



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

Reto Stauffer

<http://hclwizard.org>

Introduction

Color:

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

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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:

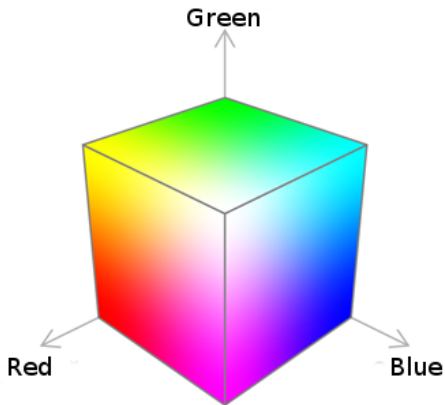
- Raise awareness of the issue.
- Introduce Hue-Chroma-Luminance (HCL) model.
 - Based on human perception.
 - Better control for choosing color palettes.
- Provide convenient software for exploring and assessing HCL-based palettes.



Common Sense

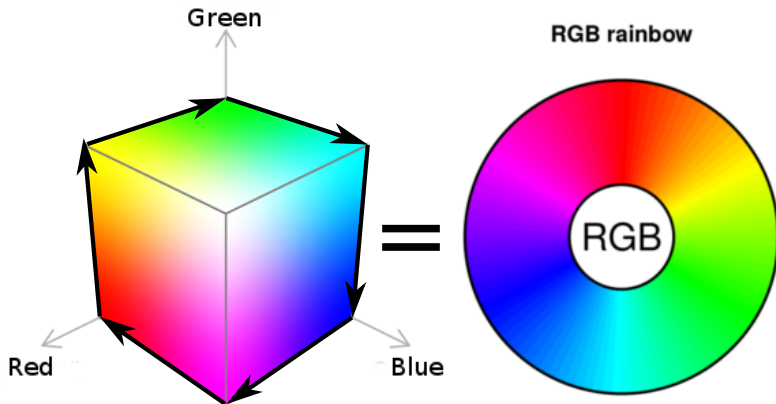
Using Red-Green-Blue Based Color Maps

RGB Rainbow



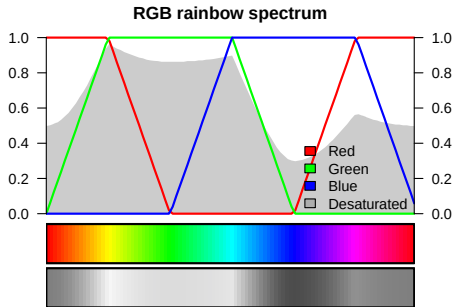
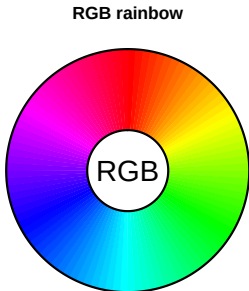
RGB color space: And the (in)famous rainbow color palette.

RGB Rainbow

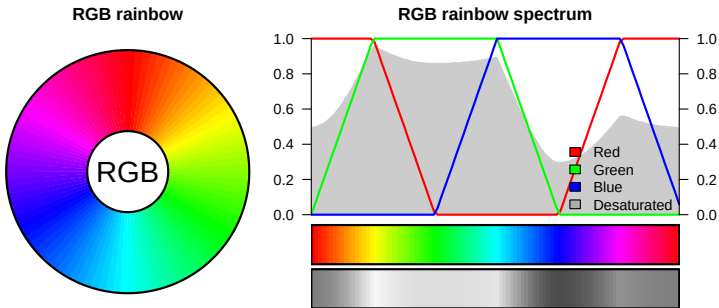


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RGB Rainbow

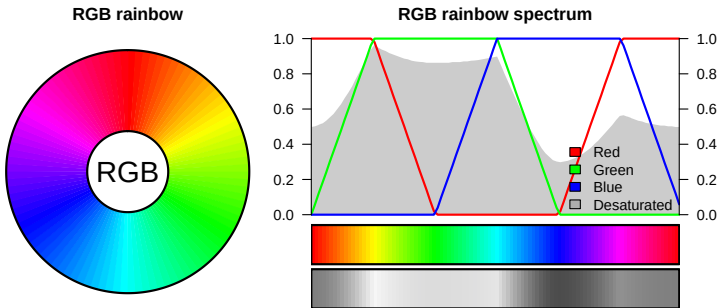


RGB Rainbow



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

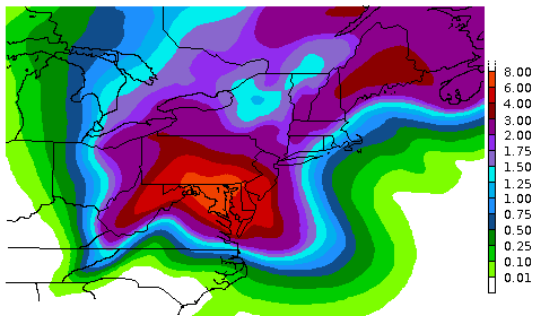
RGB Rainbow



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- Defaults only change slowly (if at all).

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

What's Wrong?

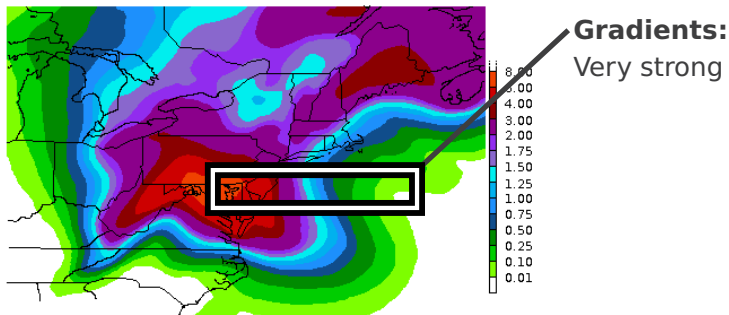


Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Original figure as published by the NOAA.

