



Somewhere Over the Rainbow: How to Make Effective Use of Colors in Meteorological 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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Color:

- Integral element in graphical displays.
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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:

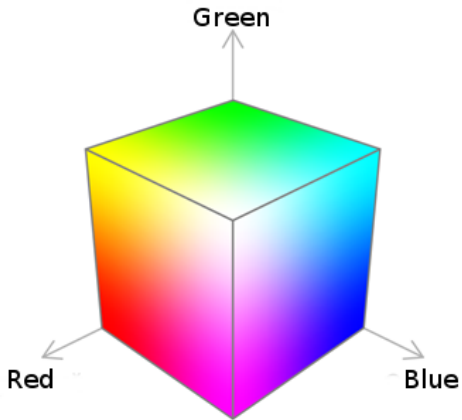
- Raise awareness of the issue.
- Introduce Hue-Chroma-Luminance (HCL) model.
 - Based on human perception.
 - Better control for choosing color palettes.
- Provide convenient software for exploring and assessing HCL-based palettes.



Common Sense

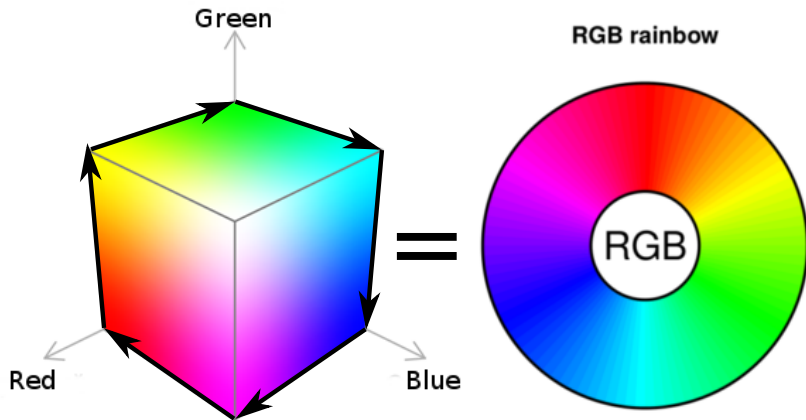
Using Red-Green-Blue Based Color Maps

RGB Rainbow



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

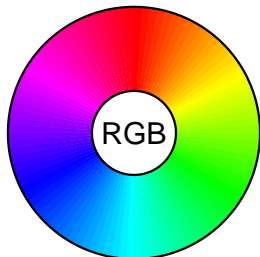
RGB Rainbow



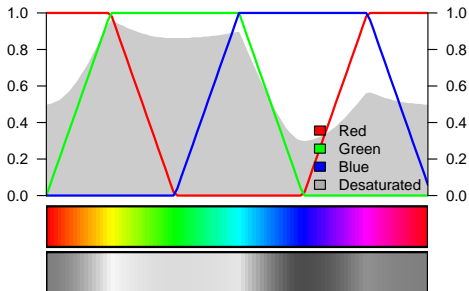
RGB color space: And the (in)famous rainbow color palette.

RGB Rainbow

RGB rainbow

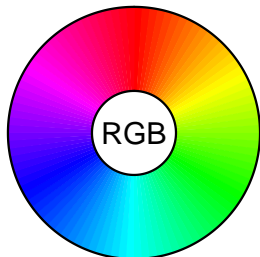


RGB rainbow spectrum

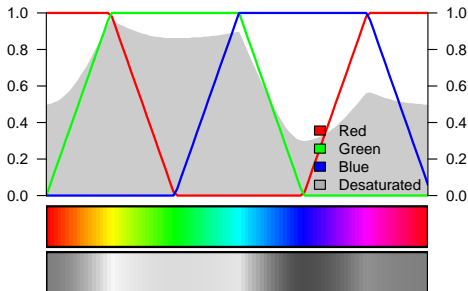


RGB Rainbow

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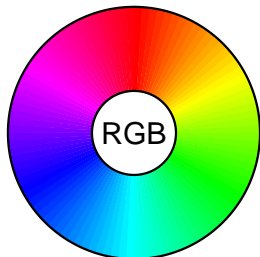
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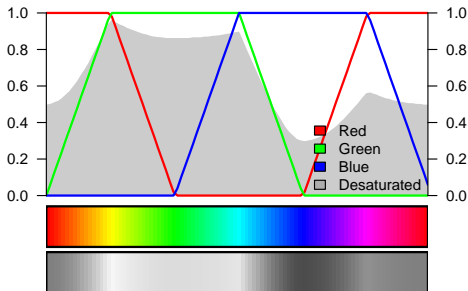
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- Conveniently used by many practitioners.
- Defaults only change slowly (if at all).

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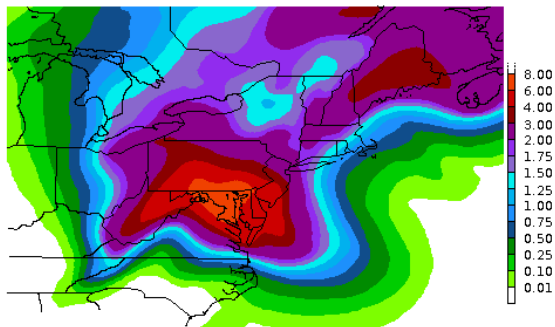
RGB rainbow spectrum



- The default color in many software packages.
- Conveniently used by many practitioners.
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Question: Everybody does it – why should it be wrong?

What's Wrong?

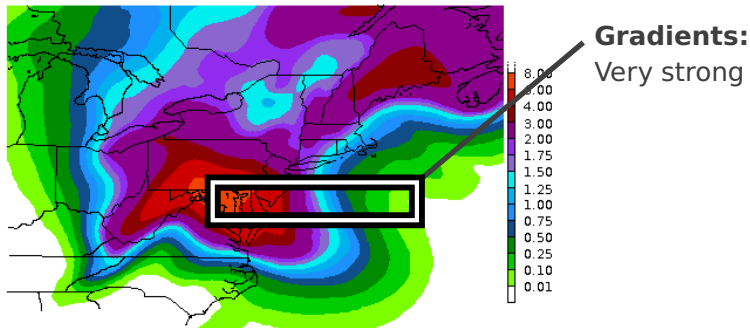


Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Original figure as published by the NOAA.

