Lecture 17 - Advanced Plotting III: Color

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Learning Objectives

After this lecture, students will be able to:

- Utilize Matplotlib's built-in colormaps, and create custom colormaps
- Apply colorbars to plots and create associated colorbars
- Design colormaps that are well suited for particular data and audiences

Check-in

- Grading pseudocode outlines now
- HW7 is now optional
- Final assignment updated with "final" questions for HW6 and HW7
- Estimating your grade

Recap

Last time, we wrote code to generate the figure below, demonstrating how to:

- Create grids of points and reshape vectors into matrices
- Use Axes.pcolormesh() and Axes.scatter()
- Format ticks, labels, grids, and titles

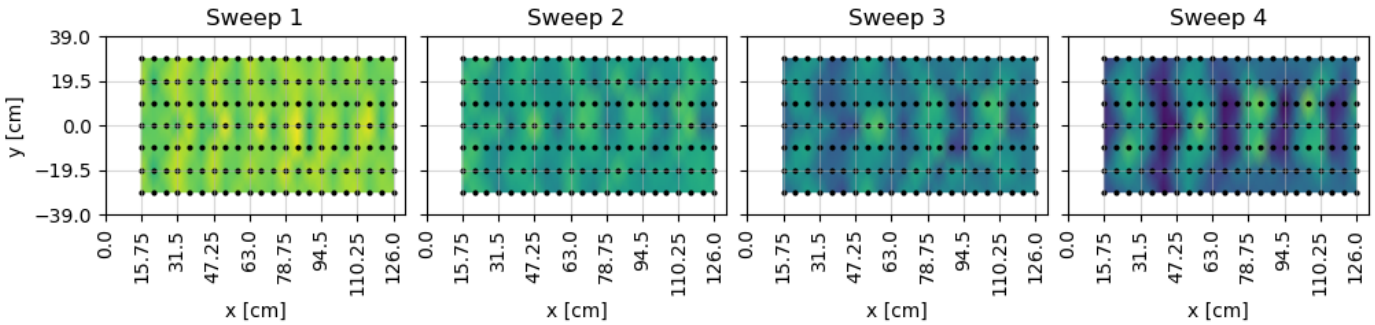
Now, we'd like to fix up the color in this figure. Let's use this to motivate a broader discussion of color and how it works in Matplotlib.

In [2]:
```
# imports
import numpy as np
import matplotlib.pyplot as plt

# Load data
fstData = np.loadtxt('freeSurface.txt', delimiter=',')
fstData = np.reshape(fstData, [7, 22, 4], order='F')

# Specify grid parameters
D = 31.5 # Turbine diameter, in cm
w = 78 # Flume width, in cm
dx = D/6 # Grid spacing in x, in cm
dy = w/8 # Grid spacing in y, in cm

# Create x and y vectors
x = np.arange(D/2, 4*D+dx, dx)
y = np.arange(-w/2+dy, w/2, dy)
```

```
# Create X and Y grids
X, Y = np.meshgrid(x, y)
```

In [4]:
```
# Create our figure
nSweeps = 4
fig, ax = plt.subplots(nrows=1, ncols=nSweeps, sharex=True, sharey=True, layout='constra

xtickVals = np.arange(0, 4*D+D/2, D/2)
ytickVals = np.arange(-w/2, w/2+w/4, w/4)

# Plot on each axes
for i in range(nSweeps):
    # Plot the free surface data
    ax[i].pcolormesh(X, Y, fstData[:,:,i],
                     vmin=np.min(fstData), vmax=np.max(fstData),
                     shading='gouraud')

    # Plot the grid points
    ax[i].scatter(X, Y, c='k', s=4)

    # Set aspect ratio
    ax[i].set_aspect('equal')

    # Set x label and title
    ax[i].set_xlabel('x [cm]')
    ax[i].set_title('Sweep ' + str(i+1))

    # Set x and y ticks
    ax[i].set_xticks(xtickVals, labels=xtickVals, rotation='vertical')
    ax[i].set_yticks(ytickVals)

    # Turn on the grid
    ax[i].grid(alpha=0.5)

# Set y label of leftmost axis only
ax[0].set_ylabel('y [cm]')

# Set x and y limits
ax[0].set_xlim([0, 4*D+dx])
ax[0].set_ylim([-w/2, w/2])
```

Out[4]:
```
(-39.0, 39.0)
```



To work more with colors, we'll import the `matplotlib.colors` module:

In [5]:
```
import matplotlib.colors as colors
```

Specifying color

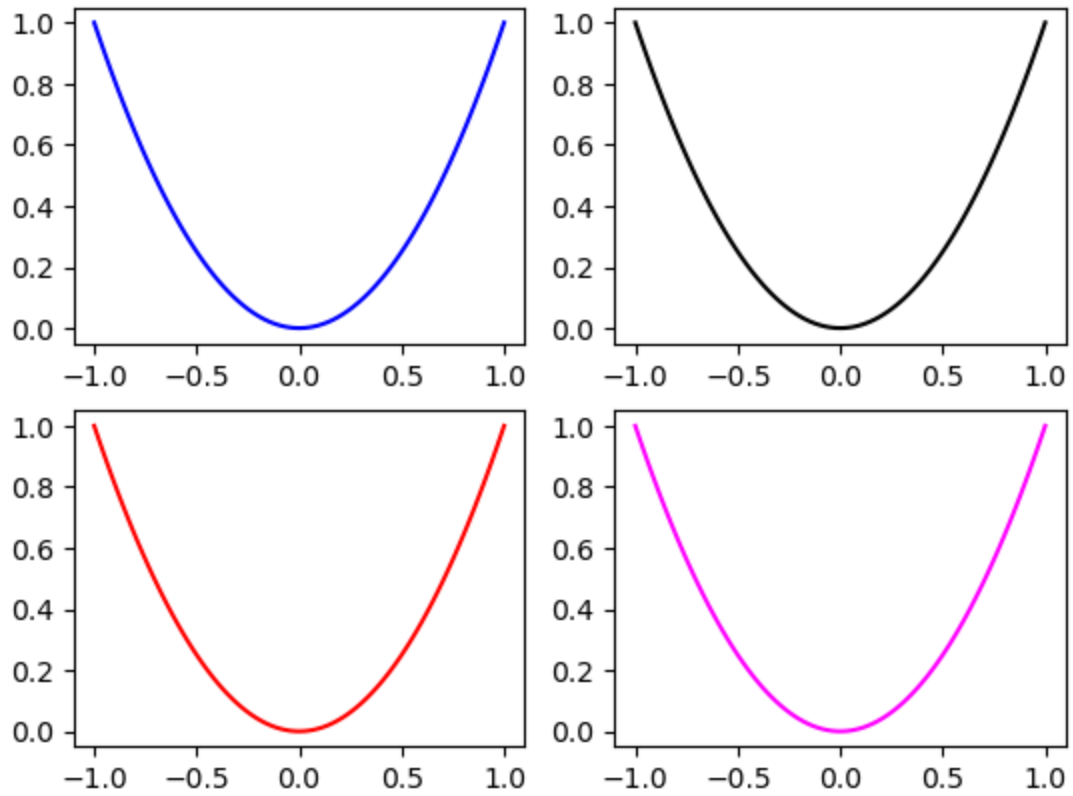
First, let's back up and think of the ways that we can specify specific colors in Matplotlib.

By name

We've seen that we can use string names for several colors when creating simple plots:

In [8]:
```
# Create some simple data
x = np.linspace(-1, 1, 100)
y = x**2

fig, ax = plt.subplots(nrows=2, ncols=2)
ax[0,0].plot(x, y, color='blue')
ax[0,1].plot(x, y, color='black')
ax[1,0].plot(x, y, color='red')
ax[1,1].plot(x, y, color='magenta')
```