NOAA forecast, www.noaa.gov, 2012-10-27.

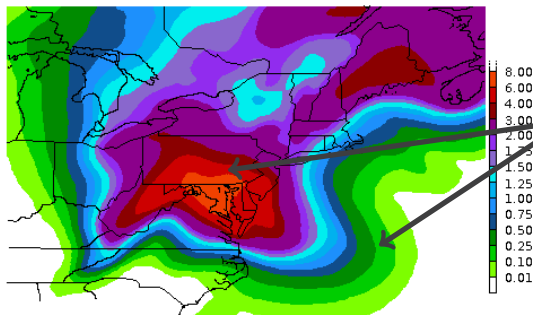
What's Wrong?



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Gradients:

Very strong

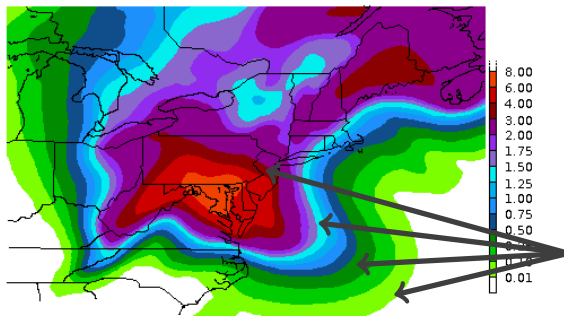
Saturation

Highly-saturated
colors

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Gradients:

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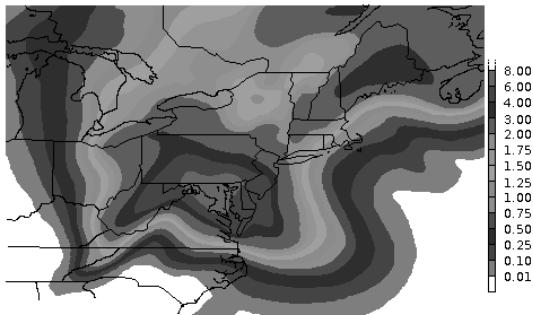
Highly-saturated
colors

Discontinuous

Bright, dark,
bright, dark, ...

Original figure as published by the NOAA.

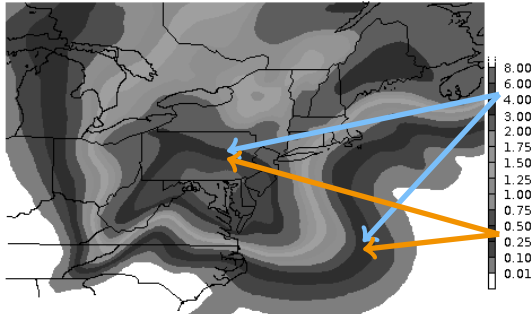
What's Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.

What's Wrong?

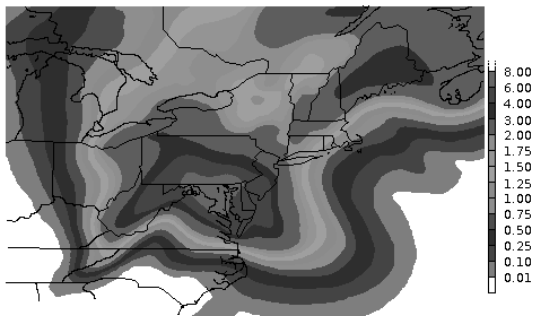


Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.

Assignment
No longer unique

What's Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

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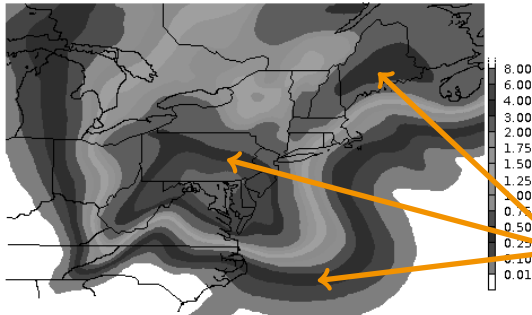
Assignment

No longer unique

Interpretation

Where is the maximum?

What's Wrong?



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Desaturated version of the original figure.

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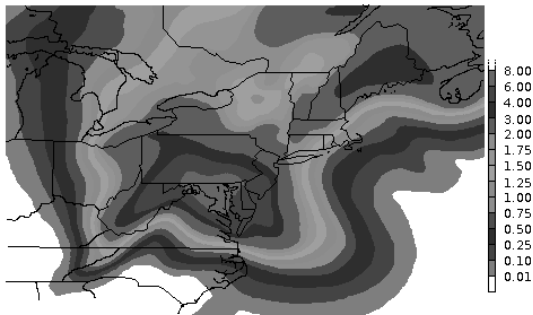
Interpretation

Where is the maximum?

Focus

On dark artefacts

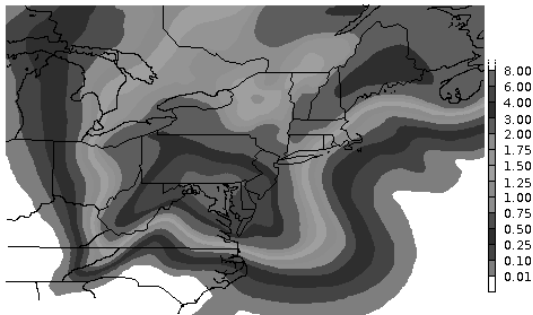
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Hurricane Sandy
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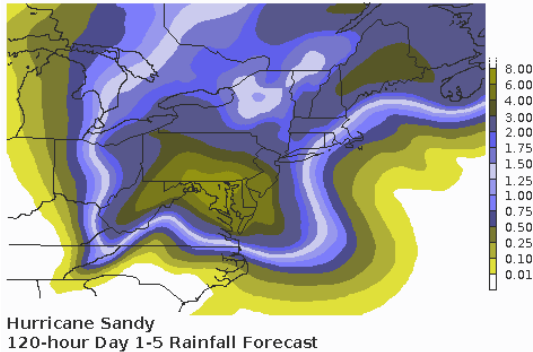