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

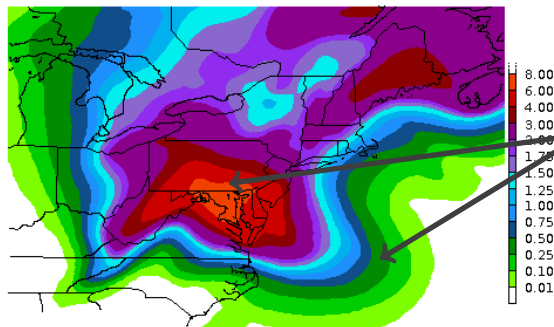
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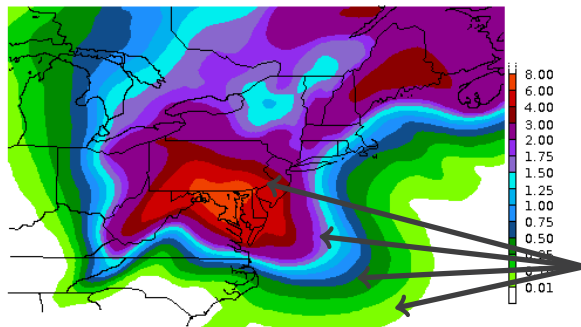
Gradients:
Very strong

Saturation
Highly-saturated
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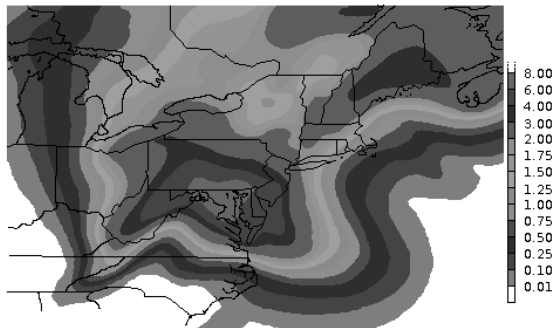
Saturation

Highly-saturated
colors

Discontinuous

Bright, dark,
bright, dark, ...

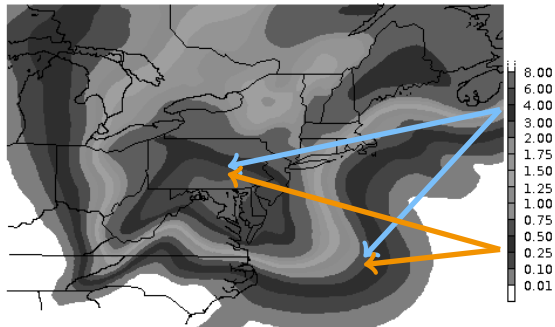
What's Wrong?



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.

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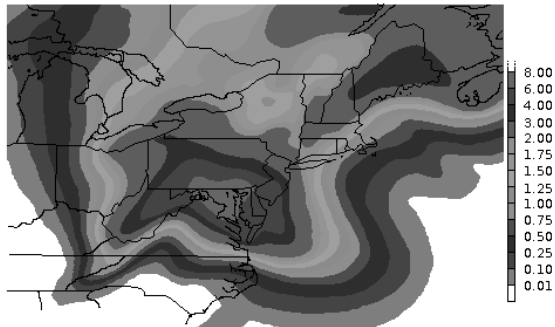


Assignment
No longer unique

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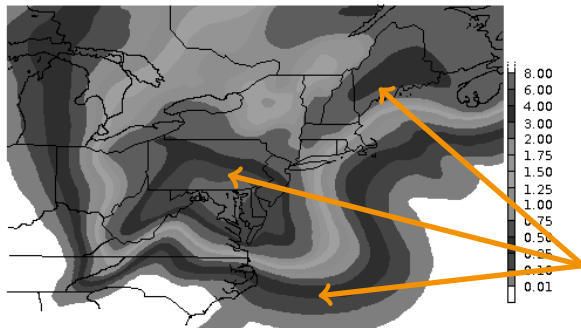
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Interpretation

Where is the maximum?

What's Wrong?



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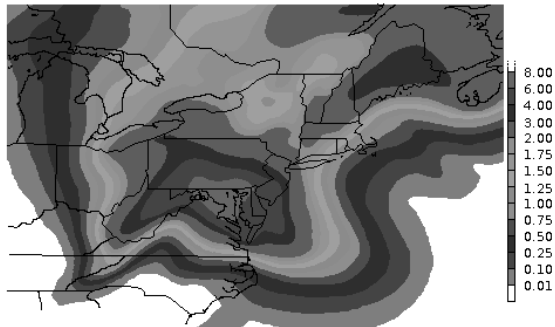
Interpretation

Where is the maximum?

Focus

On dark artefacts

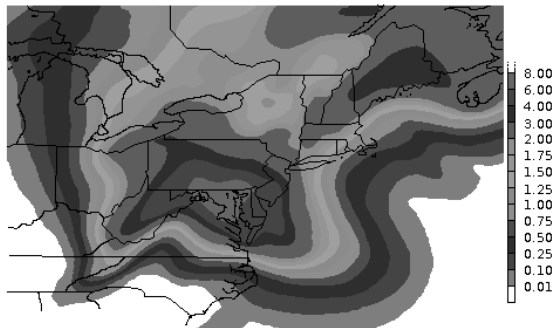
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**Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast**

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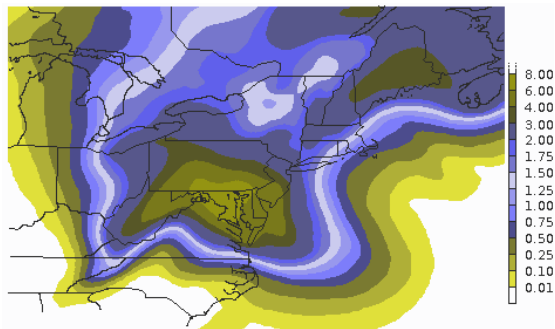


**Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast**

Desaturated version of the original figure.



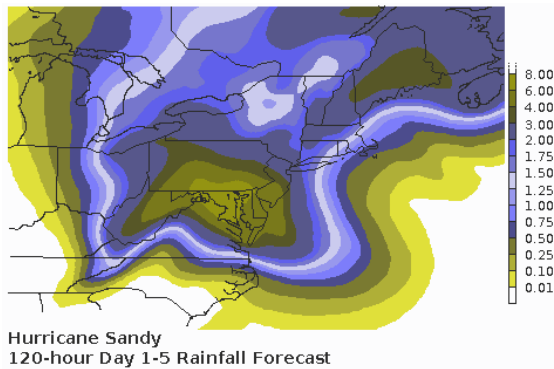
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Hurricane Sandy
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What color-blind people see (red-green weakness).
About **5% of all Europeans** are affected.

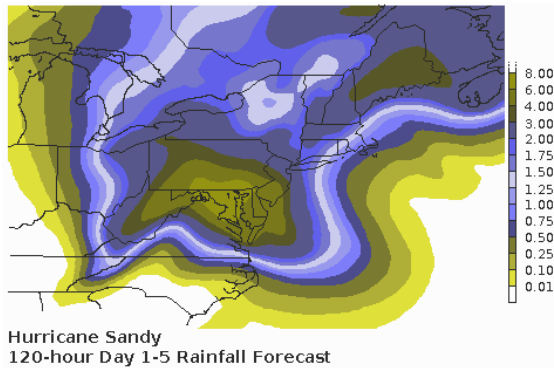
What's Wrong?