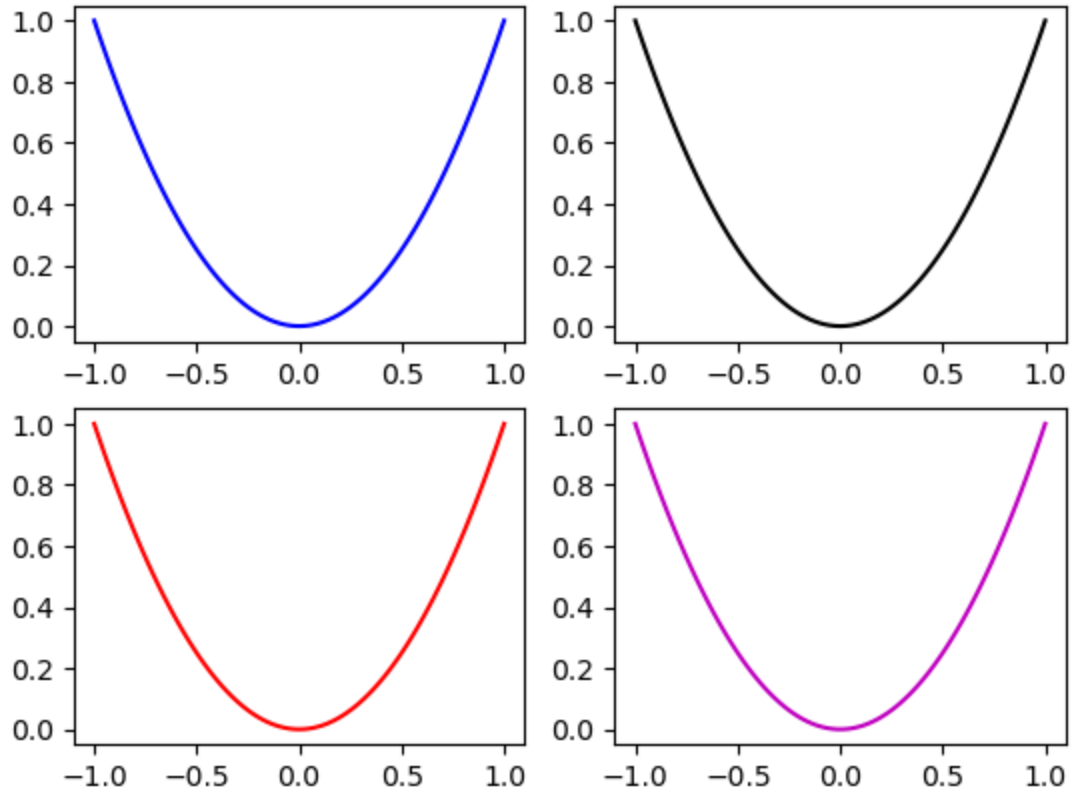
Out[8]:
```
[<matplotlib.lines.Line2D at 0x24ff7713c70>]
```



We've also seen that, for certain basic colors, there are single-character shorthands for choosing the color (this are documented on the Matplotlib website):

In [10]:
```
fig, ax = plt.subplots(nrows=2, ncols=2)
ax[0,0].plot(x, y, color='b') # Blue
ax[0,1].plot(x, y, color='k') # Black
ax[1,0].plot(x, y, color='r') # Red
ax[1,1].plot(x, y, color='m') # Magenta (note that the hue is slightly different)
```

Out[10]:
```
[<matplotlib.lines.Line2D at 0x24ff79c68e0>]
```



Turns out there are a ton of named colors that we can use:

In [12]:
```
# Get the mapping of named colors to values
allColors = colors.get_named_colors_mapping()
allColors
```

