Plotting review, 2-D plots, and mapping

ESS 116 | Fall 2024

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(Modified from Ethan Campbell and Katy Christensen's materials for UW's Ocean 215)

What we'll cover in this lesson

1. Review of plotting concepts

2. 2-D plotting

3. Mapping with Cartopy

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1. **Review of plotting concepts**

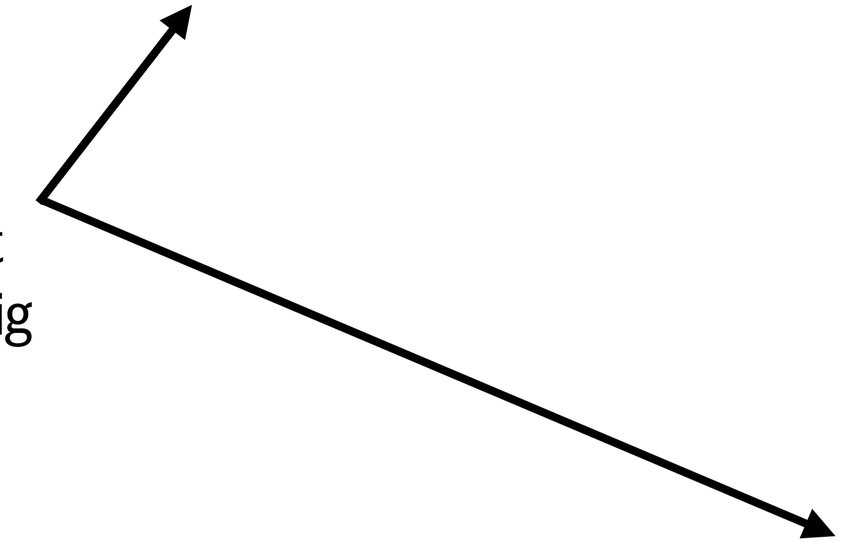
2. 2-D plotting

3. Mapping with Cartopy

Creating a figure

```
fig = plt.figure( )
```

You can add the `figsize` argument here to customize how big your figure is



```
fig, ax = plt.subplots(nrows=   , ncols=   )
```

Creating a figure

```
fig = plt.figure( )
```

When creating a figure with a single axes, you can create a variable for your axes object with this code:

```
ax=plt.axes()
```

You can add the `figsize` argument here to customize how big your figure is

```
fig, ax = plt.subplots(nrows=   , ncols=   )
```

To call the axis that is currently being plotted on, use the code: `plt.gca()`

Line plot

```
plt.plot(x, y, c='r', ls='-', marker='o', ms=5, lw=2)
```

These are all optional formatting arguments

Replace this with `ax` if you have an axes object

Line plot

```
plt.plot(x, y, c='r', ls='-', marker='o', ms=5, lw=2)
```

Replace this with `ax` if you have an axes object

`color`
input: string

`linestyle`
input: string

`marker`
input: string

`markersize`
input: float

`linewidth`
input: float

These are all optional formatting arguments

Line plot

```
plt.plot(x, y, c='r', ls='-', marker='o', ms=5, lw=2)
```

Replace this with `ax` if you have an axes object

`color`
input: string

`linestyle`
input: string

`marker`
input: string

`markersize`
input: float

`linewidth`
input: float

These are all optional formatting arguments

Line plot

```
plt.plot(x, y, 'ro-', ms=5, lw=2)
```

Color, linestyle, and marker can be combined in a single string if the color is a single letter shortcut

Optional formatting arguments

Markers

character	description
`'.'`	point marker
`','`	pixel marker
`'o'`	circle marker
`'v'`	triangle_down marker
`'^'`	triangle_up marker
`'<'`	triangle_left marker
`'>'`	triangle_right marker
`'1'`	tri_down marker
`'2'`	tri_up marker
`'3'`	tri_left marker
`'4'`	tri_right marker
`'s'`	square marker
`'p'`	pentagon marker
`'*'`	star marker
`'h'`	hexagon1 marker
`'H'`	hexagon2 marker
`'+'`	plus marker
`'x'`	x marker
`'D'`	diamond marker
`'d'`	thin_diamond marker
`'|'`	vline marker
`'_'`	hline marker

Line Styles

character	description
`'-'`	solid line style
`'--'`	dashed line style
`'-.'`	dash-dot line style
`':'`	dotted line style

Colors

The supported color abbreviations are the single letter codes

character	color
`'b'`	blue
`'g'`	green
`'r'`	red
`'c'`	cyan
`'m'`	magenta
`'y'`	yellow
`'k'`	black
`'w'`	white

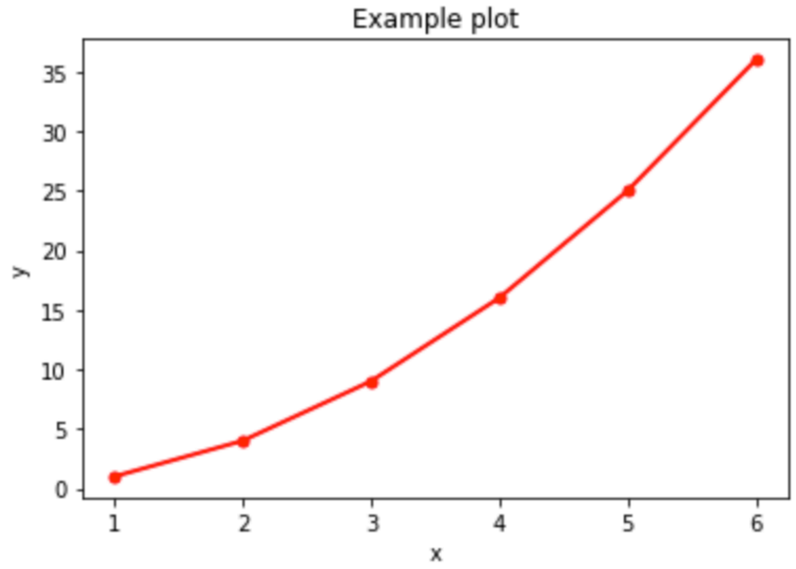
matplotlib
Version 3.3.2

https://matplotlib.org/3.3.2/api/_as_gen/matplotlib.pyplot.plot.html

Customizing line plots

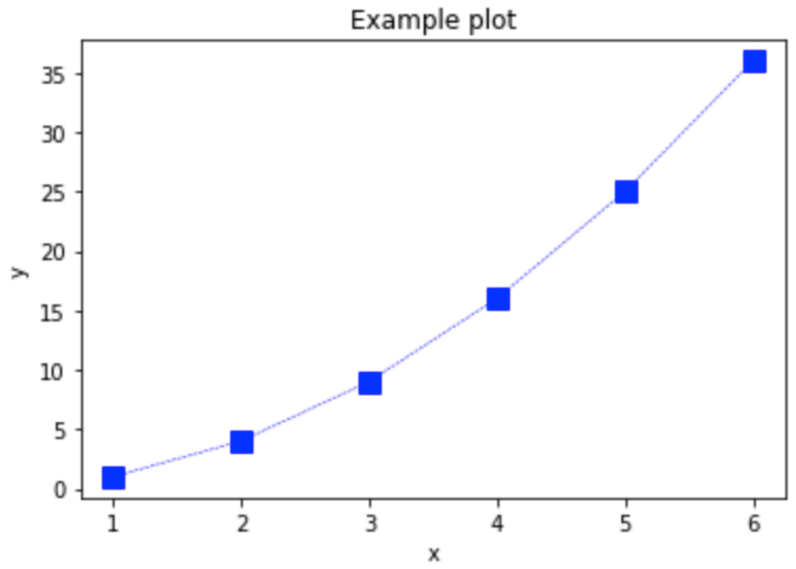
```
1 x = np.array([1,2,3,4,5,6])
2 y = x**2
3
4 fig = plt.figure()
5 plt.plot(x, y, c='r' ,ls='-' ,marker='o',ms=5 , lw=2)
6 plt.xlabel('x')
7 plt.ylabel('y')
8 plt.title('Example plot')
```

```
Text(0.5, 1.0, 'Example plot')
```




```
1 x = np.array([1,2,3,4,5,6])
2 y = x**2
3
4 fig = plt.figure()
5 plt.plot(x, y, c='b' ,ls='--' ,marker='s',ms=10 , lw=0.5)
6 plt.xlabel('x')
7 plt.ylabel('y')
8 plt.title('Example plot')
```

```
Text(0.5, 1.0, 'Example plot')
```



Scatter plot

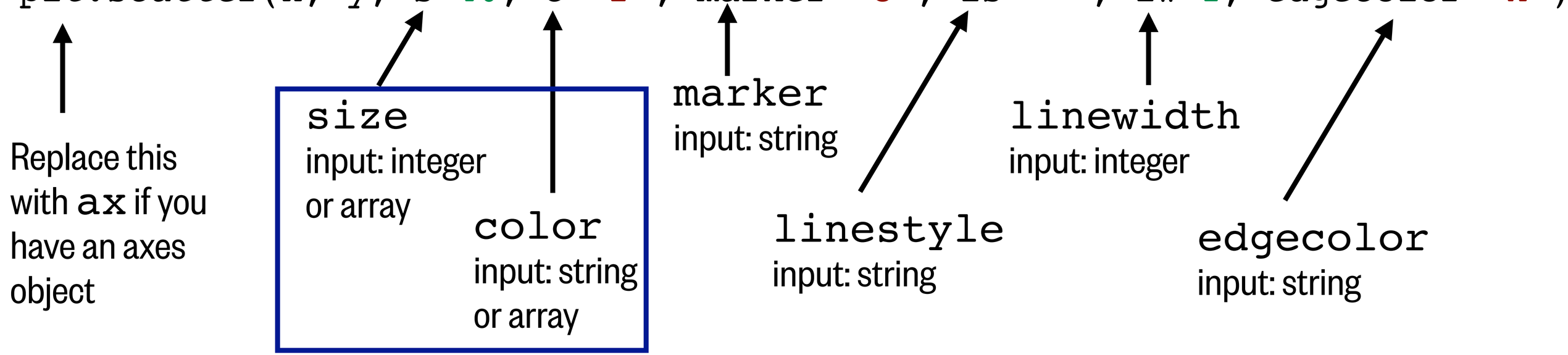
```
plt.scatter(x, y, s=40, c='r', marker='o', ls='-', lw=1, edgecolor='k')
```

These are all optional formatting arguments

Replace this with `ax` if you have an axes object

Scatter plot

```
plt.scatter(x, y, s=40, c='r', marker='o', ls='-', lw=1, edgecolor='k')
```



Scatter plot

```
plt.scatter(x, y, s=40, c='r', marker='o', ls='-', lw=1, edgecolor='k')
```

Replace this with `ax` if you have an axes object

`size`
input: integer or array

`color`
input: string or array

`marker`
input: string

`linestyle`
input: string

`linewidth`
input: integer

`edgecolor`
input: string

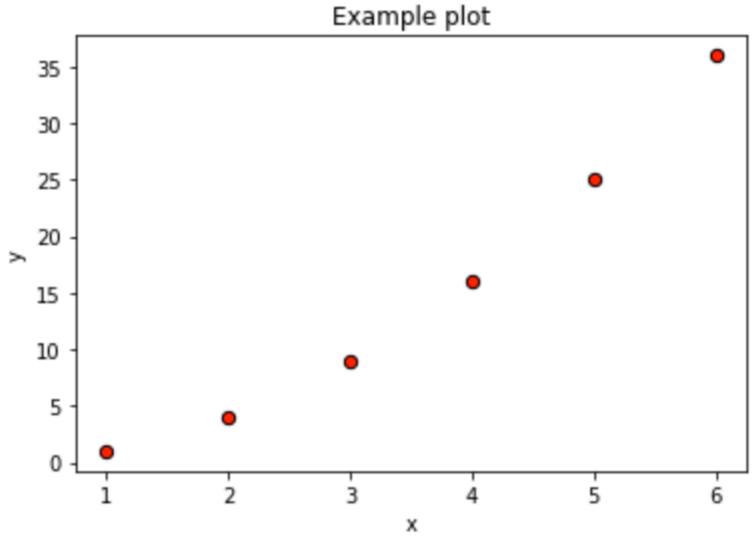
These are all optional formatting arguments

Line arguments in a scatter plot are different from line arguments in a line plot…

Scatter plot

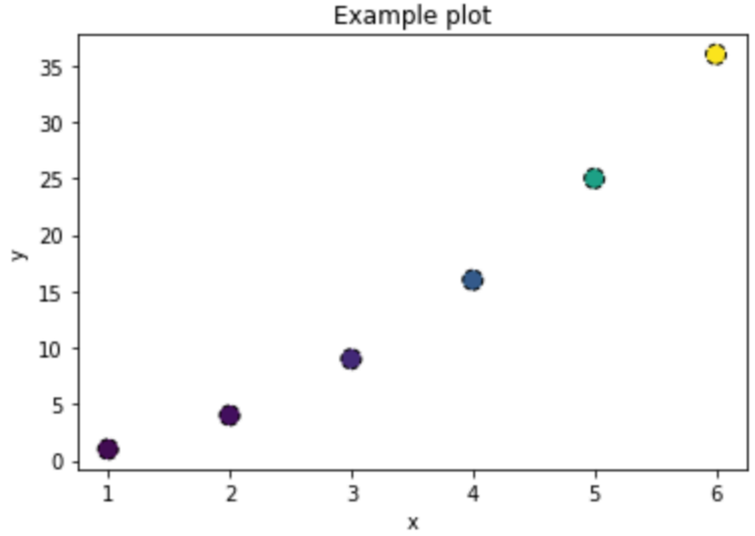
```
1 x = np.array([1,2,3,4,5,6])
2 y = x**2
3 z = x**3
4
5 fig = plt.figure()
6 plt.scatter(x,y, s=40, c='r', marker='o', ls='-', lw=1, edgecolor='k')
7 plt.xlabel('x')
8 plt.ylabel('y')
9 plt.title('Example plot')
```

```
Text(0.5, 1.0, 'Example plot')
```




```
1 x = np.array([1,2,3,4,5,6])
2 y = x**2
3 z = x**3
4
5 fig = plt.figure()
6 plt.scatter(x,y, s=100, c=z, marker='o', ls='--', lw=1, edgecolor='k')
7 plt.xlabel('x')
8 plt.ylabel('y')
9 plt.title('Example plot')
```

```
Text(0.5, 1.0, 'Example plot')
```



Considering color

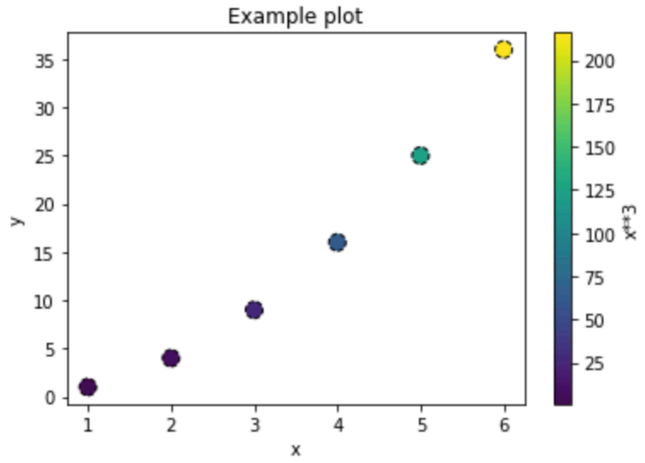
Because our color can change using scatter plot, we have to show what the colors mean using a colorbar.

Notice that I created a variable name (**`ax`**) for my axes object and a variable name (**`scat`**) for my plot.

```
x = np.array([1,2,3,4,5,6])
y = x**2
z = x**3

fig = plt.figure()
ax = plt.gca()
scat = plt.scatter(x,y, s=100, c=z, marker='o', ls='--', lw=1, edgecolor='k')
plt.xlabel('x')
plt.ylabel('y')
plt.title('Example plot')

c = plt.colorbar(scat, ax=ax)
c.set_label('x**3')
```



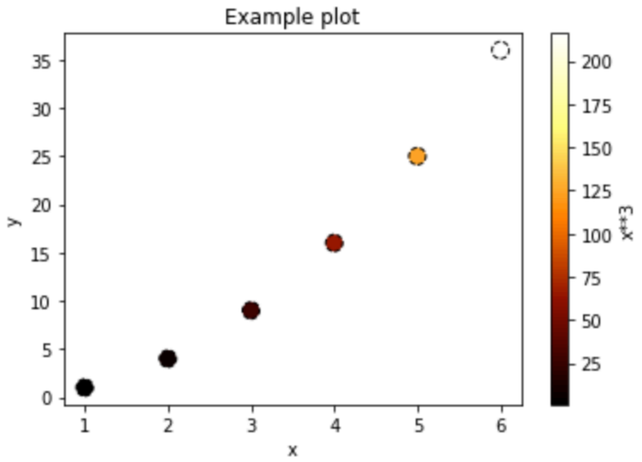
`ax` and **`scat`** are used as argument for my colorbar. This ensures that my colorbar is linked to my plot.

