Open source geospatial programming in Python

A crash course..

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September 20, 2016

Today's goals

By the end of today's workshop, you will understand several fundamental Python concepts and be able to *programatically*[1]

- Read, manipulate, and write shapefiles and raster data
- Perform simple analyses on geospatial data
- Plot data derived from geospatial sources

[1] Through program code, rather than a user interface – wictionary.org

Why geospatial Python?

- Provides a multitude of options for handling geospatial data analysis and display
- Allows easy automation of tasks and manipulation & analysis of large datasets
- Runs on Mac's (and Windows)..
- Free and open

My motivation

Turning pretty pictures into quantitative data.

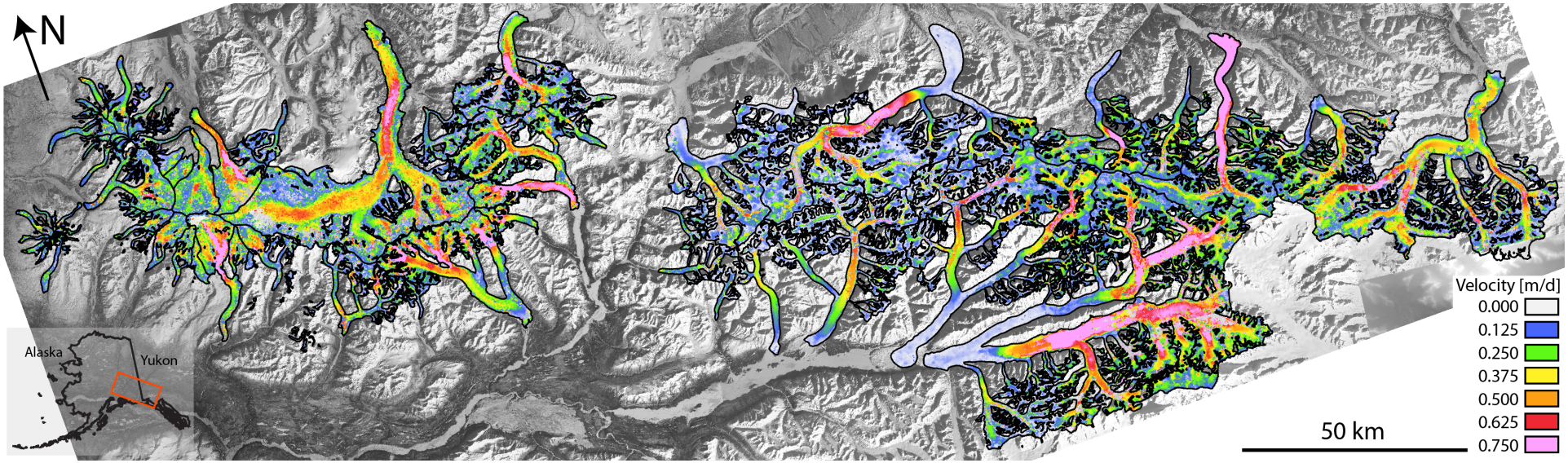


Figure: Glacier velocity on a range-wide scale over south-central Alaska.

My motivation

Repeat analysis of satellite imagery to inform our understanding of glacier dynamics.

