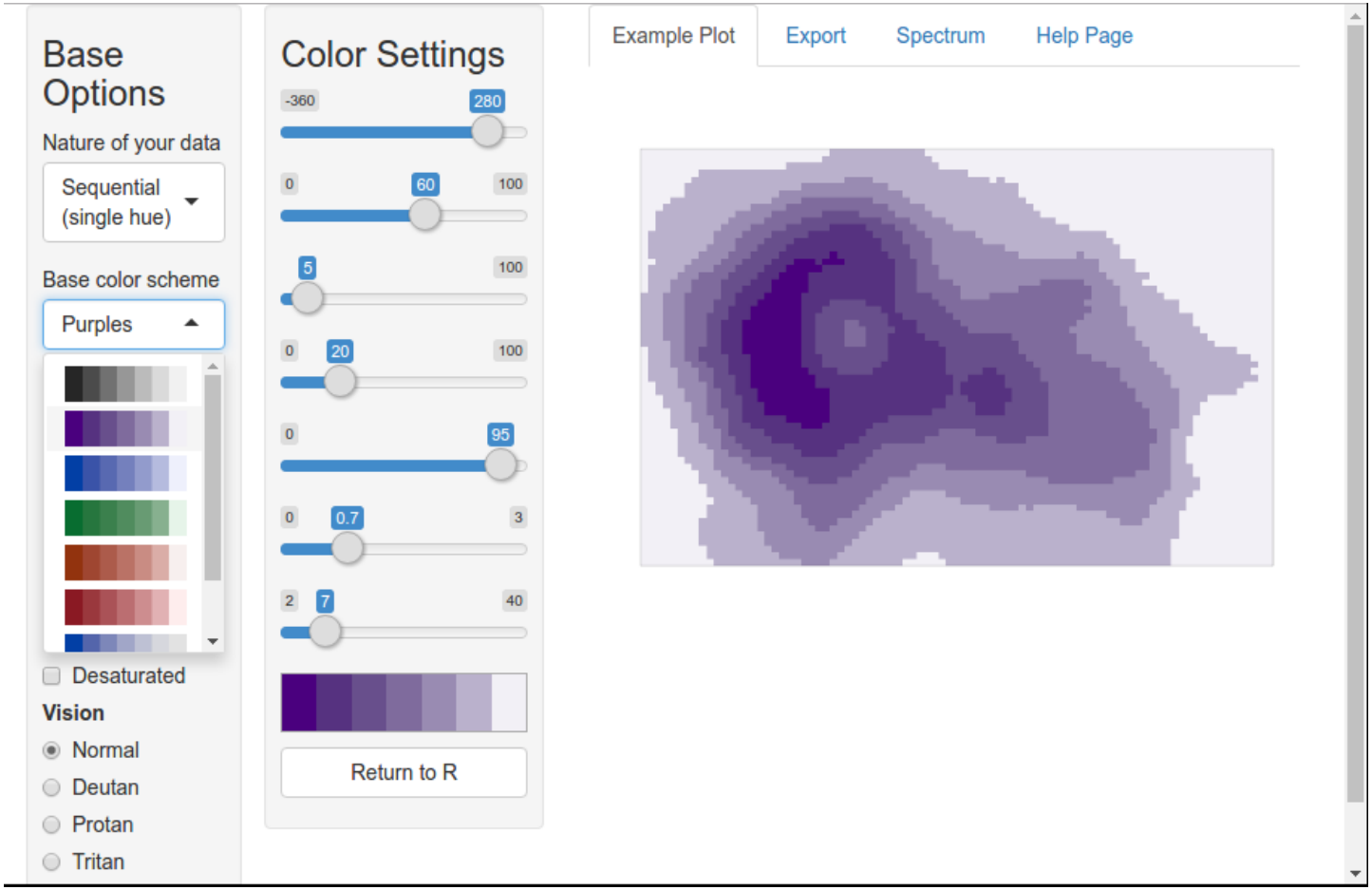

Figure: Screenshot of the hclwizard interface.

R colorspace

Use colorspace package on command-line level

```
> # choose_palette and hclwizard return a colormap function
> class(pal)
[1] "function"
> # function (n, h = c(12, 265), c = 80, l = c(25, 95), power = 0.7,
> #           fixup = TRUE, gamma = NULL, alpha = 1, ...)
```