Out[12]:
```
{'xkcd:cloudy blue': '#acc2d9',
 'xkcd:dark pastel green': '#56ae57',
 'xkcd:dust': '#b2996e',
 'xkcd:electric lime': '#a8ff04',
 'xkcd:fresh green': '#69d84f',
 'xkcd:light eggplant': '#894585',
 'xkcd:nasty green': '#70b23f',
 'xkcd:really light blue': '#d4ffff',
 'xkcd:tea': '#65ab7c',
 'xkcd:warm purple': '#952e8f',
 'xkcd:yellowish tan': '#fcfc81',
 'xkcd:cement': '#a5a391',
 'xkcd:dark grass green': '#388004',
 'xkcd:dusty teal': '#4c9085',
 'xkcd:grey teal': '#5e9b8a',
 'xkcd:macaroni and cheese': '#efb435',
 'xkcd:pinkish tan': '#d99b82',
 'xkcd:spruce': '#0a5f38',
 'xkcd:strong blue': '#0c06f7',
 'xkcd:toxic green': '#61de2a',
 'xkcd:windows blue': '#3778bf',
 'xkcd:blue blue': '#2242c7',
 'xkcd:blue with a hint of purple': '#533cc6',
 'xkcd:booger': '#9bb53c',
 'xkcd:bright sea green': '#05ffa6',
 'xkcd:dark green blue': '#1f6357',
 'xkcd:deep turquoise': '#017374',
 'xkcd:green teal': '#0cb577',
 'xkcd:strong pink': '#ff0789',
 'xkcd:bland': '#afa88b',
 'xkcd:deep aqua': '#08787f',
 'xkcd:lavender pink': '#dd85d7',
```

```
'xkcd:light moss green': '#a6c875',
'xkcd:light seafoam green': '#a7ffb5',
'xkcd:olive yellow': '#c2b709',
'xkcd:pig pink': '#e78ea5',
'xkcd:deep lilac': '#966ebd',
'xkcd:desert': '#ccad60',
'xkcd:dusty lavender': '#ac86a8',
'xkcd:purpley grey': '#947e94',
'xkcd:purply': '#983fb2',
'xkcd:candy pink': '#ff63e9',
'xkcd:light pastel green': '#b2fba5',
'xkcd:boring green': '#63b365',
'xkcd:kiwi green': '#8ee53f',
'xkcd:light grey green': '#b7e1a1',
'xkcd:orange pink': '#ff6f52',
'xkcd:tea green': '#bdf8a3',
'xkcd:very light brown': '#d3b683',
'xkcd:egg shell': '#fffcc4',
'xkcd:eggplant purple': '#430541',
'xkcd:powder pink': '#ffb2d0',
'xkcd:reddish grey': '#997570',
'xkcd:baby shit brown': '#ad900d',
'xkcd:liliac': '#c48efd',
'xkcd:stormy blue': '#507b9c',
'xkcd:ugly brown': '#7d7103',
'xkcd:custard': '#fffd78',
'xkcd:darkish pink': '#da467d',
'xkcd:deep brown': '#410200',
'xkcd:greenish beige': '#c9d179',
'xkcd:manilla': '#fffa86',
'xkcd:off blue': '#5684ae',
'xkcd:battleship grey': '#6b7c85',
'xkcd:browny green': '#6f6c0a',
'xkcd:bruise': '#7e4071',
'xkcd:kelley green': '#009337',
'xkcd:sickly yellow': '#d0e429',
'xkcd:sunny yellow': '#fff917',
'xkcd:azul': '#1d5dec',
'xkcd:darkgreen': '#054907',
'xkcd:green/yellow': '#b5ce08',
'xkcd:lichen': '#8fb67b',
'xkcd:light light green': '#c8ffb0',
'xkcd:pale gold': '#fdde6c',
'xkcd:sun yellow': '#ffdf22',
'xkcd:tan green': '#a9be70',
'xkcd:burple': '#6832e3',
'xkcd:butterscotch': '#fdb147',
'xkcd:toupe': '#c7ac7d',
'xkcd:dark cream': '#fff39a',
'xkcd:indian red': '#850e04',
'xkcd:light lavendar': '#efc0fe',
'xkcd:poison green': '#40fd14',
'xkcd:baby puke green': '#b6c406',
'xkcd:bright yellow green': '#9dff00',
'xkcd:charcoal grey': '#3c4142',
'xkcd:squash': '#f2ab15',
'xkcd:cinnamon': '#ac4f06',
'xkcd:light pea green': '#c4fe82',
'xkcd:radioactive green': '#2cfa1f',
'xkcd:raw sienna': '#9a6200',
'xkcd:baby purple': '#ca9bf7',
'xkcd:cocoa': '#875f42',
'xkcd:light royal blue': '#3a2efe',
'xkcd:orangeish': '#fd8d49',
'xkcd:rust brown': '#8b3103',
'xkcd:sand brown': '#cba560',
```

```
'xkcd:swamp': '#698339',
'xkcd:tealish green': '#0cdc73',
'xkcd:burnt siena': '#b75203',
'xkcd:camo': '#7f8f4e',
'xkcd:dusk blue': '#26538d',
'xkcd:fern': '#63a950',
'xkcd:old rose': '#c87f89',
'xkcd:pale light green': '#b1fc99',
'xkcd:peachy pink': '#ff9a8a',
'xkcd:rosy pink': '#f6688e',
'xkcd:light bluish green': '#76fda8',
'xkcd:light bright green': '#53fe5c',
'xkcd:light neon green': '#4efd54',
'xkcd:light seafoam': '#a0febf',
'xkcd:tiffany blue': '#7bf2da',
'xkcd:washed out green': '#bcf5a6',
'xkcd:browny orange': '#ca6b02',
'xkcd:nice blue': '#107ab0',
'xkcd:sapphire': '#2138ab',
'xkcd:greyish teal': '#719f91',
'xkcd:orangey yellow': '#fdb915',
'xkcd:parchment': '#fefcaf',
'xkcd:straw': '#fcf679',
'xkcd:very dark brown': '#1d0200',
'xkcd:terracota': '#cb6843',
'xkcd:ugly blue': '#31668a',
'xkcd:clear blue': '#247afd',
'xkcd:creme': '#ffffb6',
'xkcd:foam green': '#90fda9',
'xkcd:grey/green': '#86a17d',
'xkcd:light gold': '#fddc5c',
'xkcd:seafoam blue': '#78d1b6',
'xkcd:topaz': '#13bbaf',
'xkcd:violet pink': '#fb5ffc',
'xkcd:wintergreen': '#20f986',
'xkcd:yellow tan': '#ffe36e',
'xkcd:dark fuchsia': '#9d0759',
'xkcd:indigo blue': '#3a18b1',
'xkcd:light yellowish green': '#c2ff89',
'xkcd:pale magenta': '#d767ad',
'xkcd:rich purple': '#720058',
'xkcd:sunflower yellow': '#ffda03',
'xkcd:green/blue': '#01c08d',
'xkcd:leather': '#ac7434',
'xkcd:racing green': '#014600',
'xkcd:vivid purple': '#9900fa',
'xkcd:dark royal blue': '#02066f',
'xkcd:hazel': '#8e7618',
'xkcd:muted pink': '#d1768f',
'xkcd:booger green': '#96b403',
'xkcd:canary': '#fdff63',
'xkcd:cool grey': '#95a3a6',
'xkcd:dark taupe': '#7f684e',
'xkcd:darkish purple': '#751973',
'xkcd:true green': '#089404',
'xkcd:coral pink': '#ff6163',
'xkcd:dark sage': '#598556',
'xkcd:dark slate blue': '#214761',
'xkcd:flat blue': '#3c73a8',
'xkcd:mushroom': '#ba9e88',
'xkcd:rich blue': '#021bf9',
'xkcd:dirty purple': '#734a65',
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'xkcd:icky green': '#8fae22',
'xkcd:light khaki': '#e6f2a2',
'xkcd:warm blue': '#4b57db',
```

```
'xkcd:dark hot pink': '#d90166',
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'xkcd:carmine': '#9d0216',
'xkcd:dark yellow green': '#728f02',
'xkcd:pale peach': '#ffe5ad',
'xkcd:plum purple': '#4e0550',
'xkcd:golden rod': '#f9bc08',
'xkcd:neon red': '#ff073a',
'xkcd:old pink': '#c77986',
'xkcd:very pale blue': '#d6fffe',
'xkcd:blood orange': '#fe4b03',
'xkcd:grapefruit': '#fd5956',
'xkcd:sand yellow': '#fce166',
'xkcd:clay brown': '#b2713d',
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'xkcd:flat green': '#699d4c',
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'xkcd:warm pink': '#fb5581',
'xkcd:dodger blue': '#3e82fc',
'xkcd:gross green': '#a0bf16',
'xkcd:ice': '#d6fffa',
'xkcd:metallic blue': '#4f738e',
'xkcd:pale salmon': '#ffb19a',
'xkcd:sap green': '#5c8b15',
'xkcd:algae': '#54ac68',
'xkcd:bluey grey': '#89a0b0',
'xkcd:greeny grey': '#7ea07a',
'xkcd:highlighter green': '#1bfc06',
'xkcd:light light blue': '#cafffb',
'xkcd:light mint': '#b6ffbb',
'xkcd:raw umber': '#a75e09',
'xkcd:vivid blue': '#152eff',
'xkcd:deep lavender': '#8d5eb7',
'xkcd:dull teal': '#5f9e8f',
'xkcd:light greenish blue': '#63f7b4',
'xkcd:mud green': '#606602',
'xkcd:pinky': '#fc86aa',
'xkcd:red wine': '#8c0034',
'xkcd:shit green': '#758000',
'xkcd:tan brown': '#ab7e4c',
'xkcd:darkblue': '#030764',
'xkcd:rosa': '#fe86a4',
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'xkcd:pale mauve': '#fed0fc',
'xkcd:claret': '#680018',
'xkcd:dandelion': '#fedf08',
'xkcd:orangered': '#fe420f',
'xkcd:poop green': '#6f7c00',
'xkcd:ruby': '#ca0147',
'xkcd:dark': '#1b2431',
'xkcd:greenish turquoise': '#00fbb0',
'xkcd:pastel red': '#db5856',
'xkcd:piss yellow': '#ddd618',
'xkcd:bright cyan': '#41fdfe',
'xkcd:dark coral': '#cf524e',
'xkcd:algae green': '#21c36f',
'xkcd:darkish red': '#a90308',
'xkcd:reddy brown': '#6e1005',
'xkcd:blush pink': '#fe828c',
'xkcd:camouflage green': '#4b6113',
'xkcd:lawn green': '#4da409',
'xkcd:putty': '#beae8a',
'xkcd:vibrant blue': '#0339f8',
'xkcd:dark sand': '#a88f59',
'xkcd:purple/blue': '#5d21d0',
'xkcd:saffron': '#feb209',
```

```
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'xkcd:bluegrey': '#85a3b2',
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'xkcd:duck egg blue': '#c3fbf4',
'xkcd:greenish cyan': '#2afeb7',
'xkcd:petrol': '#005f6a',
'xkcd:royal': '#0c1793',
'xkcd:butter': '#ffff81',
'xkcd:dusty orange': '#f0833a',
'xkcd:off yellow': '#f1f33f',
'xkcd:pale olive green': '#b1d27b',
'xkcd:orangish': '#fc824a',
'xkcd:leaf': '#71aa34',
'xkcd:light blue grey': '#b7c9e2',
'xkcd:dried blood': '#4b0101',