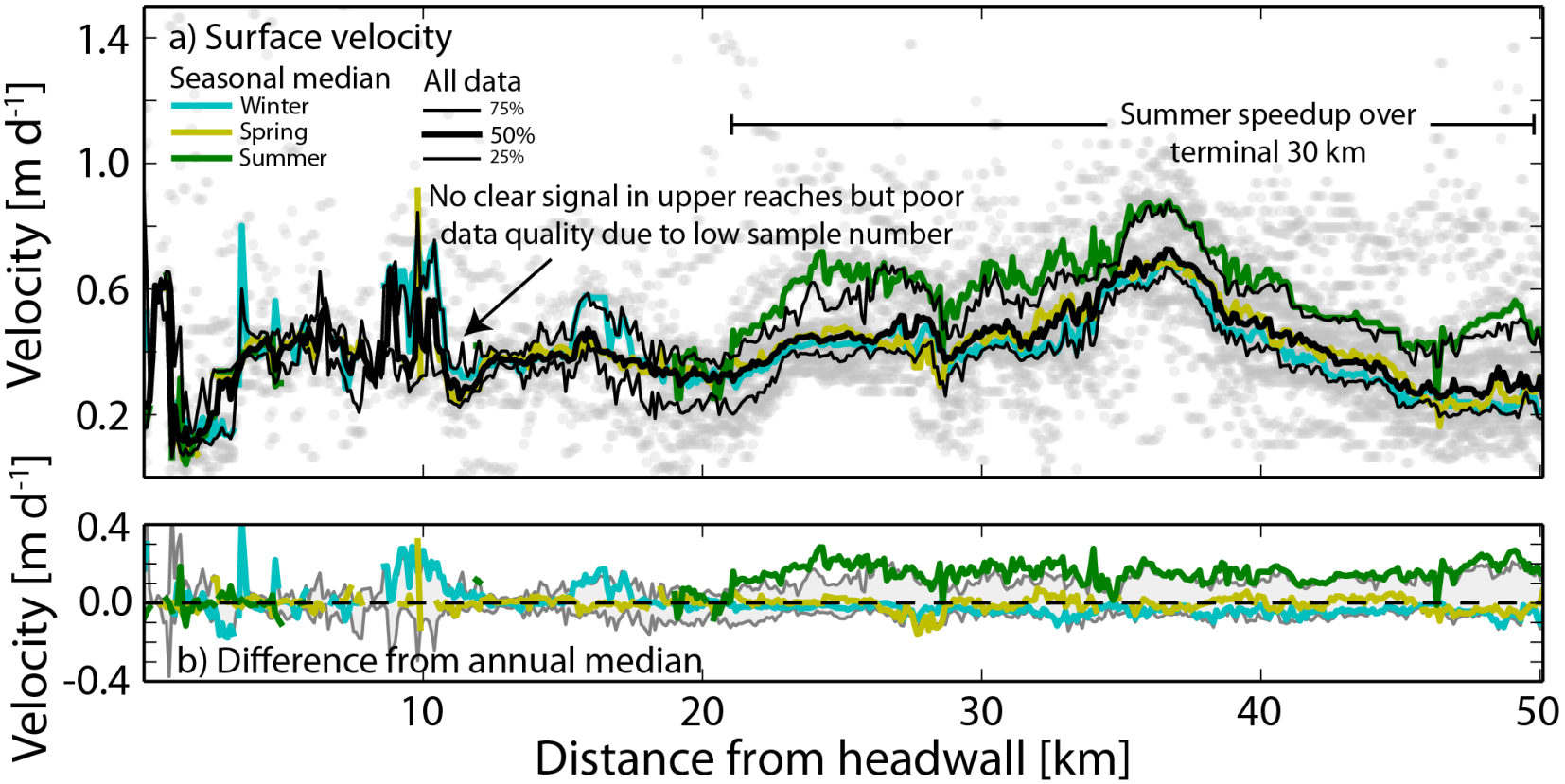


Figure: Seasonal glacier velocity along a down-glacier profile.

Python basics: indexing data

Different data structures have different ways of accessing contained values.