Colormaps

```
x = np.array([1,2,3,4,5,6])
y = x**2
z = x**3

fig = plt.figure()
ax = plt.gca()
scat = plt.scatter(x,y, s=100, c=z, marker='o', ls='--', lw=1, edgecolor='k', cmap='afmhot')
plt.xlabel('x')
plt.ylabel('y')
plt.title('Example plot')

c = plt.colorbar(scat, ax=ax)
c.set_label('x**3')
```

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x = np.array([1,2,3,4,5,6])
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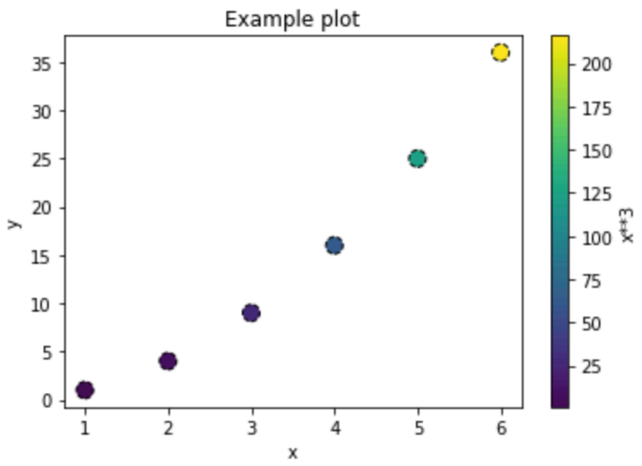
fig = plt.figure()
ax = plt.gca()
scat = plt.scatter(x,y, s=100, c=z, marker='o', ls='--', lw=1, edgecolor='k')
plt.xlabel('x')
plt.ylabel('y')
plt.title('Example plot')

c = plt.colorbar(scat, ax=ax)
c.set_label('x**3')
```

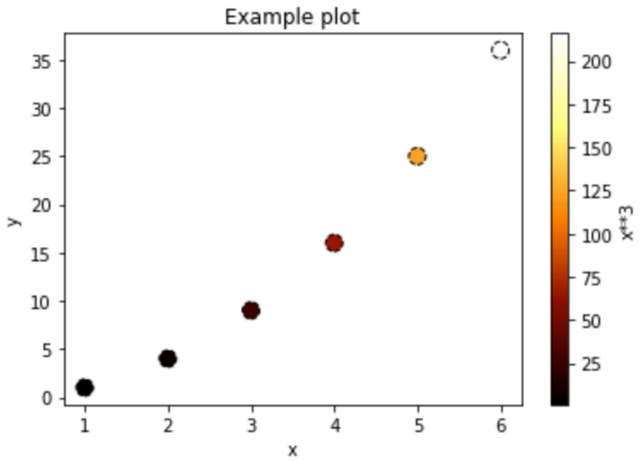


Colormaps

```
x = np.array([1,2,3,4,5,6])
y = x**2
z = x**3

fig = plt.figure()
ax = plt.gca()
scat = plt.scatter(x,y, s=100, c=z, marker='o', ls='--', lw=1, edgecolor='k', cmap='afmhot')
plt.xlabel('x')
plt.ylabel('y')
plt.title('Example plot')

c = plt.colorbar(scat, ax=ax)
c.set_label('x**3')
```



matplotlib
Version 3.3.2

https://matplotlib.org/3.1.0/tutorials/colors/colormaps.html

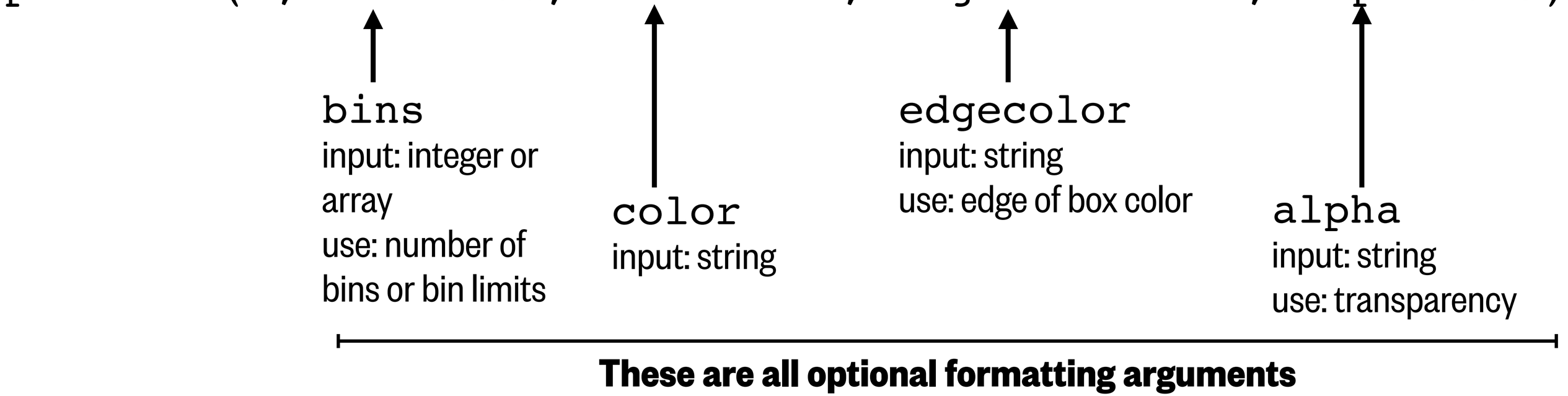
Histograms

```
plt.hist(x, bins=100, color='b', edgecolor='k', alpha=0.5)
```

These are all optional formatting arguments

Histograms

```
plt.hist(x, bins=100, color='b', edgecolor='k', alpha=0.5)
```



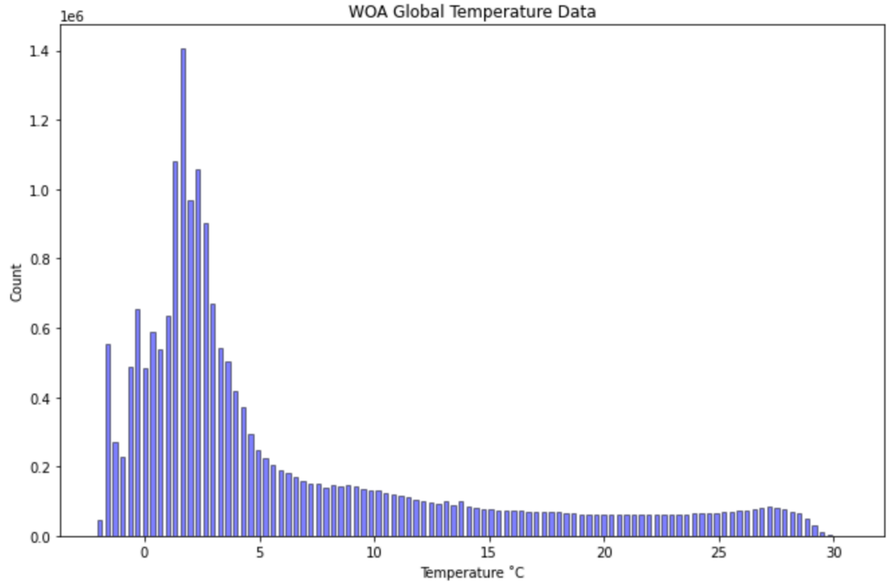
Histograms - example

From class #11 activity: WOA temperature dataset

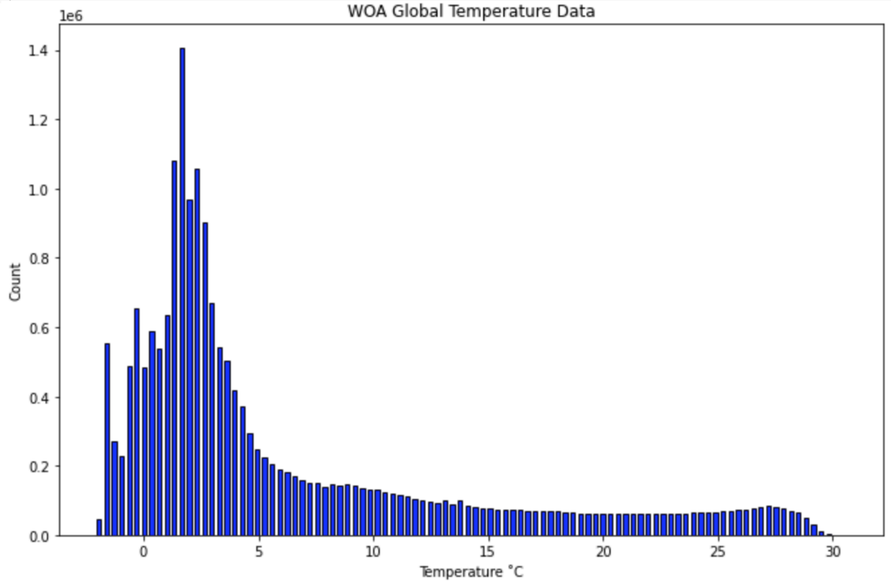
```
filepath = '/content/drive/My Drive/Data_folder/woa18_temp.nc'
temp = xr.open_dataset(filepath)
t_data = temp['t_an'].values.flatten()

```

```
fig = plt.figure(figsize=(11,7))
h = plt.hist(t_data, bins=100, rwidth=0.6, color='b',edgecolor='k', alpha=0.5)
plt.xlabel('Temperature °C')
plt.ylabel('Count')
plt.title('WOA Global Temperature Data')
```




```
fig = plt.figure(figsize=(11,7))
h = plt.hist(t_data, bins=100, rwidth=0.6, color='b',edgecolor='k', alpha=0.9)
plt.xlabel('Temperature °C')
plt.ylabel('Count')
plt.title('WOA Global Temperature Data')
```



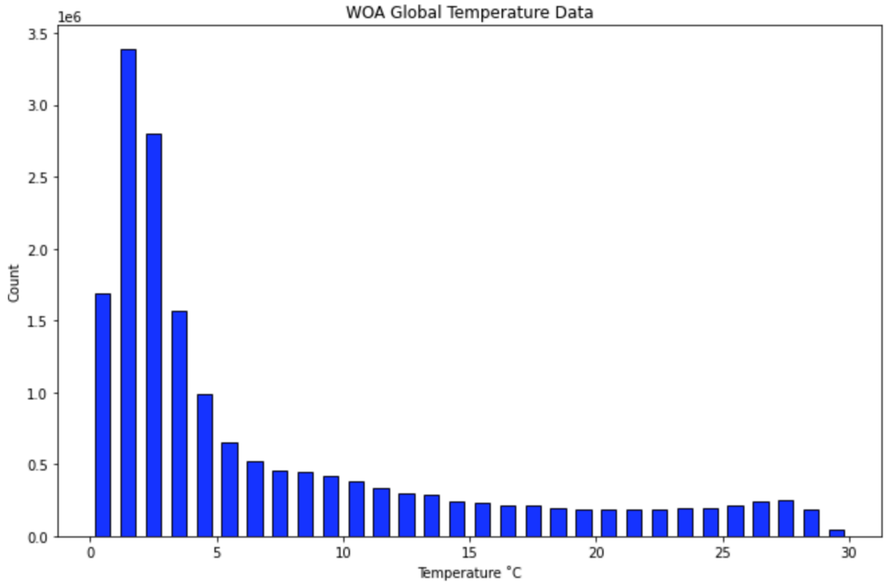
Histograms - example

From class #11 activity: WOA dataset

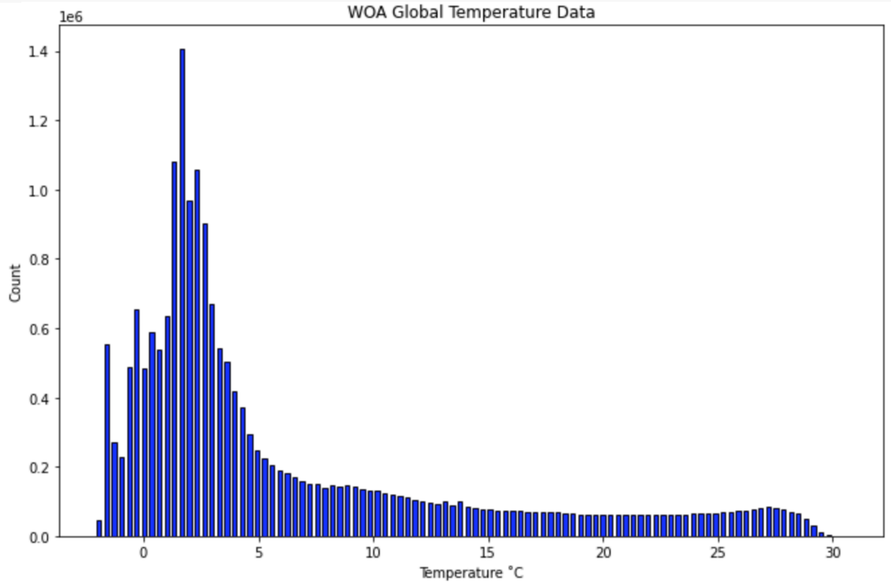
```
filepath = '/content/drive/My Drive/Data_folder/woa18_temp.nc'
temp = xr.open_dataset(filepath)
t_data = temp['t_an'].values.flatten()

```

```
fig = plt.figure(figsize=(11,7))
h = plt.hist(t_data, bins=range(0,31), rwidth=0.6, color='b',edgecolor='k', alpha=0.9)
plt.xlabel('Temperature ˚C')
plt.ylabel('Count')
plt.title('WOA Global Temperature Data')
```