'xkcd:lightish purple': '#a552e6',
'xkcd:rusty red': '#af2f0d',
'xkcd:lavender blue': '#8b88f8',
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'xkcd:light mint green': '#a6fbb2',
'xkcd:sunflower': '#ffc512',
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'xkcd:lightish red': '#fe2f4a',
'xkcd:pure blue': '#0203e2',
'xkcd:twilight blue': '#0a437a',
'xkcd:violet red': '#a50055',
'xkcd:yellowy brown': '#ae8b0c',
'xkcd:carnation': '#fd798f',
'xkcd:muddy yellow': '#bfac05',
'xkcd:dark seafoam green': '#3eaf76',
'xkcd:deep rose': '#c74767',
'xkcd:dusty red': '#b9484e',
'xkcd:grey/blue': '#647d8e',
'xkcd:lemon lime': '#bffe28',
'xkcd:purple/pink': '#d725de',
'xkcd:brown yellow': '#b29705',
'xkcd:purple brown': '#673a3f',
'xkcd:wisteria': '#a87dc2',
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'xkcd:lipstick red': '#c0022f',
'xkcd:water blue': '#0e87cc',
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'xkcd:pale': '#fff9d0',
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'xkcd:hot magenta': '#f504c9',
'xkcd:greyblue': '#77a1b5',
'xkcd:purpley': '#8756e4',
'xkcd:baby shit green': '#889717',
'xkcd:brownish pink': '#c27e79',
'xkcd:dark aquamarine': '#017371',
'xkcd:diarrhea': '#9f8303',
'xkcd:light mustard': '#f7d560',
'xkcd:pale sky blue': '#bdf6fe',
'xkcd:turtle green': '#75b84f',
'xkcd:bright olive': '#9cbb04',
'xkcd:dark grey blue': '#29465b',
'xkcd:greeny brown': '#696006',
'xkcd:lemon green': '#adf802',
```

```
'xkcd:light periwinkle': '#c1c6fc',
'xkcd:seaweed green': '#35ad6b',
'xkcd:sunshine yellow': '#fffd37',
'xkcd:ugly purple': '#a442a0',
'xkcd:medium pink': '#f36196',
'xkcd:puke brown': '#947706',
'xkcd:very light pink': '#fff4f2',
'xkcd:viridian': '#1e9167',
'xkcd:bile': '#b5c306',
'xkcd:faded yellow': '#feff7f',
'xkcd:very pale green': '#cffdbc',
'xkcd:vibrant green': '#0add08',
'xkcd:bright lime': '#87fd05',
'xkcd:spearmint': '#1ef876',
'xkcd:light aquamarine': '#7bfdc7',
'xkcd:light sage': '#bcecac',
'xkcd:yellowgreen': '#bbf90f',
'xkcd:baby poo': '#ab9004',
'xkcd:dark seafoam': '#1fb57a',
'xkcd:deep teal': '#00555a',
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'xkcd:rust orange': '#c45508',
'xkcd:dirty blue': '#3f829d',
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'xkcd:bright lilac': '#c95efb',
'xkcd:weird green': '#3ae57f',
'xkcd:peacock blue': '#016795',
'xkcd:avocado green': '#87a922',
'xkcd:faded orange': '#f0944d',
'xkcd:grape purple': '#5d1451',
'xkcd:hot green': '#25ff29',
'xkcd:lime yellow': '#d0fe1d',
'xkcd:mango': '#ffa62b',
'xkcd:shamrock': '#01b44c',
'xkcd:bubblegum': '#ff6cb5',
'xkcd:purplish brown': '#6b4247',
'xkcd:vomit yellow': '#c7c10c',
'xkcd:pale cyan': '#b7fffa',
'xkcd:key lime': '#aeff6e',
'xkcd:tomato red': '#ec2d01',
'xkcd:lightgreen': '#76ff7b',
'xkcd:merlot': '#730039',
'xkcd:night blue': '#040348',
'xkcd:purpleish pink': '#df4ec8',
'xkcd:apple': '#6ecb3c',
'xkcd:baby poop green': '#8f9805',
'xkcd:green apple': '#5edc1f',
'xkcd:heliotrope': '#d94ff5',
'xkcd:yellow/green': '#c8fd3d',
'xkcd:almost black': '#070d0d',
'xkcd:cool blue': '#4984b8',
'xkcd:leafy green': '#51b73b',
'xkcd:mustard brown': '#ac7e04',
'xkcd:dusk': '#4e5481',
'xkcd:dull brown': '#876e4b',
'xkcd:frog green': '#58bc08',
'xkcd:vivid green': '#2fef10',
'xkcd:bright light green': '#2dfe54',
'xkcd:fluro green': '#0aff02',
'xkcd:kiwi': '#9cef43',
'xkcd:seaweed': '#18d17b',
'xkcd:navy green': '#35530a',
'xkcd:ultramarine blue': '#1805db',
'xkcd:iris': '#6258c4',
'xkcd:pastel orange': '#ff964f',
'xkcd:yellowish orange': '#ffab0f',
```

```
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'xkcd:pear': '#cbf85f',
'xkcd:pinkish orange': '#ff724c',
'xkcd:midnight purple': '#280137',
'xkcd:light urple': '#b36ff6',
'xkcd:dark mint': '#48c072',
'xkcd:greenish tan': '#bccb7a',
'xkcd:light burgundy': '#a8415b',
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'xkcd:pastel green': '#b0ff9d',
'xkcd:mint': '#9ffeb0',
'xkcd:light orange': '#fdaa48',
'xkcd:bright pink': '#fe01b1',
'xkcd:chartreuse': '#c1f80a',
'xkcd:deep purple': '#36013f',
'xkcd:dark brown': '#341c02',
'xkcd:taupe': '#b9a281',
'xkcd:pea green': '#8eab12',
'xkcd:puke green': '#9aae07',
'xkcd:kelly green': '#02ab2e',
'xkcd:seafoam green': '#7af9ab',
'xkcd:blue green': '#137e6d',
'xkcd:khaki': '#aaa662',
'xkcd:burgundy': '#610023',
'xkcd:dark teal': '#014d4e',
'xkcd:brick red': '#8f1402',
'xkcd:royal purple': '#4b006e',
'xkcd:plum': '#580f41',
'xkcd:mint green': '#8fff9f',
'xkcd:gold': '#dbb40c',
'xkcd:baby blue': '#a2cffe',
```

```
'xkcd:yellow green': '#c0fb2d',
'xkcd:bright purple': '#be03fd',
'xkcd:dark red': '#840000',
'xkcd:pale blue': '#d0fefe',
'xkcd:grass green': '#3f9b0b',
'xkcd:navy': '#01153e',
'xkcd:aquamarine': '#04d8b2',
'xkcd:burnt orange': '#c04e01',
'xkcd:neon green': '#0cff0c',
'xkcd:bright blue': '#0165fc',
'xkcd:rose': '#cf6275',
'xkcd:light pink': '#ffd1df',
'xkcd:mustard': '#ceb301',
'xkcd:indigo': '#380282',
'xkcd:lime': '#aaff32',
'xkcd:sea green': '#53fca1',
'xkcd:periwinkle': '#8e82fe',
'xkcd:dark pink': '#cb416b',
'xkcd:olive green': '#677a04',
'xkcd:peach': '#ffb07c',
'xkcd:pale green': '#c7fdb5',
'xkcd:light brown': '#ad8150',
'xkcd:hot pink': '#ff028d',
'xkcd:black': '#000000',
'xkcd:lilac': '#cea2fd',
'xkcd:navy blue': '#001146',
'xkcd:royal blue': '#0504aa',
'xkcd:beige': '#e6daa6',
'xkcd:salmon': '#ff796c',
'xkcd:olive': '#6e750e',
'xkcd:maroon': '#650021',
'xkcd:bright green': '#01ff07',
'xkcd:dark purple': '#35063e',
'xkcd:mauve': '#ae7181',
'xkcd:forest green': '#06470c',
'xkcd:aqua': '#13eac9',
'xkcd:cyan': '#00ffff',
'xkcd:tan': '#d1b26f',
'xkcd:dark blue': '#00035b',
'xkcd:lavender': '#c79fef',
'xkcd:turquoise': '#06c2ac',
'xkcd:dark green': '#033500',
'xkcd:violet': '#9a0eea',
'xkcd:light purple': '#bf77f6',
'xkcd:lime green': '#89fe05',
'xkcd:grey': '#929591',
'xkcd:sky blue': '#75bbfd',
'xkcd:yellow': '#ffff14',
'xkcd:magenta': '#c20078',
'xkcd:light green': '#96f97b',
'xkcd:orange': '#f97306',
'xkcd:teal': '#029386',
'xkcd:light blue': '#95d0fc',
'xkcd:red': '#e50000',
'xkcd:brown': '#653700',
'xkcd:pink': '#ff81c0',
'xkcd:blue': '#0343df',
'xkcd:green': '#15b01a',
'xkcd:purple': '#7e1e9c',
'xkcd:gray teal': '#5e9b8a',
'xkcd:purpley gray': '#947e94',
'xkcd:light gray green': '#b7e1a1',
'xkcd:reddish gray': '#997570',
'xkcd:battleship gray': '#6b7c85',
'xkcd:charcoal gray': '#3c4142',
'xkcd:grayish teal': '#719f91',
```

```
 'xkcd:gray/green': '#86a17d',
 'xkcd:cool gray': '#95a3a6',
 'xkcd:dark blue gray': '#1f3b4d',
 'xkcd:bluey gray': '#89a0b0',
 'xkcd:greeny gray': '#7ea07a',
 'xkcd:bluegray': '#85a3b2',
 'xkcd:light blue gray': '#b7c9e2',
 'xkcd:gray/blue': '#647d8e',
 'xkcd:brown gray': '#8d8468',
 'xkcd:blue/gray': '#758da3',
 'xkcd:grayblue': '#77a1b5',
 'xkcd:dark gray blue': '#29465b',
 'xkcd:grayish': '#a8a495',
 'xkcd:light gray blue': '#9dbcd4',
 'xkcd:pale gray': '#fdfdfe',
 'xkcd:warm gray': '#978a84',
 'xkcd:gray pink': '#c3909b',
 'xkcd:medium gray': '#7d7f7c',
 'xkcd:pinkish gray': '#c8aca9',
 'xkcd:brownish gray': '#86775f',
 'xkcd:purplish gray': '#7a687f',
 'xkcd:grayish pink': '#c88d94',
 'xkcd:grayish brown': '#7a6a4f',
 'xkcd:steel gray': '#6f828a',
 'xkcd:purple gray': '#866f85',
 'xkcd:gray brown': '#7f7053',
 'xkcd:green gray': '#77926f',
 'xkcd:bluish gray': '#748b97',
 'xkcd:slate gray': '#59656d',
 'xkcd:gray purple': '#826d8c',
 'xkcd:greenish gray': '#96ae8d',
 'xkcd:grayish purple': '#887191',
 'xkcd:grayish green': '#82a67d',
 'xkcd:grayish blue': '#5e819d',
 'xkcd:gray green': '#789b73',
 'xkcd:light gray': '#d8dcd6',
 'xkcd:blue gray': '#607c8e',
 'xkcd:dark gray': '#363737',
 'xkcd:gray blue': '#6b8ba4',
 'xkcd:gray': '#929591',
 'aliceblue': '#F0F8FF',
 'antiquewhite': '#FAEBD7',
 'aqua': '#00FFFF',
 'aquamarine': '#7FFFD4',
 ...}
```