End-user
Who is it?

What color-blind people see (red-green weakness).
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What's Wrong?



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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- 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

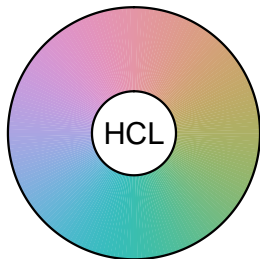


Luminance

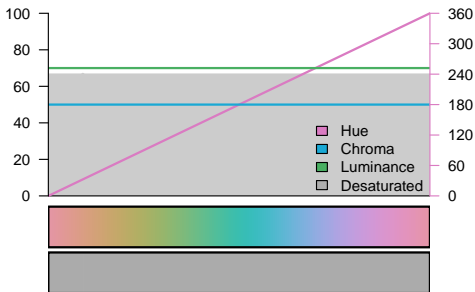


Perception-Based Way: HCL

A HCL rainbow

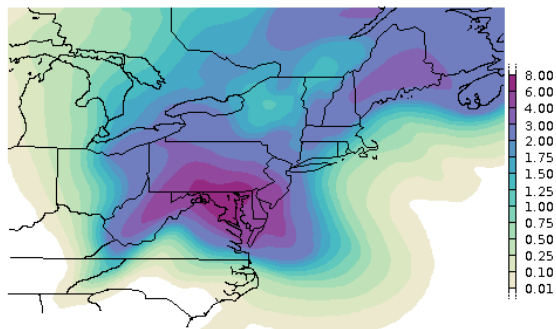


HCL rainbow spectrum



- **Hue** (*defines the color*)
- **Chroma** (*defines the coloriness*) and
- **Luminance** (*defines the brightness*)

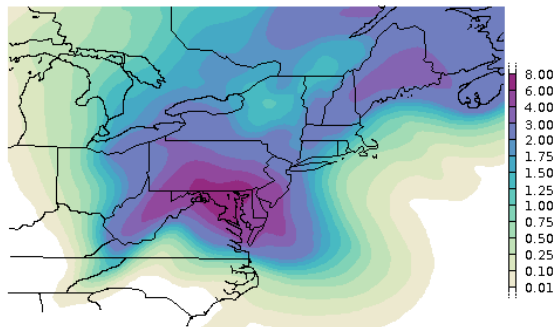
HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Same information, changed color scheme.

HCL Version

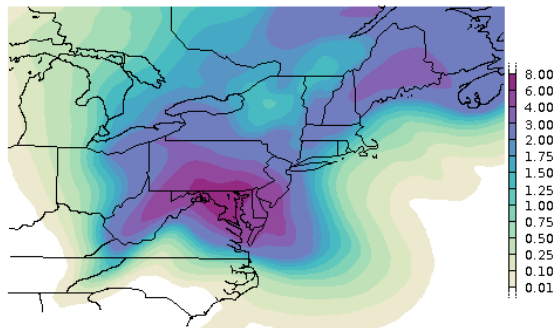


Colors:
Smooth gradients.

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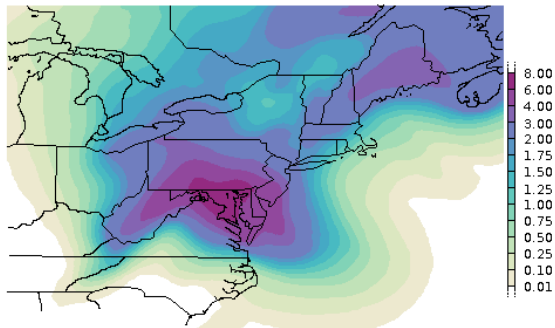
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Information:

Guiding, no hidden information.

HCL Version



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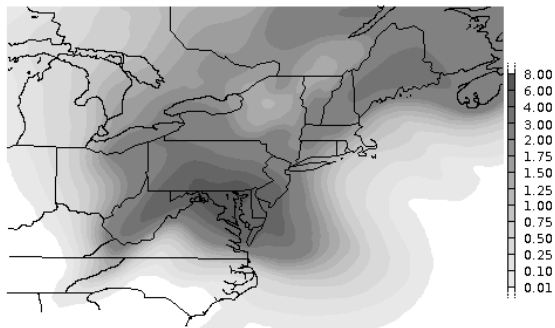
Information:

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Works:

Screen, projector, gray-scaled device.

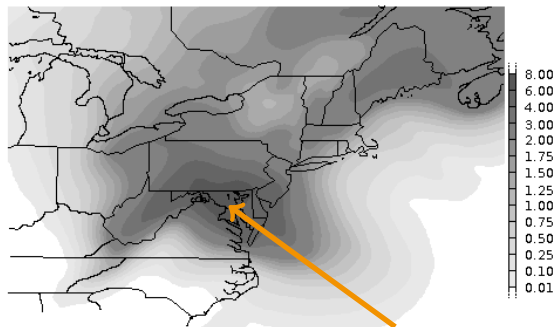
HCL Version



Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated representation of the HCL-version.

HCL Version



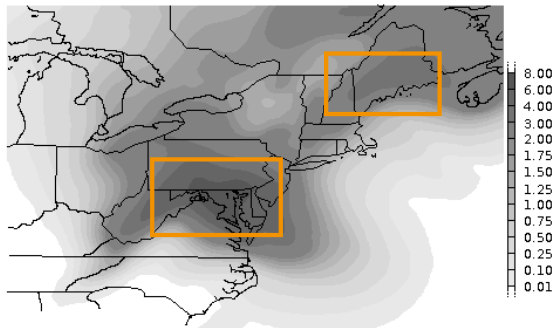
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Assignment:

Higher values \Rightarrow
lower luminance.

HCL Version



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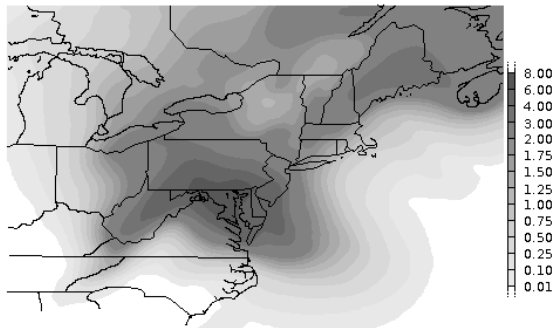
Assignment:

Higher values \Rightarrow
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Focus:

leads readers to
most important
areas.

HCL Version



Hurricane Sandy
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Desaturated representation of the HCL-version.

Summary:

Solved a lot of problems by changing the color palette.