```
fig = plt.figure(figsize=(11,7))
h = plt.hist(t_data, bins=100, rwidth=0.6, color='b',edgecolor='k', alpha=0.9)
plt.xlabel('Temperature ˚C')
plt.ylabel('Count')
plt.title('WOA Global Temperature Data')
```



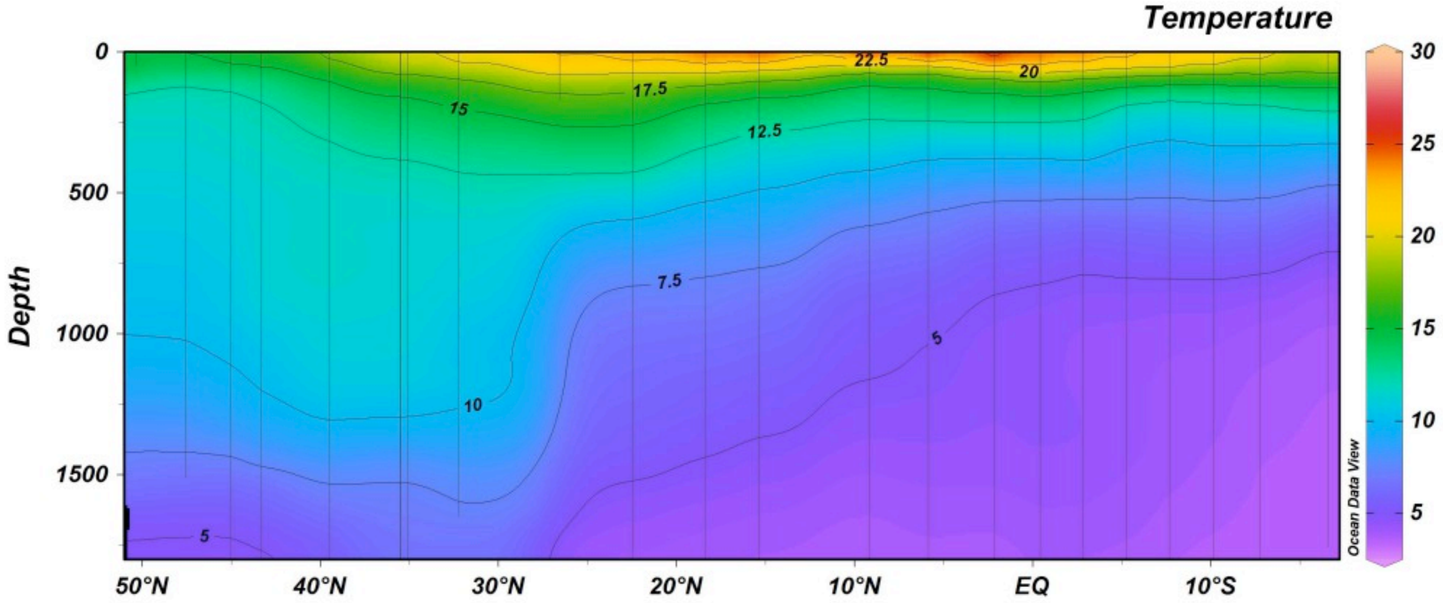
What we'll cover in this lesson

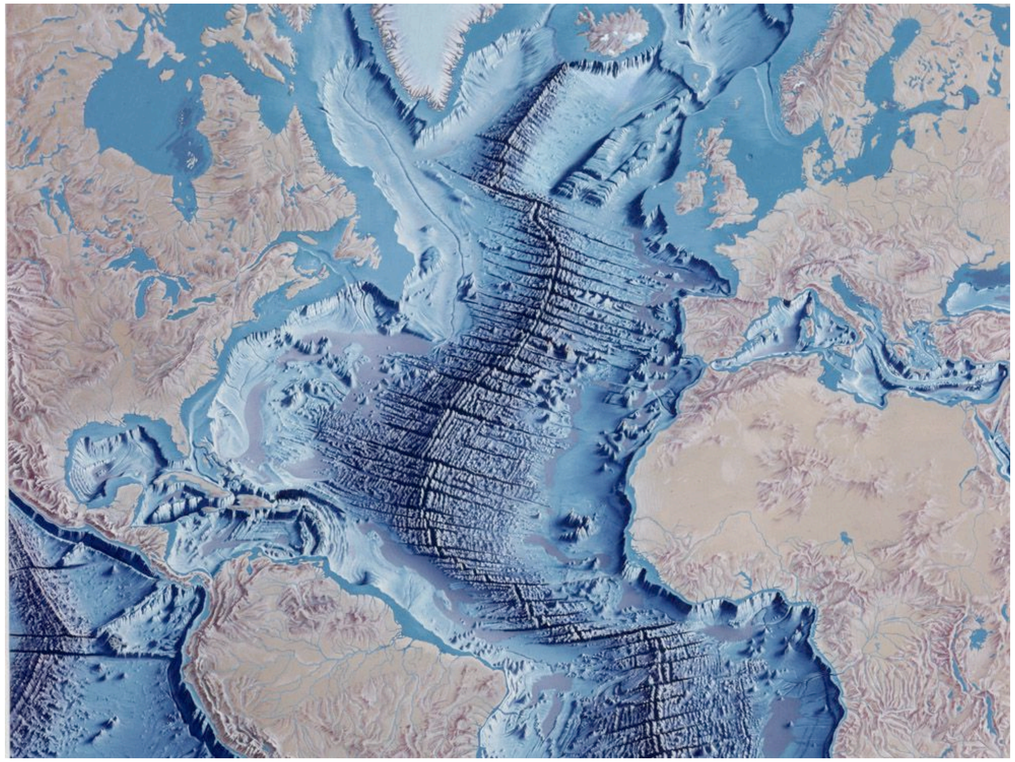
1. Review of plotting concepts

2. **2-D plotting**

3. Mapping with Cartopy

What are 2-dimensional plots?





2-dimensional plots show data in an x-y space

- Maps
- Transects
- Time vs distance evolution (Hoffmuller)

Contour plots

```
plt.contour(x, y, z, levels= , colors= , linewidths= , linestyles= )
```

input: integer or array

or

`cmap=`

These are all optional formatting arguments

Notice that colors, linewidths, and linestyles are plural! (not like with line/scatter plots)

Contour plots are used for showing data (z) on a 2-dimensional plot with corresponding x and y axes.
The length of x corresponds to the number of columns in z
The length of y corresponds to the number of rows in z

Contour plots - example

WOA oxygen dataset

```
1
2 filepath = '/content/drive/My Drive/Data_folder/woa18_oxy.nc'
3 oxy = xr.open_dataset(filepath,decode_times=False)
4
5 display(oxy)
6
7 o_data = oxy['o_an'].mean(dim='lon').isel(time=0).values
8 lat = oxy['lat'].values
9 depth = oxy['depth'].values
10
```

xarray.Dataset

▶ Dimensions: (**depth**: 102, **lat**: 180, **lon**: 360, **time**: 1)

▼ Coordinates:

time	(time)	float32	8214.0
depth	(depth)	float32	0.0 5.0 10.0 ... 5400.0 5500.0
lat	(lat)	float32	-89.5 -88.5 -87.5 ... 88.5 89.5
lon	(lon)	float32	-179.5 -178.5 ... 178.5 179.5

▼ Data variables:

o_an	(time, depth, lat, lon)	float32	...

▶ Attributes: (50)

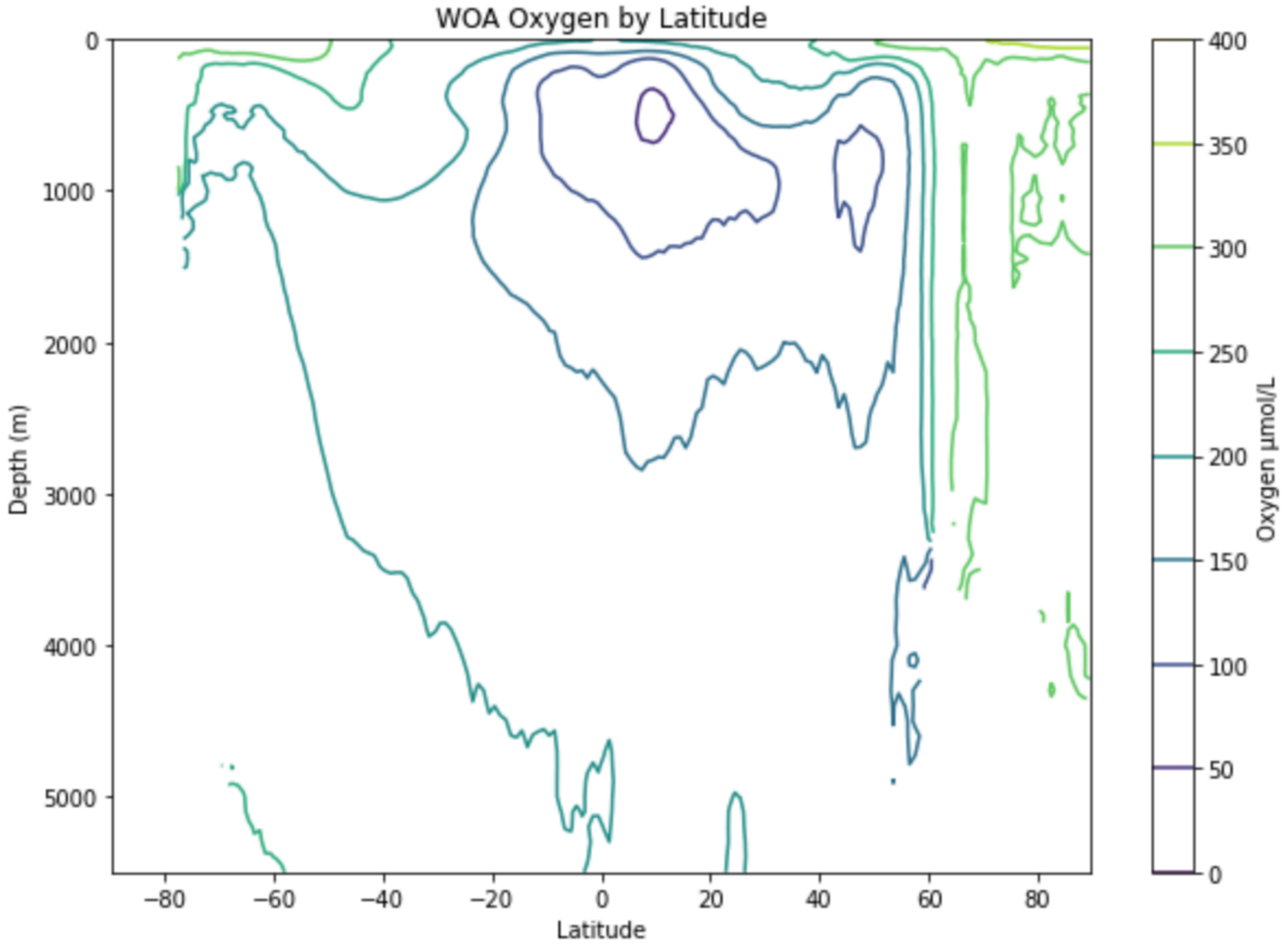
Contour plots - example

WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contour(lat, depth, o_data)
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```



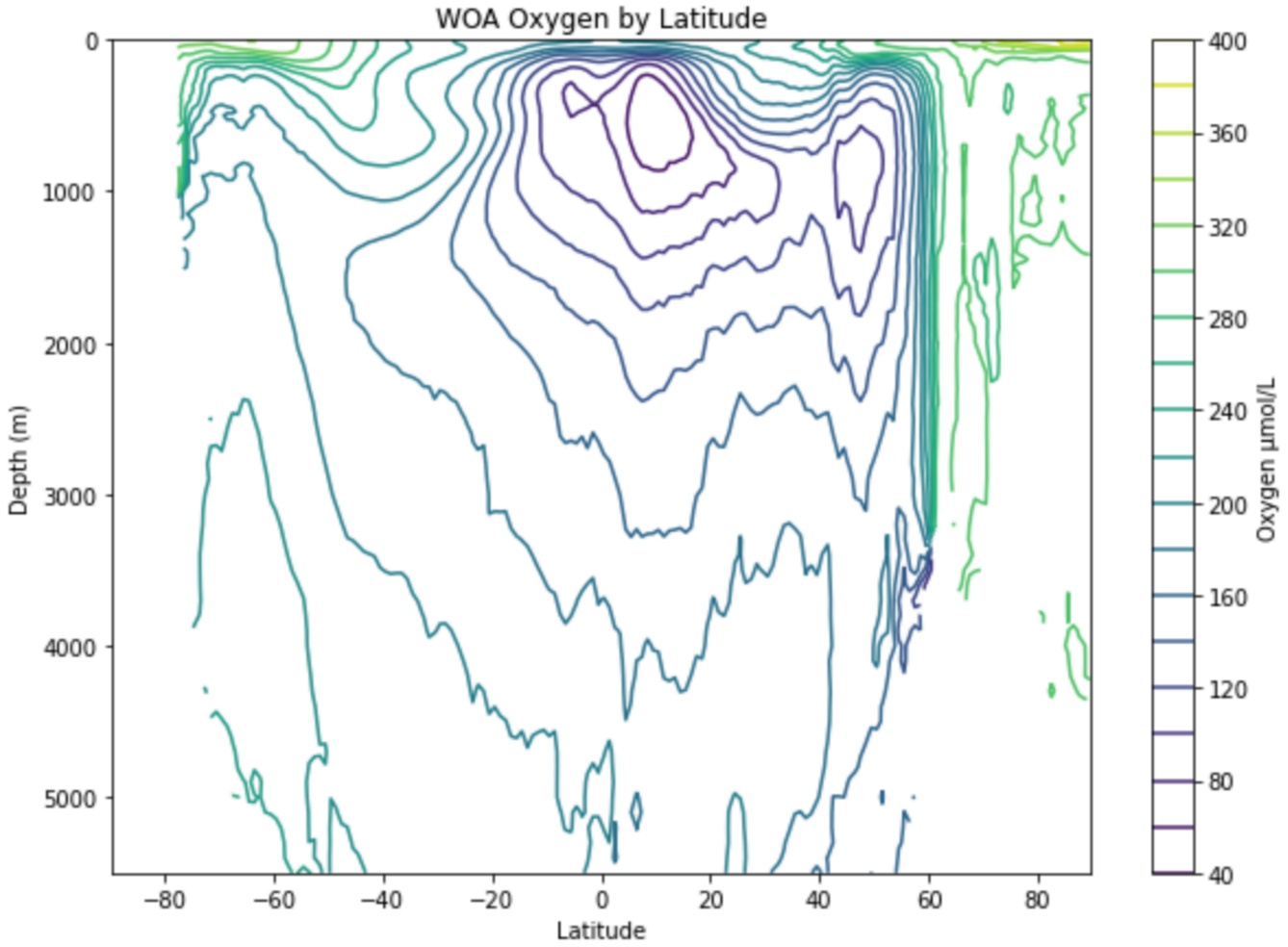
Contour plots - example

WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contour(lat, depth, o_data, levels=20)
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```



Contour plots - example

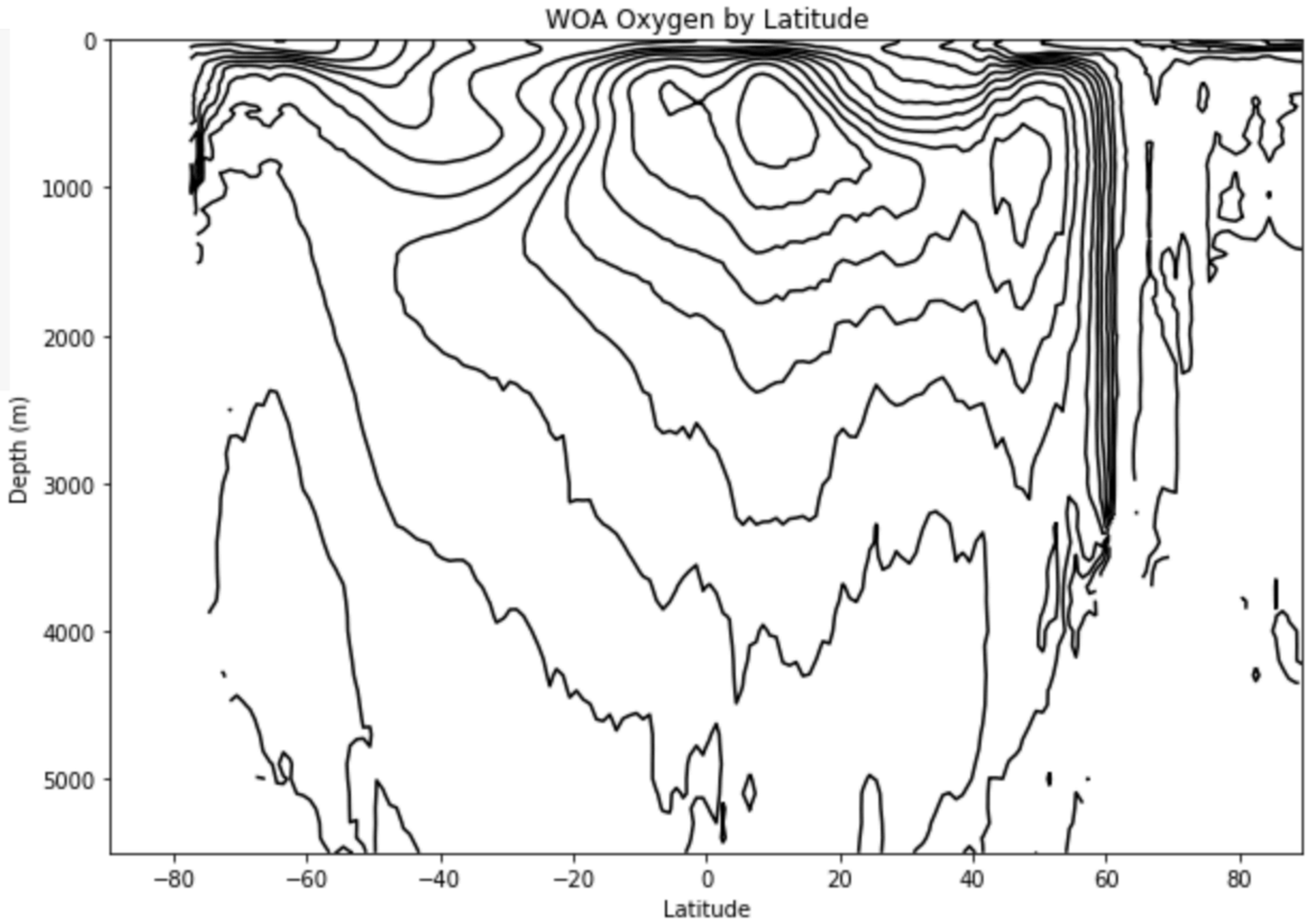
WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contour(lat, depth, o_data, levels=20, colors='k')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```

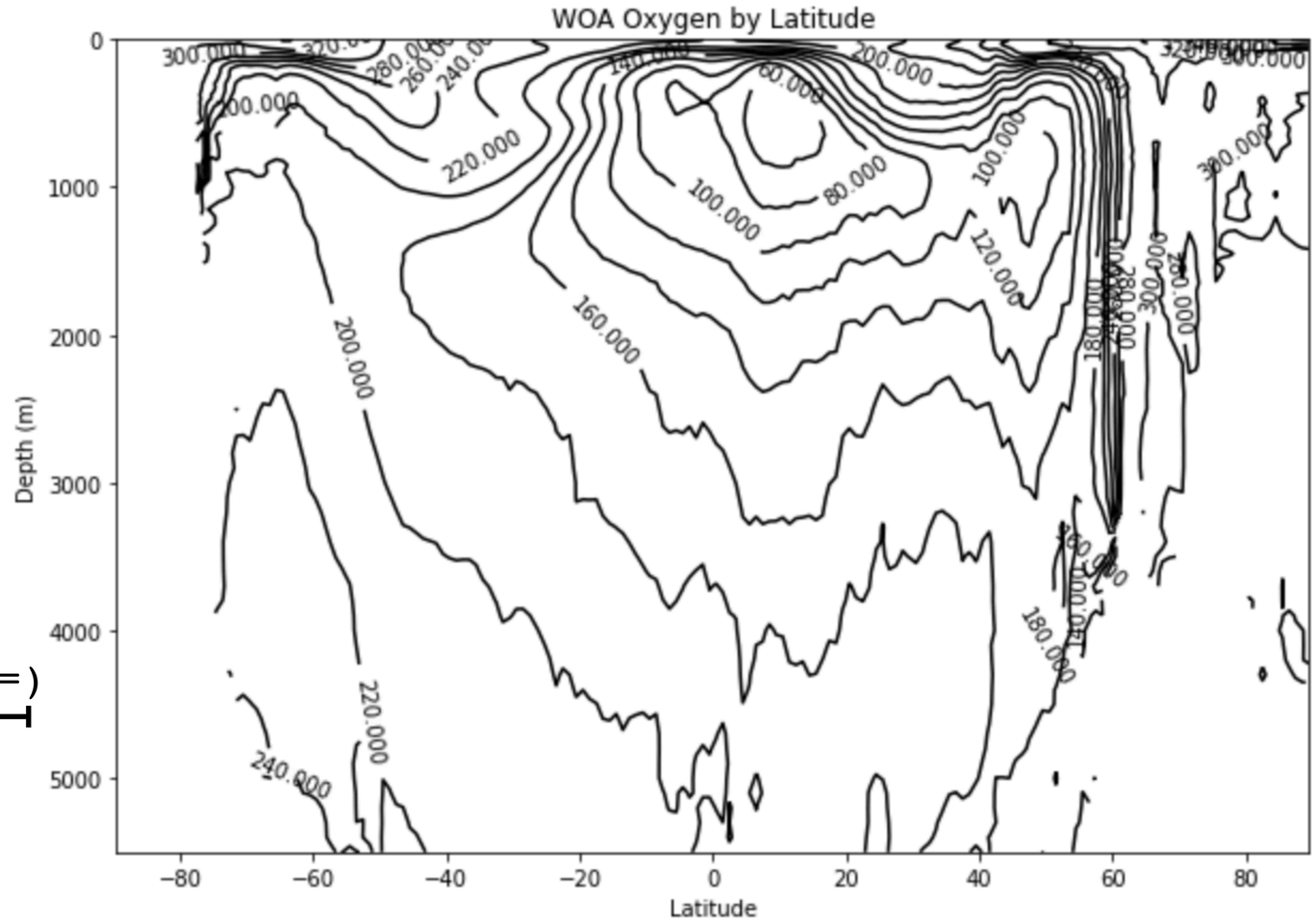
Now we don't know what the contours mean!



Contour plots - example

WOA oxygen dataset