R colorspace

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> # choose_palette and hclwizard return a colormap function
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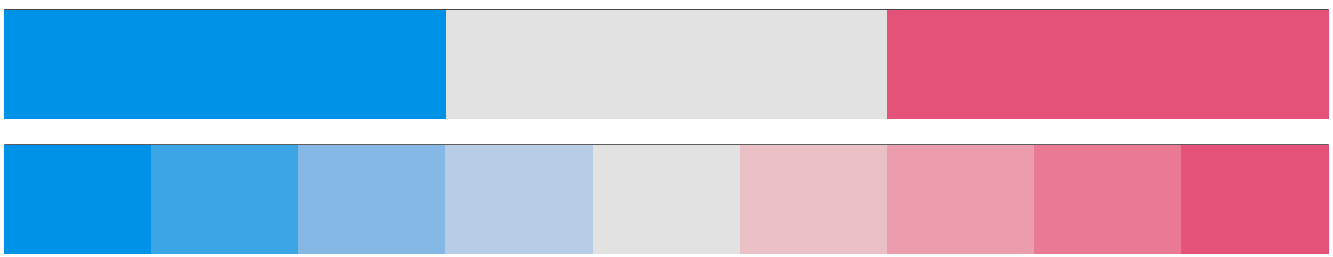
> #           fixup = TRUE, gamma = NULL, alpha = 1, ...)
```

Draw a color map with *N* colors:

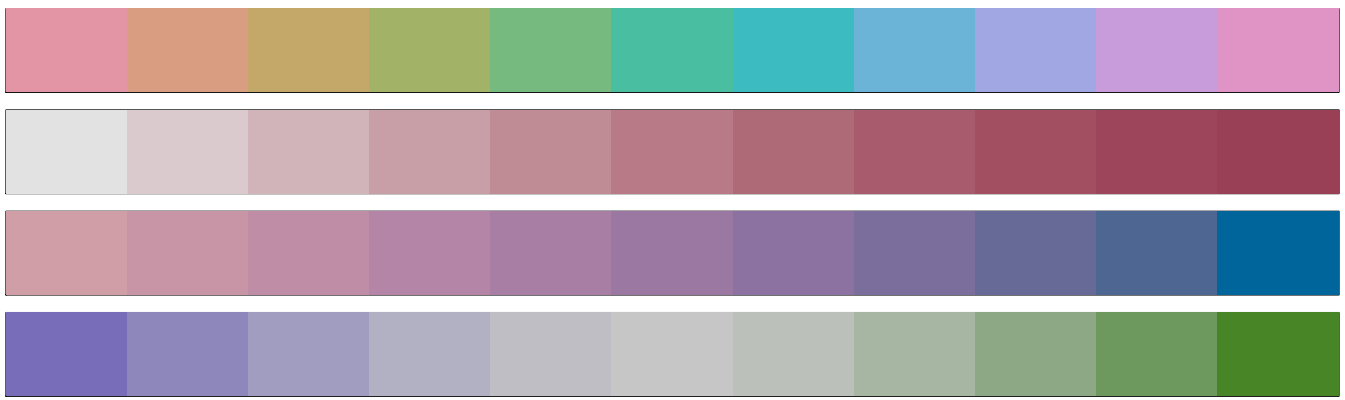
```
> pal(3)
[1] "#0092E7" "#E2E2E2" "#E45279"
> pal(9)
[1] "#0092E7" "#3BA5E6" "#86B8E5" "#B7CDE5" "#E2E2E2" "#EAC0C7" "#EC9DA
[8] "#EA7A93" "#E45279"
```



R colorspace