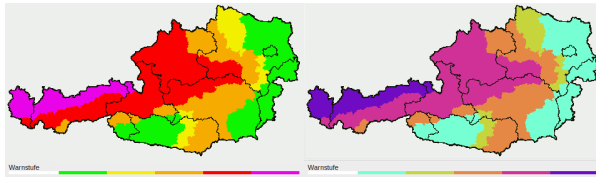
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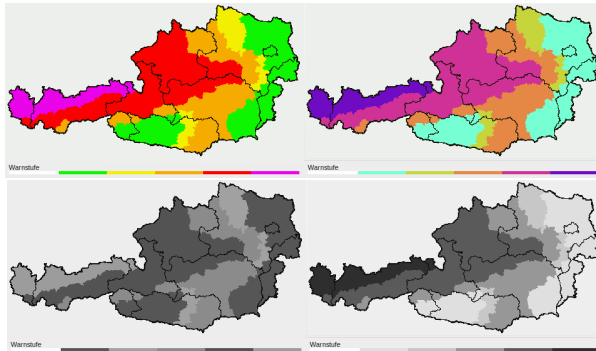
Warning Map Example



Colorized
Original (left)
HCL idea (right)

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

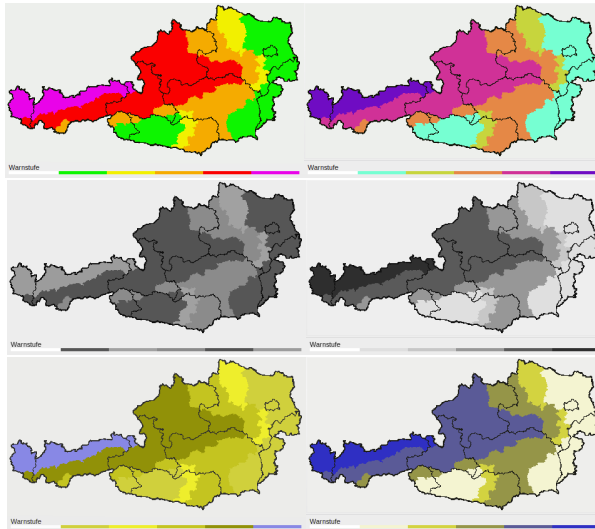
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Gray-scale

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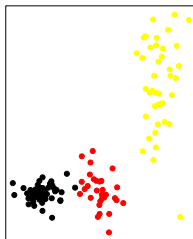
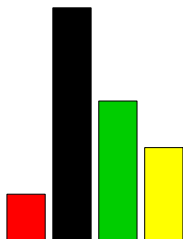
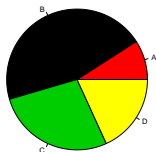
Colorized
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HCL idea (right)

Gray-scale

Deuteranopia
Red-Green
weakness

Color Palettes: Qualitative

Goal: Code quantitative data.



Color Palettes: Qualitative

Goal: Code quantitative data.

dynamic [30, 300]



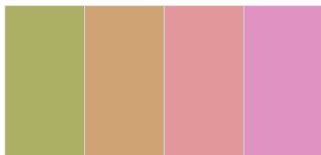
harmonic [60, 240]



cold [270, 150]

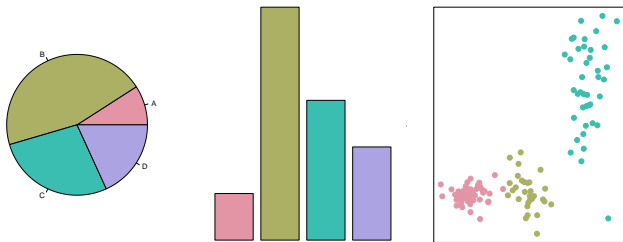


warm [90, -30]



Color Palettes: Qualitative

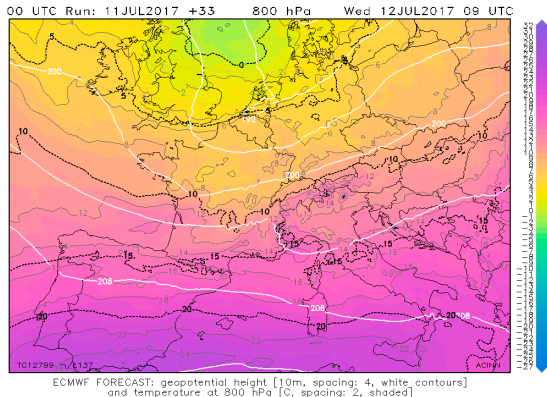
Goal: Code quantitative data.



Solution: Take colors with different hues, but keep chroma and luminance constant.

Color Palettes: Qualitative

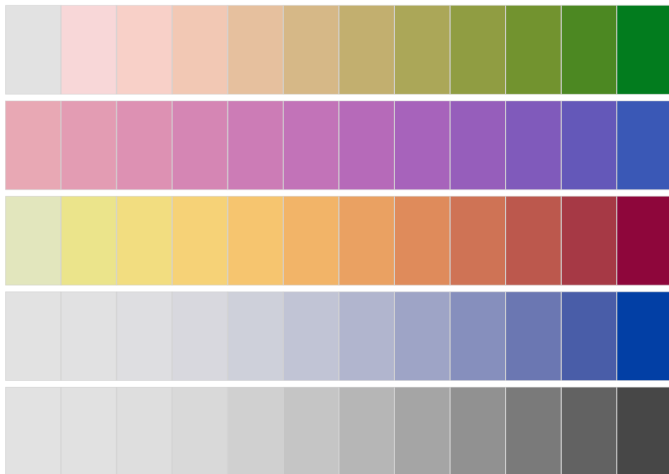
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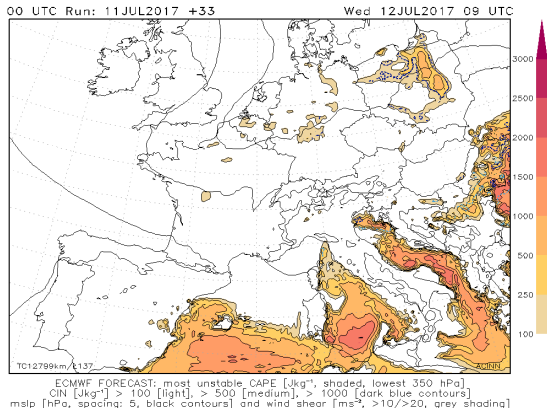
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Goal: Code quantitative data (e.g., probabilities) where one side is of main interest.