```
2 fig = plt.figure(figsize=(10,7))
3 ax = plt.gca()
4
5 cntr = plt.contour(lat, depth, o_data, levels=20, colors='k')
6
7 ax.invert_yaxis()
8 plt.xlabel('Latitude')
9 plt.ylabel('Depth (m)')
10 plt.title('WOA Oxygen by Latitude')
11
12 plt.clabel(cntr)
```



`plt.clabel(`plot variable`, levels=, fontsize=, colors=)`

Optional

Contour plots - example

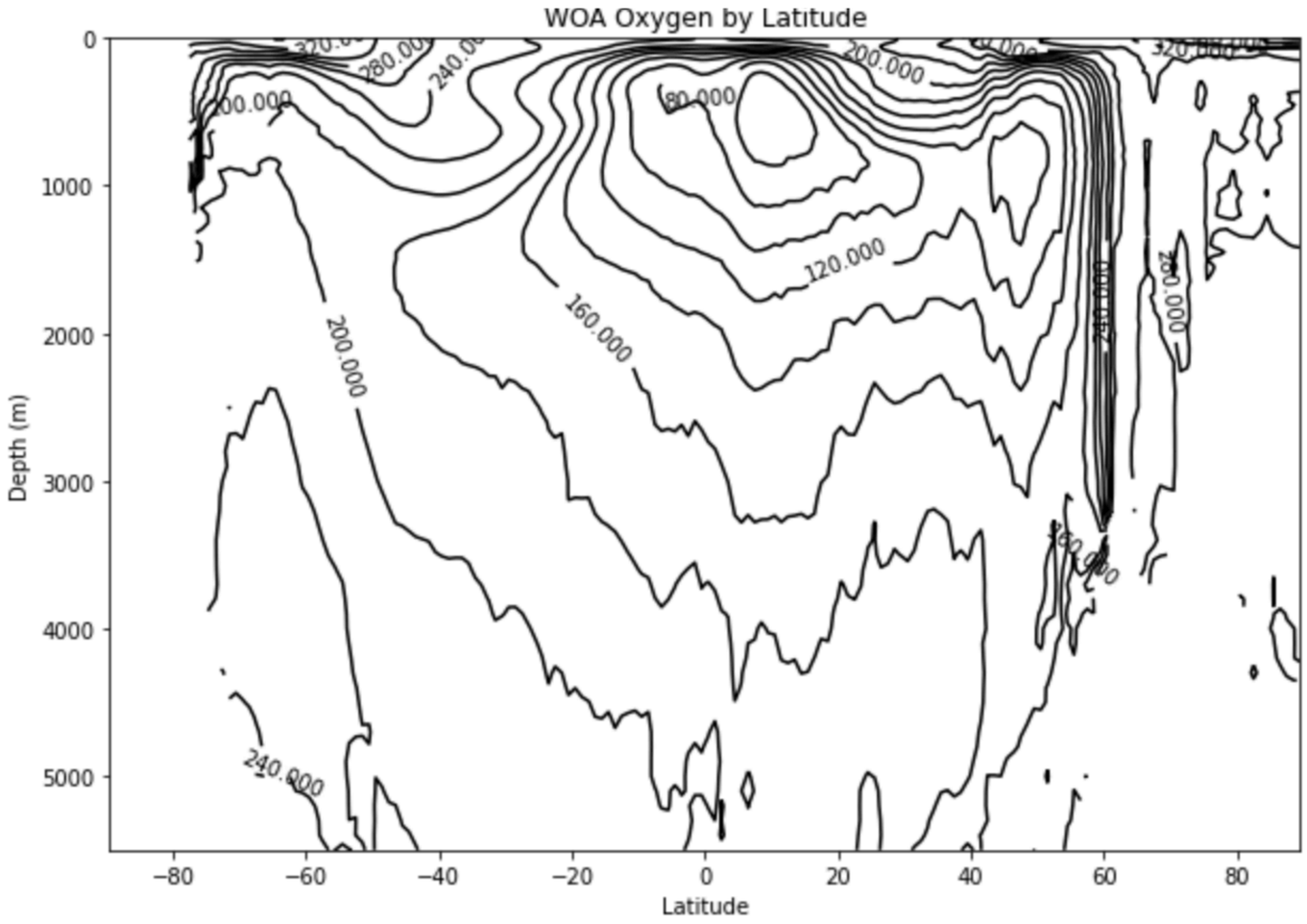
WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contour(lat, depth, o_data, levels=20, colors='k')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')

plt.clabel(cntr, levels=cntr.levels[::2])
```



Contourf plots

```
plt.contour(x, y, z, levels= , colors= , linewidths= , linestyles= )
```

```
plt.contourf(x, y, z, levels= , cmap= )
```

Contourf plots fill the spaces between the contour lines using the colormap.

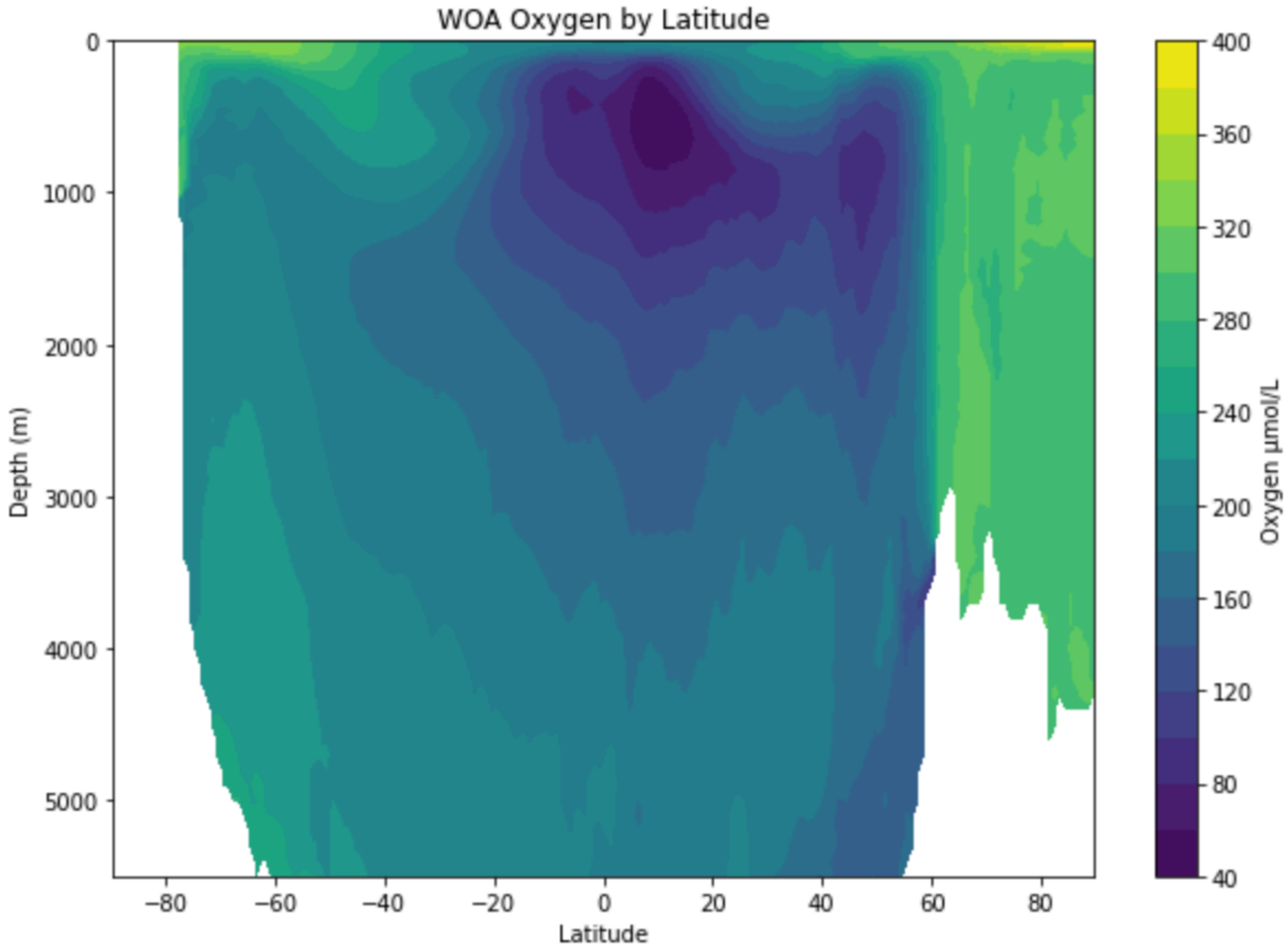
Contour plots - example

WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contourf(lat, depth, o_data, levels=20)
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```



Now we need our colorbar back!

Contour plots - example

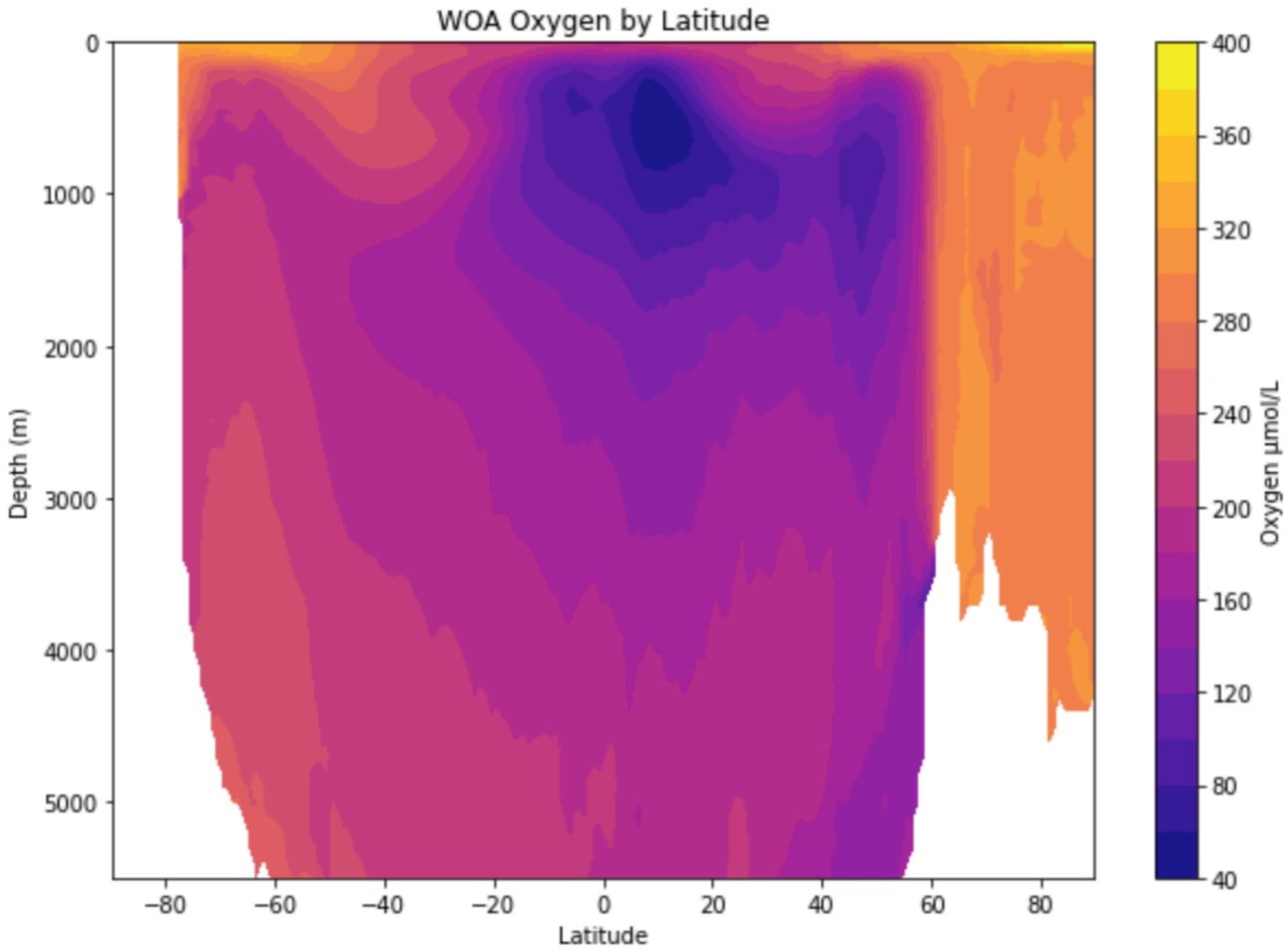
WOA oxygen dataset

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contourf(lat, depth, o_data, levels=20,cmap='plasma')
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```