Basic colorspace wrapper methods:

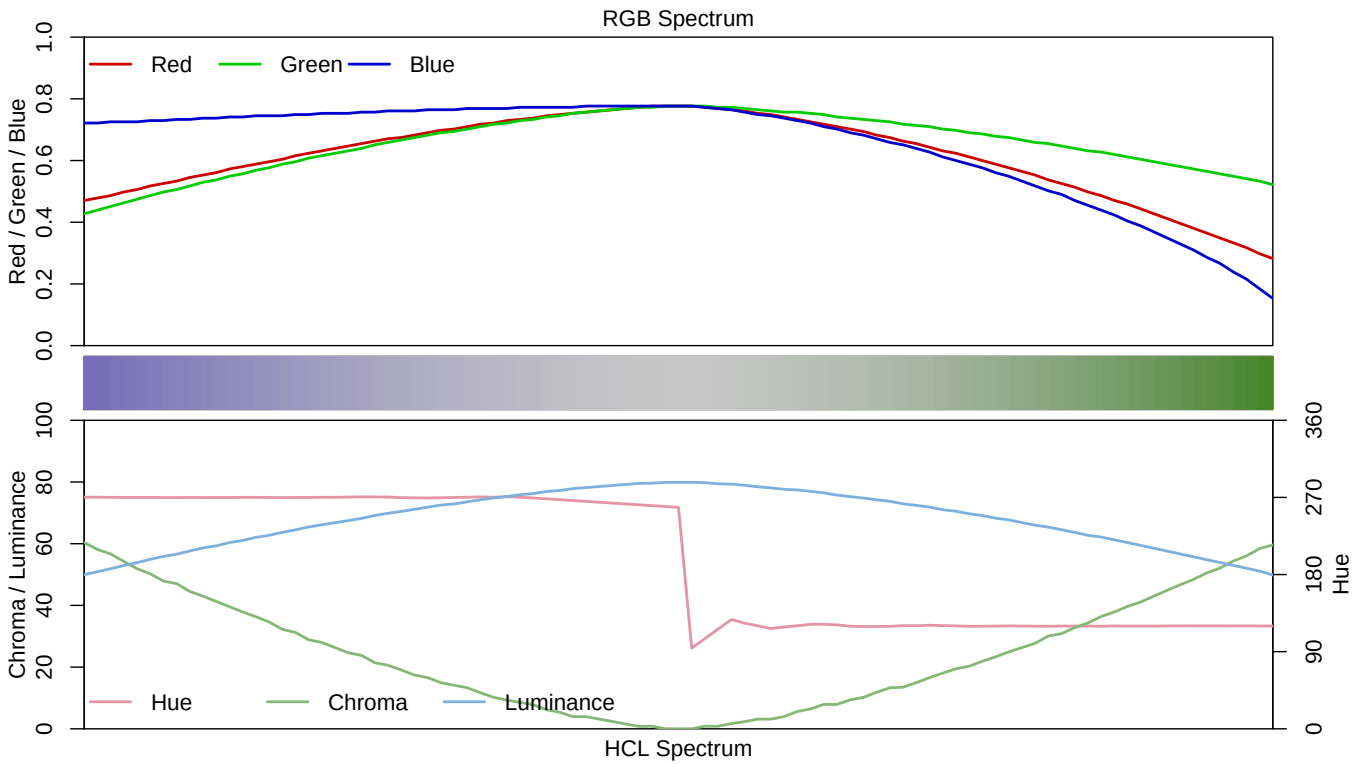
```
> qual <- rainbow_hcl(n=11)
> seq  <- sequential_hcl(n=11, h=0, l=c(90,40), c.=c(0,60))
> heat <- heat_hcl(n=11, h=c(0,-120), l=c(70,40), c.=c(30,60))
> div  <- diverge_hcl(n=11, h=c(270,120), c=60, l=c(50,80))
```



R colorspace

Assess the spectrum of a color map:

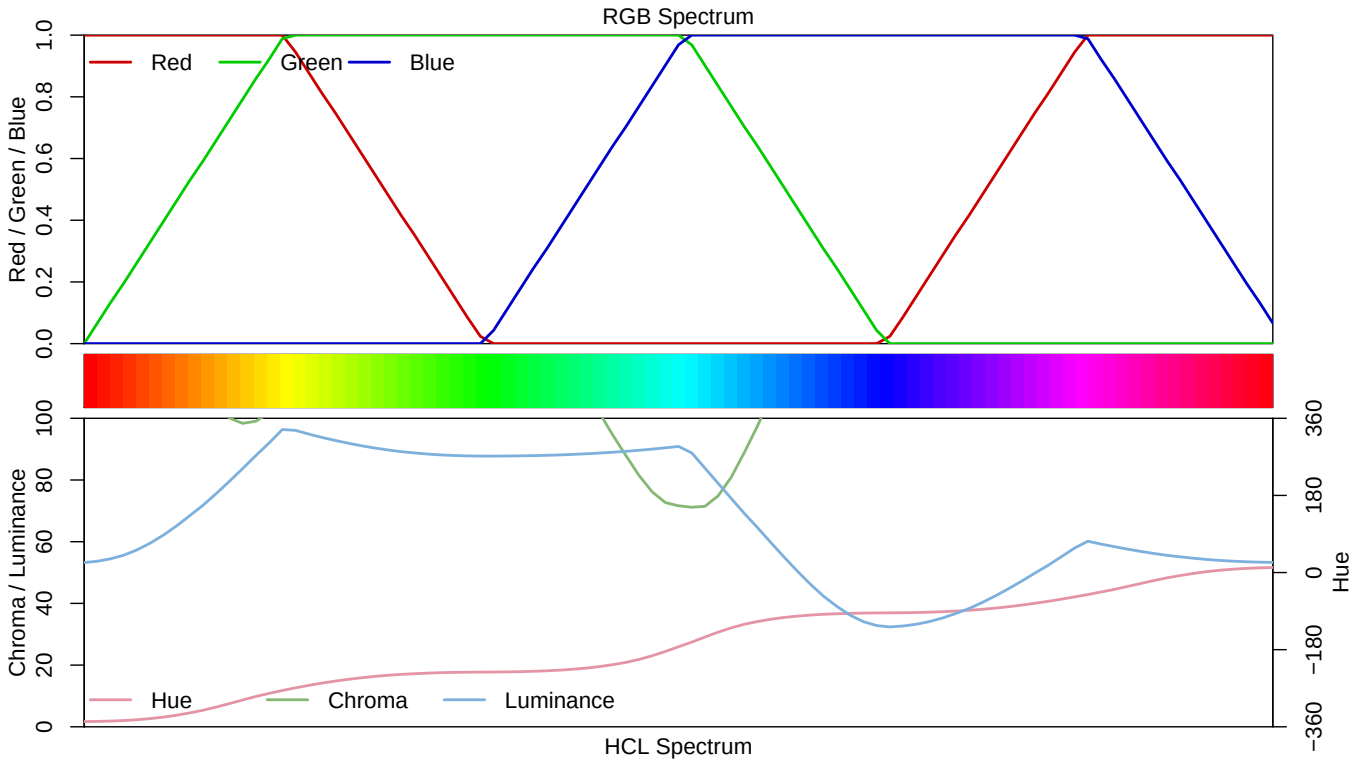
```
> div  <- diverge_hcl(n=91, h=c(270,120), c=60, l=c(50,80))
> specplot( div )
```



R colorspace

Assess the spectrum of a color map:

```
> rainbow  <- rainbow(91)
> specplot( rainbow )
```



R colorspace

Use colorspace to convert colors:

```
> div  <- diverge_hcl(n=5, h=c(270,120), c=60, l=c(50,80))
> RGB <- hex2RGB( div );       RGB

             R         G         B
[1,] 0.4705882 0.4274510 0.7215686
[2,] 0.6666667 0.6549020 0.7568627
[3,] 0.7764706 0.7764706 0.7764706
[4,] 0.6039216 0.6862745 0.5803922
[5,] 0.2823529 0.5215686 0.1529412

> # Convert to HCL
> HCL <- as(RGB,"polarLUV");   HCL

            L             C         H
[1,] 49.96609 60.378199003 270.31045
[2,] 69.49331 20.598091195 270.26623
[3,] 79.88122  0.006140369  94.09931
[4,] 69.23223 21.080046408 119.96933
[5,] 49.85643 59.608000199 119.81271
```

R colorspace

One of the “core functions” is `polarLUV`:

```
> L <- seq(100, 30, lengt=12)
> C <- seq(40,  80, length=12)
> H <- rep( c(0,120,240), c(4,4,4) )
> HCL <- polarLUV(H=H, C=C, L=L)
```

R colorspace

One of the “core functions” is `polarLUV`:

```
> L <- seq(100, 30, lengt=12)
> C <- seq(40,  80, length=12)
> H <- rep( c(0,120,240), c(4,4,4) )
> HCL <- polarLUV(H=H, C=C, L=L)
```

Convert colors to hexadeimal representation:

```
> hexT <- hex( as(HCL,"RGB"), fixup=TRUE)
> hexF <- hex( as(HCL,"RGB"), fixup=FALSE)
```

R colorspace

One of the "core functions" is `polarLUV`:

```
> L <- seq(100, 30, lengt=12)
> C <- seq(40,  80, length=12)
> H <- rep( c(0,120,240), c(4,4,4) )
> HCL <- polarLUV(H=H, C=C, L=L)
```

What does the `fixup=TRUE`:

```
> as(HCL,"RGB")
```

```
                R          G          B
 [1,]  1.50358973 0.85466492 0.95620852
 [2,]  1.33963389 0.70133126 0.80120053
 [3,]  1.18684461 0.56676651 0.66377437
 [4,]  1.04495144 0.44977227 0.54287660
 [5,]  0.27519179 0.56279146 0.20191278
 [6,]  0.19728039 0.46266385 0.12965811
 [7,]  0.13385835 0.37503736 0.07240051
 [8,]  0.08354332 0.29909188 0.02861425
 [9,] -0.01705634 0.20360461 0.48078327
[10,] -0.05184201 0.15500028 0.41481690
[11,] -0.07965869 0.11583956 0.36140338
[12,] -0.10459109 0.08556191 0.32440858
```

Summary

Choice of colors:

- Use color with care!
- Think about who the readers/users are.
- Avoid large areas of flashy, highly-saturated colors.
- Employ monotonic luminance scale for numerical data.

Try it yourself:

- `http://hclwizard.org`
- *colorspace* in R.

References

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Lumley T. (2006): Color Coding and Color Blindness in Statistical Graphics, *ASA Statistical Computing & Graphics Newsletter*, **17**(2), 4–7.

Ihaka R. (2003): Colour for Presentation Graphics, *Proceedings of the 3rd International Workshop on Distributed Statistical Computing*, Vienna (A), ISSN 1609-395X, `www.ci.tuwien.ac.at/Conferences/DSC-2003/Proceedings`.

Thank you for your attention!