By Hex

With the exception of a few colors (the shorthand colors from earlier), all colors above are mapped to a Hex value. This is a base-16 (0-9 + A-F = 16 unique characters) representation for each color. This is commonly used in graphic and web design communicates the amount of red, blue, and green in a particular color.

In [13]:
```
allColors['fuchsia'] # Hexadecimal representation of fuchsia
```

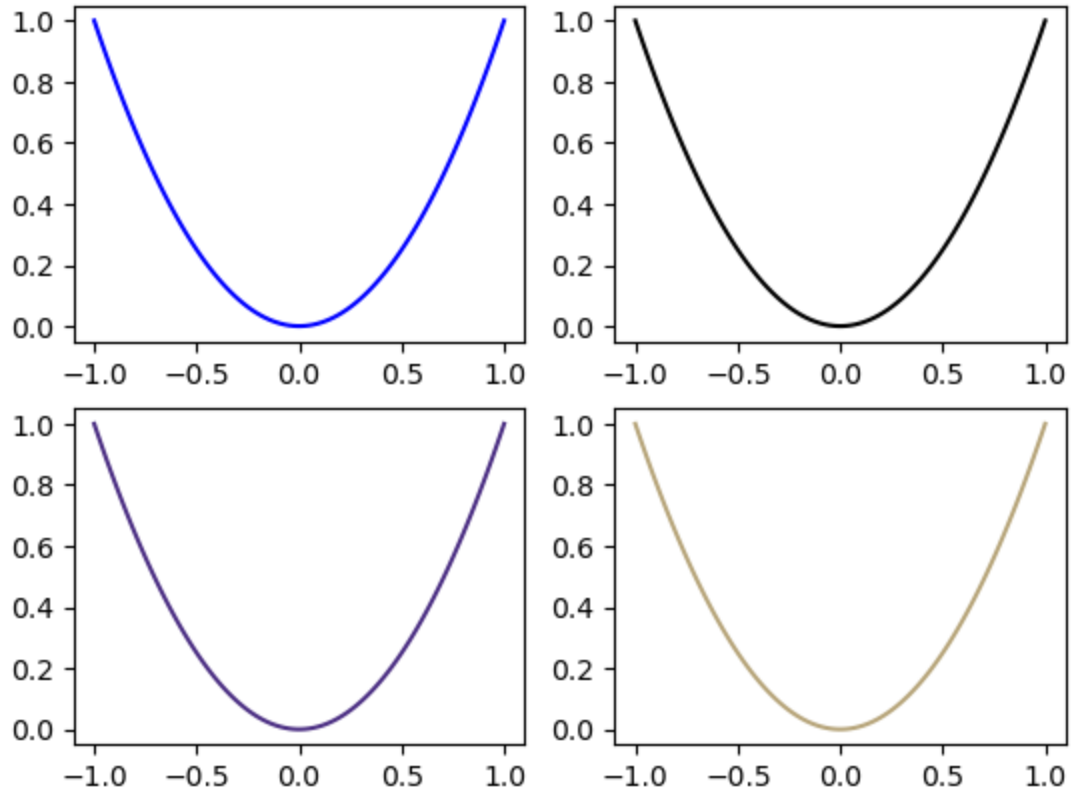
Out[13]:
```
'#FF00FF'
```

For example, let's say that we wanted to make a plot using UW colors (go dawgs). We can find the hex codes for the purple and gold online **here**.

- Purple: 4b2e83
- Gold: b7a57a This allows us to match the exact colors of UW across media:

In [137…
```
fig, ax = plt.subplots(nrows=2, ncols=2)
ax[0,0].plot(x, y, color='b') # Blue
ax[0,1].plot(x, y, color='k') # Black

uwPurple = '#4b2e83' # UW purple
uwGold = '#b7a57a' # UW Gold

ax[1,0].plot(x, y, color=uwPurple) # UW purple
ax[1,1].plot(x, y, color=uwGold) # UW Gold
```

Out[137]:
```
[<matplotlib.lines.Line2D at 0x24ff9352be0>]
```



By RGB

At the end of the day, all of these colors are specifying the amount of red, green and blue in the final color. This is represented most-simply as a 1x3 vector of the red contribution, green contribution, and blue contribution, each from 0 to 1.

For example:

In [33]:
```
# Built-in red, green, blue
print('r:', colors.to_rgb('r'))
print('g:', colors.to_rgb('g')) # Note: (0, 1, 0) is more of a lime green
print('b:', colors.to_rgb('b'))


print('black:', colors.to_rgb('black'))
print('white:', colors.to_rgb('white'))

print('UW purple:', colors.to_rgb('#4b2e83')) # UW purple
print('UW gold:', colors.to_rgb('#b7a57a')) # UW Gold
```

```
r: (1.0, 0.0, 0.0)
g: (0.0, 0.5, 0.0)
b: (0.0, 0.0, 1.0)
black: (0.0, 0.0, 0.0)
white: (1.0, 1.0, 1.0)
```

```
UW purple: (0.29411764705882354, 0.1803921568627451, 0.5137254901960784)
UW gold: (0.7176470588235294, 0.6470588235294118, 0.47843137254901963)
```

These RGB codes are the foundations for our **colormaps**, but may be constructed from any of the valid color specifications.

Colormaps

Colormaps link a range of values to a range of colors (specified as these RGB vectors). To access built-in colormaps:

Built-in colormaps

Just like there are "built-in" colors, there are also "built-in" color maps. To easiest way to access these colormaps is to import `matplotlib` itself, and then access `matplotlib.colormaps`

In [51]:
```
import matplotlib as mpl

colormaps = mpl.colormaps

print(colormaps)
```

```
ColormapRegistry; available colormaps:
'magma', 'inferno', 'plasma', 'viridis', 'cividis', 'twilight', 'twilight_shifted', 'tur
bo', 'Blues', 'BrBG', 'BuGn', 'BuPu', 'CMRmap', 'GnBu', 'Greens', 'Greys', 'OrRd', 'Oran
ges', 'PRGn', 'PiYG', 'PuBu', 'PuBuGn', 'PuOr', 'PuRd', 'Purples', 'RdBu', 'RdGy', 'RdP
u', 'RdYlBu', 'RdYlGn', 'Reds', 'Spectral', 'Wistia', 'YlGn', 'YlGnBu', 'YlOrBr', 'YlOrR
d', 'afmhot', 'autumn', 'binary', 'bone', 'brg', 'bwr', 'cool', 'coolwarm', 'copper', 'c
ubehelix', 'flag', 'gist_earth', 'gist_gray', 'gist_heat', 'gist_ncar', 'gist_rainbow',
'gist_stern', 'gist_yarg', 'gnuplot', 'gnuplot2', 'gray', 'hot', 'hsv', 'jet', 'nipy_spe
ctral', 'ocean', 'pink', 'prism', 'rainbow', 'seismic', 'spring', 'summer', 'terrain',
'winter', 'Accent', 'Dark2', 'Paired', 'Pastel1', 'Pastel2', 'Set1', 'Set2', 'Set3', 'ta
b10', 'tab20', 'tab20b', 'tab20c', 'magma_r', 'inferno_r', 'plasma_r', 'viridis_r', 'civ
idis_r', 'twilight_r', 'twilight_shifted_r', 'turbo_r', 'Blues_r', 'BrBG_r', 'BuGn_r',
'BuPu_r', 'CMRmap_r', 'GnBu_r', 'Greens_r', 'Greys_r', 'OrRd_r', 'Oranges_r', 'PRGn_r',
'PiYG_r', 'PuBu_r', 'PuBuGn_r', 'PuOr_r', 'PuRd_r', 'Purples_r', 'RdBu_r', 'RdGy_r', 'Rd
Pu_r', 'RdYlBu_r', 'RdYlGn_r', 'Reds_r', 'Spectral_r', 'Wistia_r', 'YlGn_r', 'YlGnBu_r',
'YlOrBr_r', 'YlOrRd_r', 'afmhot_r', 'autumn_r', 'binary_r', 'bone_r', 'brg_r', 'bwr_r',
'cool_r', 'coolwarm_r', 'copper_r', 'cubehelix_r', 'flag_r', 'gist_earth_r', 'gist_gray_
r', 'gist_heat_r', 'gist_ncar_r', 'gist_rainbow_r', 'gist_stern_r', 'gist_yarg_r', 'gnup
lot_r', 'gnuplot2_r', 'gray_r', 'hot_r', 'hsv_r', 'jet_r', 'nipy_spectral_r', 'ocean_r',
'pink_r', 'prism_r', 'rainbow_r', 'seismic_r', 'spring_r', 'summer_r', 'terrain_r', 'win
ter_r', 'Accent_r', 'Dark2_r', 'Paired_r', 'Pastel1_r', 'Pastel2_r', 'Set1_r', 'Set2_r',
'Set3_r', 'tab10_r', 'tab20_r', 'tab20b_r', 'tab20c_r'
```

Then, to get a particular colormap, use `dict`-like notation: **Note**: "bad", "over" and "under" are the colors used for values that are invalid (bad) or outside the range of values the colormap maps to.