Hurricane Sandy
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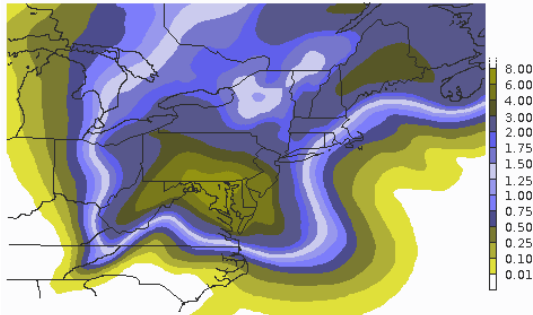
What's Wrong?



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

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

What's Wrong?



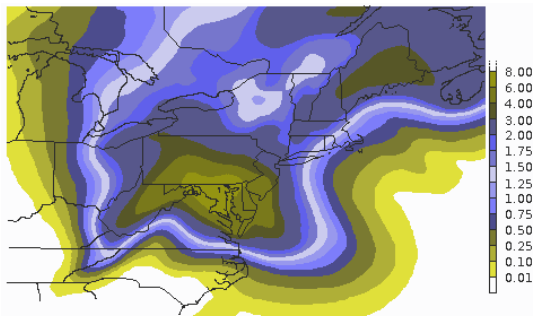
Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

End-user
Who is it?

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

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What's Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

End-user

Who is it?

Consider

Visual
constraints?

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

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

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.

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In practice:

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

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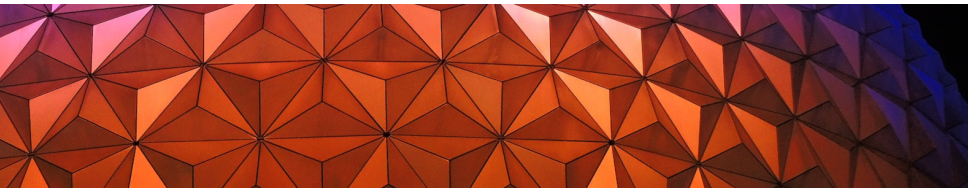
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- not be unappealing,
- highlight the important information,
- not mislead the reader,
- work everywhere and for everyone.

In practice:

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

Potential problems:

- For end users – reviewers, supervisor, colleague, 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: Colorfulness.
- Luminance: Brightness.

Hue



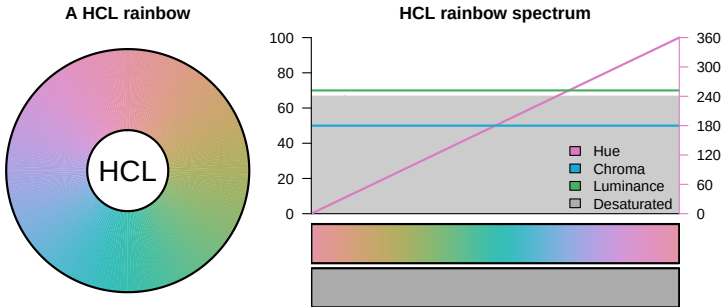
Chroma



Luminance

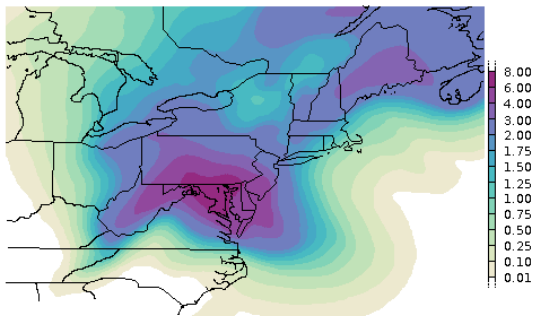


Perception-Based Way: HCL



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

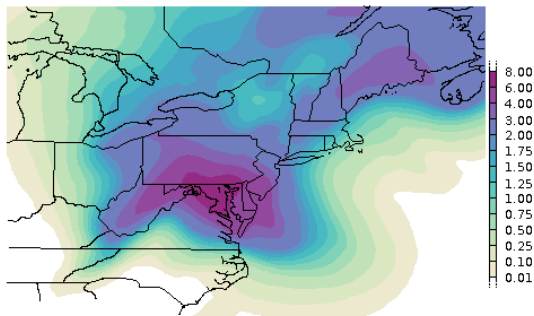
HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Same information, changed color scheme.

HCL Version

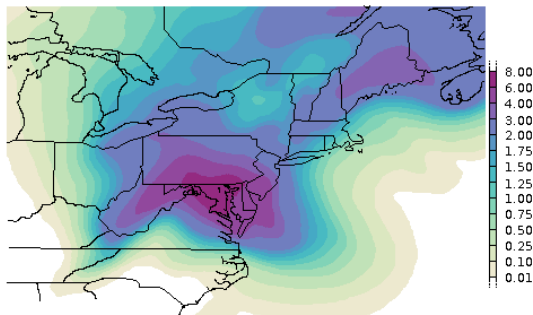


Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Colors:
Smooth
gradi-
ents.

Same information, changed color scheme.