Change the color using the cmap argument



Contour plots - example

WOA oxygen dataset

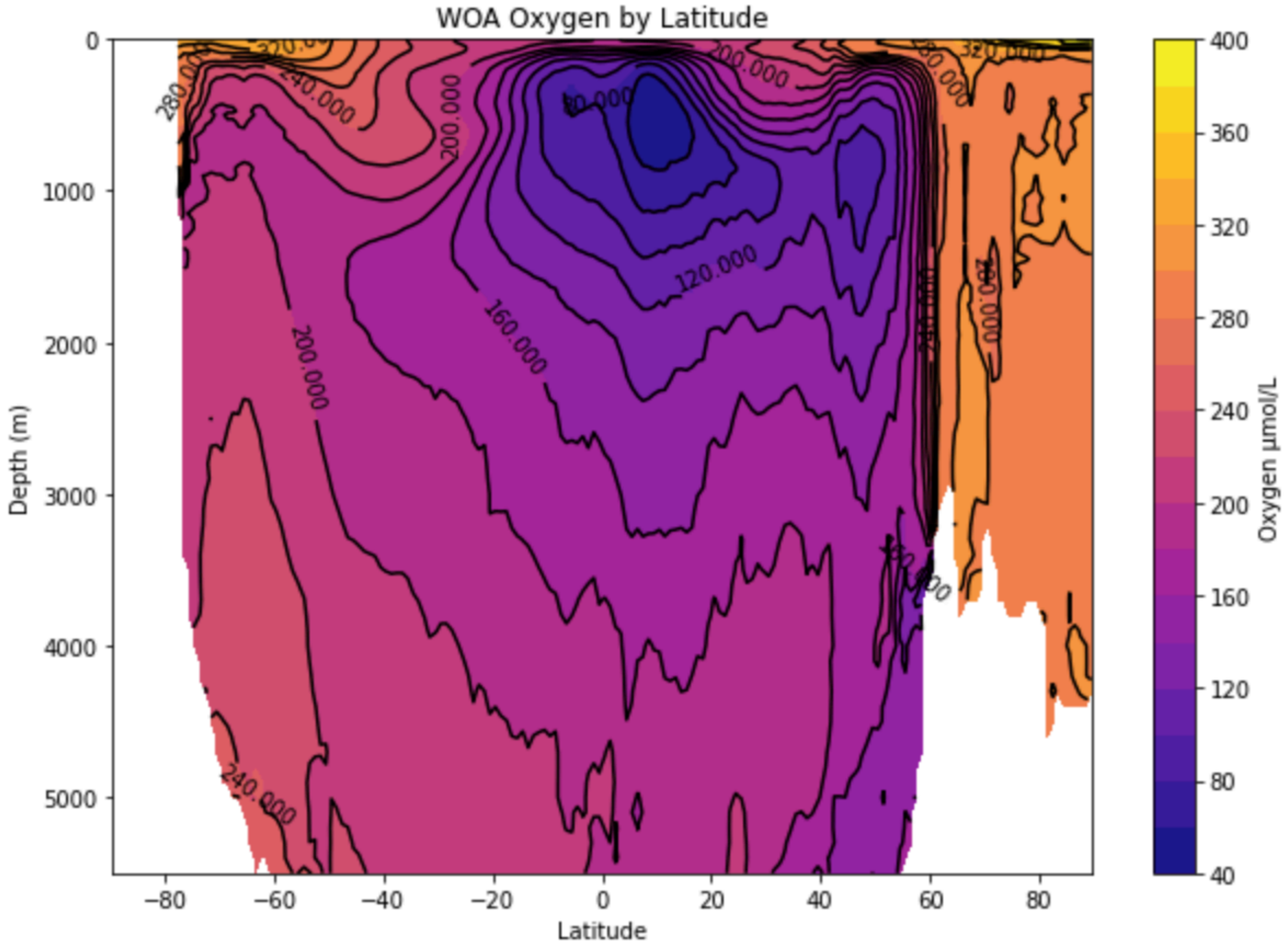
```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

cntr = plt.contourf(lat, depth, o_data, levels=20,cmap='plasma')
cntr_lines = plt.contour(lat, depth, o_data, levels=20,colors='k')
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')

plt.clabel(cntr_lines, levels=cntr.levels[::2])
```

Put labels on the filled plot by plotting another contour on top and using clabel



Pseudo-color plots

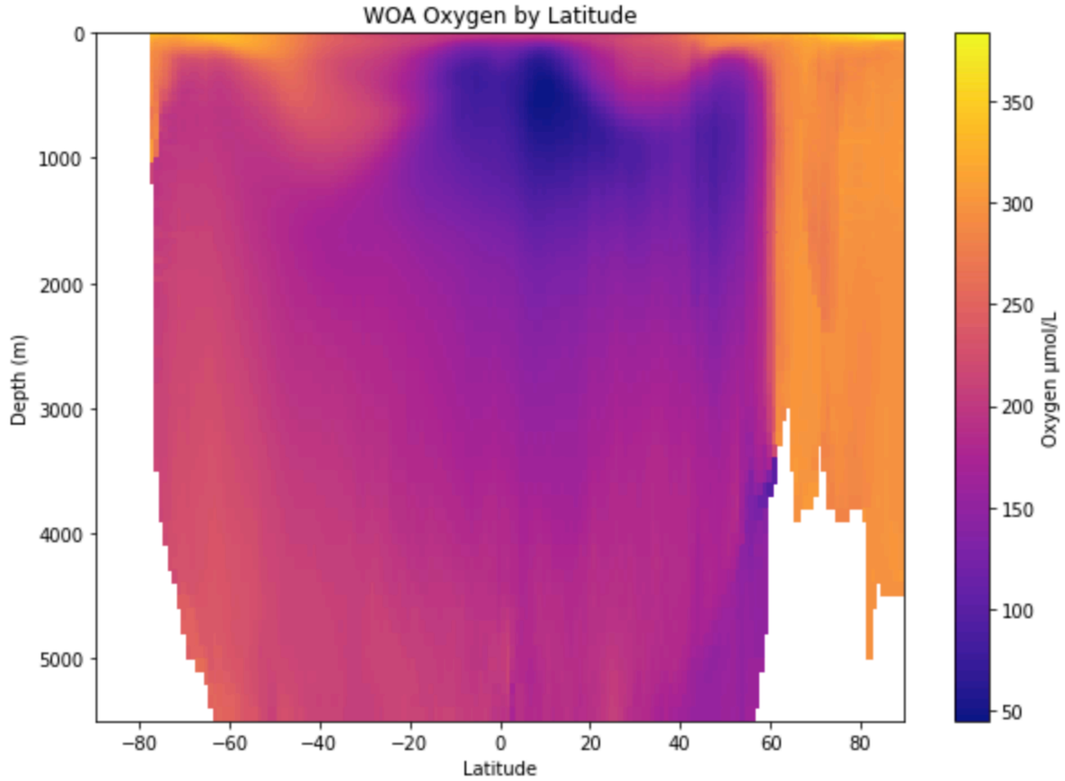
```
plt.pcolormesh(x, y, z, cmap= , linewidths= , edgecolor= )
```

These are all optional formatting arguments

```
fig = plt.figure(figsize=(10,7))
ax = plt.gca()

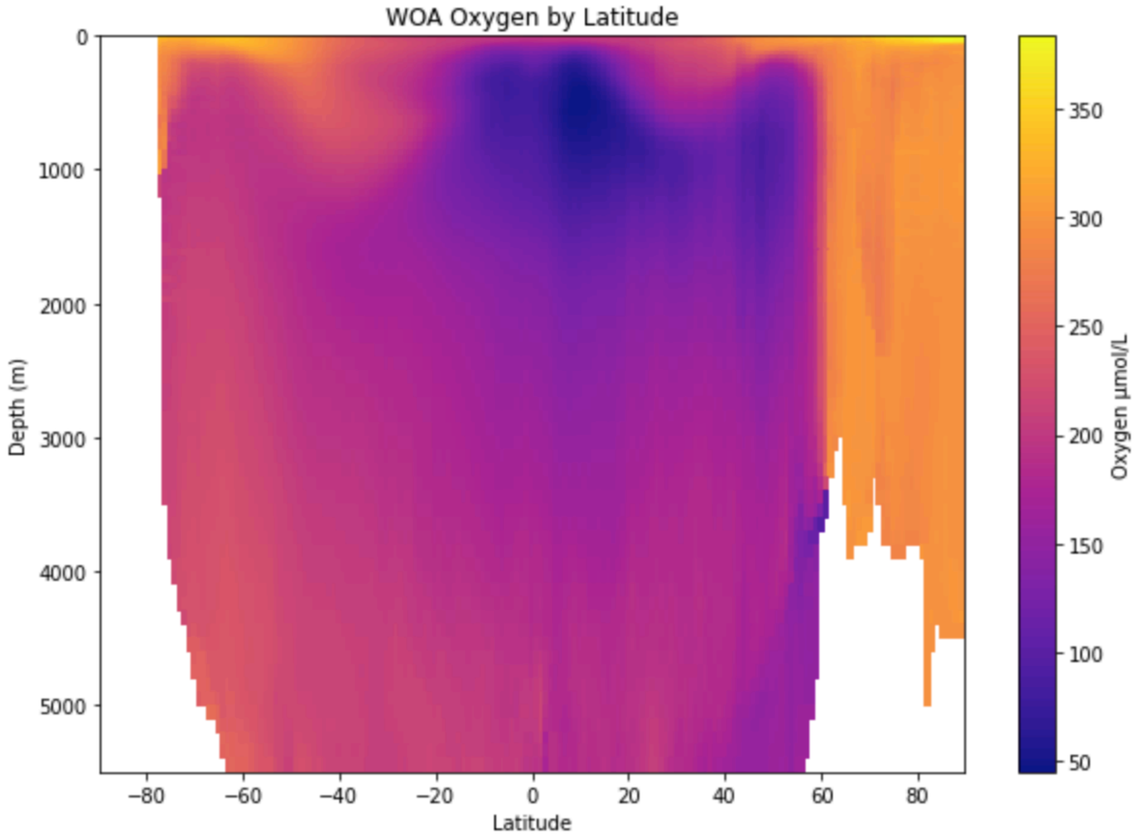
cntr = plt.pcolormesh(lat, depth, o_data, cmap='plasma')
c = plt.colorbar(cntr, ax=ax)
c.set_label('Oxygen µmol/L')

ax.invert_yaxis()
plt.xlabel('Latitude')
plt.ylabel('Depth (m)')
plt.title('WOA Oxygen by Latitude')
```



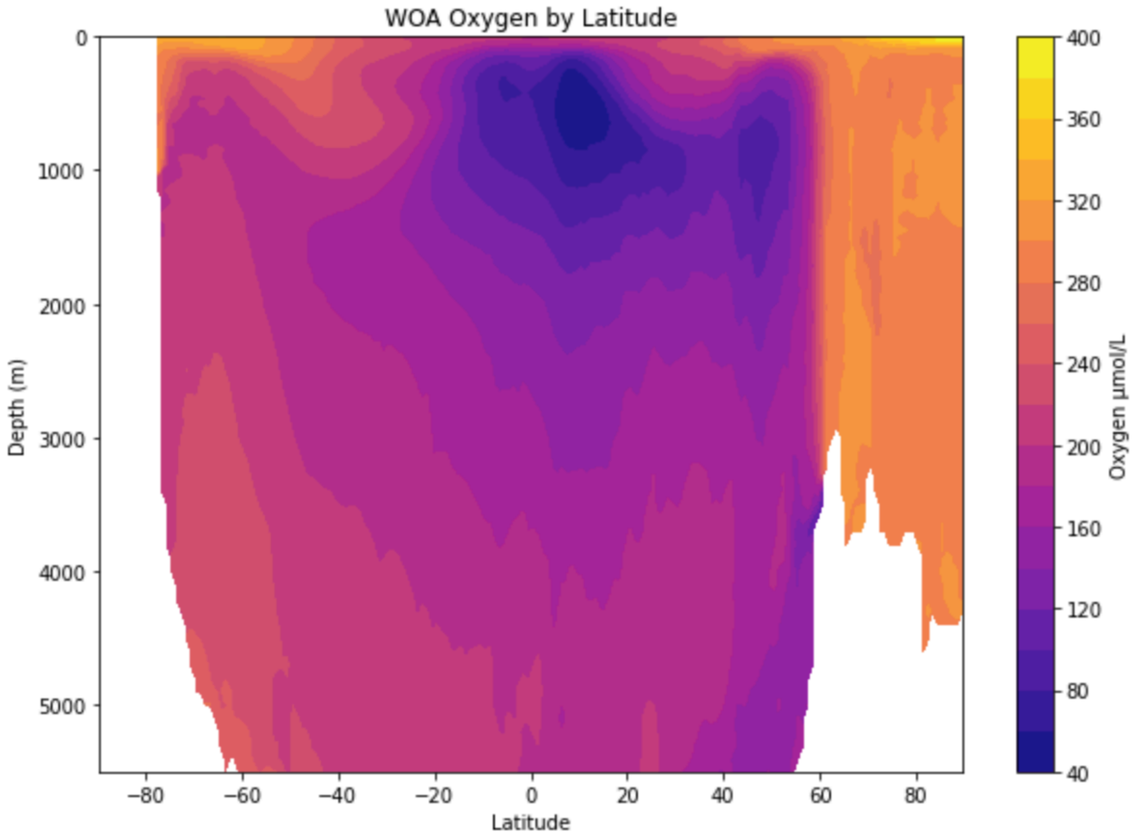
Difference between `contourf` and `pcolormesh`

`pcolormesh()`



Grid point estimates
Better for noisy data

`contourf()`



Interpolate between isolines
Better for large scale patterns

What we'll cover in this lesson

1. Review of plotting concepts

2. 2-D plotting

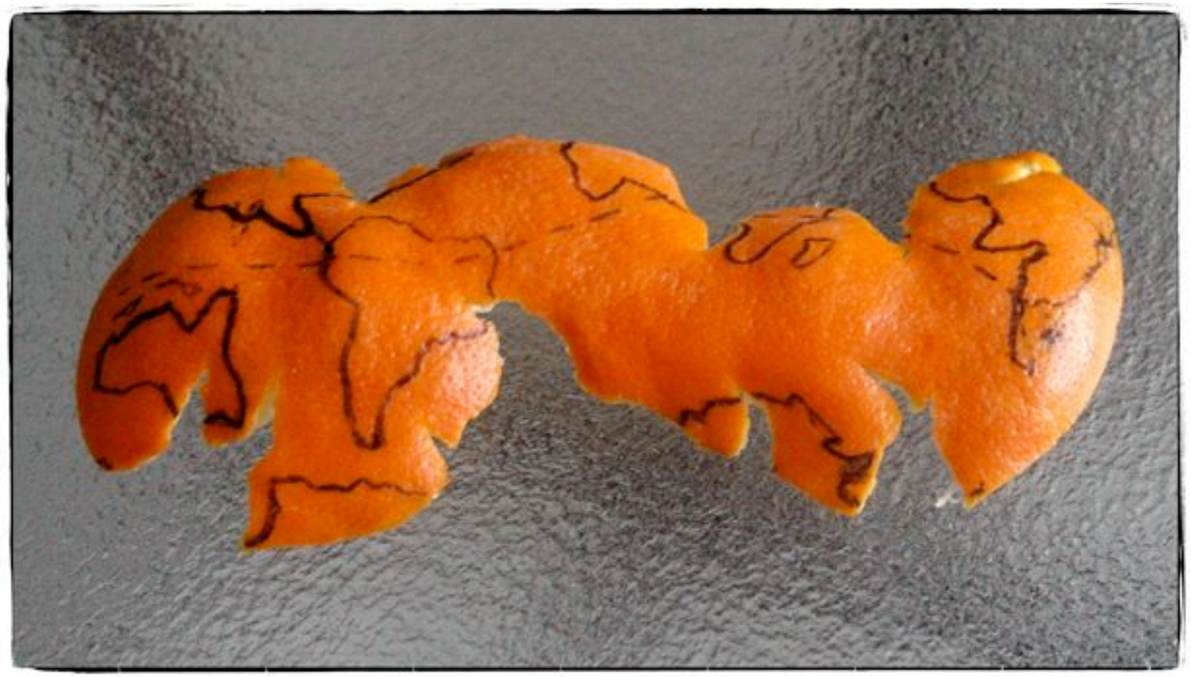
3. **Mapping with Cartopy**

Every map is wrong in some way...

https://www.scienceabc.com/social-science/what-is-wrong-with-all-our-maps-mercator-maps.html

Every map is wrong in some way...

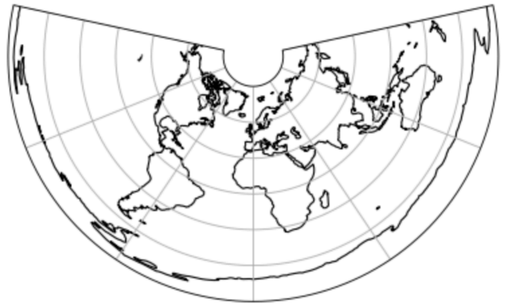
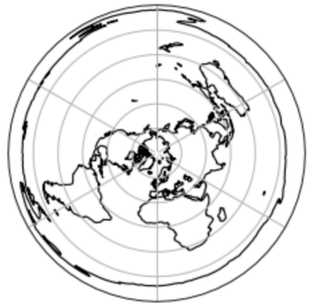
The surface of a sphere is different to a 2D surface, so we have to cut the sphere somewhere.

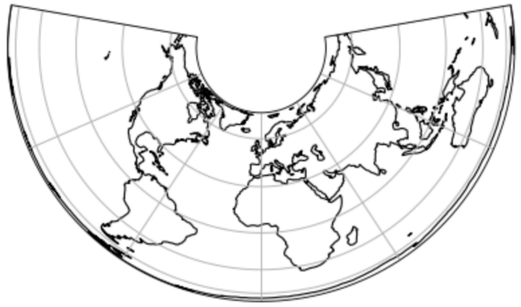


The surface cannot be represented on a plane without distortion.

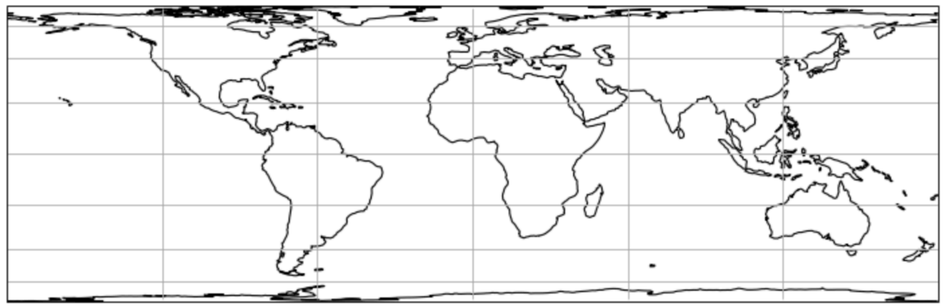
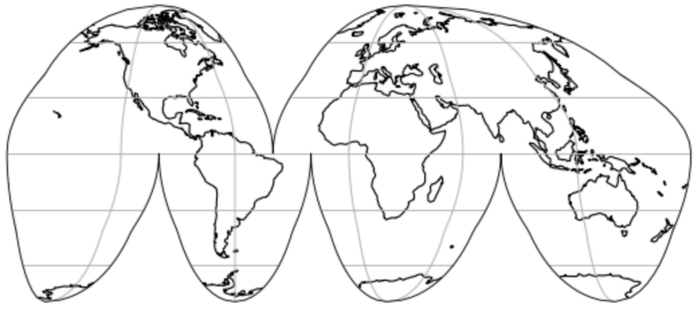
https://rabernat.github.io/research_computing_2018/maps-with-cartopy.html

Using projections to visualize geographic data

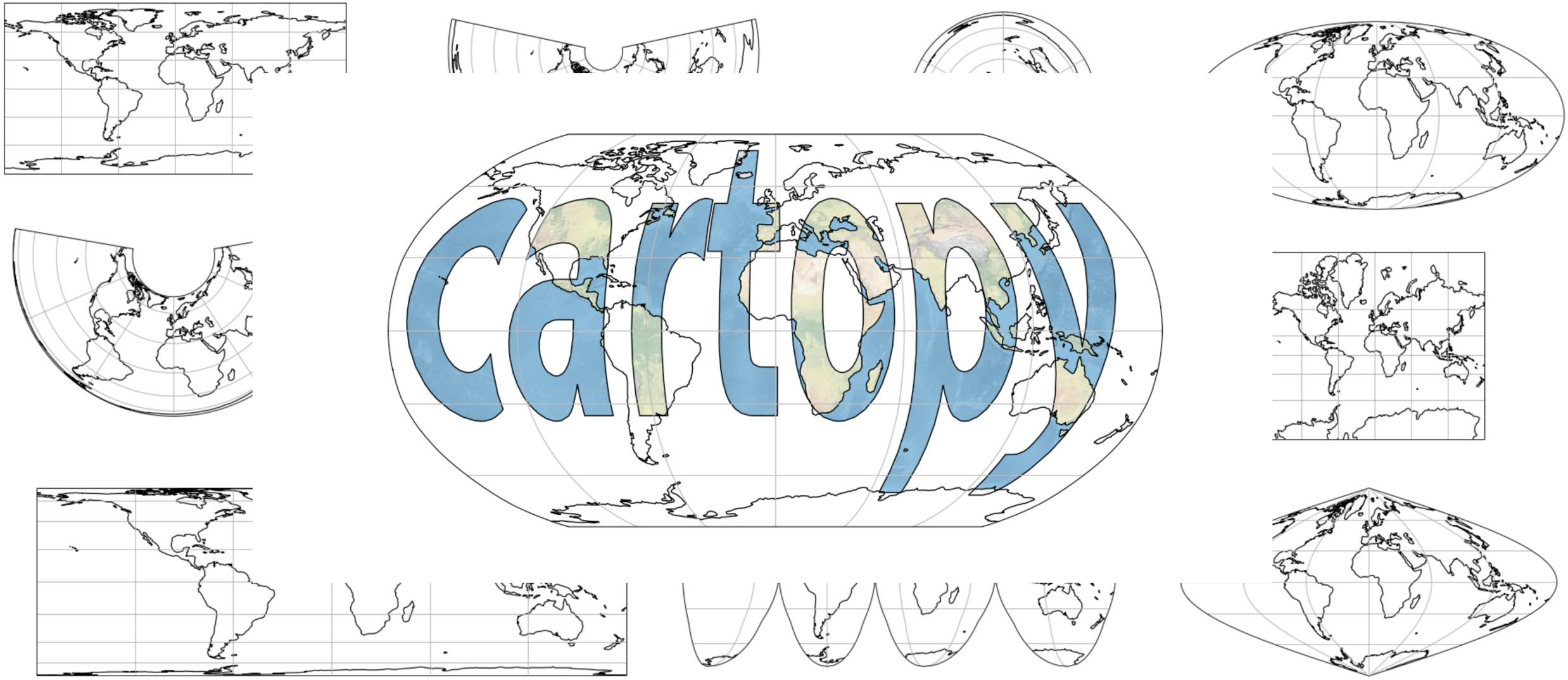









Using projections to visualize geographic data



Using projections to visualize geographic data

<class 'cartopy.crs.PlateCarree'>

<class 'cartopy.crs.Mercator'>

<class 'cartopy.crs.InterruptedGoodeHomolosine'>

<class 'cartopy.crs.Robinson'>

<class 'cartopy.crs.Orthographic'>

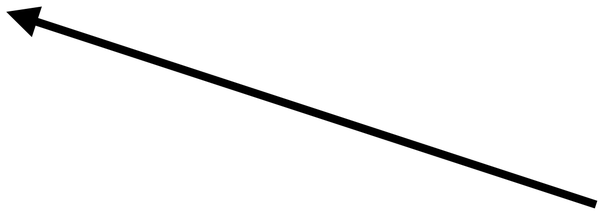
Full list of projections available:

https://scitools.org.uk/cartopy/docs/latest/crs/projections.html

Loading `cartopy`

Cartopy is not readily available in the Google Colab environment, so we need to load it into our notebook before importing.

```
!apt-get -qq install python-cartopy python3-cartopy
!pip uninstall -y shapely
!pip install shapely --no-binary shapely
```



You should only have to run
these lines once per Colab notebook.

Loading `cartopy`

Instead of importing all of Cartopy, we will only be importing select parts

```
import cartopy.crs as ccrs
import cartopy.feature as cfeature
from cartopy.mpl.gridliner import LONGITUDE_FORMATTER, LATITUDE_FORMATTER
```

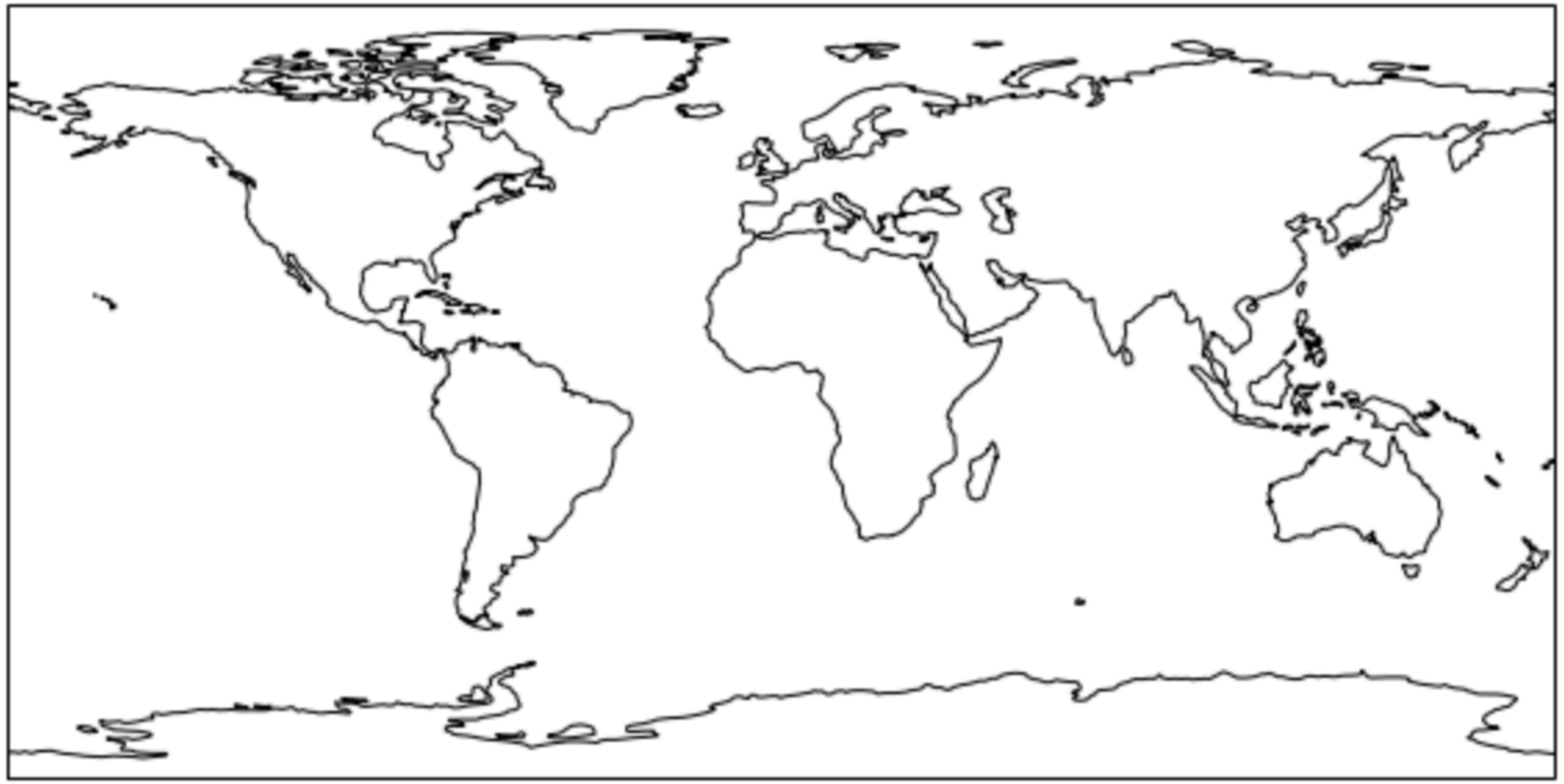
crs - helps with projections
feature - creates map features (e.g. land, rivers, borders)
gridliner - formats our axis and tick labels

Let's start with a coast

```
1     fig = plt.figure(figsize=(10,10))
2     ax = plt.axes(projection=ccrs.PlateCarree())
3     ax.coastlines(resolution='110m',color='k')
```

Optional arguments

```
<cartopy.mpl.feature_artist.FeatureArtist at 0x7f043ec2c780>
```

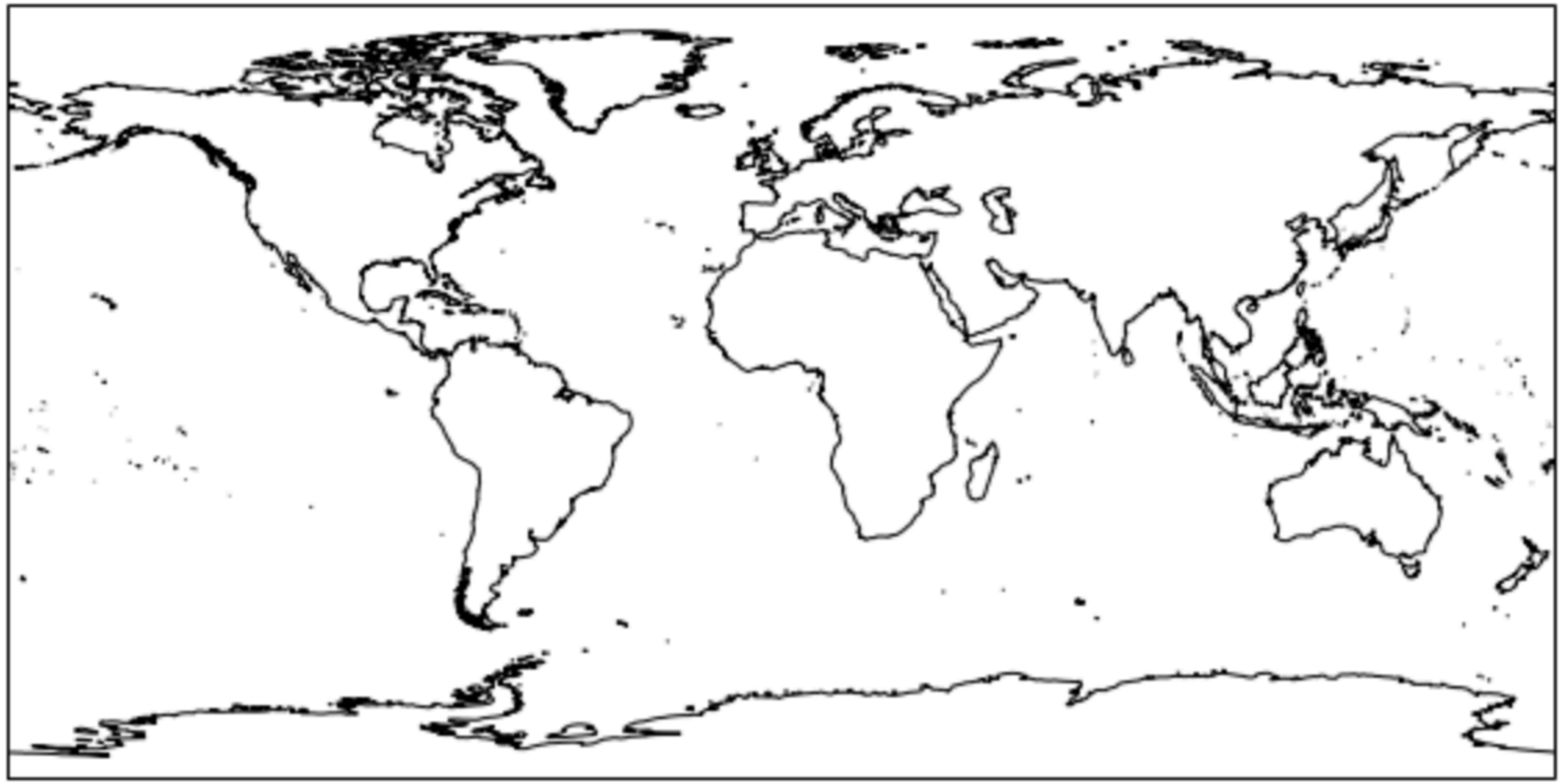


Low resolution: 110m

Let's start with a coast

```
1     fig = plt.figure(figsize=(10,10))
2     ax = plt.axes(projection=ccrs.PlateCarree())
3     ax.coastlines(resolution='50m',color='k')
```

```
<cartopy.mpl.feature_artist.FeatureArtist at 0x7f043d9a77b8>
```

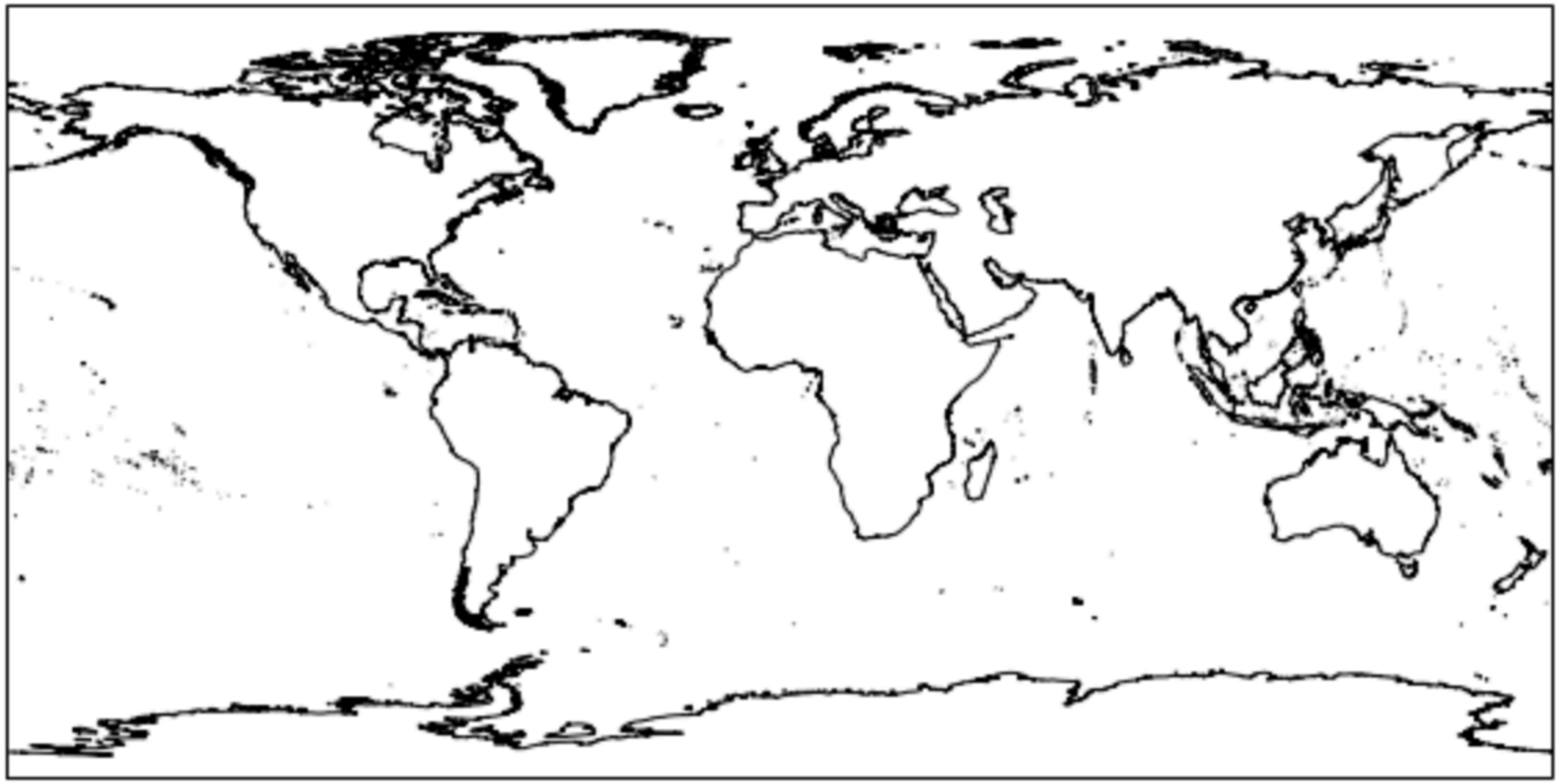


Med resolution: 50m

Let's start with a coast

```
1     fig = plt.figure(figsize=(10,10))
2     ax = plt.axes(projection=ccrs.PlateCarree())
3     ax.coastlines(resolution='10m',color='k')
```

```
<cartopy.mpl.feature_artist.FeatureArtist at 0x7f043d5c1400>
```



High resolution: 10m

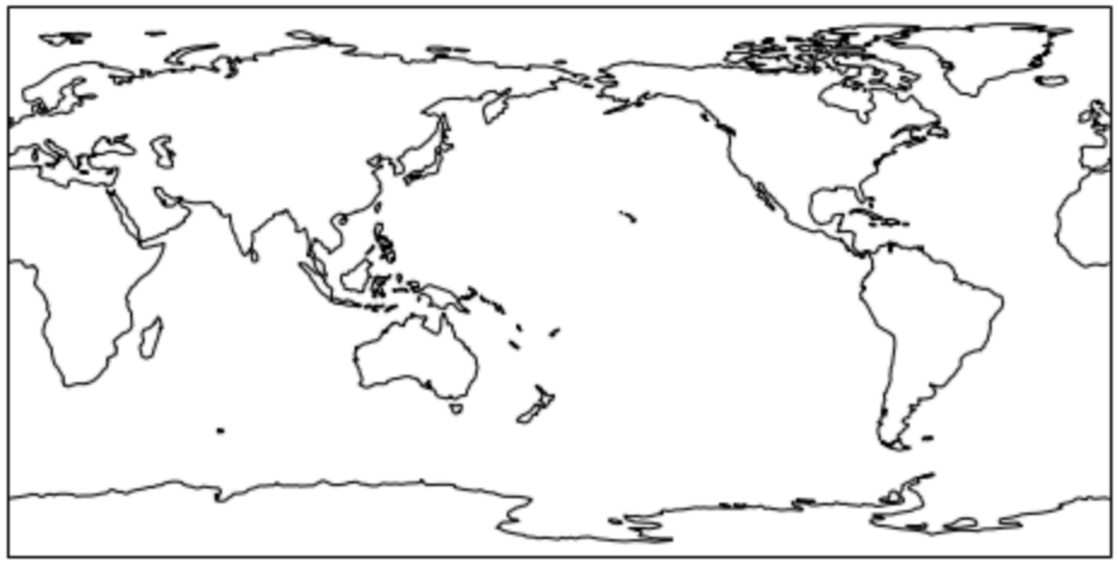
Let's start with a coast

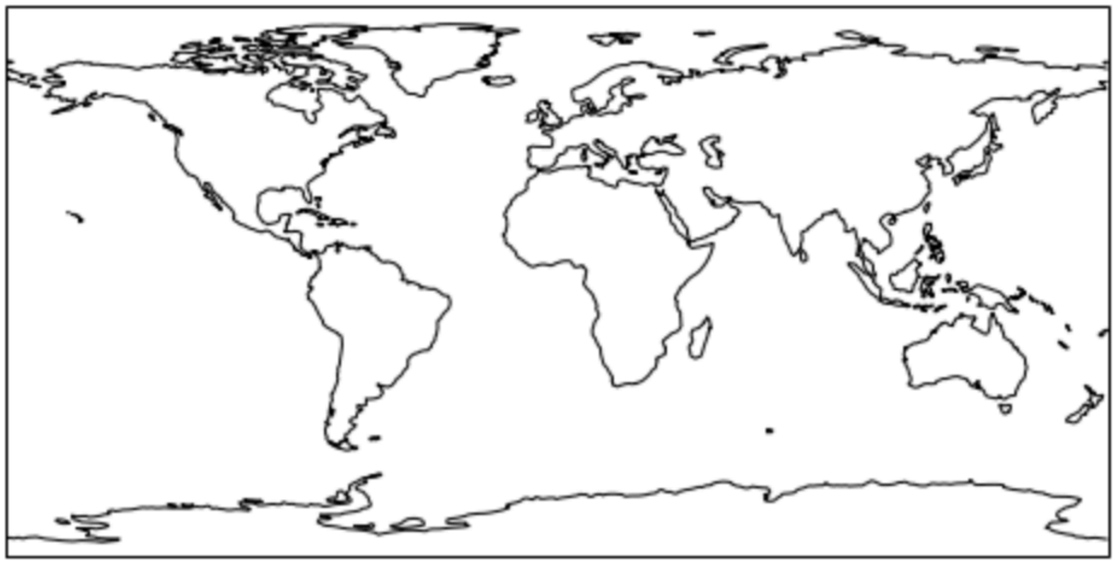
```
1 fig= plt.figure(figsize=(18,12))
2
3 ax1 = fig.add_subplot(1,2,1,projection=ccrs.PlateCarree(central_longitude=180))
4 ax1.coastlines()
5
6 ax2 = fig.add_subplot(1,2,2,projection=ccrs.PlateCarree())
7 ax2.coastlines()
```

changes map center

fig.add_subplot allows you to add more axes on a figure after it's already created

```
<cartopy.mpl.feature_artist.FeatureArtist at 0x7f0430f6c208>
```





Let's add a grid

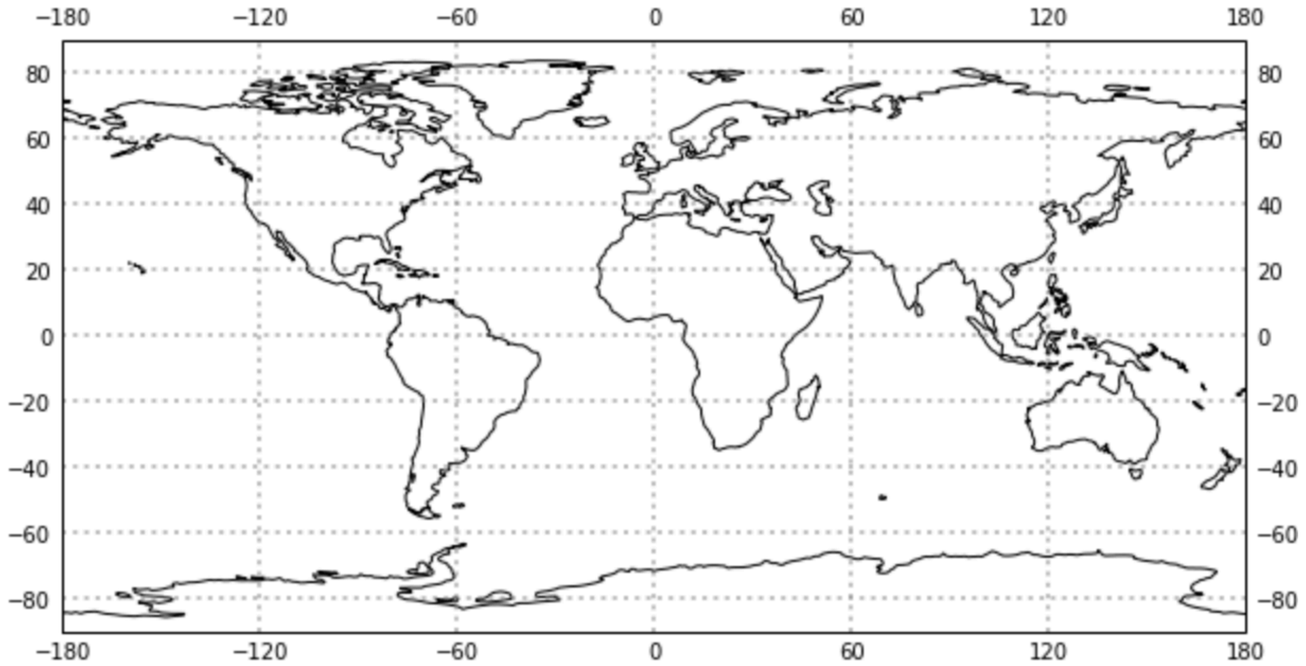
```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

```

Gridlines arguments

- Projection
- draw_labels
- Line formatting (lw, c, alpha, ls, etc.)



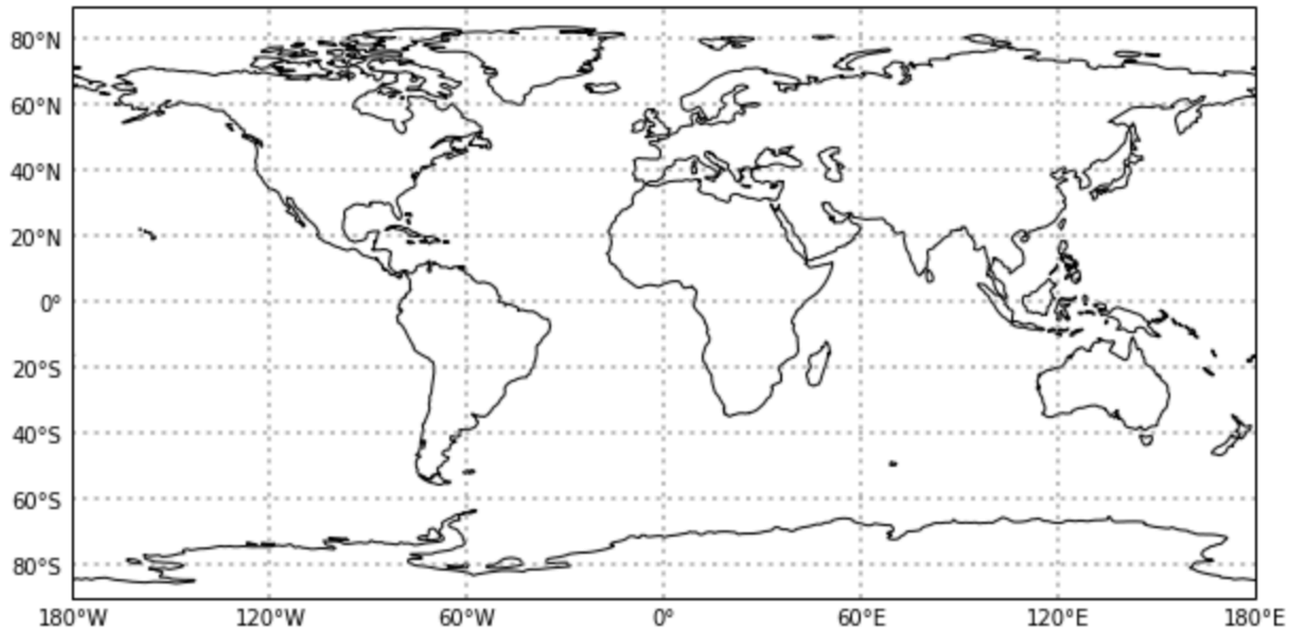
Let's format our grid

```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER
```

- Removed the upper and right labels
- Formatted the tick labels into ° E/W



Let's add some features

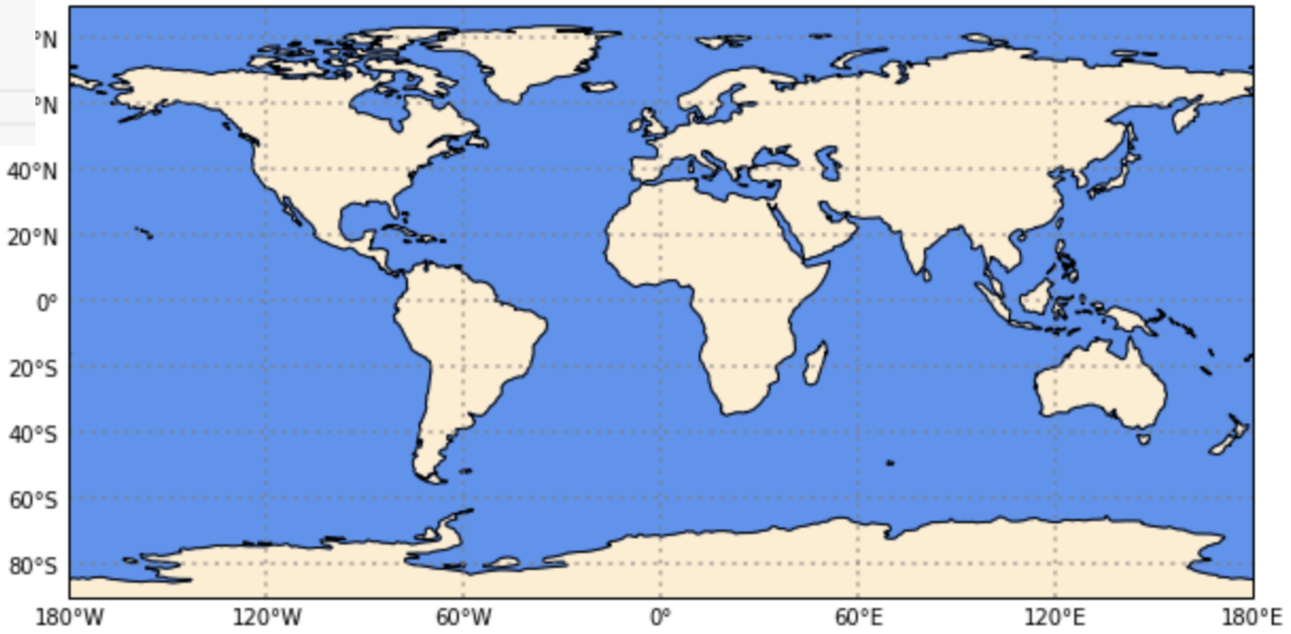
```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER

ax.add_feature(cfeature.LAND, color='papayawhip')
ax.add_feature(cfeature.OCEAN, color='cornflowerblue')
```

- Add features using cfeature (110m resolution)
- Add color arguments



Let's zoom in

```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

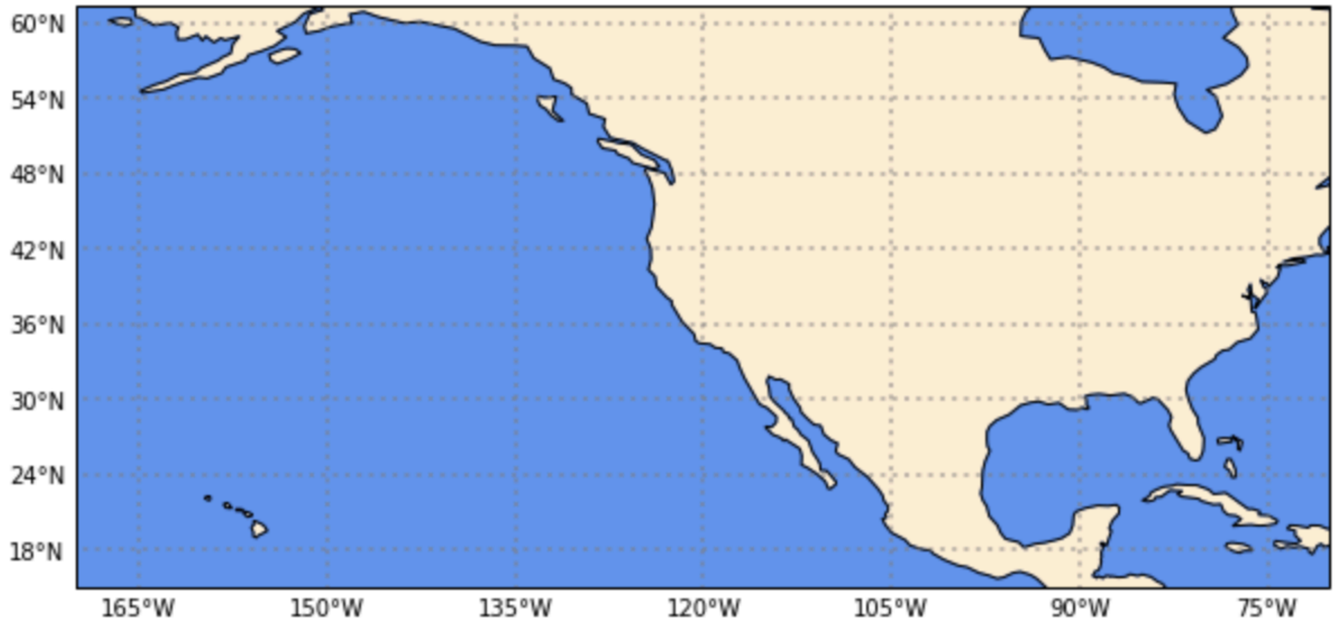
gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER

ax.add_feature(cfeature.LAND, color='papayawhip')
ax.add_feature(cfeature.OCEAN, color='cornflowerblue')

extent = [-170,-70,15,50]
ax.set_extent(extent)

```

ax.set_extent([x1, x2, y1, y2])



And add more features

```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

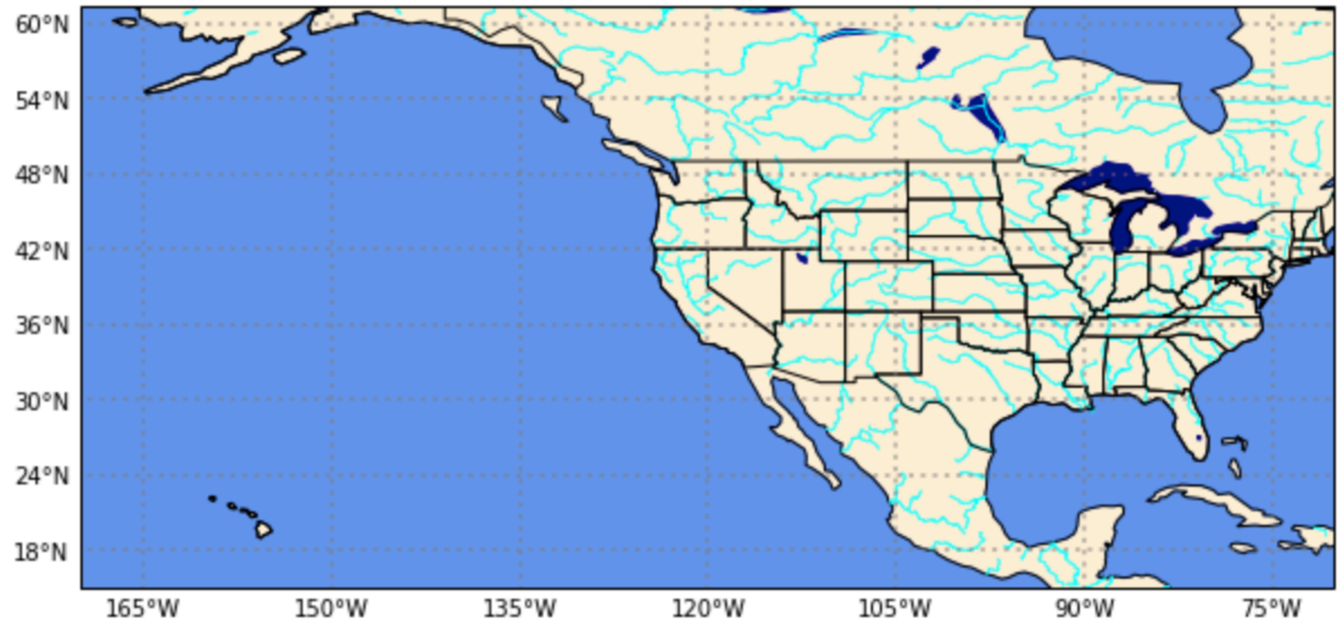
gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER

ax.add_feature(cfeature.LAND, color='papayawhip')
ax.add_feature(cfeature.OCEAN, color='cornflowerblue')

extent = [-170,-70,15,50]
ax.set_extent(extent)

ax.add_feature(cfeature.LAKES,color='navy')
ax.add_feature(cfeature.RIVERS.with_scale('10m'),edgecolor='aqua')
ax.add_feature(cfeature.STATES,edgecolor='k')
```



Let's put data on the map

```
fig = plt.figure(figsize=(10,10))
ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines(resolution='110m',color='k')

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=2, color='gray', alpha=0.5, linestyle=':')

gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER

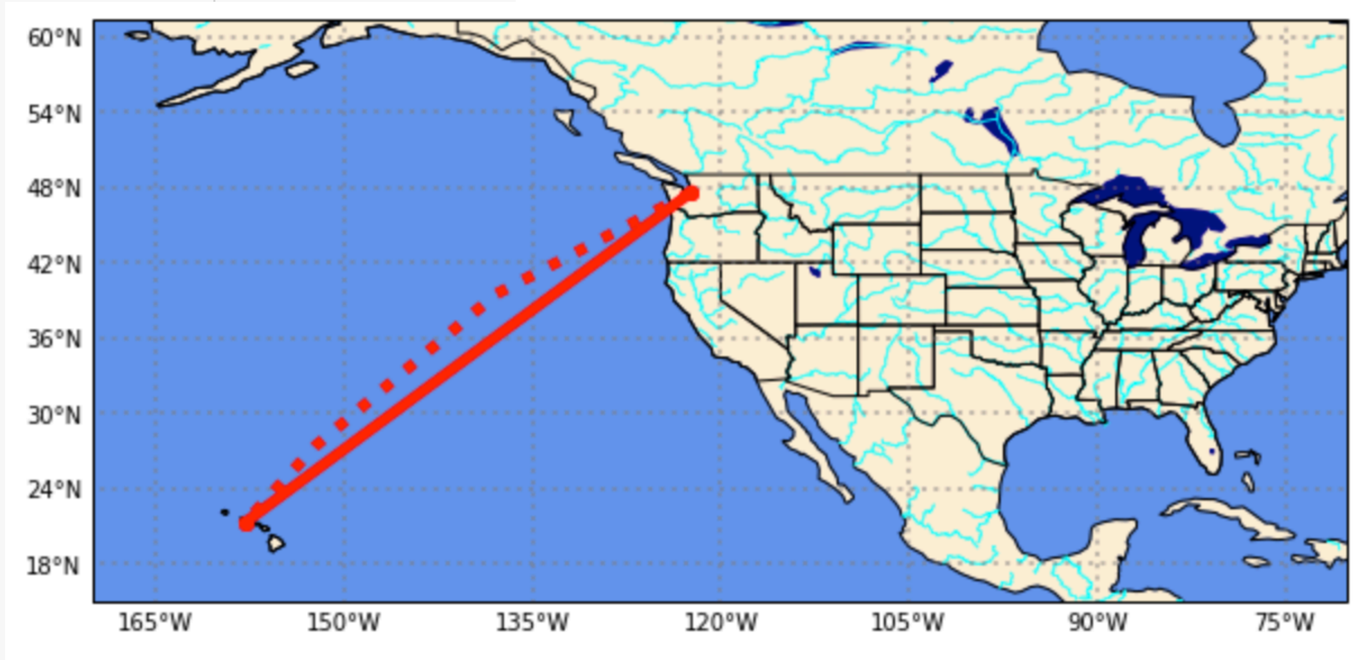
ax.add_feature(cfeature.LAND, color='papayawhip')
ax.add_feature(cfeature.OCEAN, color='cornflowerblue')

extent = [-170,-70,15,50]
ax.set_extent(extent)

ax.add_feature(cfeature.LAKES,color='navy')
ax.add_feature(cfeature.RIVERS.with_scale('10m'),edgecolor='aqua')
ax.add_feature(cfeature.STATES,edgecolor='k')

seattle = [-122.332, 47.606]
honolulu = [-157.8583, 21.3069]

ax.plot([seattle[0],honolulu[0]],[seattle[1],honolulu[1]],'ro-',lw=5,transform=ccrs.PlateCarree())
ax.plot([seattle[0],honolulu[0]],[seattle[1],honolulu[1]],'ro:',lw=5,transform=ccrs.Geodetic())
```



Combining 2-d plotting and mapping

```
# Using our Oxygen data
# Change the path to wherever you have the data
filepath = '/content/drive/My Drive/Data_folder/woa18_oxy.nc'

# Read the data - times are in a bad format, so don't parse them
oxy = xr.open_dataset(filepath,decode_times=False)

# Take the average of the data along longitudes and select the only time level
# Make numpy arrays for lat, depth, and o_data
lat = oxy['lat'].values
lon = oxy['lon'].values
o_data = oxy['o_an'].sel(depth=0,method='nearest').isel(time=0).values

fig = plt.figure(figsize=(15,8))
ax = plt.axes(projection=ccrs.PlateCarree())

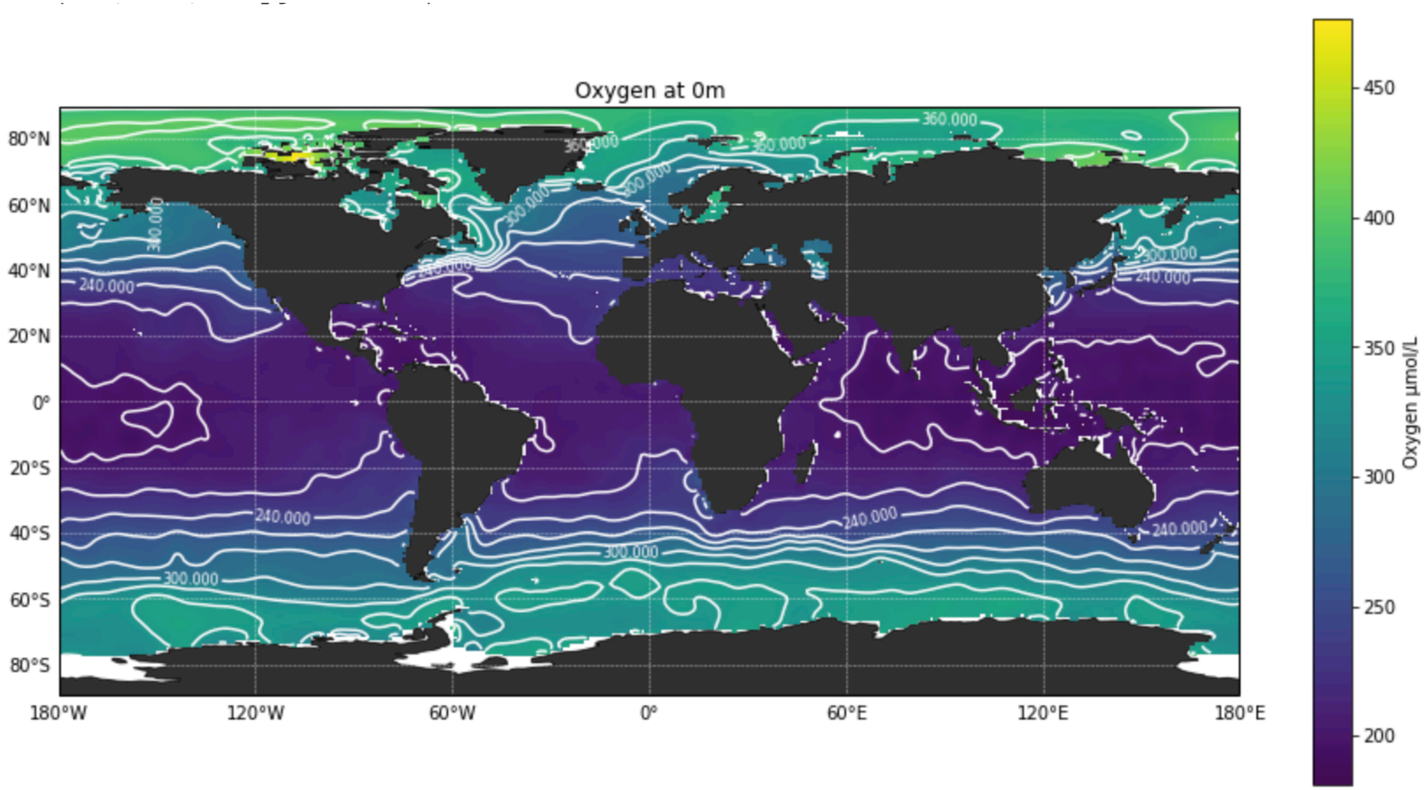
pcm = ax.pcolormesh(lon,lat,o_data,transform=ccrs.PlateCarree())
cntr = ax.contour(lon,lat,o_data,levels=17,transform=ccrs.PlateCarree(),colors='w')
ax.clabel(cntr,levels=cntr.levels[::3],colors='w',fontsize=8)

c = plt.colorbar(pcm, ax=ax)
c.set_label('Oxygen µmol/L')

ax.add_feature(cfeature.LAND, color='k',alpha=0.8)

gl = ax.gridlines(crs=ccrs.PlateCarree(), draw_labels=True,
                  linewidth=0.5, color='w', alpha=0.7, linestyle='--')
gl.xlabels_top = False
gl.ylabels_right = False
gl.xformatter = LONGITUDE_FORMATTER
gl.yformatter = LATITUDE_FORMATTER

ax.set_title('Oxygen at 0m')
```



Extra resources for this lesson

Cartopy tutorial: https://rabernat.github.io/research_computing_2018/maps-with-cartopy.html

Cartopy+Matplotlib: https://scitools.org.uk/cartopy/docs/latest/matplotlib/geoaxes.html#cartopy.mpl.geoaxes.GeoAxes.coastlines

Cartopy grids: https://scitools.org.uk/cartopy/docs/latest/matplotlib/gridliner.html

Contourf: https://matplotlib.org/3.1.1/api/_as_gen/matplotlib.pyplot.contourf.html

Contour: https://matplotlib.org/3.1.1/api/_as_gen/matplotlib.pyplot.contour.html

Pcolormesh: https://matplotlib.org/3.3.2/api/_as_gen/matplotlib.pyplot.pcolormesh.html

Mapping problems: https://www.scienceabc.com/social-science/what-is-wrong-with-all-our-maps-mercator-maps.html