In [91]:
```
mpl.colormaps['viridis']
```

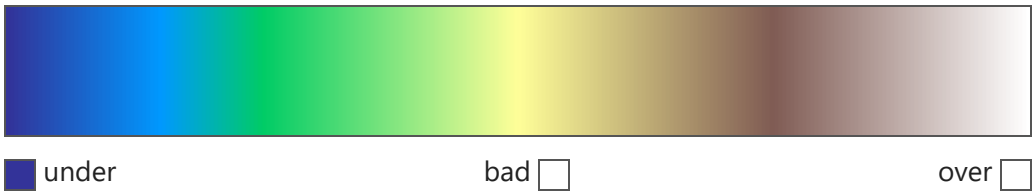
Out[91]:

viridis

under bad over

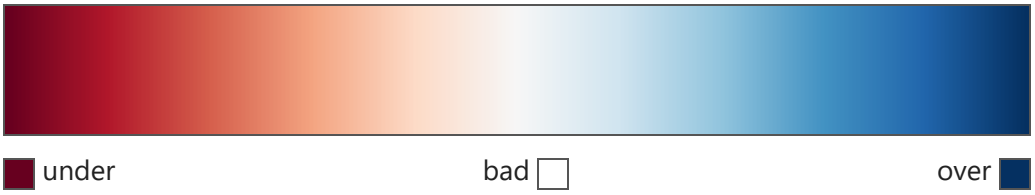
In [92]:
```
mpl.colormaps['terrain']
```

Out[92]: **terrain**



In [93]:
```
mpl.colormaps['RdBu']
```

Out[93]: **RdBu**



Side note: alternative way to access built-in colormaps

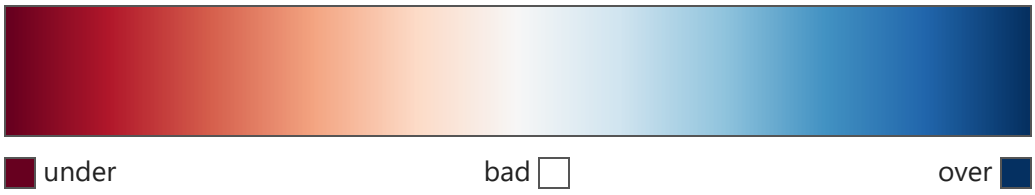
Alternatively, you may also see folks import `matplotlib.cm`, followed by dot notation or a call to the `get_cmap()` function to access particular colormaps. The `cm` module allows you to "register" your own colormaps so matplotlib remembers them, but otherwise these two approaches are identical.

In [115…
```
import matplotlib.cm as cm

cm.RdBu
```

Out[115]: **RdBu**

In [116…
```
cm.get_cmap('RdBu')
```

Out[116]: **RdBu**



Applying to figures

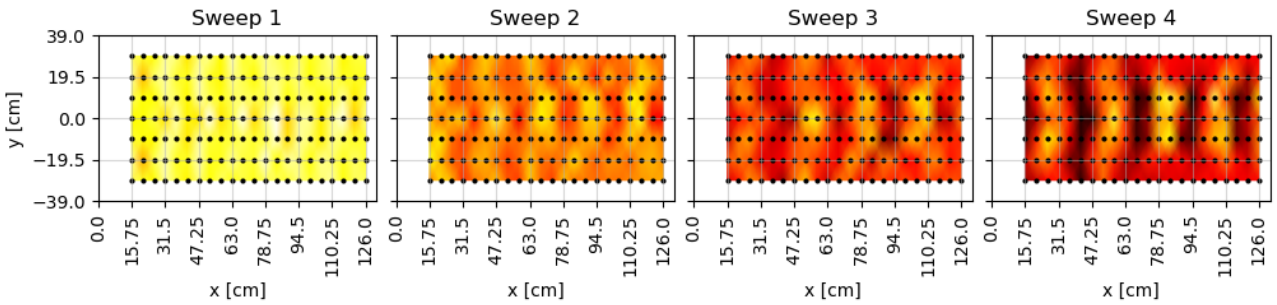
Let's now return to our plot. How can we apply a particular colormap to our plots?

Applying to plots

Many plotting functions that are well-suited for colormaps have a parameter, `cmap`, that allows us to set the colormap associated with a particular output. So let's do that in our `pcolormesh()` call! For the colormap in the target plot, we want to use the built-in `hot` map.

In [69]:
```
# Create our figure
nSweeps = 4
fig, ax = plt.subplots(nrows=1, ncols=nSweeps, sharex=True, sharey=True, layout='c

xtickVals = np.arange(0, 4*D+D/2, D/2)
ytickVals = np.arange(-w/2, w/2+w/4, w/4)

# Plot on each axes
for i in range(nSweeps):
    # Plot the free surface data (NOW WITH COLORMAP)
    ax[i].pcolormesh(X, Y, fstData[:,:,i],
                     cmap = mpl.colormaps['hot'],
                     vmin=np.min(fstData), vmax=np.max(fstData),
                     shading='gouraud')

    # Plot the grid points
    ax[i].scatter(X, Y, c='k', s=4)

    # Set aspect ratio
    ax[i].set_aspect('equal')

    # Set x label and title
    ax[i].set_xlabel('x [cm]')
    ax[i].set_title('Sweep ' + str(i+1))

    # Set x and y ticks
    ax[i].set_xticks(xtickVals, labels=xtickVals, rotation='vertical')
    ax[i].set_yticks(ytickVals)

    # Turn on the grid
    ax[i].grid(alpha=0.5)

# Set y label of leftmost axis only
ax[0].set_ylabel('y [cm]')

# Set x and y limits
ax[0].set_xlim([0, 4*D+dx])
ax[0].set_ylim([-w/2, w/2])
```

Out[69]:
```
(-39.0, 39.0)
```



Adding colorbars

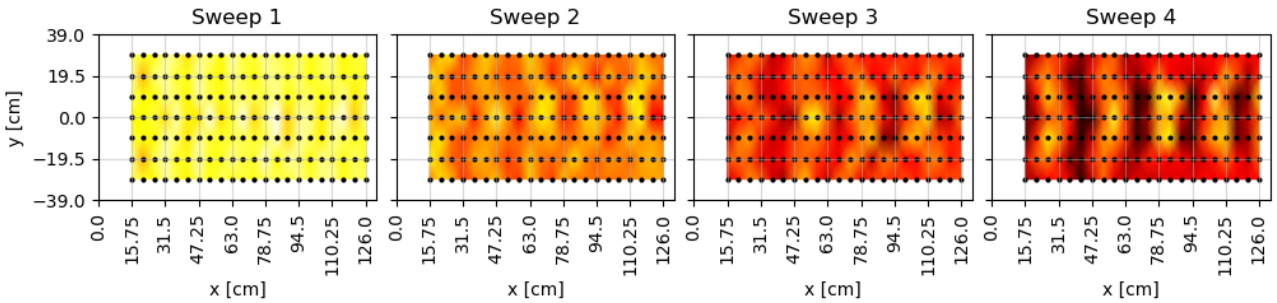
Now, to add a colorbar, we can create one with the `fig.colorbar` command. Notes on syntax:

- The first argument is a `ScalarMappable`: basically an Artist that a colormap can represent. In this case, it should be the output of our `pcolormesh` function call.
- The `ax` argument is which Axes in our figure the colormap will "steal space from". In other words, which Axes (one or multiple) the colorbar will sit next to.
- The `location` argument specifies the position of the colorbar, as a string. Some examples are `top`, `bottom`, `left`, `right`.