HCL Version



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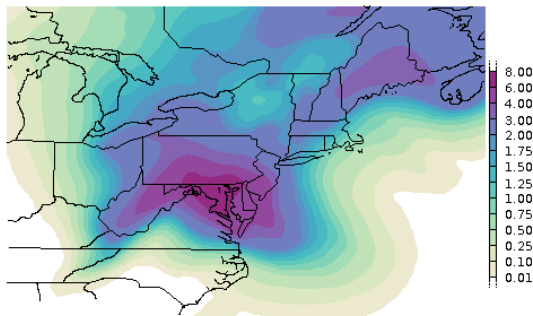
Colors:

Smooth gradients.

Information:

Guiding, no hidden information.

HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Same information, changed color scheme.

Colors:

Smooth gradients.

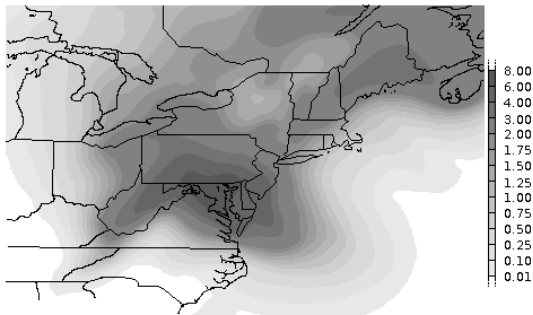
Information:

Guiding, no hidden information.

Works:

Screen, projector, gray-scaled device.

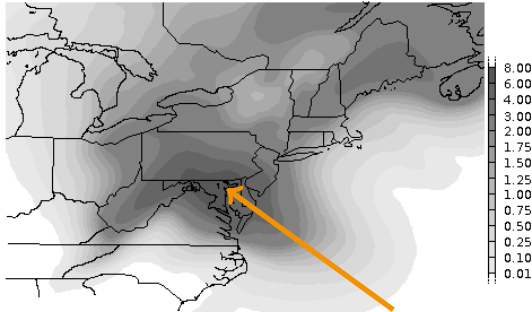
HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated representation of the HCL-version.

HCL Version



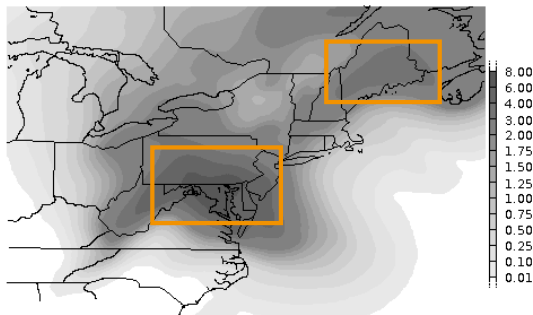
Hurricane Sandy
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Desaturated representation of the HCL-version.

Assignment:

Higher values $\Rightarrow$
lower luminance.

HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated representation of the HCL-version.

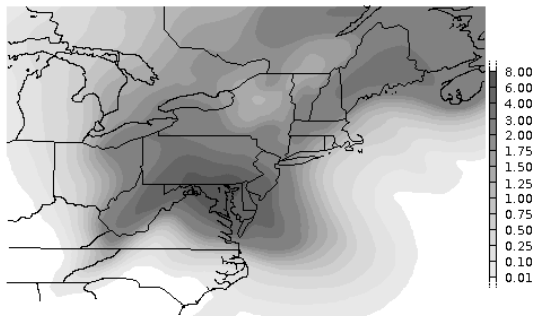
Assignment:

Higher values $\Rightarrow$
lower luminance.

Focus:

leads readers to
most important ar-
eas.

HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Assignment:

Higher values $\Rightarrow$
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Focus:

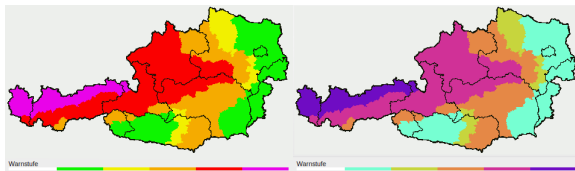
leads readers to
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Desaturated representation of the HCL-version.

Summary:

Solved a lot of problems by changing the color palette.

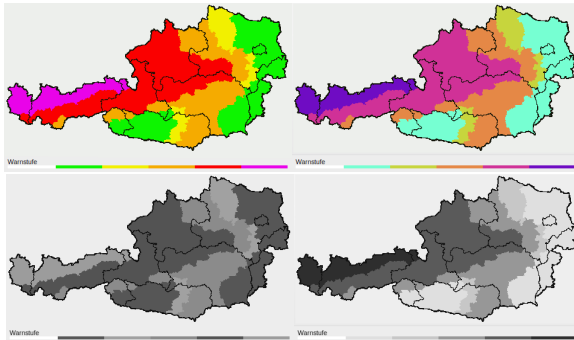
Warning Map Example



Colorized
Original (left)
HCL idea (right)

UBIMET GmbH, www.uwz.at, 2013-05-31.

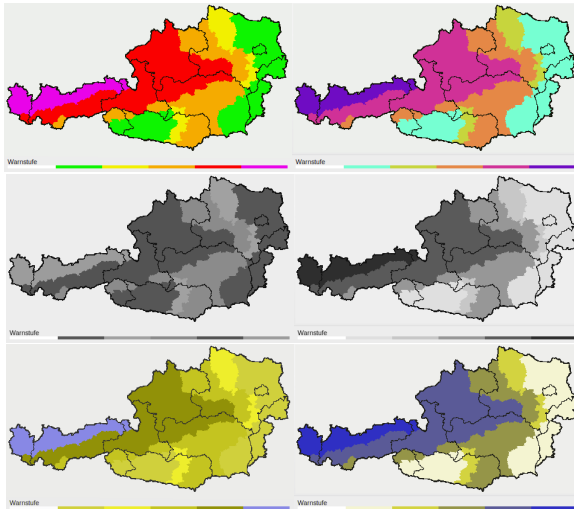
Warning Map Example



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Gray-scale

Warning Map Example



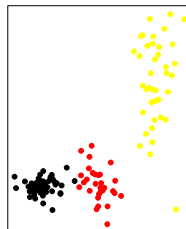
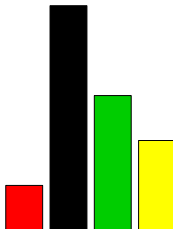
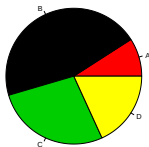
Colorized
Original (left)
HCL idea (right)

Gray-scale

Deuteranopia
Red-Green
weakness

Color Palettes: Qualitative

Goal: Code quantitative data.