- **Tuples**: Square brackets with [row][column] indexing. Start = 0.

```
t = ( (1,2) , (5,9) ) , t[0][1] = 9
```

- **Lists**: Square brackets with [order] indexing.

```
l = [ 1, 2, 5, 9], l[2] = 5
```

- **Dictionaries**: Square brackets with ['key'] indexing.

```
d = { 'age':( (33,31,19) ), \
'name': ['john','claire','steve'] }
d['age'] = (33,31,19), d['age'][0] = 33
```

Python basics: for loops

A **for loop** is a way to get Python to repeat a specified sequence of tasks many times. Python's for loop structure is very particular about indenting, unlike some other languages. A Python for loop looks like:

```
1 a = [ 13, 5, 2, 4, 9, 16]
2 for i in range(0,len(a)):
3         print "Value " + i + " is " + a[i]
4 print "Done with loop"
```

Figure: Around and around we go. Image from wikipedia.org

Python basics: importing packages

Part of what allows Python to be so lightweight is that is only loads the tools you ask for. These tools are called "packages"; today we will be using:

```
# load a module and give it a short-hand
import matplotlib.pyplot as plt
import numpy as np
# load one module from a package
from shapely import geometry
# load a whole package
import fiona
import rasterio
```

Geospatial datatypes

Python can readily handle geospatial data. Geospatial data comes in two basic classes:

Raster: A representation of the world as a surface divided into a regular grid of cells. E.g., satellite imagery, DEMs. *GDAL, Rasterio*.

Vector: A representation of the world using points, lines, and polygons. E.g., roads, study area boundaries. *OGR, Shapely, Fiona*.

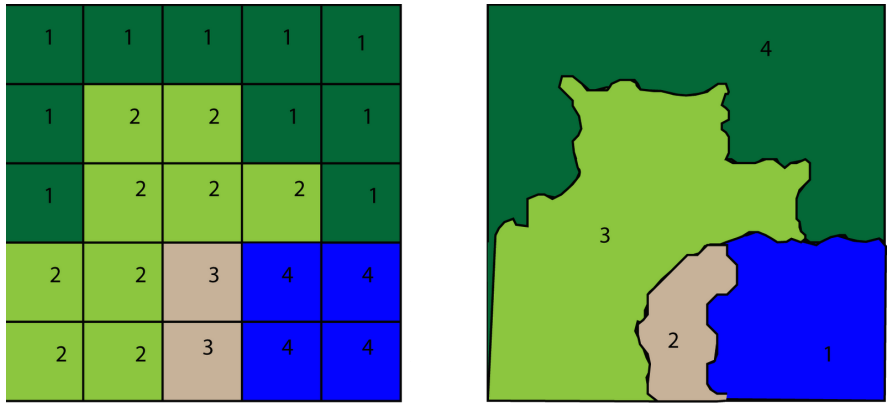


Figure: Raster (left) and vector (right) representations of a landscape.

Today's dataset

State shapefiles from
https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html

First hit when Google "us state outlines shapefile" $\rightarrow$ "nation-based files" $\rightarrow$ "state" $\rightarrow$ "cb_2015_us_state_20m.zip"

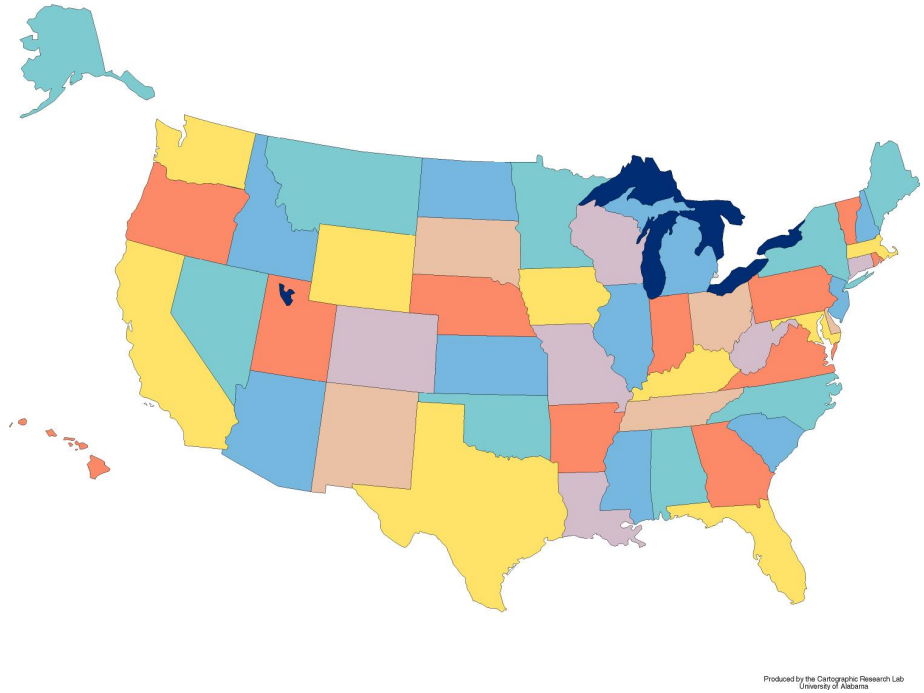


Image: alabamamaps.ua.edu

Reading vector data: Fiona

Fiona and Shapely are lightweight wrappers for the underlying OGR module, which is pretty clunky and not 'Pythonic'. Reading a shapefile with Fiona is pretty easy, as shown below.

```
1  stateFn = fullPath + 'cb_2015_us_state_20m.shp'
2  # open collection stateFn with 'r' for 'read'
3  states = fiona.open(stateFn,'r')
4
5  # Some basic information
6  len(states) # number of features within collection
7  states.crs # collection coordinate reference system (CRS)
8  states.schema # Information on fields and geometry type
9  state = states[0] # get the first feature and name it 'state'
10
11 # loop over features, print state names and USPS abbrev.
12 for state in states:
13         print state['properties']['NAME'], \
14               state['properties']['STUSPS']
```

Manipulating vector data: Shapely

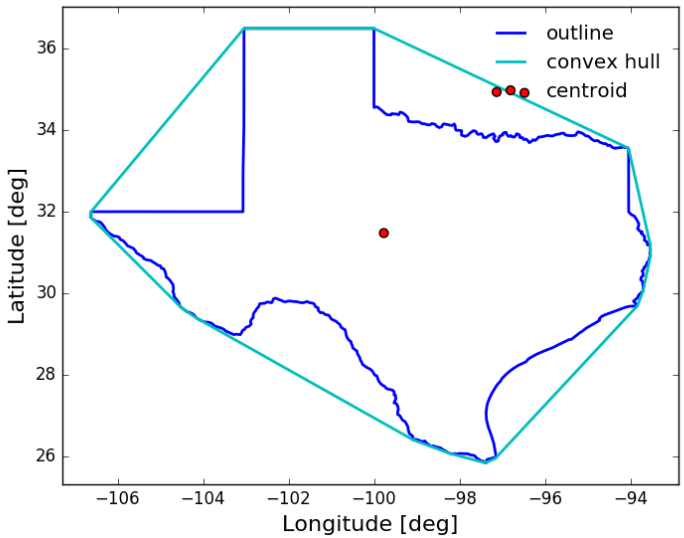
Fiona reads shapefiles, but Shapely is where the real geospatial power lies. Creating a Shapely geometry from a Fiona input looks like:

```
state = states[0] # get the first feature and name it 'state'
state.viewkeys() # ['geometry', 'type', 'id', 'properties']
shape = geometry.shape(state['geometry']) # make shapely geom
ext = shape.exterior # get the 'exterior' ring geom
x,y = ext.xy # 'exterior' ring coords
cent = ext.centroid # geometric centroid geom
cx,cy = cent.xy # centroid coords
hull = shape.convex_hull # convex hull geom
hx,hy = hull.exterior.xy # convex hull coords
```

See http://toblerity.org/shapely/manual.html for the many object attributes.

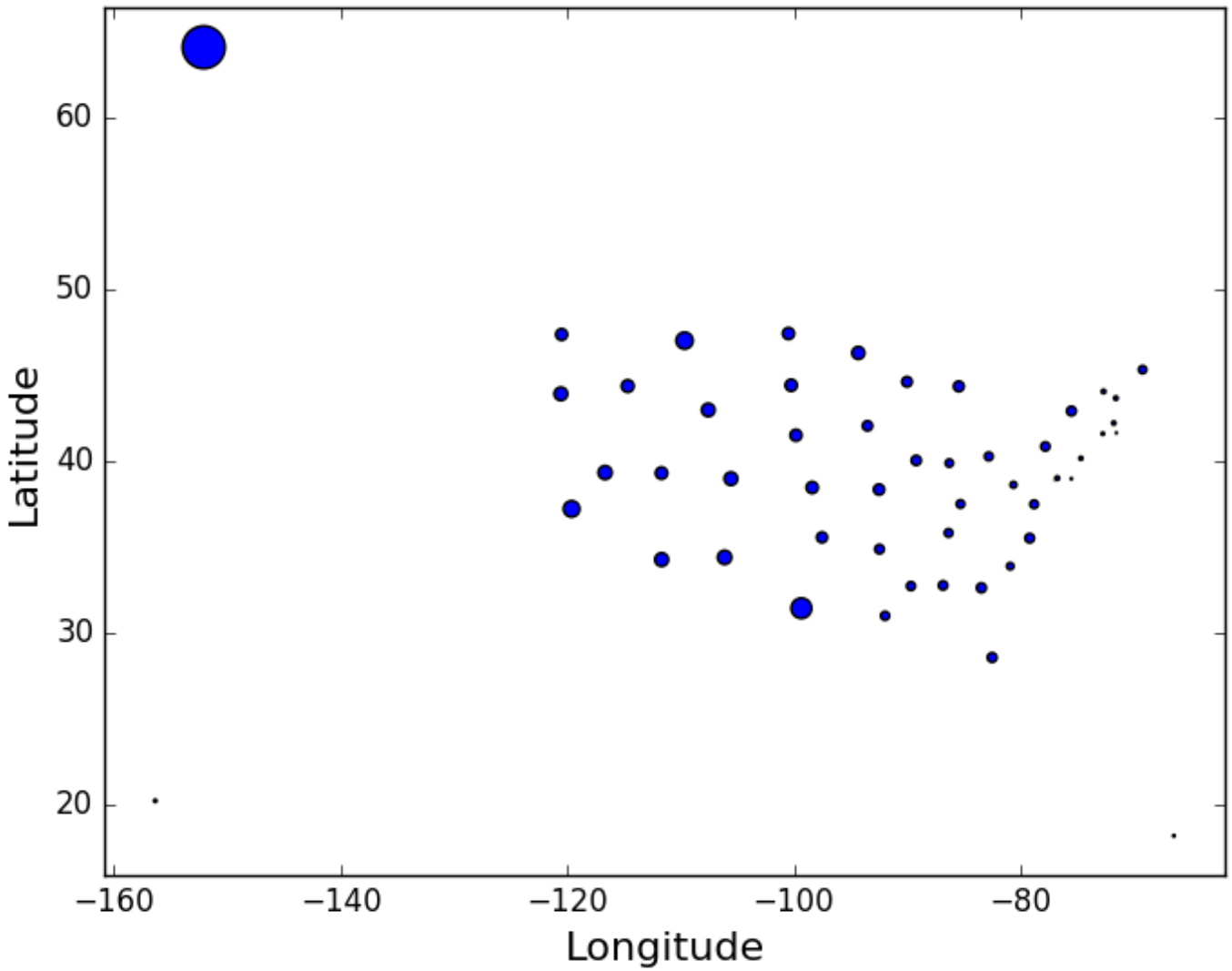
Plotting data: Matplotlib

```
plt.plot(x,y,c='b',lw=2,label='outline') # c = color, lw = linewidth
plt.plot(hx,hy,c='c',lw=2,label='convex hull') # label on legend
plt.scatter(cx,cy,s=40,marker='o',facecolor='r',label='centroid')
plt.xlabel('Longitude [deg]',fontsize=16) # ^s = size
plt.ylabel('Latitude [deg]',fontsize=16)
plt.legend(loc=1,frameon=False) # loc 1 = upper right corner
plt.axis('tight') # less white space
plt.savefig('texas_shapely.png',r=300) # r = resolution
plt.show()
plt.close()
```



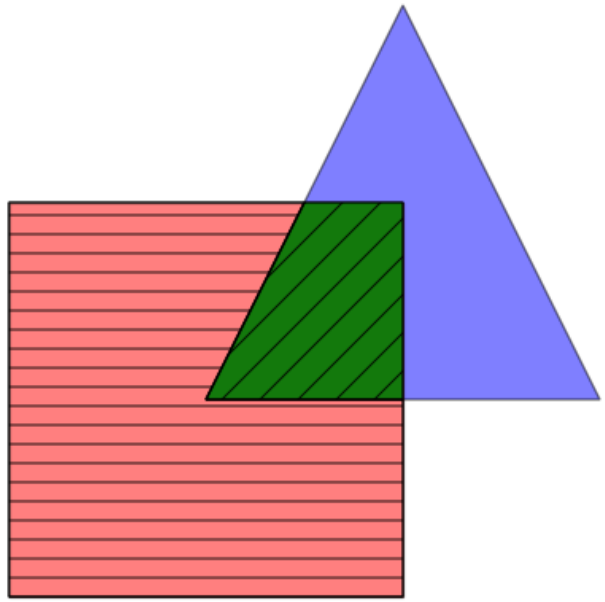
Vector data: Fiona and Shapely

```
# Initialize empty lists for later storage
cxList = []
cyList = []
areaList = []

for state in states: # loop over all features in collection
        # make temporary shapely geometry
        tmpShp = geometry.shape(state['geometry'])
        tmpX,tmpY = tmpShp.centroid.xy # x,y coords of centroid
        tmpArea = tmpShp.area # get geom's area
         # add data to lists for storage
        cxList.append(tmpX)
        cyList.append(tmpY)
        areaList.append(tmpArea)

plt.scatter(cxList,cyList,s=areaList*10)
plt.axis('tight')
plt.xlabel('Longitude',fontsize=16)
plt.ylabel('Latitude',fontsize=16)
plt.savefig('statesByArea.png',r=300)
plt.show()
plt.close()
```


60
50
40
30
20
Latitude
−160
−140
−120
−100
−80
Longitude

Vector data: Shapely operations

```
# Dummy data with simple geometries
square = geometry.Polygon([(0,0),(1,0),(1,1),(0,1)])
triangle = geometry.Polygon([(0.5,0.5),(1.5,0.5),(1,1.5)])
square.intesects(triangle) # Returns true if overlap
isect = square.intersection(triangle) # 'overlap'
diff = square.difference(triangle) # 'subtracts'
uni = square.union(triangle) # 'combines'
```



Vector data: Writing out

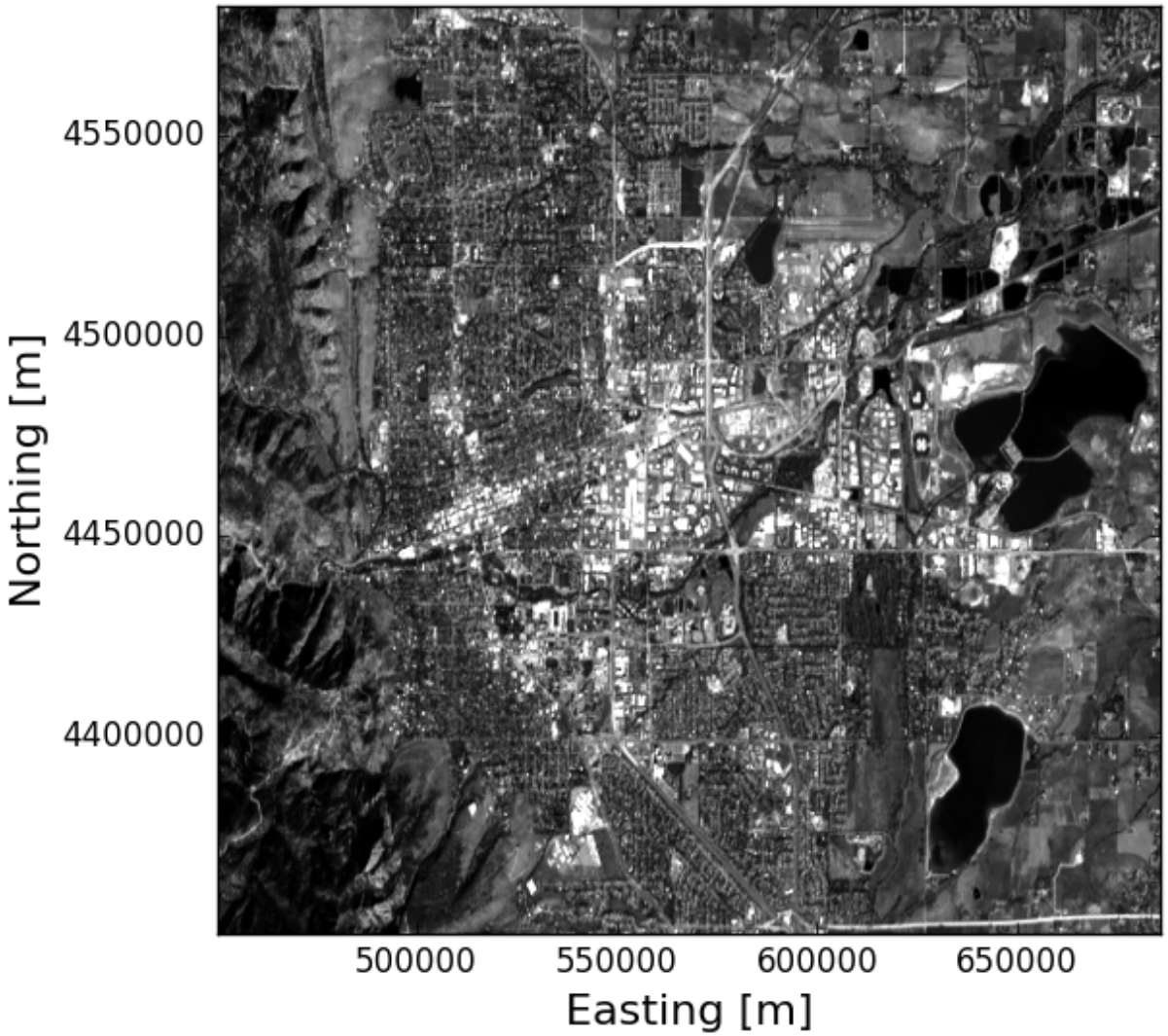
Writing out vector data.

Raster data: Plotting

Rasterio is a wrapper for GDAL, which, like OGR, is a little clunky and unintuitive to the average Python programmer. Opening, subsetting, and plotting an image with Rasterio and Matplotlib looks like:

```
src = rasterio.open(rasterFn) # open raster
# turn band 1 to numpy array; only use subset of rows and columns
sub = src.read(1,window=w) # w = ( (rMin,rMax), (cMin,cMax) )
# plot image; clim = min/max brightness; use 'gray' colormap
plt.imshow(sub,cmap='gray',clim=((bLow,bHigh)),
           extent=((xmin,xmax,ymin,ymax))) # x,y coords not row,col
plt.show()
```

Raster data: Plotting



Raster data: Transformation

Transforming between image coordinates and pixel coordinates is very easy.

```
row,col = src.index(x,y) # get pixel coords from ground coords
x,y = src.affine * (row,col) # get ground from pixel coord
```

As is finding out important image info.

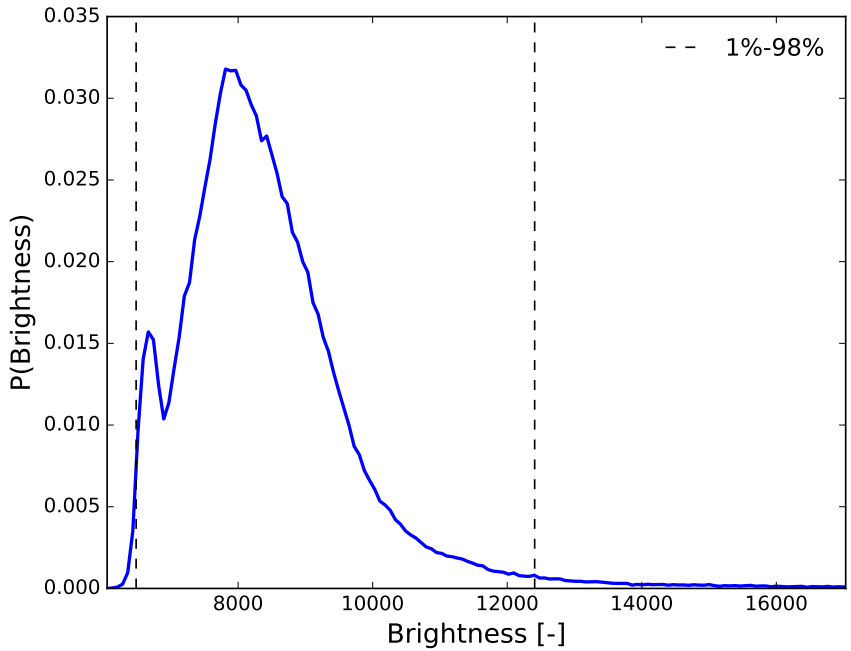
```
crs = src.crs # coordinate reference system
bnd = src.bounds # image bounding box coordinates
nRow = src.height # number of pixels N-S
nCol = src.height # number of pixels E-W
```

Raster data: Analysis and manipulation

You can do anything with an image-derived array as you would with a regular numpy array. For example,

- Measure value at a certain pixel (lat/lon) over time
- Histogram to get image characteristics
- Difference to images to get change over time
- Perform mathematical operations combining multiple arrays to create a new raster
- Image enhancement and processing using e.g., `scikit.image`, `cv2`, or `scipy`

Raster data: Analysis and manipulation




```
1 p2,p98 = np.percentile(sub,[2,98])
2 hist,edges = np.histogram(sub,bins=500)
```

Raster data: Writing

Writing out GeoTIFFs is straight forward. You create a new file with geospatial attributes (`crs`, `height`, etc.) and then specify with which dataset to populate the empty file.

```
'''
'w' = write, dtype = datatype (i.e., int, float)
crs = coordinate reference, driver = file format
transform = geographic transformation coefficients
'''
out = rasterio.open('boulderSub.tif', 'w', driver='GTiff',
                    height=sub.shape[0], width=sub.shape[1],
                    count=1, dtype=sub.dtype,
                    crs=src.crs, transform=src.transform)
out.write(sub,1) # write data to file
out.close() # 'flush' file
```

The `crs` and `transform` arguments can be taken from an existing dataset, as done here, or created anew.

`src.crs = CRS({'init':u'epsg:32613'})`

`src.transform = [450292.5,15.0,0.0,4582207.5,0.0,-15.0]`

Extensions: other useful packages

- **GDAL**: library underlying Rasterio. Has some really nice tools for working with DEMs.
- **OGR**: library underlying Shapely and Fiona. Has nice tools for translating vector data between formats.
- **PyProj**: projection and coordinate transformation.
- **GeoJSON**: storing geospatial information in a `dict`-like structure.
- **GeoPandas**: data structure and data analysis tool for geospatial data.
- **Descartes**: makes plotting Shapely geometries a little easier.

Thanks! william.armstrong@colorado.edu