Let's catch the last pcolormesh created in a variable called `mesh`, and add a call to fig.colorbar at the bottom of the script:

In [80]:
```
# Create our figure
nSweeps = 4
fig, ax = plt.subplots(nrows=1, ncols=nSweeps, sharex=True, sharey=True, layout='c

xtickVals = np.arange(0, 4*D+D/2, D/2)
ytickVals = np.arange(-w/2, w/2+w/4, w/4)

# Plot on each axes
for i in range(nSweeps):
    # Plot the free surface data (NOW WITH COLORMAP)
    mesh = ax[i].pcolormesh(X, Y, fstData[:,:,i],
                            cmap = mpl.colormaps['hot'],
                            vmin=np.min(fstData), vmax=np.max(fstData),
                            shading='gouraud')

    # Plot the grid points
    ax[i].scatter(X, Y, c='k', s=4)

    # Set aspect ratio
    ax[i].set_aspect('equal')

    # Set x label and title
    ax[i].set_xlabel('x [cm]')
    ax[i].set_title('Sweep ' + str(i+1))

    # Set x and y ticks
    ax[i].set_xticks(xtickVals, labels=xtickVals, rotation='vertical')
    ax[i].set_yticks(ytickVals)

    # Turn on the grid
    ax[i].grid(alpha=0.5)

# Set y label of leftmost axis only
ax[0].set_ylabel('y [cm]')

# Set x and y limits
ax[0].set_xlim([0, 4*D+dx])
ax[0].set_ylim([-w/2, w/2])
```

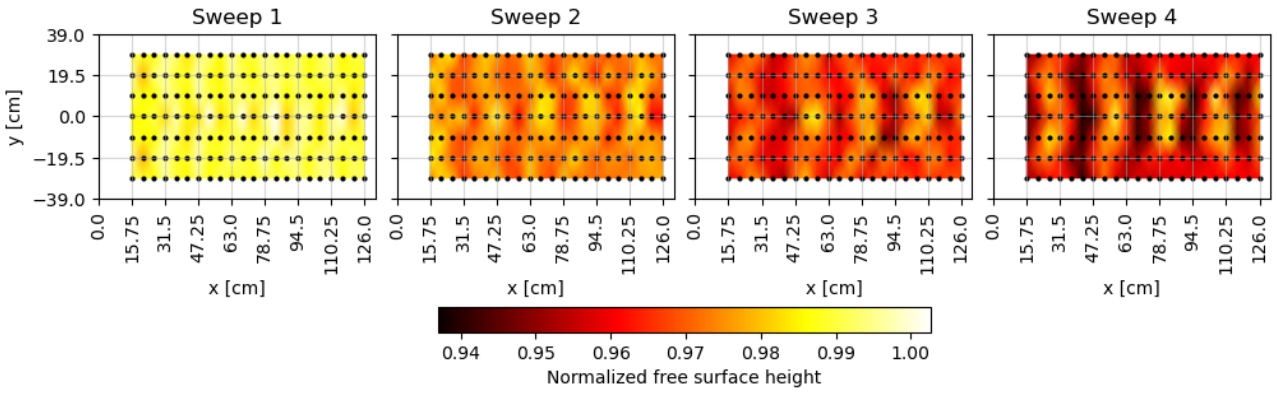
Out[80]:
```
(-39.0, 39.0)
```



Just like everything else, the colorbar is an `Artist` object and has properties that we can set when creating it or after the fact. Let's set the label:

In [81]:
```
# Create our figure
nSweeps = 4
fig, ax = plt.subplots(nrows=1, ncols=nSweeps, sharex=True, sharey=True, layout='c

xtickVals = np.arange(0, 4*D+D/2, D/2)
ytickVals = np.arange(-w/2, w/2+w/4, w/4)
```

```
# Plot on each axes
for i in range(nSweeps):
    # Plot the free surface data (NOW WITH COLORMAP)
    mesh = ax[i].pcolormesh(X, Y, fstData[:,:,i],
                            cmap = mpl.colormaps['hot'],
                            vmin=np.min(fstData), vmax=np.max(fstData),
                            shading='gouraud')

    # Plot the grid points
    ax[i].scatter(X, Y, c='k', s=4)

    # Set aspect ratio
    ax[i].set_aspect('equal')

    # Set x label and title
    ax[i].set_xlabel('x [cm]')
    ax[i].set_title('Sweep ' + str(i+1))

    # Set x and y ticks
    ax[i].set_xticks(xtickVals, labels=xtickVals, rotation='vertical')
    ax[i].set_yticks(ytickVals)

    # Turn on the grid
    ax[i].grid(alpha=0.5)

# Set y label of leftmost axis only
ax[0].set_ylabel('y [cm]')

# Set x and y limits
ax[0].set_xlim([0, 4*D+dx])
ax[0].set_ylim([-w/2, w/2])

cbar = fig.colorbar(mesh, ax=ax, location='bottom', label='Normalized free surface
# Alternatively, could set as cbar.set_label('Normalized free surface height')
```



Our figure now completely matches the target output!

Creating custom colormaps

We can get pretty far with built-in colormaps, but we can create our own too. To make our own colormaps, we need to understand the types of colormap objects that exist in matplotlib:

`ListedColormaps`

`ListedColormaps` are colormaps that consist of a **list of colors that map to a range of values**. These maps are well-suited for representing discrete values.

For example, consider the default colormap, `viridis`.

In [140…
```
cmap = cm.get_cmap('viridis')
cmap
```

Out[140]:

In [118…
```
type(cmap)
```

Out[118]:
```
matplotlib.colors.ListedColormap
```

We can view the colors that underly this colormap using the `.colors` attribute. By default, this is an array of 256 RGB triplets.

In [103…
```
cmap.colors
```

Out[103]:
```
[[0.267004, 0.004874, 0.329415],
 [0.26851, 0.009605, 0.335427],
 [0.269944, 0.014625, 0.341379],
 [0.271305, 0.019942, 0.347269],
 [0.272594, 0.025563, 0.353093],
 [0.273809, 0.031497, 0.358853],
 [0.274952, 0.037752, 0.364543],
 [0.276022, 0.044167, 0.370164],
 [0.277018, 0.050344, 0.375715],
 [0.277941, 0.056324, 0.381191],
 [0.278791, 0.062145, 0.386592],
 [0.279566, 0.067836, 0.391917],
 [0.280267, 0.073417, 0.397163],
 [0.280894, 0.078907, 0.402329],
 [0.281446, 0.08432, 0.407414],
 [0.281924, 0.089666, 0.412415],
 [0.282327, 0.094955, 0.417331],
 [0.282656, 0.100196, 0.42216],
 [0.28291, 0.105393, 0.426902],
 [0.283091, 0.110553, 0.431554],
 [0.283197, 0.11568, 0.436115],
 [0.283229, 0.120777, 0.440584],
 [0.283187, 0.125848, 0.44496],
 [0.283072, 0.130895, 0.449241],
 [0.282884, 0.13592, 0.453427],
 [0.282623, 0.140926, 0.457517],
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```

```
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[0.993248, 0.906157, 0.143936]]
```
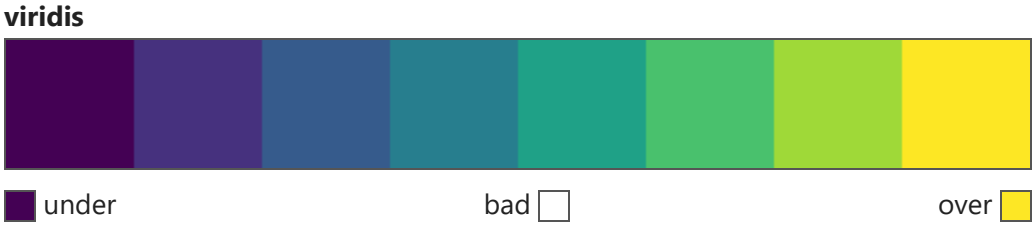

If we want a discretized version of this colormap, we can get one using by supplying a second argument to `cm.get_cmap`. For example, a viridis map that spans 8 values instead of 256:

In [142…
```
cmap = cm.get_cmap('viridis', 8)
cmap
```

Out[142]:



In [143…
```
cmap.colors
```

Out[143]:
```
array([[0.267004, 0.004874, 0.329415, 1.      ],
       [0.275191, 0.194905, 0.496005, 1.      ],
       [0.212395, 0.359683, 0.55171 , 1.      ],
       [0.153364, 0.497   , 0.557724, 1.      ],
       [0.122312, 0.633153, 0.530398, 1.      ],
       [0.288921, 0.758394, 0.428426, 1.      ],
       [0.626579, 0.854645, 0.223353, 1.      ],
       [0.993248, 0.906157, 0.143936, 1.      ]])
```

You can get a particular value in the colormap by providing a number between 0 and `len(cmap.colors)`. Non-integer values are interpolated via nearest neighbor.

In [144…
```
print('First color:', cmap(0)) # The first color
print('Second color:', cmap(1)) # The second color
print('Color at 7.6', cmap(7.6)) # Nearest neighbor interpolation
```