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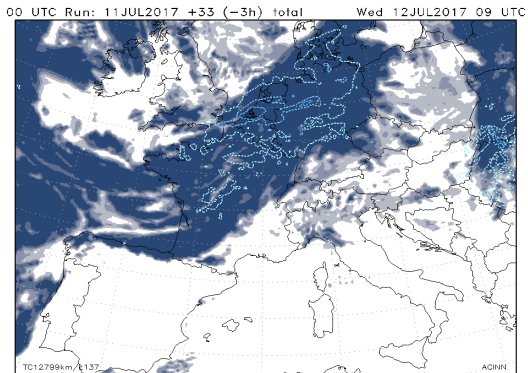
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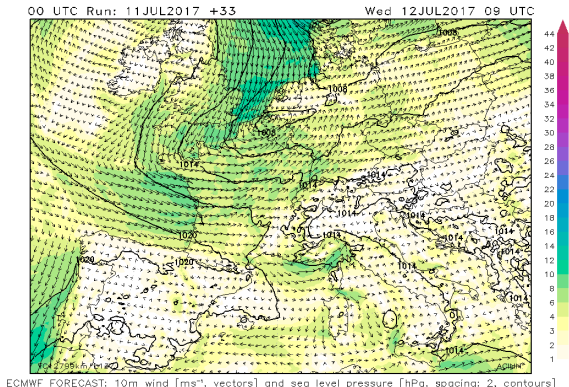


precipitation > 1 [mm, light blue]; > 5 [mm, middle blue]; > 10 [mm, dark blue contour]

Solution: Constant hue and changing chroma/luminance.

Color Palettes: Sequential

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Solution: Constant hue and changing chroma/luminance.

Color Palettes: Diverging

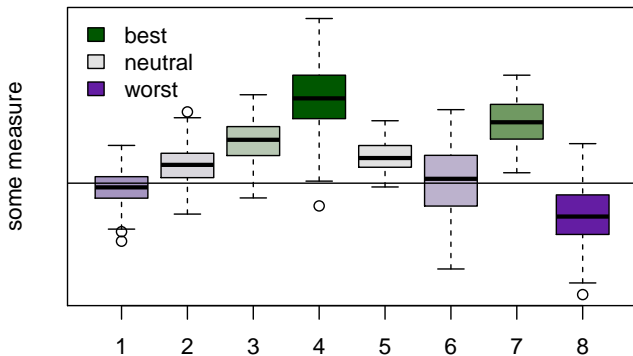
Goal: Code quantitative data and highlight both ends of the spectrum (e.g., anomalies, wet/dry, probabilities, ...).



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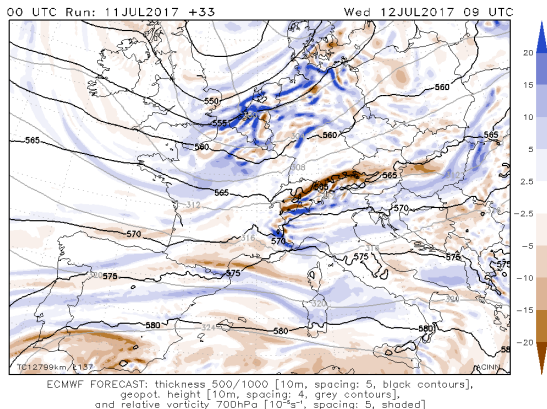
Model Comparison



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

Color Palettes: Diverging

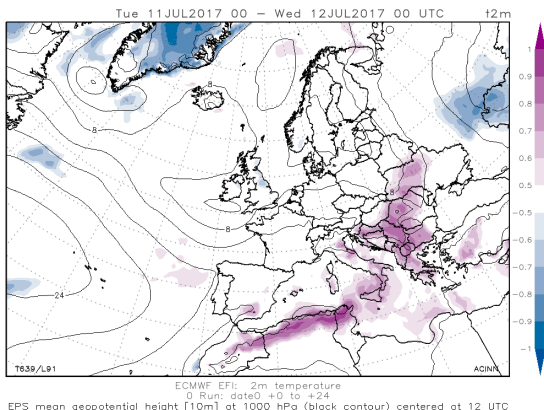
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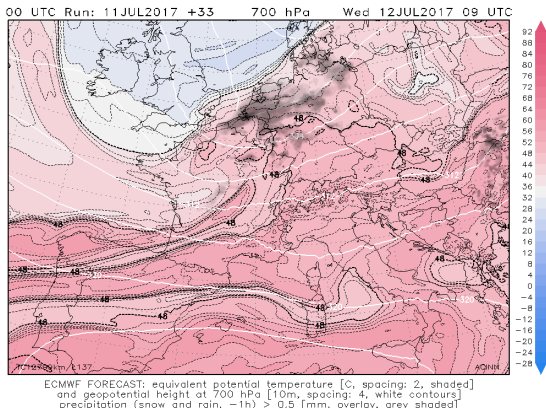
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Experiences With Practitioners

In the beginning

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

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In the beginning

- Hesitation of colleagues.
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- “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

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>.

The image shows two overlapping screenshots of the hclwizard.org website. The top screenshot is a wide view of the homepage, featuring a dark navigation bar with links: START, WHY HCL, COLOR SCHEME, HOW TO USE, R COLORSPACE, ONLINE CREATOR, REFERENCES, NEWS, and ABOUT. Below the navigation is a large banner with a colorful geometric pattern and the text: «New Version of the HCL color scheme creator is available.» with a red 'Try it!' button and the 'HCL WIZARD' logo. The bottom screenshot is a mobile view of the 'Why Use HCL Colors?' page, showing a navigation menu, the 'HC what?' logo, and the page title. The main content area contains three columns of text, each with an icon: 'Why Use HCL Colors?' (HC what? logo), 'HCL Color Space Properties' (color palette icon), and 'Make Use of HCL!' (HCL diagram icon). The text in the mobile view is partially cut off.

START WHY HCL COLOR SCHEME HOW TO USE R COLORSPACE ONLINE CREATOR REFERENCES NEWS ABOUT

«New Version of the HCL color scheme creator is available.» **Try it!** **HCL WIZARD**

HCL WIZARD NAVIGATION

HC what?

Why Use HCL Colors?

The Hue-Chroma-Luminance colorspace is an alternative color space to the famous Red-Green-Blue color space (or others) providing some interesting and important features. This page takes you into the HCL 'space' and gives useful explanations, links, hints, and tools!

HC what?

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HCL Color Space Properties

In contrast to the [in]famous Red-Green-Blue color space the HCL color space provides perception-based properties which allows to design efficient color schemes for technical graphics, but also for design applications.

Make Use of HCL!

Rather than only providing information the wizard shows you how to make use of the HCL color space. For programmers, useful software links and references are provided. For non-programmers or for 'on the fly' color map creators we provide an interactive online interface for everyone!

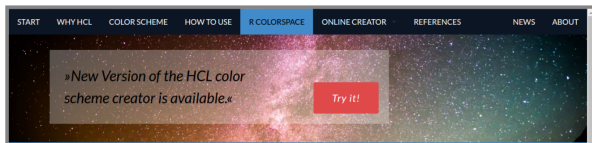
Small Bugfixes

got informed about two smaller bugs on the new page. Thanks

hclwizard.org/why-hcl

Older News

Broken HCL Creator [fixed]



R colorspace Package

Using the colorspace package in R

The open source software R provides a package called (Ihaka, Murrell, Hornik, Fisher, & Zelleis, 2016) which uses Ihaka's colorspace library. The package offers some preset color palettes (`rainbow_hcl`, `terrain_hcl`, `heat_hcl`, ...) to compare to the default RGB color palettes. Furthermore there is a graphical user interface (GUI) where you can design your own color palette. The function therefore is called `choose_palette()` (needs some dependent packages) and use them for your own work.

The first thing you need is an R installation on your computer. The installation packages for all available

colorspace Package

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open source software R provides a package called (Ihaka, Murrell, Hornik, Fisher, & Zelleis, 2016) which uses Ihaka's colorspace library. The package offers some preset color palettes (`rainbow_hcl`, `terrain_hcl`, `heat_hcl`, ...) to compare to the default color palettes. Furthermore there is a graphical user interface (GUI) where you can design your own color palette. The function therefore is called `choose_palette()` (needs some dependent packages) and use them for your own work.

first thing you need is an R installation on your computer. The installation packages for all available operating systems (Windows, OSX, Linux) can be found on the <http://cran.r-project.org>. The installation is no adventure and the R base version just needs a few MB of space. For beginners the R-Studio GUI is recommended (or a similar R editor).

If R is successfully installed on your system you can install optional packages like the colorspace package. You can simply do that over your GUI interface or install them by using following code line:

```
install.packages('colorspace')
```



"I'm an advanced R-user, but I never heard about the colorspace package. How can I use this awesome feature?"



Download R Package

The current version of the R colorspace package can be downloaded from the cran website:
Visit: [cran.package.colorspace](http://cran.r-project.org/colorspace)



R-Forge Repository

Base Options

Nature of your data
Diverging

Base color scheme
PIYg

Example
Map

Control Options

Reverse

Correct colors

Desaturated

Vision

Normal

Deutan

Protan

Tritan

Color Settings

HUE 1: -360 to 360 (340)

HUE 2: -360 to 360 (120)

CHROMA: 0 to 100 (45)

LUMIN. 1: 0 to 100 (35)

LUMIN. 2: 0 to 100 (60)

POWER 1: 0 to 3 (0.7)

NUMBER: 2 to 40 (7)

Return to R


Example Plot

Export Spectrum Help Page

Base Options

Nature of your data
Sequential (multiple hues) ▾

Base color scheme
Viridis ▾



Vision
 Normal
 Deutan
 Protan
 Tritan

Color Settings

HUE 1: -360 to 360 (300)

HUE 2: -360 to 360 (75)

CHROMA: 0 to 100 (50)

CHROMA: 0 to 100 (50)


LUMIN. 1: 0 to 100 (15)

LUMIN. 2: 0 to 100 (50)

POWER 1: 0 to 3 (0.5)

POWER 2: 0 to 3 (1.5)

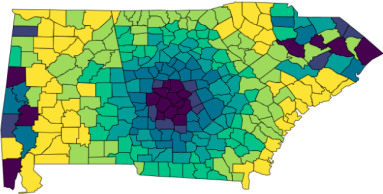
NUMBER: 2 to 40 (2)



Return to R

Example Plot

[Export](#) [Spectrum](#) [Help Page](#)



Base Options

Nature of your data
Sequential (multiple hues) ▾

Base color scheme
Plasma ▾

Example
Mosaic ▾

Control Options

Reverse
 Correct colors
 Desaturated

Vision
 Normal
 Deutan
 Protan
 Tritan

Color Settings

HUE 1: -360 to 360 (100) SET

HUE 2: -360 to 360 (100) SET

CHROMA: 0 to 100 (80) SET

CHROMA: 0 to 100 (100) SET

LUMIN. 1: 0 to 100 (15) SET

LUMIN. 2: 0 to 100 (50) SET

POWER 1: 0 to 3 (2) SET

POWER 2: 0 to 3 (0.8) SET

NUMBER: 2 to 40 (7) SET



Return to R

Example Plot [Export](#) [Spectrum](#) [Help Page](#)



Base Options

Nature of your data
Sequential (multiple hues) ▾

Base color scheme
Plasma ▾

Example
Mosaic ▾

Control Options

Reverse

Correct colors

Desaturated

Vision

Normal

Deutan

Protan

Tritan

Color Settings

HUE 1: -360 to 360 (100) SET

HUE 2: -360 to 360 (100) SET

CHROMA: 0 to 100 (50) SET

CHROMA: 0 to 100 (100) SET

LUMIN. 1: 0 to 100 (10) SET

LUMIN. 2: 0 to 100 (50) SET

POWER 1: 0 to 3 (2) SET

POWER 2: 0 to 3 (0.9) SET

NUMBER: 2 to 40 (20) SET

Return to R

Example Plot | Export | Spectrum | Help Page

RAW | GrADS | Python | matlab

RGB values [0-1]	RGB values [0-255]	HEX colors, no alpha
0.000 0.094 0.537	0 24 137	#001889
0.173 0.047 0.537	44 12 137	#2C0CB9
0.310 0.000 0.541	79 0 138	#4F008A
0.404 0.000 0.549	103 0 140	#67008C
0.482 0.000 0.553	123 0 141	#7B008D
0.553 0.000 0.553	141 0 141	#8D008D
0.612 0.000 0.545	156 0 139	#9C008B
0.671 0.078 0.533	171 20 136	#AB1488
0.718 0.149 0.518	183 38 132	#B72684
0.765 0.212 0.494	195 54 126	#C3367E
0.804 0.275 0.463	205 70 118	#CD4676
0.839 0.333 0.420	214 85 107	#D6566B
0.871 0.396 0.373	222 101 95	#DE655F
0.894 0.459 0.310	228 117 79	#E4754F
0.910 0.522 0.227	232 133 58	#E8853A
0.922 0.588 0.098	235 150 25	#EB9619
0.929 0.651 0.000	237 166 0	#EDA600
0.925 0.718 0.000	236 183 0	#ECB700
0.918 0.784 0.000	234 200 0	#EACB00
0.902 0.855 0.000	230 218 0	#E6DA00
0.878 0.925 0.000	224 236 0	#E0EC00
0.855 1.000 0.278	218 255 71	#D8FF47

Color Map

Download Download Download

The screenshot displays the hclwizard.org web interface, which is used for configuring color maps. The interface is divided into several sections:

- Base Options:** Includes "Nature of your data" (Sequential (multiple hues)), "Base color scheme" (Plasma), and "Example" (Mosaic).
- Control Options:** Includes checkboxes for "Reverse", "Correct colors" (checked), and "Desaturated". It also has "Vision" options: "Normal" (selected), "Deutan", "Protan", and "Tritan".
- Color Settings:** A series of sliders and input fields for adjusting color parameters: HUE 1 (100), HUE 2 (100), CHROMA (60), CHROMA (100), LUMIN 1 (15), LUMIN 2 (60), POWER 1 (3), POWER 2 (0.8), and NUMBER (20). Each slider has a "SET" button next to it. Below the sliders is a color bar and a "Return to R" button.
- Code Editor:** A text area showing a list of color definitions in a palette format, with tabs for "RAW", "GrADS", "Python", and "matlab". The code includes comments for "Define colors palette" and "Setting region to load".

At the bottom left of the interface, the URL `127.0.0.1:3055/#tab-4440-2` is visible.

References

Interactive colormap designer: hclwizard.org

Some inspiration can be found on: ertel2.uibk.ac.at

Zeileis, A., K. Hornik, and P. Murrell (2009): Escaping RGBland: Selecting colors for statistical graphics. *Computational Statistics & Data Analysis*, **53**(9), 3259–3270. <http://doi.org/10.1016/j.csda.2008.11.033>.

Stauffer, R., G.J. Mayr, M. Dabernig, and A. Zeileis (2015): Somewhere Over the Rainbow: How to Make Effective Use of Colors in Meteorological Visualizations. *Bulletin of the American Meteorological Society*, **96**(2), 203–216. <http://doi.org/10.1175/BAMS-D-13-00155.1>.

Ihaka R., P. Murrell, K. Hornik, J.C. Fisher, and A. Zeileis (2016): colorspace: Color Space Manipulation. R package version 1.3-2. URL <https://CRAN.R-project.org/package=colospace>

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



Thank you for your attention!

And Today? (Rempel et al. 2017)

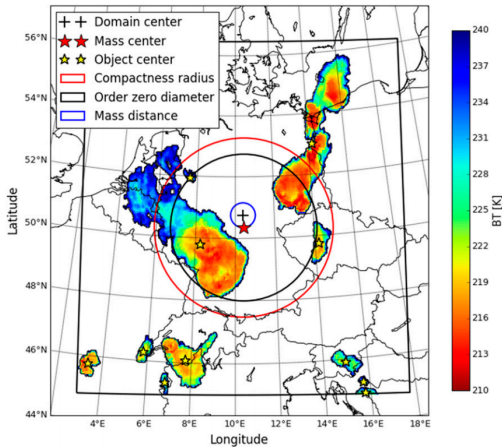


Figure: Rempel et al. (2017): MWR **145**(8).

And Today? (Rampel et al. 2017)

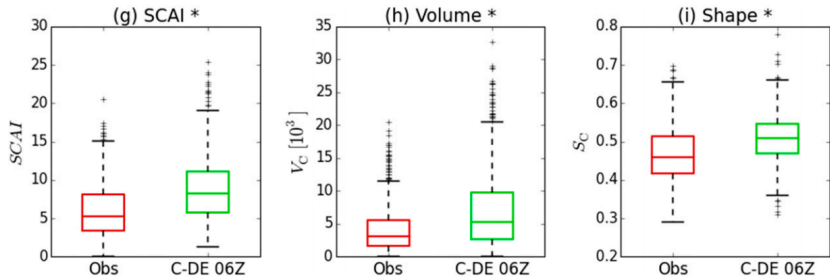


Figure: Rampel et al. (2017): MWR **145**(8).

And Today? (Rampel et al. 2017)

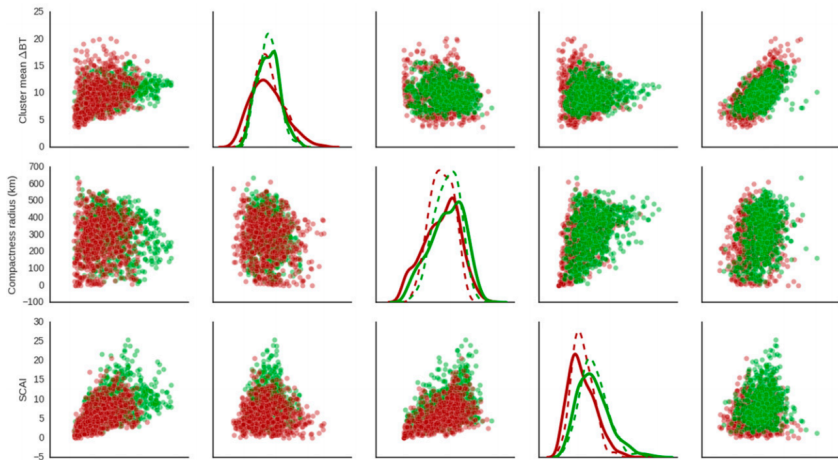


Figure: Rempel et al. (2017): MWR **145**(8).

And Today?



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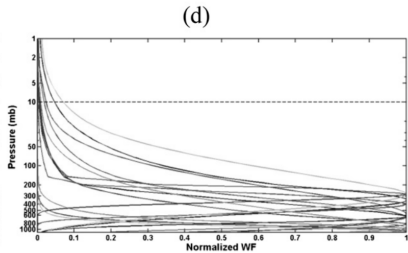
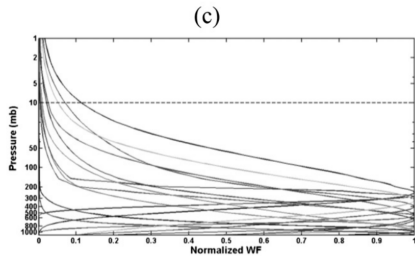
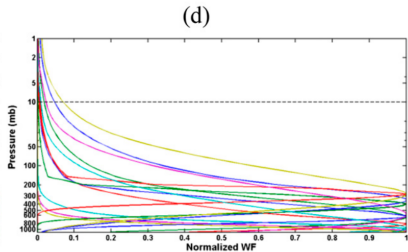
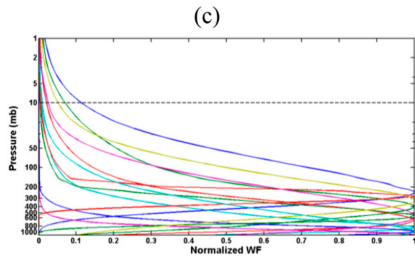
2015
Articles Published
119

Impact Factor
1.972* (#36)

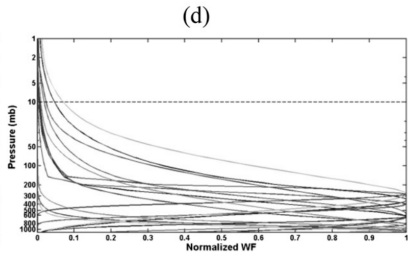
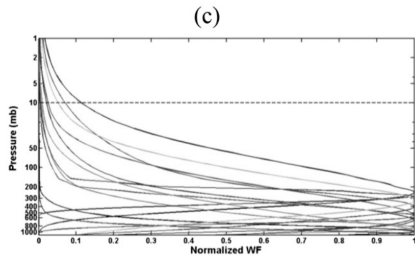
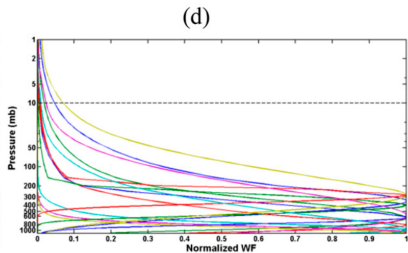
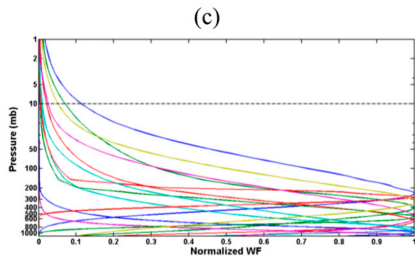
** 2015 Thompson-ISI Impact Factor (and ranking out of 84 journals) in the Meteorology and Atmospheric Science category*

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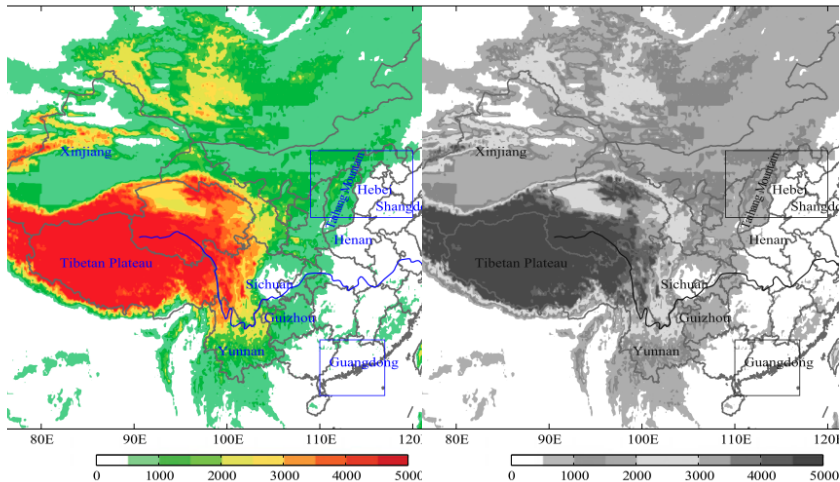
And Today? (Lin et al. 2017)



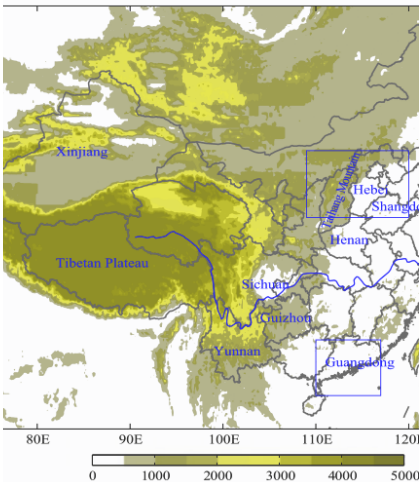
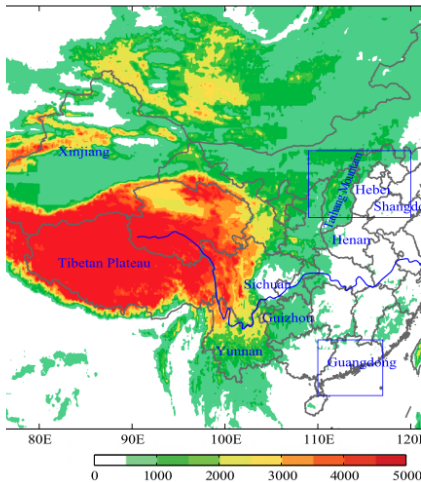
And Today? (Lin et al. 2017)



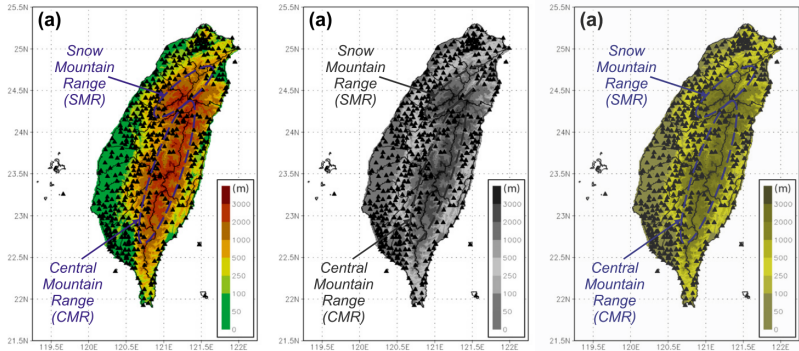
And Today? (Yang et al. 2017)



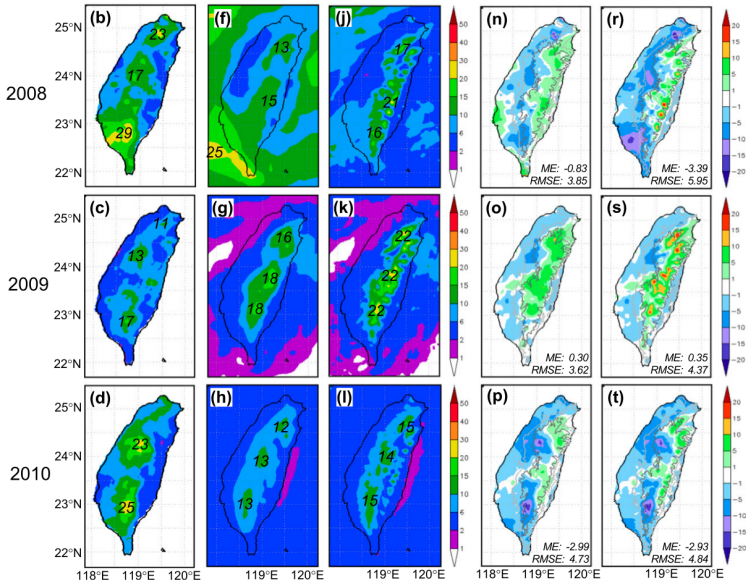
And Today? (Yang et al. 2017)



And Today? (Wang et al. 2017)



And Today? (Wang et al. 2017)



And Today? (Lien et al. 2017)