Color Palettes: Qualitative

Goal: Code quantitative data.

dynamic [30, 300]



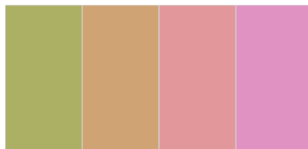
harmonic [60, 240]



cold [270, 150]

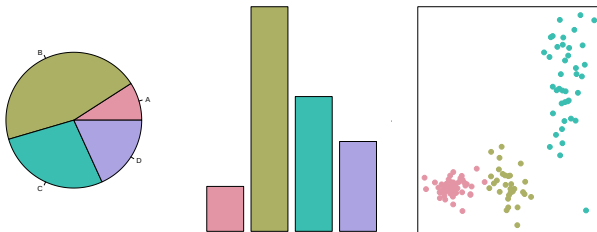


warm [90, -30]



Color Palettes: Qualitative

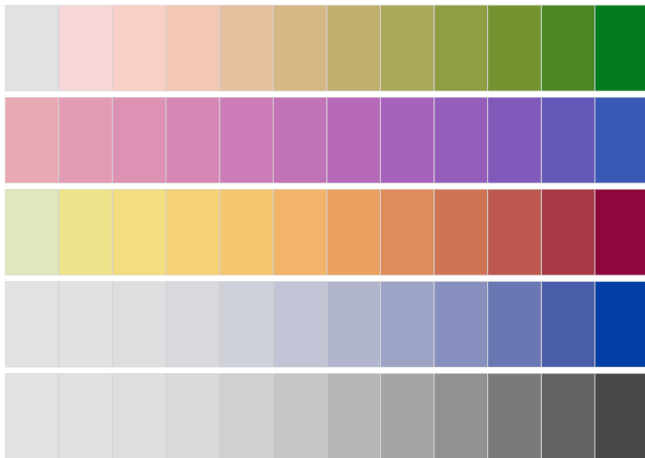
Goal: Code quantitative data.



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

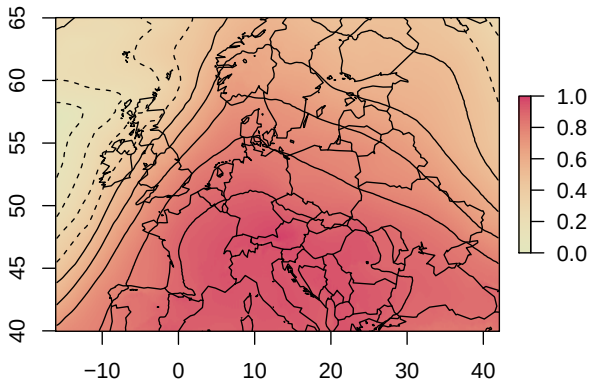
Color Palettes: Sequential

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



Color Palettes: Sequential

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



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

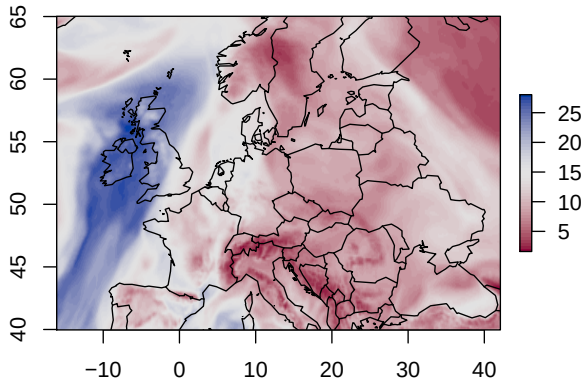
Color Palettes: Diverging

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



Color Palettes: Diverging

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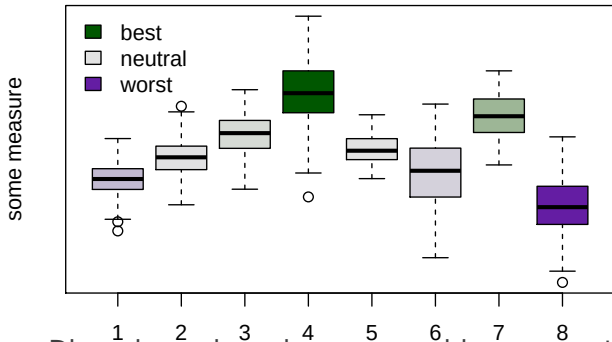


Solution: Diverging color schemes; combine sequential schemes with smooth transition.

Color Palettes: Diverging

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

Model Comparison



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 . . .”

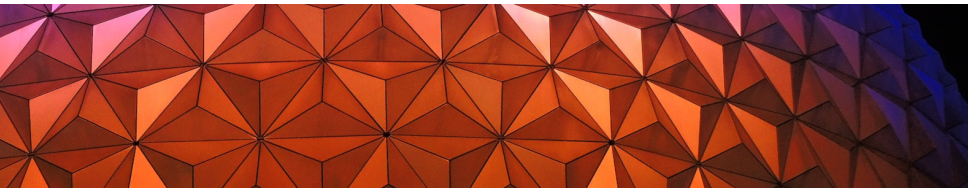
Experiences With Practitioners

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)?”



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

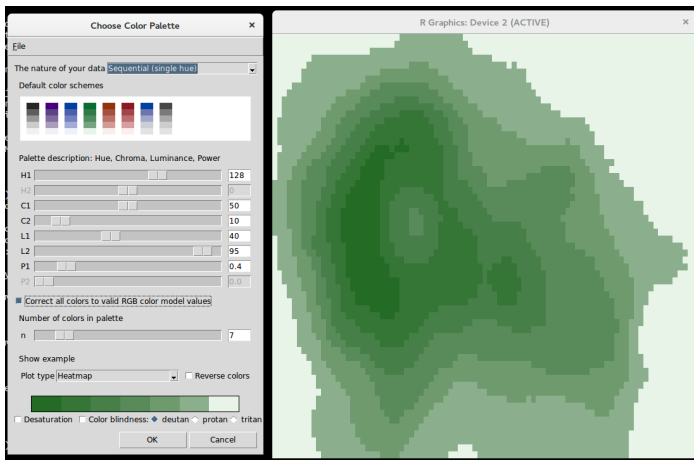


Figure: Screenshot of the tikz choose_palette interface.

R colorspace

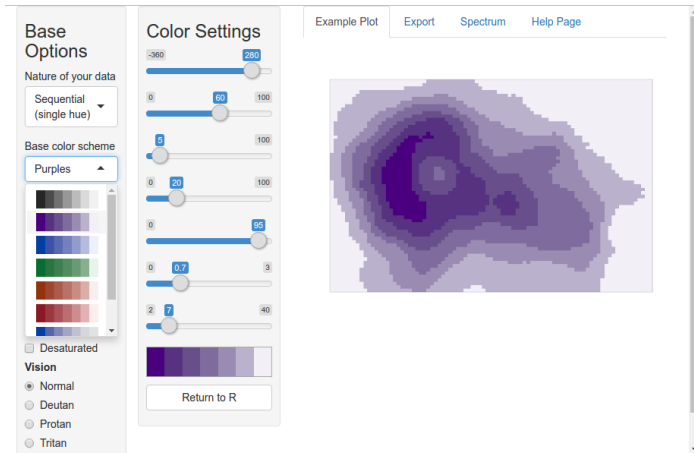


Figure: Screenshot of the hclwizard interface.

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

Use colorspace package on command-line level

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> # choose_palette and hclwizard return a colormap function  
> class(pal)
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```
[1] "function"
```

```
> # function (n, h = c(12, 265), c = 80, l = c(25, 95), power = 0.7,  
> #           fixup = TRUE, gamma = NULL, alpha = 1, ...)
```

Draw a color map with N colors:

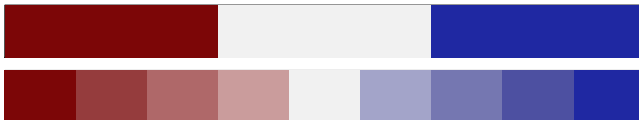
```
> pal(3)
```

```
[1] "#7C0607" "#F1F1F1" "#1F28A2"
```

```
> pal(9)
```

```
[1] "#7C0607" "#953C3D" "#AF6869" "#CA9C9C" "#F1F1F1" "#A3A4C9" "#757777"
```

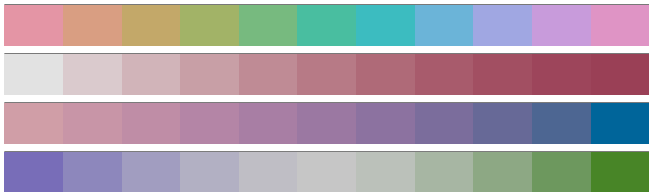
```
[8] "#4D50A1" "#1F28A2"
```



R colorspace

Basic colorspace wrapper methods:

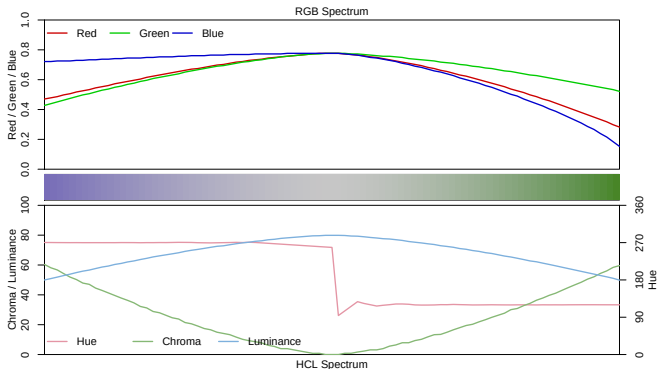
```
> qual <- rainbow_hcl(n=11)
> seq  <- sequential_hcl(n=11, h=0, l=c(90,40), c.=c(0,60))
> heat <- heat_hcl(n=11, h=c(0,-120), l=c(70,40), c.=c(30,60))
> div  <- diverge_hcl(n=11, h=c(270,120), c=60, l=c(50,80))
```



R colorspace

Assess the spectrum of a color map:

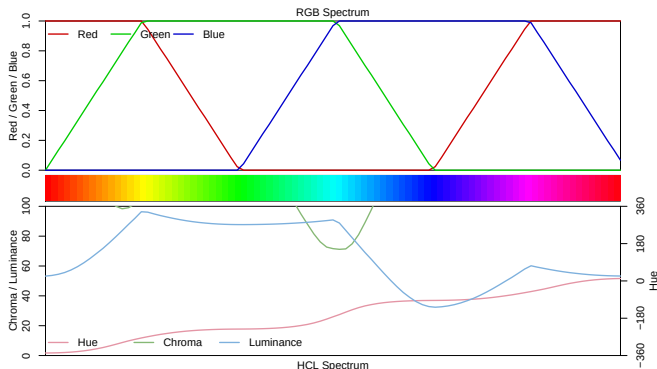
```
> div <- diverge_hcl(n=91, h=c(270,120), c=60, l=c(50,80))  
> specplot( div )
```



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, length=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

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```
> L <- seq(100, 30, length=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 hexadecimal representation:

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



R colorspace

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```
> L <- seq(100, 30, length=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

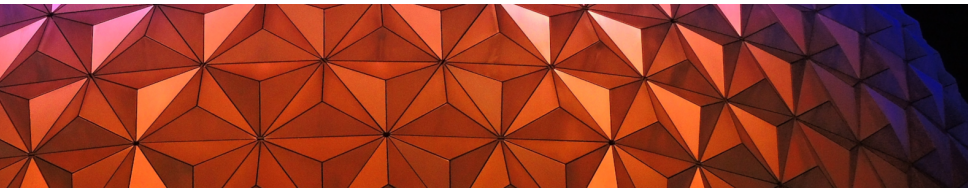
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Thank you for your attention!

And Today? (Rempel et al. 2017)

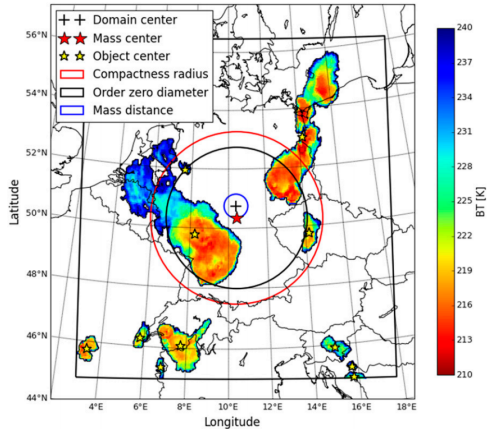


Figure: Rempel et al. (2017): MWR **145**(8).

And Today? (Rempel et al. 2017)

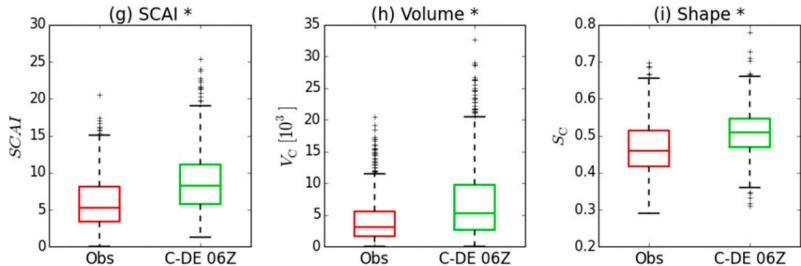


Figure: Rempel et al. (2017): MWR **145**(8).

And Today? (Rempel et al. 2017)

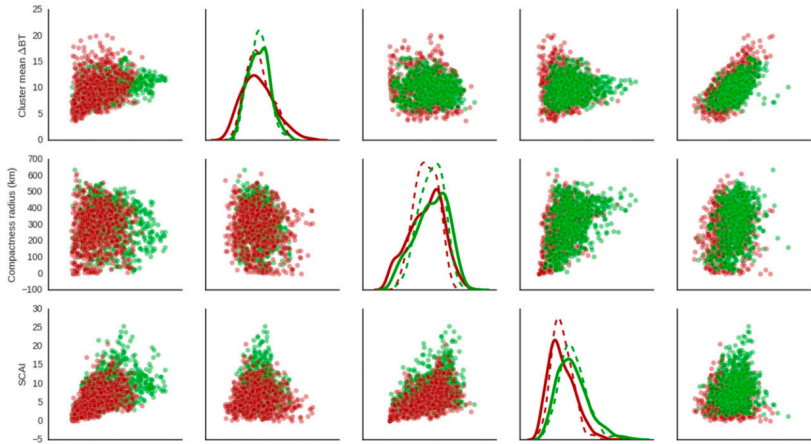


Figure: Rempel et al. (2017): MWR **145**(8).

And Today?



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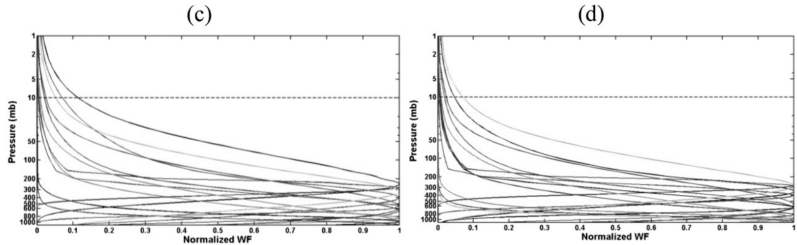
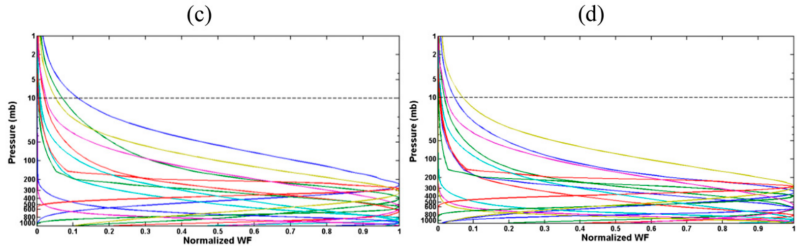
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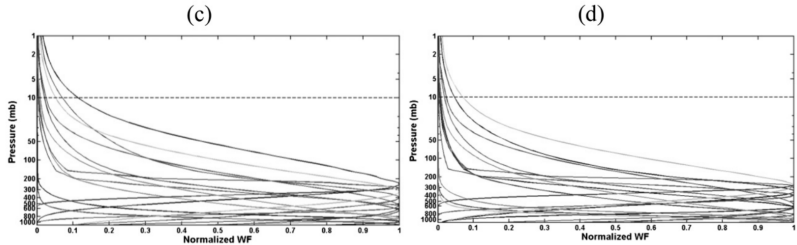
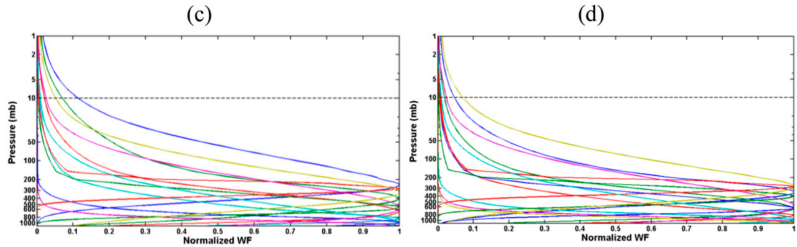
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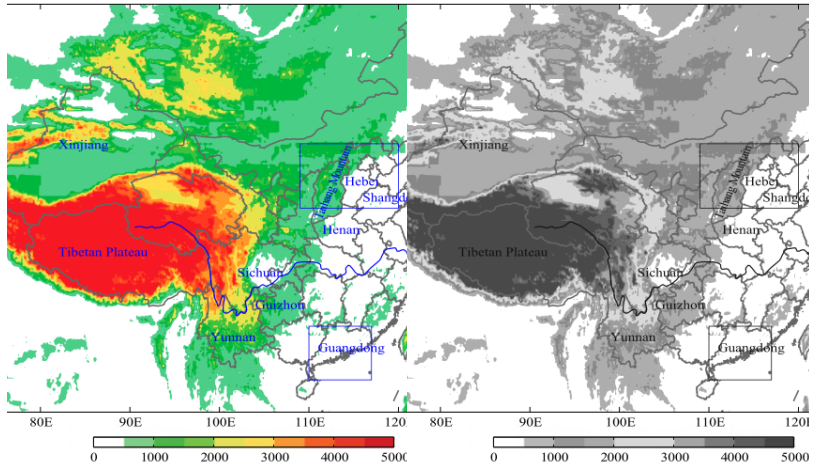
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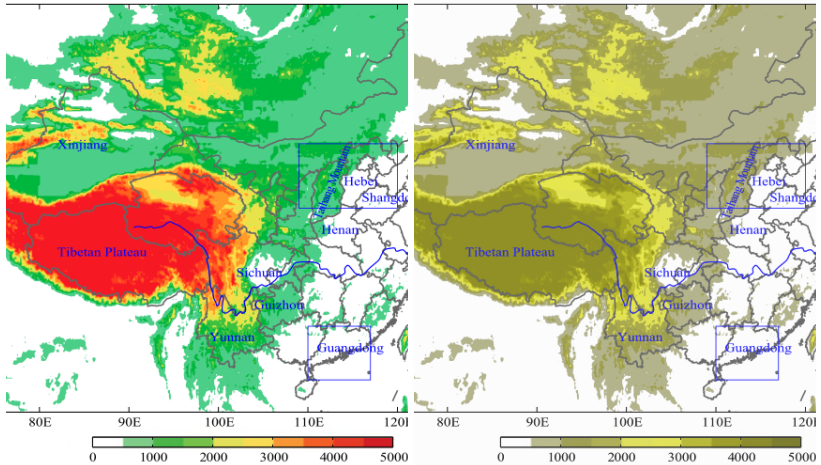
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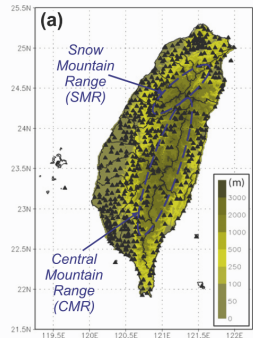
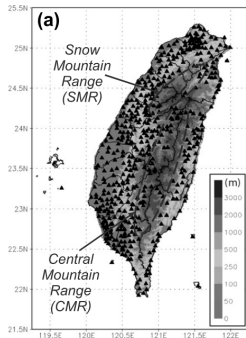
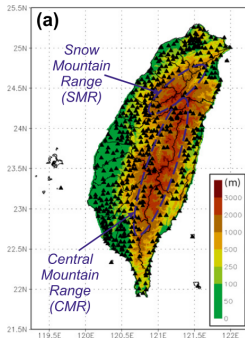
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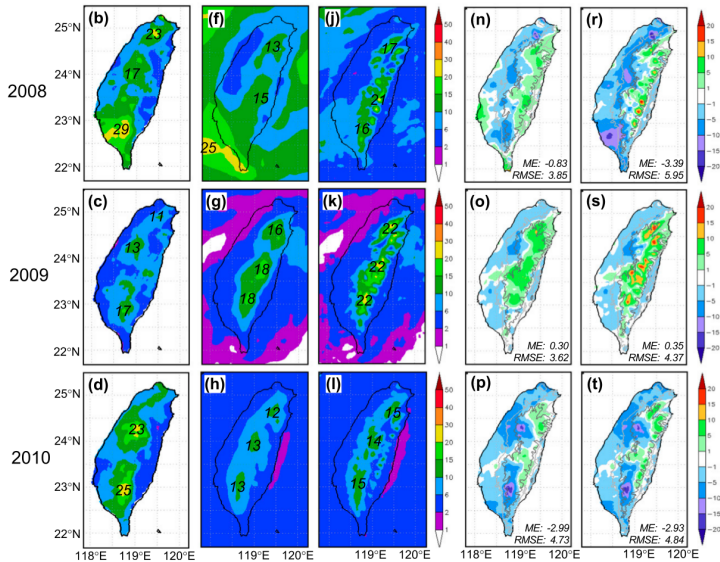
And Today? (Yang et al. 2017)



And Today? (Wang et al. 2017)



And Today? (Wang et al. 2017)



And Today? (Lien et al. 2017)