```
First color: (0.267004, 0.004874, 0.329415, 1.0)
Second color: (0.275191, 0.194905, 0.496005, 1.0)
Color at 7.6 (0.993248, 0.906157, 0.143936, 1.0)
```

We can create such a colormap simply by providing a list of colors to `matplotlib.colors.ListeColormap()`. Let's use our UW colors again:

In [157…
```
customMap = colors.ListedColormap([uwPurple, 'white', uwGold], name='goDawgs')
customMap
```

Out[157]:

In [145…
```
customMap.colors
```

Out[145]:
```
['#4b2e83', 'white', '#b7a57a']
```

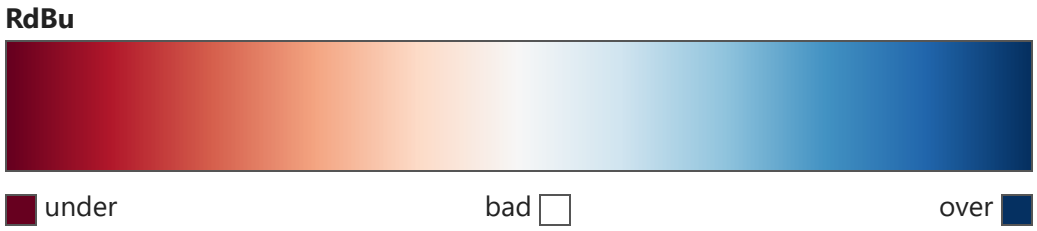
LinearSegmentedColormaps

In contrast, `LinearSegmentedColormaps` linearly interpolate between "anchor" colors. This is a continuous verison of the `ListedColormap` (basically, a list of infinite colors).

An example is the built in `RdBu` colormap, which interpolates between red and white, and white and blue:

In [147…
```
cmap = cm.get_cmap('RdBu')
cmap
```

Out[147]:



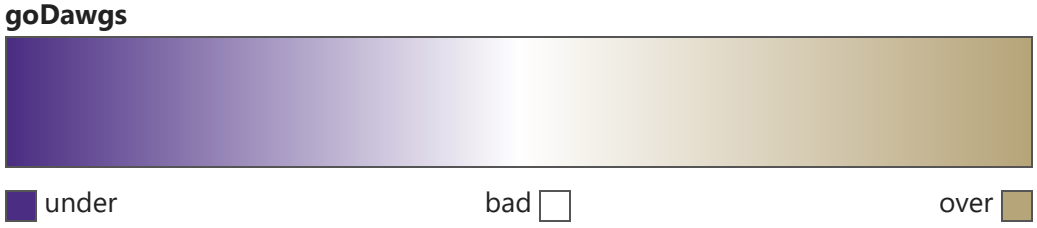
In [148…
```
type(cmap)
```

Out[148]:
```
matplotlib.colors.LinearSegmentedColormap
```

We can create such a colormap from a list of names like before (note that `name` is a required argument now for some reason):

In [156…
```
customMap = colors.LinearSegmentedColormap.from_list('goDawgs', [uwPurple, 'w
customMap
```

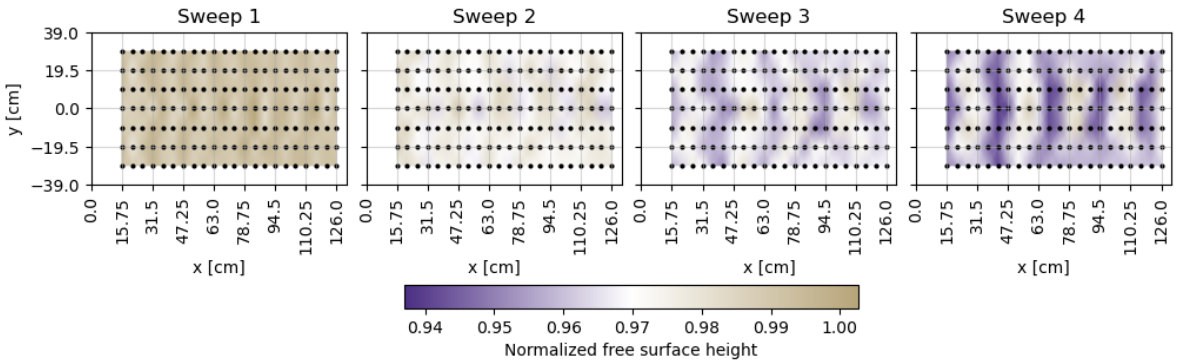
Out[156]:



Let's use it in our figure by creating the colormap outside of the loop, then using it each time we call pcolormesh

In [158…
```
# Create our figure
nSweeps = 4
fig, ax = plt.subplots(nrows=1, ncols=nSweeps, sharex=True, sharey=True, la

xtickVals = np.arange(0, 4*D+D/2, D/2)
ytickVals = np.arange(-w/2, w/2+w/4, w/4)

goDawgs = colors.LinearSegmentedColormap.from_list('goDawgs',  [uwPurple, '
```

```
# Plot on each axes
for i in range(nSweeps):
    # Plot the free surface data (NOW WITH COLORMAP)
    mesh = ax[i].pcolormesh(X, Y, fstData[:,:,i],
                            cmap = goDawgs,
                            vmin=np.min(fstData), vmax=np.max(fstData),
                            shading='gouraud')

    # Plot the grid points
    ax[i].scatter(X, Y, c='k', s=4)

    # Set aspect ratio
    ax[i].set_aspect('equal')

    # Set x label and title
    ax[i].set_xlabel('x [cm]')
    ax[i].set_title('Sweep ' + str(i+1))

    # Set x and y ticks
    ax[i].set_xticks(xtickVals, labels=xtickVals, rotation='vertical')
    ax[i].set_yticks(ytickVals)

    # Turn on the grid
    ax[i].grid(alpha=0.5)

# Set y label of leftmost axis only
ax[0].set_ylabel('y [cm]')

# Set x and y limits
ax[0].set_xlim([0, 4*D+dx])
ax[0].set_ylim([-w/2, w/2])

cbar = fig.colorbar(mesh, ax=ax, location='bottom', label='Normalized free
# Alternatively, could set as cbar.set_label('Normalized free surface heigh
```



Choosing/designing colormaps

So which colormaps do we use? A few things to consider:

Types of colormaps

We should pick colormaps that match our data. We can divide colormaps into several categories.

Sequential: A continuous progression of color from one "end" to another

- Good for data that is increasing/decreasing in one direction

- Built-in examples: viridis, plasma, hot, etc

In [164…
```
cm.get_cmap('plasma')
```

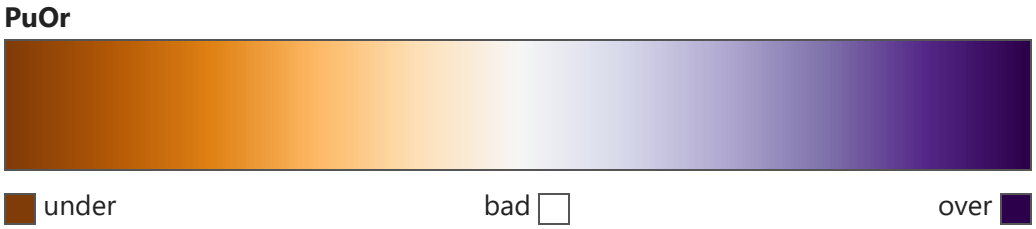
Out[164]:

Diverging: A colormap of two colors that meet in the middle at a "neutral" color

- Good for data that is symmetric about 0 or some center value.
- Good for characterizing fluctuations, oscillations, positives and negatives
- Built-in examples: RdBu, PuOr, etc

In [165…
```
cm.get_cmap('PuOr')
```

Out[165]:



Cyclic: Maximum and minimum colors are the same

- Good for periodic data
- Built-in examples: twilight

In [166…
```
cm.get_cmap('twilight')
```

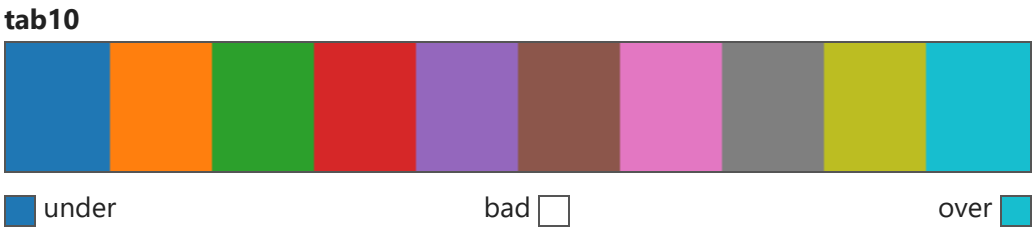
Out[166]:

Categorical

- Good for data that doesn't have an intrinsic order to it
- Example: default plotting colors (e.g., tab10)

In [167…
```
cm.get_cmap('tab10')
```

Out[167]:



Accessibility

We also want to make sure that our colormaps allow our data to be seen and understood by all people. We should balance contrast with considering those with some degree of colorblindness. Some general guidelines.

- Avoid the rainbow colormap. It's tempting to use but leaves much room for confusion. **Check out this article on why we continue to use it even though we shouldn't.**
- Use available tools to help choose good colormaps that are accessible and highlight your data well.
  - **Color blindness simulator**
  - **Color brewer**

In [ ]: